Evaluation of Techno-economic and Environmentally Sustainable Renewable Energy Potential of Rice Processing Plant

By

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Reg # 00000277417

Session 2018-20

Supervised by

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Abstract

Increasing energy demand, fuel costs, emissions, and global warming of industrial sectors are the key drivers driving green and cleaner energy production. Owing to limited resources, electricity extracted from fossil fuels is not a viable energy source, due to which a sustainable and cost-effective energy production system must be strengthened. Two scenarios, (a) biomass fuel feedstock, and (b) solar PV system, are studied to evaluate techno-economic and environmentally feasible solutions for a rice processing plant. The biomass situation is further sub-divided into three scenarios (100% rice, 100% wood, 50-50% rice and wood) as fuel feedstock, resulting in 19% fuel cost reduction and 98.1% GHG emissions reduction by proposing 100% rice fuel feedstock to be a viable option in biomass fuel feedstock. The second scenario focuses on a 1MW solar PV installation that is divided into company-owned and 75% bank-financed systems, generating 1,544 MWh and 2,034 MWh of electricity exported to the grid for fixed and two-axis systems, respectively, with GHG emission reduction potential of 632 tCO_2 with a payback period of 2.7 years for fixed axis and 832 tCO_2 for two-axis solar PV systems with a payback period of 3.2 years. The best option for industrial facilities is biomass-based rice husk fuel feedstock, which is locally accessible and has a total GHG emission reduction potential of 84% of the whole process, making it the best conceivable scenario for policymakers to incorporate.

Keywords: Renewable Energy; Industrial Energy Management; Solar Photovoltaic System; Biomass; Greenhouse gases; RETScreen

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List of Abbreviations

GHG	Greenhouse gas
PV	Photo Voltaic
η_P	Optimum Efficiency
η_r	Array Efficiency
β	Temperature Co-efficient
T_c	Monthly Average Solar Cell Temperature
T_r	Reference Temperature
NOCT	Nominal Operating Cell Temperature
K_t	Clearance Index
T_α	Ambient Dry Bulb Temperature
V_{mp}	Maximum Power Voltage
I_{mp}	Maximum Power Current
V_{oc}	Open Circuit Voltage
I_{sc}	Short Circuit Current

List of Publications

1. **Jamsheed Sajid**, Muhammad Bilal Sajid, Muhammad Muneeb Ahmad, Muhammad Kamran, Naveed Ahmed, Mariam Mahmood, Akhtar Abbas "Energy, economic, and GHG emissions assessment of biomass and solar PV systems for an industrial facility". Renewable Energy. Submitted: 09 November 2021. Under Review: 11 November 2021.
2. Ahmad Ayaz, **Jamsheed Sajid,** Naveed Ahmed "Performance Investigation of novel Improved Cooking Stove Model for cold rural population". In 1st International Conference on Energy, Power and Environment (ICEPE-2021)**.** Presented: 11 November 2021.
3. Yasir Saleem, **Jamsheed Sajid,** Naveed Ahmed "Thermal analysis of sensible heat thermal energy storage system using circular-shaped slag and concrete for medium to high-temperature applications". In 1st International Conference on Energy, Power and Environment (ICEPE-2021)**.** Presented: 11 November 2021.

CHAPTER 1

Introduction

1.1 Background

Pakistan's current electricity generation is oriented towards thermal power plants, mainly powered by imported fossil fuels, especially coal, fuel oil, and LPG. Aside from carbon emissions, it has a substantial economic situation and volatile oil prices in its oil market prices. There is a need for indigenous sources of renewable sources to achieve financial stability to fill the supply-demand gap.

Rising energy consumption, environmental emissions, and CO2 emissions are the key factors that accelerate green and sustainable energy supplies [1]. In the twenty-first century, the world's developed and emerging economies are fighting with dual-energy challenges: engaging in a sustainable energy technologies system and meeting the needs of people who have lacked access to basic energy systems. The International Energy Agency report states that global primary energy demand will rise by 53% in 2030, and around 70% of this is expected to contribute from developing nations [2]. Renewable energy is a critical option for addressing energy scarcity and lowering greenhouse gas (GHG) emissions. Several technologies, such as solar energy, wind energy, geothermal energy, and biomass energy, have been implemented worldwide; however, renewable energy suitability depends on the in situ conditions rather than being universal [3].

