JOURNAL OF RENEWABLE ENERGY AND SMART GRID TECHNOLOGY
Vol.20, No. 1, January-June 2025

Energy Development Assessment of Biomass Power Plant with Rice Husk Fuel Source in Thailand: Analysis of the Performance, LCOE and Carbon Emissions Reduction

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Article info:

Received: 14 December 2024
Revised: 28 January 2025
Accepted: 25 February 2025
DOI:
10.69650/rast.2024.260099

Keywords:

Biomass Power Plant
Rice Husk
Levelized Cost of Electricity
Electricity Power Generation
System Advisor Model (SAM)

ABSTRACT

This study was conducted from the technical and financial from two rice husk power plants in Thailand. A proposed rice husk power plants use Rankine cycle power plant as a combustion configuration for electricity generation. The simulation in this research uses the System Advisor Model (SAM) to study the plant performance and financial analysis. This research investigates by using input technical plant data, and the financial variable assumptions. The results in this research can be concluded that the LCOE (the Levelized cost of electricity) of the electricity generation from the rice husk power plants at 6.62-6.63 ¢/kWh. The potentials of CO_2 reduction of rice husk plants in this study are 38,319 tons/year for plant A, and 53,923 tons/year for plant B. These results can be used as a useful tool for developing strategic plans for biomass power plants in Thailand.

1. Introduction

Rice husk is the outer shell of the rice grain, removed during the milling process. It's a by-product of rice production and is often considered a waste product.

1.1 Rice Husk Used for Electricity Generation Technology [1]

1) Combustion: Rice husk can be burned directly in a biomass boiler to produce steam, which drives a turbine to generate electricity. This is a common method due to its simplicity and direct use of the biomass.

2) Gasification: This process converts rice husk into a combustible gas (syngas) by heating it in a low-oxygen environment. The syngas can then be used to drive a gas turbine or engine for electricity generation.

3) Pelletization: Rice husks can be compressed into pellets, which can be more efficient for combustion and transport. These pellets are then burned in a biomass power plant.

1.2 Benefits for Thailand

1) Sustainability: Utilizing rice husks for energy helps reduce waste and decreases dependence on fossil fuels. Thailand's large rice industry provides a steady supply of husks.

2) Economic Benefits: It can create jobs and stimulate the local economy, especially in rural areas where rice is grown.

3) Energy Security: By harnessing locally available biomass, Thailand can improve its energy security and reduce energy imports.

4) Environmental Impact: Burning rice husks emits less carbon dioxide compared to fossil fuels. Additionally, it helps manage agricultural waste, reducing the risk of environmental pollution

1.3 Potential of rice husk for power generation in Thailand

Thailand is one of the world's largest rice producers, generating around 20 million tons of rice annually. This results in a substantial amount of rice husk, estimated at approximately 4-5 million tons per year. The steady supply of rice husks offers a reliable and consistent feedstock for power generation throughout the year. Rice husks have an energy content (LHV) of about 14-16 MJ/kg [1], which is lower than some other biomass materials but still significant. When processed properly, they can effectively be used for power generation. Modern combustion technologies and biomass power plants can handle rice husks efficiently. Advanced designs, such as fluidized bed boilers, can improve combustion efficiency and reduce emissions.

