An economic sustainability analysis of hybrid solar-biomass system for sugar industries in India

Uma análise de sustentabilidade econômica de um sistema híbrido solar-biomassa para indústrias de açúcar na Índia

Un análisis de sostenibilidad económica de un sistema híbrido solar-biomasa para industrias azucareras en India

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ABSTRACT
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. Till date, inadequate attention has been paid to the integration of Renewable Energy (RE) sources in the industrial sectors of TamilNadu, India. Since industries have been key drivers of electricity consumption in the past decade, this paper aims at the simulation and analysis of hybrid Biomass-Solar Photovoltaic system for electrification of the process industries, especially sugar industries. The main objective of the paper is to minimize the cost of energy and Green House Gas (GHG) emissions leading to sustainable development. The economic feasibility analysis is performed using Hybrid Optimization Model for Electric Renewables (HOMER) software and the sustainability analysis with the help of Clean Development Mechanism that can be adopted for the sugar industry. The simulation results support the effectiveness of the proposed grid connected solar-biomass hybrid system for the sugar industry with the net present cost of 16 million dollars (M$) combined with emission reductions of 6,266 tons/year.

Keywords: power generation economics, hybrid renewable energy system, solar energy source, biomass energy source, software Homer, sugar industry, India.
RESUMO
Os sistemas de energia renovável têm ganhado mais importância em países em desenvolvimento não apenas devido ao aumento da preocupação com a sustentabilidade ambiental, mas também para resolver a iminente crise energética que prejudica o desenvolvimento econômico. Até o momento, pouca atenção foi dada à integração de fontes de Energia Renovável (RE) nos setores industriais de Tamil Nadu, na Índia. Como as indústrias têm sido os principais impulsionadores do consumo de eletricidade na última década, este artigo tem como objetivo a simulação e análise de um sistema híbrido de Biomassa-Fotovoltaica Solar para eletrificação das indústrias de processamento, especialmente as indústrias de açúcar. O principal objetivo do artigo é minimizar o custo de energia e as emissões de Gases de Efeito Estufa (GEE), levando ao desenvolvimento sustentável. A análise de viabilidade econômica é realizada usando o software Hybrid Optimization Model for Electric Renewables (HOMER) e a análise de sustentabilidade com a ajuda do Mecanismo de Desenvolvimento Limpo que pode ser adotado para a indústria açucareira. Os resultados da simulação apoiam a eficácia do sistema híbrido de biomassa-fotovoltaica solar conectado à rede proposto para a indústria açucareira, com um custo líquido presente de 16 milhões de dólares (M$) combinado com reduções de emissões de 6.266 toneladas/ano.

Palavras-chave: economia de geração de energia, sistema híbrido de energia renovável, fonte de energia solar, fonte de energia de biomassa, software Homer, indústria de açúcar, Índia.

RESUMEN
Los sistemas de energía renovable han ido adquiriendo más importancia en países en desarrollo no solo debido al aumento de la preocupación por la sostenibilidad ambiental, sino también para resolver la inminente crisis energética que dificulta el desarrollo económico. Hasta la fecha, se ha prestado poca atención a la integración de fuentes de Energía Renovable (RE) en los sectores industriales de Tamil Nadu, India. Dado que las industrias han sido los principales impulsores del consumo de electricidad en la última década, este artículo tiene como objetivo la simulación y análisis de un sistema híbrido de Biomasa-Fotovoltaica Solar para la electrificación de las industrias procesadoras, especialmente las industrias azucareras. El objetivo principal del artículo es minimizar el costo de la energía y las emisiones de Gases de Efecto Invernadero (GEI), llevando al desarrollo sostenible. El análisis de viabilidad económica se realiza utilizando el software Hybrid Optimization Model for Electric Renewables (HOMER) y el análisis de sostenibilidad con la ayuda del Mecanismo de Desarrollo Limpio que puede ser adoptado para la industria azucarera. Los resultados de la simulación respaldan la eficacia del sistema híbrido de biomasa-fotovoltaica solar conectado a la red propuesto para la industria azucarera, con un costo neto presente de 16 millones de dólares (M$) combinado con reducciones de emisiones de 6.266 toneladas/año.