1.2 Renewable Energy Contribution

The bulk of carbon dioxide (CO2) emissions are due to coal, diesel oil, and fossil fuels, which started rising during the Industrial Revolution due to many industries startup worldwide. Due to cement processing and fossil fuel usage, there have been more than 400 billion tons of CO_2 emissions since 1751. On the other hand, renewable energy is one of the best sources to achieve climate goals. Unlike non-renewable fuels, renewable

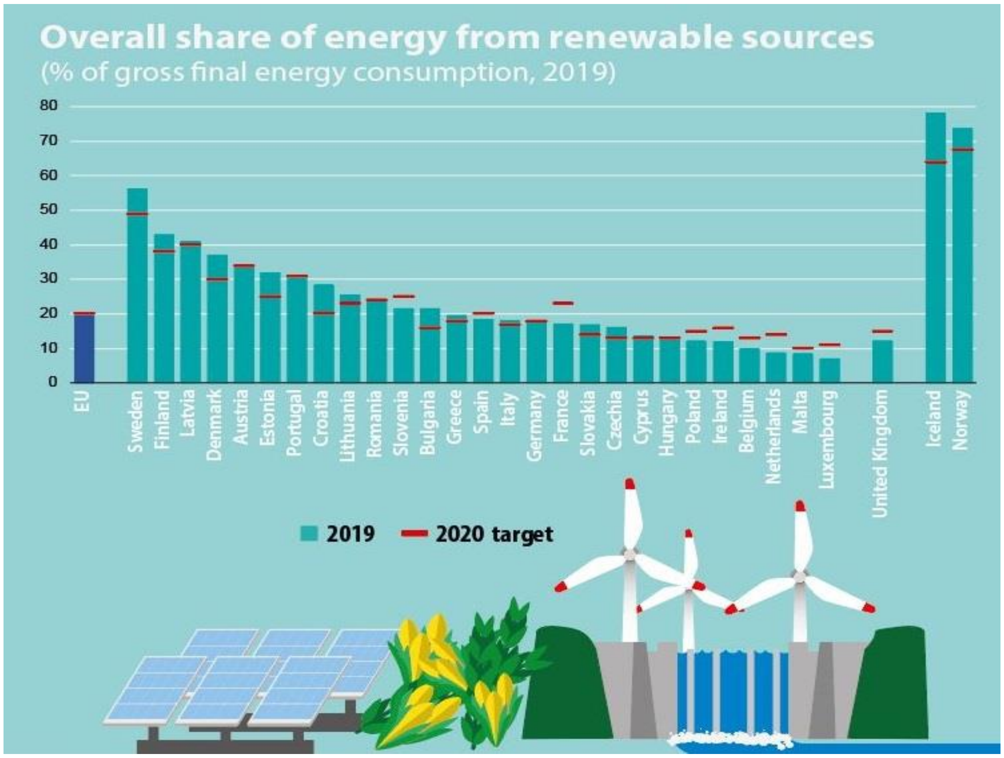

Figure 1- 1 Overall share of energy from renewable sources [15]

energy has power, economic and environmental protection benefits [4]. The overall share of energy from renewable energy resources are shown in Figure 1-1.

In 2017, renewable energies accounted for 54.5% of total energy consumption in Sweden, 41% in Finland, 35.8% in Denmark, 28.1% in Portugal, 18.3% in Italy, and 16.3% in France [4].

1.3 Biomass as a source of energy generation

Energy plays a vital role in socio-economic growth by enhancing the quality of life and raising living standards [5]. Humankind has used different energy sources, from coal, wood, oil, and nuclear to petroleum power, at various evolution stages. In recent years, political and public fear about energy and environmental protection has contributed to the better and brighter future of renewable energy resources. One of the best solutions to this complex issue and achieving a sustainable energy mix source is biomass [6]. Electricity generation through biomass is thought to be the best possible solution for commercial biomass exploitation due to its high content of power production in nature. Cogeneration technology is a viable choice for power generation due to the sequential use of fuel to generate electricity and steam in process industries like paper, rice mills, and sugar industries [7]. Pakistan's government is looking for an alternative energy source that should be cost-effective and environment-friendly to maintain economic stability and address the current energy crises. Renewable energies made up 1.1% of the country's overall energy mix in 2018, and the government has set a goal to increase its share by 5% until the year 2030 [8]. Biomass accounts for a contribution of 10-15% of all energy consumed worldwide; it accounts for up to 90% in some developing countries [9].