1.4 Literature reviews

The Levelized Cost of Electricity (LCOE) for a biomass power plant can vary widely depending on several factors including the technology used, feedstock availability, plant location, scale, and specific project conditions. Advanced technologies might have higher capital costs but could offer better efficiency and lower operating costs. As of the latest data, the LCOE for biomass power plants typically ranges from about $60 to $120 per megawatt-hour (MWh). The project of biomass gasification can achieve a short term simple and invest payback and lower LCOE when compares to direct combustion technology [2]. The biomass power plant fed with rice straw can achieve the nominal and real LCOE of 10.55 and 6.33, respectively [3]. Four renewable energy modeling tools, SAM, PVsyst, HOMER, and RETScreen, were used to model in comparisons in solar photovoltaic systems (PVS), wind turbine systems (WTS), and solar photovoltaic-wind turbine hybrid systems (PVWHS) for residential applications in Thailand [4-5]. A biomass Rankine cycle power plant fed with rice straw fuel, and the model simulated its performance using the System Advisor Model (SAM). Based on the simulation, the average nominal Levelized Cost of Electricity (LCOE) is 0.1055 USD/kWh, and the average real LCOE is 0.0633 USD/kWh. SAM model can be used in solar thermal energy integrated with fossil fuel power plant simulation systems. The integration of solar thermal energy into the Besmaya Natural Gas Combined Cycle (NGCC) power plant, located in Baghdad, Iraq., the results show that the fossil-based power plant has a generation capacity of 750 MW. Initially, the Natural Gas Combined Cycle (NGCC) power plant was estimated to produce 2,119,318 tons of CO_2 per year. However, with improvements in the new configuration by the integration of the system with a solar thermal power plant, the new system can reduce CO_2 to 18,064 tons per year [6]. SAM (System Advisor Model) simulator is a powerful tool that helps assess not only the LCOE values but also the financial feasibility of energy projects, particularly in the renewable energy sector. SAM simulation case in Colombia showed that heat transferred by the boiler by using a rice husk fuel source with a capacity of 3,180 kW and with an efficiency ranging from 50% to 52% throughout the year. This means the rice husk can generate both electricity and thermal energy. The financial analysis indicated that the internal rate of return (IRR) was 6% higher than the opportunity interest rate (OIR), making the project a financially promising investment [7].

1.5 Feed-in tariffs for electricity generation from biomass

As of the most recent updates, Thailand offers feed-in tariffs for electricity generation from biomass to encourage the development of renewable energy. The feed-in tariffs rates and application procedures, are controlled by the Energy Regulatory Commission (ERC) of Thailand, the Ministry of Energy. The feed-in tariffs rates for biomass power generation in Thailand have been generally around THB 2.5 to THB 4.0 per kWh (0.09 USD/kWh) [5]. The feed-in tariff system for rice husks and other biomass sources in Thailand has played an essential role in supporting the growth of renewable energy, particularly in agricultural regions where rice husks are abundant. The feed-in tariff rate is given to renewable investors that can have an initiation for investment for profit. Internal rate of return (IRR) is commonly used for the measurement of the profitability of the project. And, also the Net Present Value (NPV) is widely used to measure the inflows and outflows of cash over the lifetime of the project. It is normally the NPV value must be positive that is required to initiate an investment in the project [8].

2. Methodology

This research uses input data needed to perform the economic analysis are investment cost and initial capital cost, operations cost and maintenance costs, fuel cost (rice husk) including the transportation cost and the storage cost. The rice husk power plants in this research located in two provinces in the northeastern area of Thailand with the installed capacity of 12.4 MW and 17.4 MW, respectively. The direct combustion technology of rice husk power plant is shown in Figure 1.

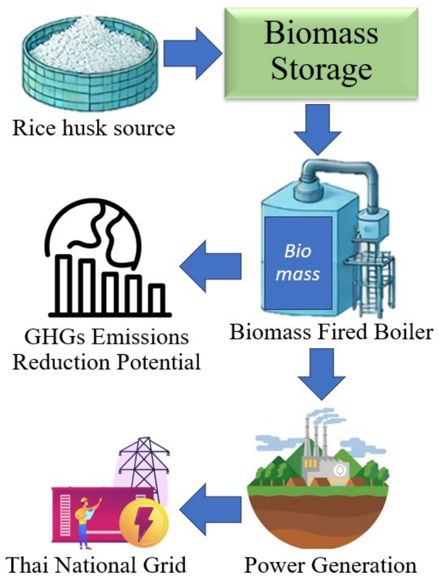

Fig.1 Rice husk power plant configuration.

2.1 Energy output

The model calculates the annual electricity generation output E by the following formula;

$$E = \sum_{0}^{8760} Q \times \eta \times t \tag{1}$$

where
E is the net annual output in kilowatts-hours (kWh).
t is the time (hour).
η is the Ranking cycle efficiency.