Palabras clave: economía de generación de energía, sistema híbrido de energía renovable, fuente de energía solar, fuente de energía de biomasa, software Homer, industria azucarera, India.
1 INTRODUCTION

The present energy situation worldwide and in the Indian context clearly points out that the world is racing ahead towards an era where the conventional energy forms becomes exhaustive in their respective capacities and costlier. Hence, many countries in the world thrive to supply electrical energy to their citizen that is reliable, environmental friendly and economical. During the recent years the share of renewable energy has steadily increased due to the initiative taken by the Indian government. India has rich potential of solar, wind and biomass resources particularly in TamilNadu [1, 2]. Among the sources of power, the total renewable energy capacity in the state of Tamil Nadu is 8,075 MW about 12% among the other sources of power. Tamil Nadu has high solar insolation nearly 6.0 KWh/sq.m and approximate 300 clear sunny days in a year and wind energy is the dominant form of renewable energy in the state. Biomass is a versatile source of energy that can be converted to various forms such as electricity, process heat, liquid and gaseous fuels. Till now, 18 biomass power plants each with a capacity of 7-10 MWere available in the state (www.teda.in/achievements).

World countries depend on power to fuel their economic growth. TamilNadu being one of the industrialized state in India and with its urban growth, demand for energy is burgeoning. The state has been confronted with huge power crisis in the last few years. According to the statistics of Central Electricity Authority of India (CEA), energy deficit of the state has been around 6.2 % in 2009-10. This deficit has increased rapidly in the last few years to 17.5 % in 2012-13 (www.cea.nic.in). Industries are the worse-affected sector among the consumers due to power deficits in the state and are penalized for uncontrolled emissions. Hence, alternative sources of power supply are to be found out that mitigate energy costs and consequently reduce the emissions for the sustainable future of industries.

The recent past has witnessed rise in literature pertaining to autonomous and and grid connected RE sources across the world. Many researchers and environmentalists ventured into the research on RE sources like PV, Wind and Biomass as an alternative to traditional energy sources due to technological advancements coupled with increasing demand for electrical power [3]. But, the intermittent nature of renewable energy sources has paved for hybrid RE systems. In India, biomass energy system has been experimented to offer a more economicaly feasible solution for villages and the environmental impacts due to a biomass generation system have also been discussed [4-6]. Hybrid power systems provide a reliable power supply in all load conditions [7, 8]. Moreover, operating
costs for the utilizing renewable energy sources in remote locations is lesser compared to
diesel based generation and emissions are also reduced [9]. In many literature, hybrid RE
system backed up with energy storage has been analyzed for its suitability in a particular
region [10-12]. Most of the research work focuses on the supply of power to residential,
rural areas and institutions [13-16]. The industrial sectors have been provided little
attention to cater the socio economic development of the whole region. Further, the
carbon credits obtained by such RE systems though Clean Development Mechanism
(CDM) are also not focused [17]. By taking these factors into account, this paper has been
contemplated to bridge the gap with a due consideration to process industries.

Among the process industries, sugar sector is the second largest agriculture based
industry next to textiles in India and it competes with Brazil [18]. The main waste product
of sugar production is a material known as bagasse which can be used or cogeneration,
generating power and steam to meet the operational requirements of the plant and export
the surplus power to the electricity boards. Only in recent years, with an increasing price
of sugarcane and low tariff fixation, commercial cogeneration has become less attractive,
from the sugar mill point of view. Still, cogeneration potential is appreciable in India
which can reduce the demand – supply gap in future. Hence, this work focuses on the
feasibility analysis of large scale grid connected renewable power generation for sugar
industry through the resources available in the locality and CDM implementation for
sustainable development in future. The sugar industry selected for the sustainability
analysis is Sakthi Sugars Private Limited in Sivagangai district, Tamil Nadu. With the
data collected from the sugarcane industry whose overview is provided in section 2, the
sustainability of using Biomass-Solar hybrid system is analyzed using HOMER software
tool in section 3. Then, environmental benefits of CDM implementation and the carbon
credits are estimated in section 4, followed by the results and discussion in section 5. The
outcomes of feasibility analysis are presented in the conclusion section.