By enhancing energy sustainability and avoiding climate change, the Europe 2020 plan aims to, among other things, build a prosperous and increasing low-carbon economy. Promoting renewable energies, especially wood and wood waste, is critical to achieving this aim, with bioenergy, in particular, expected to play a vital role. Biomass can help minimize direct greenhouse gas emissions (GHG) compared to fossil fuels; however, the entire life cycle's consequences are less pronounced [10]. When combined with a traditional system or any other modern method of electricity generation such as solar, wind, or biogas, Biomass energy can lower energy costs and CO2 emissions because it is a more efficient and environmentally sustainable technology [11].

1.4 Solar PV Electricity Generation

PV technology is used to generate electricity in many countries worldwide, as shown in Figure 1-2. There has been a massive increase in the installation of solar PV systems in the residential, commercial, and industrial sectors throughout the world because of improvements in solar PV system efficiency, lower initial costs, and shorter payback periods, global cumulative PV installed capacity rose from 1.3 GWp in 2002 to 229.5 GWp in 2015. The global PV cumulative installed capacity increased by 50.909 GWp (29%) in 2015 compared to 2014. The annual rise in 2012, 2013, and 2014 was 43%, 38%, and 28%, respectively. China remained the world leader in PV installation in 2015, with a total installed capacity of 43.5 GWp, as shown in Table 1-1 [12].

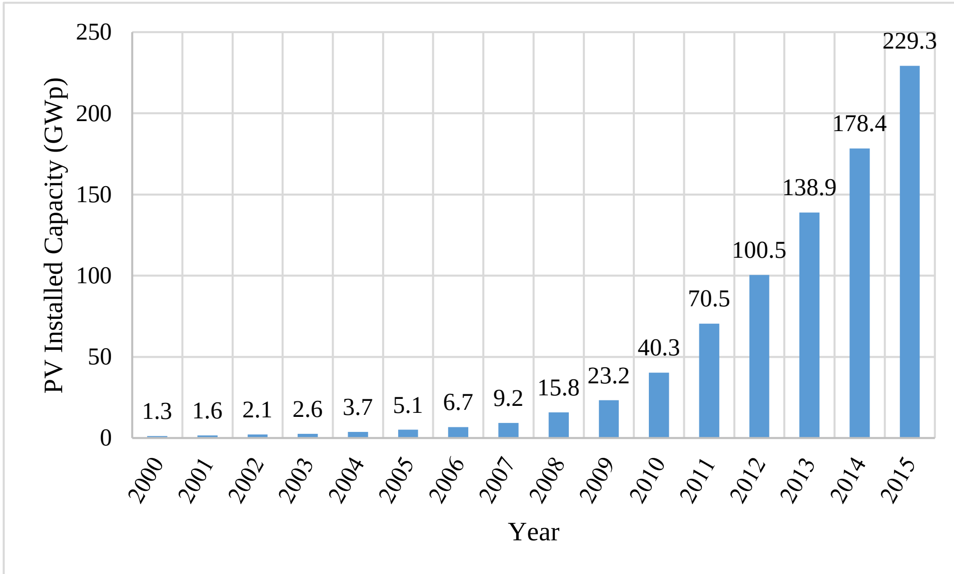

Figure 1- 2 Global cumulative PV installed capacity [12]

The increase in renewable energy-generated electricity from 2009 to 2019 is primarily due to expanding three renewable energy sources across Europe: solar power, wind power, and solid biofuels (including renewable wastes). Hydropower and wind accounted for 70% of the generation capacity from renewable sources, solar power at 13%, solid biofuels at 8%, and other renewable sources at 9%. Solar power is the fastest-growing source, accounting for 1% of all electricity in 2008. This means solar-generated electricity has increased dramatically, from 7.4 TWh in 2008 to 125.7 TWh in 2019 [13].

Table 1- 1 National cumulative PV installed capacity of top countries [12]

Country	National PV installed capacity (GWp)
China	43.5
Germany	39.7
Japan	34.4
United States of America (USA)	25.6
Italy	18.9
United Kingdom (UK)	9.1
France	6.6
Spain	5.4
India	5.2

PV equipment is effective in remote areas, including Public Park lighting, cathodic safety on pipelines, utility peak load shaving, telecommunication towers, exterior home lighting, and various other applications [14].

1.5 Scope of the study

This work analyzes the renewable energy potential of Iqbal Rice Mills (Pvt.) limited. The study's primary focus is to provide a techno-economic and environment-friendly solution for penetrating biomass fuels in the industry.