LHV is calculated subtracting the latent heat of vaporization of water in the fuel sources, the relation of HHV (higher heating value) and LHV (lower heating value) calculated by the following formula;

$$LHV = HHV - latent\ heat\ of\ vaporization \tag{2}$$

2.2 Economic Analysis and SAM Energy Model

The economic feasibility is estimating the $LCOE$ using the SAM energy model [9]. The $LCOE$ is the electricity cost of the rice husk power plants, is estimated based on the period of 25 years lifetime of power plant installation. $LCOE$ is calculated by the following equation;

$$LCOE = \frac{Initial\ costs + \sum_{n=1}^{N} \frac{Annual\ cost_n}{(1+d)^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d)^n}} \tag{3}$$

where N is the economic lifetime of the project; n is a point in time (n = 0 means year 0); d is the discount rate; Q is the annual electricity generation (kWh). The annual cost consists of the fixed cost, the variable cost, and the fuel cost. This present value of the sum of the operating expenses is called OPEX while the initial costs is called CAPEX.

LCOE is the net present value of the total life time costs of the renewable energy project divided by the quantity of energy generated over the project life time.

Nominal discount rate is calculated by the following formula;

$$r_{nominal} = [(1 + Inflation\ rate) \times (1 + r_{real})] - 1 \quad (4)$$

2.3 SAM energy model literature reviews

System Advisor Model (SAM) is a software tool developed by the U.S. Department of Energy (DOE) that helps evaluate the performance and financial viability of renewable energy projects. It can be used to estimate LCOE for different renewable energy systems by modeling both the system's performance and the costs involved in building and operating the system. SAM energy model is used in this research, studying the economic feasibility of the rice husk power plants with the analysis of estimating the LCOE from rice husk fuel sources. The LCOE in this research is estimated through the period of the rice husk power plants of 25 years. It is estimated by calculating the present value of all costs during the lifetime of the power plant divided by the present value of the total amount of energy produced during the lifetime of the power plant. So LCOE is defined as the net present value of the unit cost of electricity through the period of the rice husk power plant. LCOE is normally expressed as dollars per unit of electricity generation (USD/kWh). The cost data input for LCOE calculation includes capital cost (cost of initial power plant installation), cost of fuel (rice husk cost), and operation and maintenance costs.

The explanation of how to calculate the Levelized Cost of Energy (LCOE) using SAM:

1) Set Up the Project Details:

First, The plant designers choose the type of renewable energy (like solar, wind, or geothermal). Then, define the key project details, such as the system size (e.g., how much power it will produce) and where it will be located. The system needs the providing data on the available resources in that location (like how much solar energy or wind energy). The system needs things like system efficiency and any factors that could affect how the system performs.

2) Input Financial Information:

Next, designer needs to provide financial details: the initial cost to build the system, the ongoing costs to operate and maintain it, and any other financial factors like interest rates or tax incentives.

And then also set the project's expected lifetime and choose a discount rate to account for the fact that money today is worth more than money in the future.

3) Estimate Energy Production:

SAM will use the resource data (like solar potentials or wind patterns) to estimate how much energy in the system will produce over its lifetime. It will simulate the system's performance based on factors like local weather, system efficiency, and potential losses.

4) Calculate the LCOE:

LCOE is calculated by dividing the total costs of the system by the total energy it will produce over its lifetime. This gives you the cost per unit of energy (like how much to pay per kWh or MWh of electricity). The LCOE nominal values are affected by the real LCOE depending on the real discount rate and the inflation rate in each country. The values of both nominal LCOE and real LCOE in larger power plant capacity are significantly lower than those of the smaller ones. In the research study of the conversion in combustion technology for converting the rice straw fuel sources to electricity generation with the installed capacity ranging from 5, 8, 10, 15, and 20 MW in Thailand, the results showed that it can generate the cost of electricity with 0.0899, 0.0789, 0.0768, 0.0725, 0.0676 USD/kWh respectively [10].

2.4 Emissions Reduction

The potential of CO_2 reduction can be calculated with based on the national grid emission value, in this research uses grid emission from power generation in Thailand of 0.4857 kg/kWh, data from Ministry of Energy in 2022 [11].