2 OVERVIEW OF SAKTHI SUGARS PRIVATE LIMITED

The Sakthi Sugars, Sivaganga unit was established in the year 1988–1989 at
Padamathur in Sivaganga District, Tamil Nadu. It has an advanced infrastructure
equipped with Auto Setting Mills and the technical know-how to process raw sugar. The
plant has been started with a capacity of 2500 Tons Crashed per Day (TCD), has expanded
to 4000 TCD. The plant recorded the highest cane crush of 10 lakh Million Tons (MT) in
the 2007-2008 season. The capacity and energy requirement of the sugar mill is shown in Table 1. The mill has 33 MW cogeneration power plant on site that is running on bagasse and coal based on the availability. Bagasse is used during the season and coal during off-season depending on the power requirement of the plant. The cogeneration plant supplies

Table 1. Capacity and energy requirement of sugar factory

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushing capacity</td>
<td>TCD</td>
<td>4000</td>
</tr>
<tr>
<td></td>
<td>TPH</td>
<td>166.67</td>
</tr>
<tr>
<td>Specific power consumption of sugar plant</td>
<td>KWh/ton of cane</td>
<td>25</td>
</tr>
<tr>
<td>Power required for crushing</td>
<td>MW</td>
<td>4.17</td>
</tr>
<tr>
<td>Specific steam consumption of sugar plant</td>
<td>% on cane</td>
<td>42</td>
</tr>
<tr>
<td>Steam required for rated crushing capacity</td>
<td>TPH</td>
<td>70</td>
</tr>
<tr>
<td>Bagasse required for steam generation</td>
<td>TPH</td>
<td>48</td>
</tr>
</tbody>
</table>

*TPH-Tons Per Hour
Source: Sakthi Sugars Ltd, Sivagangai

power to the sugar plant and exports the excess power to the TamilNadu electricity board.

In the proposed work, the bagasse generated is used as the fuel during the crushing season of 145 days and bagasse saved during season along with the procured bagasse or equivalent biomass will be used instead of coal for off-season operation of the cogeneration project. Thus the proposed cogeneration plant will operate for 330 days in a year and export the green power to TNEB grid.

3 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 paper is on the economic and environmental aspects of sustainability. In this paper, an initial assessment of the available resources, cost and demand of the sugar industry is accomplished to analyze the techno-economic viability of biomass based hybrid renewable energy systems using HOMER tool. Datainputs given to the software tool HOMER is obtained from initial assessment performed in the chosen region. The optimized results of the feasibility analysis are obtained from the software tool which simulates 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 sub-sections.
3.1 RENEWABLE ENERGY RESOURCES AVAILABILITY

Solar, Bagasse and Biomass are the renewable energy sources considered for the sustainability analysis because of the resource availability in the region. The solar energy resource data for the sugar mill with 9.85°N latitude and 78.37°E longitude are obtained from NASA Surface Meteorology and Solar Energy website (https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi) and it is found that the daily global solar irradiation is 5.10 KWh/m² on an average, ascertains enough solar potential in the region and the availability of considerable amount of solar energy in all the days of the year. One of the important resource input to the HOMER tool is the monthly radiation data required for the feasibility analysis of the Solar - biomass hybrid plant in the chosen region. The tool calculates the clearness index for the corresponding solar radiation. The solar radiation profile for one-year period is shown in Table 2.