I. Energy efficiency analysis
II. Economic feasibility analysis
III. Emission reduction analysis

1.6 Organization of the thesis

- Chapter 1: Introduction

Global Energy Efficiency, Renewable energy, Biomass, Solar energy, Justification of research, Objectives

- Chapter 2: Literature review

Global Energy requirements, Biomass as boiler fuel around the world, Biomass potential in Pakistan, Solar PV technology in the globe, Solar energy progress in Pakistan, solar radiations

- Chapter 3: Methodology

Industrial sustainability assessment, RETScreen software modeling, Structure flow of research, the approach of study

- Chapter4: A case study

Historical data collection and usage

- Chapter 5: Results and Discussion

Formulation of major parameters, Graphical representation of results

- Chapter6: Conclusion

Conclusion and Future work

Summary

This chapter gives a brief introduction of energy technologies and renewable energy contributions to power generation globally. The subsequent sections shed some light on energy management using biomass and solar PV systems for energy generation.

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CHAPTER 2

Literature Review

2.1 Biomass as a Fuel for Boilers

Any fuel that is to be used for industrial boilers should be evaluated based on specific characteristics such as cost, availability in varying weather, political conditions, transportation, storage, and boiler technology that utilizes the fuel [1]. Industries worldwide are searching for alternative fuels to replace traditional fossil fuels, i.e., coal, oil, and natural gas. This is due to the volatility in their prices and availability, in addition to the concerns related to the negative environmental impacts of such fuels.

Biomass is one of the earliest energy sources due to its affordability and widespread availability. When biomass is burned directly as a fuel, or it is converted into other types of fuels (e.g., ethanol, methane), carbon dioxide is released into the atmosphere, which is equal to the amount that was absorbed from the atmosphere during plant growth, thus creating a closed carbon cycle or zero carbon emissions (Figure 2-1). Naturally, the decomposition of biomass in the environment will release the same amount of carbon dioxide. As opposed to that, burning fossil fuels releases large quantities of non-biogenic carbon dioxide into the atmosphere, ultimately contributing to climate change.

There are two significant biomass sources: energy crops and waste residues such as forest residues, wood chips, and rice husk. Conventionally, the essential fuelwood sources are woody residues and waste collected from timber industries such as particleboard, sawmills, and pulp mills. In recent times, the use of risk husk and rice straw has increased considerably as these are low cost, and their service has no impact on food price, thus avoiding the 'food versus fuel' debate. Moreover, rice husk is abundantly available, being a vital food crop [2].

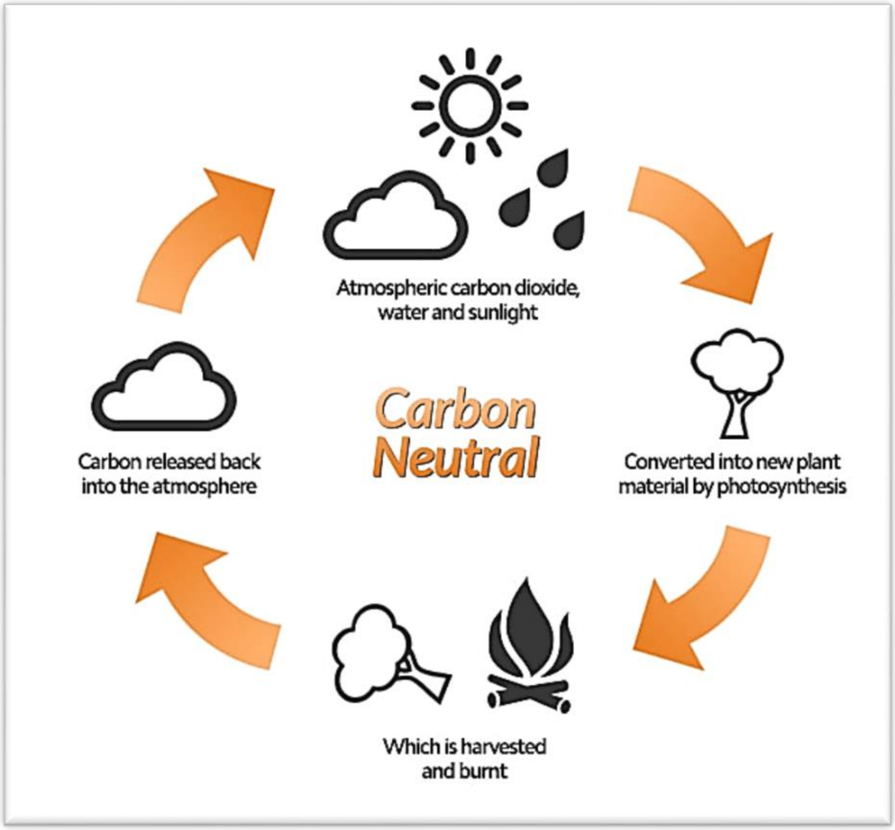

Figure 2- 1 Carbon neutral cycle (Adopted from [3])