The emission reduction of CO_2 can be calculated from the following formula;

$$CO_2\ reduction = Annual\ electricity\ generation \times Grid\ emission \quad (5)$$

2.5 Rice husk power plant descriptions

Rice husk power plants under this study are two plants (plant A and Plant B). Rice husk power plant A located in the Eastern area of Thailand (Surin province). The technology used in power plant A is direct combustion. In this process, rice husks are burned to generate heat, which is then used to produce steam. The steam then drives a turbine connected to a generator, producing electricity. With the installation of a high efficiency and environmentally friendly step-grate combustion system that can burn a wide range of biomass fuels. The project is estimated to consume about 81,034 tons of rice husk fuel annually. Power plant A can generate electricity with the amount of 93.008 GWh/year at an annual capacity factor of 85.8%. The rice husk fuel source can be available from within the province and from nearby provinces. Power plant B is located in the Northern area of Thailand (Pichit province). This power plant also has a simple power cycle consisting of a boiler, turbine, and generator as the system in power plant A using a direct combustion technology. Power plant B can generate electricity in the amount of 130.882 GWh/year at an annual capacity factor of 85.9%. The power plant B consumes rice husk as a main fuel source of about 113,909 tons annually. The fuel source can be available from Pichit province and from nearby provinces such as Nakhon Sawan, and Kamphaeng Phet within a radius of 100 kilometers. More details in technical values for power plant A and power plant B are shown in Table 2. The time frame of both the technical input data and finance input data [12] in this research is based on the data in the year 2022.

3. Results and discussion

On the basis of the plant performance and financial data inputs (in Table 1), the annual energy generation and the LCOE, for the lifetime of 25 years of the projects have been investigated for rice husk power plants. The economic analysis also considers the factor of the inflation rate and the discount rate in this calculation. Table 1 represents the cost data required for the calculation of the economic analysis using SAM model. The economic input assumptions and the output results are shown in Table 1 and Table 2, respectively. Both nominal LCOE and real LCOE in rice husk power plant B are lower than the values in power plant A. The nominal LCOE value is higher than that of the real LCOE shown in Table 1 and Table 2, this is because the nominal LCOE is related to the inflation rate described in equation (5). So it can be determined that when the inflation rate is 0%, the nominal LCOE value is equal to the real LCOE. The LCOE results in this research can be discussed as comparable with other literature in Thailand, for example, the study in the conversion in combustion technology for converting the rice straw fuel sources to electricity generation with the capacity installation of 15 and 20 MW, the results showed that it can generate the cost of electricity (real term values) with 0.0725, 0.0676 USD/kWh respectively [10]. The costs of electricity are a few higher than the values in this research, it is because biomass (rice straw) with higher costs of fuel transportation and fuel storage than that in this study. In summary, the LCOE or the cost of electricity in biomass power plants depends on capital investment cost, cost of fuels (with fuel transportation and fuel storage cost), and operation and maintenance costs. Also, the real discount rate plays a role in the values of both the nominal LCOE and real LCOE while the inflation rate directly affects the values of nominal LCOE.

However, real LCOE has normally been used as a basis for electricity cost generated from renewable energies in comparisons from one country to other countries, it is because it does not include the inflation rate in its calculation. And the inflation rates can be varied in different countries. Interestingly, the average real LCOE of electricity generated from biomass fuel in Egypt can be competitive with the electricity cost from other fuel resources. SAM simulation software is used for the technical and economic feasibility study and can be used with a mixed integer linear programming (MILP) model and can be proposed and applied to optimally design in biomass power plants. The results of this research show that Egypt has enough agricultural residues to produce 10 million tons of dry biomass each year, which could generate 11 TWh of electricity annually. The Levelized Cost of Electricity (LCOE) is around 0.0677 per kWh. For example, LCOE from fossil fuels is 0.085 USD/kWh while LCOE from solar PV is 0.083 USD/kWh, LCOE from wind energy is 0.055 USD/kWh, and LCOE from biomass resources is only 0.0677 USD/kWh [13]. The assessment results show that biomass power plants are a practical and affordable way to generate sustainable development from renewable energy.

Table 1 Economic model input assumptions.