Table 2. Monthly averaged solar radiation on a horizontal surface (KWh/m²/day)

<table>
<thead>
<tr>
<th>Lat 9.85 ; Long 78.4</th>
<th>22-year Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>4.66</td>
</tr>
<tr>
<td>February</td>
<td>5.50</td>
</tr>
<tr>
<td>March</td>
<td>6.18</td>
</tr>
<tr>
<td>April</td>
<td>5.69</td>
</tr>
<tr>
<td>May</td>
<td>5.69</td>
</tr>
<tr>
<td>June</td>
<td>5.18</td>
</tr>
<tr>
<td>July</td>
<td>4.98</td>
</tr>
<tr>
<td>August</td>
<td>5.15</td>
</tr>
<tr>
<td>September</td>
<td>5.32</td>
</tr>
<tr>
<td>October</td>
<td>4.59</td>
</tr>
<tr>
<td>November</td>
<td>4.12</td>
</tr>
<tr>
<td>December</td>
<td>4.18</td>
</tr>
<tr>
<td>Average</td>
<td>5.10</td>
</tr>
</tbody>
</table>

Source: https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi.

3.2 BIOMASS FUEL VIABILITY

There is no formal government published biomass assessment study report are available in Sivagangai district. Hence data has been obtained from TamilNadu Chemical Products (TCP) Limited, manufacturer and exporter of sodium hydro sulphite and liquid sulphur-di-oxide. The company has conducted a detailed biomass assessment study in Sivagangai district to implement 6 MW grid connected biomass plant in its location. The quantum of biomass required for 6 MW project is about 200 Ton/day and the biomass is available surplus within 25 kms in district of Sivagangai.

The major biomass fuel in the location of the sugar mill is Prosopisjuliflora which grows with little or no maintenance and organized trimming and watering use of fertilizer.
The other fuels available are eucalyptus bark, coconut shell, sugarcane waste as seen in Table 3. Sugarcane crushed in the sugar plant has been ranging from 8-10 lakh MT during the last three years 2018-19, 2019-20 and 2020-21.

Table 3 Excess biomass availability in Sivagangai district

<table>
<thead>
<tr>
<th>S.No</th>
<th>Biomass fuel type</th>
<th>Surplus (tons/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Prosopis Juliflora</td>
<td>358,300</td>
</tr>
<tr>
<td>2</td>
<td>Eucalyptus bark</td>
<td>308,200</td>
</tr>
<tr>
<td>3</td>
<td>Coconut shell</td>
<td>42,793</td>
</tr>
<tr>
<td>4</td>
<td>Chilly stem</td>
<td>155,280</td>
</tr>
<tr>
<td>5</td>
<td>Sugarcane residue</td>
<td>15,200</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>879,773</td>
</tr>
</tbody>
</table>

Source: Agricultural department office, Madurai

3.3 LOAD PROFILE

The sugar industry operates 145 days except during plant maintenance based on bagasse availability. The load type served is AC. The daily load is found to be 67 MWh on an average with peak value of 5.5 MW and the data are used as load inputs in HOMER tool. The approximate seasonal load profile of the sugar mill is given in Figure 1.

3.4 COMPONENT COST

HOMER tool also requires economic inputs of RES components for performing the simulation. The PV panels are connected in series. The capital cost and replacement cost for a 1 KW solar PV panels along with balance of system components is $6000 and $5000 respectively as obtained from the manufacturer. The operation and maintenance (O&M) costs is chosen as $10/year owing to least maintenance requirement for PV system. With the lifespan of PV panels of 20 years, 90% de-rating factor is chosen to account for temperature variations and dust on the panels.

The investment cost, replacement cost and the O&M cost of 1 MW biomass generation system is about 1 M$, 0.8 M$ and 0.01$/h respectively. The maximum annual capacity shortage is 10%.
The prices considered in the simulation using HOMER are the data obtained from local Indian manufactures. The life-time is 25 years for biomass system.

3.5 TECHNO - ECONOMIC ANALYSIS OF HYBRID RENEWABLE ENERGY SYSTEM

The feasibility analysis of the chosen hybrid solar-biomass cogeneration system is performed for the sugar plant of Sakthi sugars limited and the results of the system configurations are analyzed in the subsequent sections. Simulation and feasibility analysis using HOMER software has been performed for three scenarios based on the consideration of all possible generation source options. The schematic diagram of the scenarios enumerating the sources of supply for each of the three scenarios is shown in Figure 2.
The three cases analyzed for the economic feasibility are bagasse based cogeneration, biomass system and solar-biomass hybrid system. In the first scenario, the demand of the industry is met with grid connected bagasse based cogeneration system, which is the current practice in the sugar industry during the cane season. 5.5 MW bagasse generator has been used. The factory load and thermal load is met with bagasse fuel, which is the waste product of the sugar mill and the start-up load requirements from the state electricity board. Scenario-2 deals with the grid connected biomass system proposed for the off-season during which there is no bagasse availability. The Biomass generator has been modelled to supply the auxiliary load and export the surplus power to the grid.

Scenario-3 is the proposed hybrid configuration based on hybrid RE sources. Biomass-solar hybrid system has been selected for the sugar mill as there is enough biomass and solar resource availability in the chosen region and Government subsidies for renewable energy usage are given in order to compensate the low tariff rate fixed for biomass power. Solar-PV system is used to augment the biomass power during the day time. PV system reduces the biomass usage in the plant thereby reducing the fuel cost for the owner. A DC-AC converter is used proportional to the rating of PV system for power conversion.
3.6 CDM FOR ECONOMIC SUSTAINABILITY

CDM can be considered as an important mechanism for sustainable development in developing countries. The prime aim of the CDM is to reduce greenhouse gas emissions cost effectively. Due to the global concern over carbon emissions from conventional power generation sources, many countries are pushing for the integration of renewable energy sources into the power generation mix. CO2 emissions can be significantly reduced by progressing towards lower carbon, renewable energy based systems like Solar and Biomass generation systems. 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 [19]. The possible CO2 emission reduction in biomass co-generation system for sugar industries has been estimated through CDM method in this section. Data obtained from Sakthi sugars private limited have been used for the theoretical estimation of Certified Emission Reduction (CER) potential for the existing 32 MW cogeneration plant.

As per Appendix B of simplified modalities and procedures for small scale CDM project activities (http://cdm.unfccc.int/Panels/ssc_wg.pdf), the proposed biomass cogeneration project falls under category : Type I – Renewable Energy Project (small scale) and category : ‘C’ – Thermal Energy for the user. As per the 2006 Intergovernmental Panel on Climate Change [16], the baseline emission calculations are calculated as follows:

The total emission reduction ERy due to the biomass system during a given year y is calculated as follows:

\[ ER_y = ER_{electricity,y} + BE_{biomass,y} + ER_{heat,y} - PE_y - L_y \]

where,

- \( ER_y \): The emissions reductions due to biomass generation in tons of CO2.
- \( ER_{electricity,y} \): The emission reductions due to substitution of coal based electricity generation in tons of CO2.
- \( ER_{heat,y} \): The emission reductions due to substitution of coal for heat displacement in tons of CO2.
- \( BE_{biomass,y} \): The emissions due to natural decay or burning of biomass sources in tons of CO2 equivalents.
- \( PE_y \): The project emissions in tons of CO2.
- \( L_y \): The emissions due to leakage in tons of CO2.
The baseline emissions due to displacement of electricity is obtained by multiplying the net electricity generated in the sugar plant due to bagasse based cogeneration and the CO₂ emission factor.

4 RESULTS AND DISCUSSION

The results of the economic feasibility and environmental benefits through CDM implementation are presented and discussed in the subsequent sub-sections.

4.1 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 4. In the first scenario 31,318 MWh/yr (98%) of electricity is produced by the bagasse generator with a net present cost of 0.14 M$ as it is the existing cogeneration system in the sugar factory. The remaining 2% is purchased from the grid for startup requirements.

The thermal load of the sugar mill is met by the boiler and generator and the monthly thermal production is shown in Figure 3. But, CO₂ emissions are about 497 tons/year, which is due to the power purchases from the conventional grid for the start-up load requirements.