Parameters	**Data**	**Reference**
Lifetime	25 years	Plant data, [3]
Fuel cost	25 USD/ton	Plant data, [3]
Inflation rate	6.08%	Bank of Thailand [12]
Real discount rate	9.0%	Bank of Thailand [12]
Logistics cost		
Distance-delivery cost	4 USD/ton	Plant data and [3], [13]
Variable delivery cost	0.06 USD/ton -mi	Plant data and [3], [13]
Direct capital cost		
Boiler(s) cost	500 USD/kW	Plant data and [3], [13]
Generator cost	320 USD/kW	Plant data and [3]
Rice husk storage cost	180 USD/kW	Plant data and [3]
Other equipment cost	185 USD/kW	Plant data and [3], [13]
Engineering, and construction cost	15% of direct cost	Plant data and [3], [14]
Land cost	5% of direct cost	Plant data and [3], [14]
Total installation per capacity cost	1577 USD/kW	Plant data, and [3],[13]
Total operations, maintenance cost		
Fixed cost	28 USD/kW	Plant data and [3], [15]
Variable cost	3.5 USD/MWh	Plant data and [3], [15]

The data in Table 3 show the greenhouse gas emission (GHG emissions) in the process of electricity generation in different technology. The electricity generated with fossil fuels such as coal and natural gas (CCGT) can release high GHG emissions (CO_2, SO_2, and NOx). However, when compares among renewable resources such as biomass, solar PV, wind power, large hydro, and small hydro. Biomass power plant technology is one of interesting choices for electricity generation in sustainable energy development in Thailand. The potentials of CO_2 reduction of rice husk plants are 38,319 tons/year for plant A, and 53,923 tons/year for plant B. The benefits of using rice husks resources are a renewable resource, as they are a byproduct of an agricultural process of milling. Using rice husks for energy helps reduce reliance on non-renewable fossil fuels. It also provides an additional revenue for rice farmers by creating a market for what would otherwise be waste.

From the results of this research can be discussed that the SAM energy model can be used as a tool for the calculation of both real and nominal levelized cost of electricity (LCOE) values. The input values from Table 1 are obtained from plant data and the references while we can get the output values by SAM energy

Table 2 Overall outputs and plant performance and financial values.

	Performance data and Financial output data	Plant A	Plant B
Performance	Annual biomass (tons/year)	81,034	113,909
	Annual Energy producing (GWh)	93.008	130.882
	Plant Capacity (MW)	12.367	17.385
	Annual Capacity Factor (%)	85.8	85.9
	Net heat rate (GJ/MWh)	13.53	13.53
	Average boiler efficiency (%)	81.1	81.1
	Thermal efficiency (%)	28.4	28.5
Financial data	LCOE nominal (¢/kWh)	10.40	10.39
	LCOE real (¢/kWh)	6.63	6.62
	Total cost (million $)	19.506	27.420
	Fuel cost, rice husk ($/ton)	40.0	40.0
	Average rice husk price (¢/kWh)	3.48	3.48
	Performance data and Financial output data	Plant A	Plant B

Table 3 Greenhouse gas emissions by different technologies [16].

Energy sources	CO_2 emissions g/kWh	SO_2 emissions g/kWh	NOx emissions g/kWh
Coal	955	11.8	4.3
Natural gas (CCGT)	430	-	0.5
Solar PV	98-167	0.2-0.34	0.18-0.30
Large hydro	3.6-11.6	0.009-0.024	0.003-0.006
Small hydro	9	0.03	0.07
Biomass power	17-27	0.07-0.16	1.1-2.5
Wind power	7-9	0.02-0.09	0.02-0.06