Figure 3. Monthly average thermal production by bagasse cogeneration

The aim of the second scenario is to meet the electricity demand of the sugar industry by biomass system during off-season, when there is bagasse availability is scarce. This configuration produces 6,803 MWh yr⁻¹ of electricity, with consumption of
57,130 tons of biomass feedstock per year. The Net Present Cost (NPC) is about 14 $ and the Levelized Cost Of Energy (LCOE) is 0.11 $ / KWh. Scenario-3 is the proposed hybrid configuration with higher renewable penetration. The proposed system produces 5,290 MWh yr⁻¹ electricity with biomass fuel consumption of 56,854 tons/ year and 3,681 MWh yr⁻¹ electricity with Solar. The surplus power is exported to the grid as per third party purchase agreement. The present tariff for biomass power generation is 0.05 $ in TamilNadu because of which the industry is getting down. The monthly energy purchased and sold from and to the grid is shown in Figure 4.

Figure 4. Monthly purchase and sale to the grid

<table>
<thead>
<tr>
<th>System Architecture</th>
<th>1.500 kW Grid</th>
<th>1.000 kW Inverter</th>
<th>1.000 kW PV</th>
<th>1.000 kW Biomass Generator</th>
<th>Total NPC ($16.786, 419)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Cost Summary</th>
<th>Cash Flow</th>
<th>Electrical</th>
<th>PV</th>
<th>Bio</th>
<th>Converter</th>
<th>Grid</th>
<th>Emissions</th>
<th>Time Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>599.658</td>
<td>0</td>
<td>599.658</td>
<td>1.500</td>
<td>599.658</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Feb</td>
<td>525.195</td>
<td>0</td>
<td>525.195</td>
<td>1.500</td>
<td>525.195</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Mar</td>
<td>516.553</td>
<td>0</td>
<td>516.553</td>
<td>1.500</td>
<td>516.553</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Apr</td>
<td>502.714</td>
<td>0</td>
<td>502.714</td>
<td>1.500</td>
<td>502.714</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>516.857</td>
<td>0</td>
<td>516.857</td>
<td>1.500</td>
<td>516.857</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Jun</td>
<td>520.174</td>
<td>0</td>
<td>520.174</td>
<td>1.500</td>
<td>520.174</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Jul</td>
<td>511.651</td>
<td>0</td>
<td>511.651</td>
<td>1.500</td>
<td>511.651</td>
<td>0</td>
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</tr>
<tr>
<td>Aug</td>
<td>599.684</td>
<td>0</td>
<td>599.684</td>
<td>1.500</td>
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<tr>
<td>Sep</td>
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<td>1.500</td>
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<tr>
<td>Oct</td>
<td>627.274</td>
<td>0</td>
<td>627.274</td>
<td>1.500</td>
<td>627.274</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>Annual</td>
<td>7,370.274</td>
<td>901</td>
<td>7,370.274</td>
<td>1.500</td>
<td>7,370.274</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Source: results from Homer tool

With the proposed hybrid PV-biomass system, the plant can derive more revenue during off-season also. The Net Present Cost (NPC) is $ 16 M$ and the LCOE is 0.124 $ / KWh as seen in Table 4.

Table 4. Cost and emission results

<table>
<thead>
<tr>
<th>Parameters (Units)</th>
<th>Economic parameters and CO2 Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPC(M$)</td>
<td>Scenario 1</td>
</tr>
<tr>
<td>LCOE ($/KW-hr)</td>
<td>0.021</td>
</tr>
<tr>
<td>Operating Cost ( MS/year)</td>
<td>0.14</td>
</tr>
<tr>
<td>CO2 Emissions (tons/year)</td>
<td>497</td>
</tr>
</tbody>
</table>

Source: results from Homer tool

On comparing the three cases, it can be seen that the NPC and COE of the PV-biomass hybrid system is higher than case 1 and case 2 due to the high feedstock rate of Biomass system and high capital cost involved in PV system. This can be ascertained in
the sensitivity analysis, when the renewable fraction (RF) is increased from 10% to 80%. It can be seen from the Figure 5 that the NPC and COE increases with increase in RF % indicated by black rectangle box.