CCGT: Combined Cycle Gas Turbines

model simulations in Table 2. These LCOEs both real and nominal levelized costs of electricity can be used as a key decision maker for investment in biomass fuel sources for electricity generation in Thailand (in rice husk power plant). Rice husk power plants in Thailand offer a renewable, relatively low-cost option for electricity generation, especially in regions where rice production is high and rice husks are abundantly available. The LCOE can be competitive compared to fossil fuel-based power generation. The cost of capital (interest rates on loans, equity return) will impact the LCOE. In Thailand, financing conditions for renewable projects may be initiated by government incentives, such as feed-in tariffs or other financial support. CO_2 emission reduction potentials due to the electricity generated by rice husk power plants and calculated by multiplication of the total amount of energy production with the national grid emission factor. In this study, CO_2 emission reduction potential in rice husk plant A and plant B was calculated by using the national grid emission factor of 0.412 kg/kWh with annual electricity generation of 93.008 GWh/year and 130.882 GWh/year in plant A and plant B, respectively. So, the results of CO_2 emission reduction potential in rice husk are 38,319 tons/year for plant A, and 53,923 tons/year for plant B. Biomass power plants play an important role in CO_2 emission reduction potential in Thailand. From the statistical data in 2022 [11], biomass power plants can generate electricity to the grid with a total installation capacity of 3,759.4 MW. It has been summarized that this can produce electricity to the grid totally of 20,228.8 GWh. This amount of electricity generation from solid biomass which can be classified by fuel sources 12.06% from rice husk, 51.45% from sugarcane, 32.71% from other agricultural residual waste, and 3.78% from others (such as black liquor). So, this can calculate the overall potential of rice husk power plants in Thailand with a total electricity generation of 2,439.59 GWh. So, it can simply calculate the potentials of CO_2 emission reduction by multiplication this value with the national grid emission factor in this research, as shown in equation (5). It can be summarized that rice husk power plants in Thailand have CO_2 emission reduction potentials of 1.005 million tons/year. However, when comparing to the total CO_2 emissions (mostly from natural gas 58.28%, coal and lignite 40.78%, and oil 0.94%) of 88.889 million tons/year in the power generation sector in 2022, it is only 1.13% that rice husk power plants can reduce this CO_2 emissions.

4. Conclusion

In summary, the potential for rice husk-based electricity generation in Thailand is substantial, offering environmental, economic, and social benefits. Rice husk is already being used in several biomass power plants in Thailand. These plants convert rice husk into electricity, helping to meet the country's growing energy demands while promoting sustainability. Additionally, Thailand has been exploring the potential of rice husk as part of its renewable energy strategy to reduce dependence on fossil fuels. With continued technological advancements and supportive policies, rice husks can play a significant role in Thailand's renewable energy. This study was conducted from technical and financial of two rice husk power plants in Thailand. SAM software is used to study the plant performance and financial analysis. Rice husk power plants typically have moderate to high capital costs due to the need for specialized equipment for biomass combustion, electricity generation, and the handling and storage of rice husks. The availability and consistency and the distance of rice husk as a fuel source also impact these costs. The cost of rice husks is also depending on local availability and transportation costs. In this study, Two rice husk power plants have installed capacity of 12.4 MW and 17.4 MW can generate electricity of 93.008 GWh/year and 130.882 GWh/year in plant A and in plant B, respectively. The average boilers efficiency is 81.1% of both power plants. The results in this research can be concluded that the real LCOE (the Levelized cost of electricity) of the electricity generation from the rice husk power plants at 6.62-6.63 ¢/kWh, and the nominal values of LCOE at 10.39-10.40 ¢/kWh. The CO_2 reduction potentials of rice husk power plants in this study are 38,319 tons/year for plant A, and 53,923 tons/year for plant B. Biomass energy, including rice husks, is considered carbon-neutral. The CO_2 emitted during combustion is roughly equivalent to the CO_2 absorbed by the rice plants during their growth. Thus, the use of rice husks for power generation can help mitigate the carbon footprint compared to burning fossil fuels. So electricity generation from rice husk power plants offers a combination of economic, environmental, and social benefits for Thailand. They support sustainable development by utilizing local agricultural waste for renewable energy, improving energy security, creating jobs, and reducing environmental pollution. Given Thailand's vast rice production, rice husk power could play an important role in the country's energy transition and long-term sustainability goals. Thailand's involvement in renewable energy projects may also position the country as a regional leader in clean energy technology.

Acknowledgements

The author would like to acknowledge Bangkokthonburi University and Rajamangala University of Technology Suvarnabhumi, Nonthaburi for the financial support rendered for the conduct in this research.

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