Figure 5. Sensitivity analysis for increase in renewable fraction

Sensitivity analysis for grid connected PV-biomass hybrid system in case 3 is performed with feed in tariff (FIT) as sensitivity variable. FIT is the price fixed for selling electricity to the grid by the private owners. Table 5 describes the variation in operating costs for case 3, as FIT increases. The table elucidate that if FIT value is increased, the net present cost and the operating costs of the system decrease. As the cost of energy (COE) is dependent on the operating cost, increment in the FIT reduces the energy cost. It can be seen that even if renewable energy based generation is increasing, unit cost of energy is reducing confirming the decrease in energy cost with appreciable hike in feed in tariff (FIT).

Moreover, the hybridization of the PV system with Biomass reduces the biomass consumption and improves the performance and operational life of the generator. The operating cost of the PV-Biomass hybrid system is 1.5 M$ lower than that of biomass based generation system which is around 2.6 M $.

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<table>
<thead>
<tr>
<th>FIT ($)</th>
<th>Net present cost ($)</th>
<th>Operating cost ($)</th>
<th>COE ($)</th>
<th>Cost of purchase from Grid (KWh)</th>
<th>Energy sold to Grid (KWh)</th>
<th>REF* (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>16,511,352</td>
<td>1,543,293</td>
<td>0.13</td>
<td>7,612,235</td>
<td>0</td>
<td>45</td>
</tr>
<tr>
<td>0.05</td>
<td>16,73,858</td>
<td>1,540,024</td>
<td>0.123</td>
<td>7,619,066</td>
<td>58</td>
<td>48</td>
</tr>
<tr>
<td>0.10</td>
<td>16,360,596</td>
<td>1,530,609</td>
<td>0.099</td>
<td>7,581,997</td>
<td>11,688</td>
<td>60</td>
</tr>
</tbody>
</table>

*REF- Renewable Energy Fraction. Source: results from Homer tool
The comparison of costs and emissions of the three scenarios as in table justifies the hybrid biomass - solar system to be the most sustainable energy option for the sugar industry. The hybrid system is profitable for the industry with increased value of FIT. Moreover, if the price of the system components is lowered due to the advent of new technologies, renewables will have significant contribution in future.

4.2 ECONOMICAL AND ENVIRONMENTAL BENEFITS

With the power produced from biomass generation system carbon dioxide (CO$_2$) emissions are reduced compared to the emissions from power that would have been generated mainly by coal. About 0.8 to 1.2 kg of CO$_2$ emission reduction per kWh have been reported for the technology implemented in nation wide biomass projects [20]. Implementation of such biomass power projects also can contribute to additional cost savings every year through the sale the CERs internationally. The emission reductions due to biomass generation system in the 32 MW bagasse cogeneration plant is calculated for the year 2014 is as follows:

- Power export to the grid = 126749 MWh
- Southern Region Grid emission factor = 0.850 tCO$_2$/ MWh
- Emission Reduction = $126749 \times 0.850$ tCO$_2$
- $=107736$ tCO$_2$

The project emissions observed during the year is 10,462 tCO$_2$ as per the plant data provided. The Net Emission Reductions by project has been estimated to be 97,274 tons CO$_2$. If the sugar plant taken for case study registers under Clean Development Mechanism (CDM), the total credits for the power producer from the emissions reduced is about 1.4 million dollars per year for 32 MW bagasse cogeneration plant. The carbon credits that would be obtained can be utilized for lowering the financial risks involved in the industry utilizing such renewable energy sources.

5 CONCLUSION

This work aims at the sustainable development through techno-economic feasibility of PV/Biomass hybrid system for sugar industry in the chosen region of Padamathur in Sivagangai district and environmental viability through CDM. It can be concluded that hybrid renewable energy systems can help in reducing the dependency on conventional grid for power supply to the buildings and get additional financial benefits by selling the surplus power. But, green energy generation can be deployed throughout
the country only by incentives and policies of the Government thereby leading to sustainable development.

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REFERENCES