Biomass co-firing is a technique where coal and biomass are combusted together. This can help industrial boilers substitute fossil fuels, decreasing fuel costs and minimizing harmful emissions while enhancing boiler efficiency. There are three different methods to implement the co-firing technique [4]:

1. Direct co-firing in which mixture biomass and coal are prepared and then fed to the boiler.
2. Parallel co-firing is a technique in which biomass is fed to the boiler separately from coal without affecting the conventional system.
3. Indirect co-firing involves gasification of biomass which is then utilized in a boiler.

Direct co-firing is the most widely used technique as it is cost-effective and straightforward, whereas indirect co-firing is complex but provides a high level of fuel flexibility [4].

2.2 Literature on Biomass-based Boilers

Numerous studies have evaluated the techno-economic feasibility of installing biomass-based boilers in industrial facilities. Chau et al. [5] conducted a techno-economic analysis of a wood pellet boiler to provide a British Columbia greenhouse heating. Results indicated that using a wood pellet boiler to meet 40 percent of the annual heating load is more cost-effective than using a natural gas boiler to complete the entire demand. In addition to that, a wood biomass boiler can reduce over 3000 tons of CO_2 equivalents of greenhouse emissions per year. Nunes et al. [6] studied the energy efficiency potential of employing biomass boilers in Portugal's textile industry. It was found that a transition from conventional fuels such as propane gas, naphtha, and natural gas to wood chips can result in 35% savings in energy costs associated with steam generation. Shen et al. [7] analyzed different techniques to address industrial boilers' energy and environmental problems in China. The study considered replacing coal with alternative fuels such as biomass for small-scale industrial boilers. Still, it concluded that the Chinese government is currently promoting electricity generation through biomass, making the penetration of biomass-based boilers complex in industrial applications.

The price of wood biomass has escalated in recent years due to its increasing use in boilers, which has encouraged low-quality wood residues and non-woody materials in boilers. This was investigated by Carvalho et al. [8] by assessing the techno-environmental performance of a 15-kW pellet boiler utilizing various pelletized biomass fuels such as straw, maize, hay, wheat bran, etc. It was concluded that boiler control should be optimized to adjust to the ignition parameters of the agricultural fuels. Furthermore, the heat exchangers in boilers operating with such powers must be cleaned regularly to avoid efficiency drops. Similarly, Arachchige and Sandupama [9] evaluated alternative fuels for wood-based biomass boilers in Sri Lanka. It was calculated that rice straw could meet 257 days of steam demand annually, whereas the annual energy potential of rice husk can meet 246 days of steam demand in Sri Lanka.

2.3 Solar Photovoltaic (PV) Systems for Electricity Generation

Energy is an essential determinant of industrial development since it is required for industrial processes and equipment such as motors, compressed air, boilers, etc. Owing to a rapid increase in fossil fuel prices and environmental concerns, the industrial sector is trying to shift towards renewable energy sources. Among all renewable energy technologies, solar PV has garnered popularity as a promising source to generate clean and cost-effective electricity for industrial applications.

In industrial facilities, PV modules can be installed on rooftops of industrial units and warehouses. The output of a solar PV system depends upon location and climate, space available, shading from trees and surrounding objects, orientation and tilt angle of the PV modules, and the type of PV technology used. Moreover, other technical and economic factors should also be considered: system degradation, maintenance costs, and financial incentives. There are two configurations of PV systems as far as the connection with the utility grid is concerned. An off-grid PV system is not connected to the electricity grid, which makes battery storage necessary. As batteries are costly and high-maintenance, off-grid systems are expensive and generally suitable for remote areas with no electricity access.

In contrast, grid-tied PV systems are connected to the utility power grid, which means they do not require battery storage. This significantly reduces the installation costs and makes such systems beautiful for residential and commercial applications. Moreover, grid-connected systems can export surplus electricity back to the grid, offsetting the electricity units consumed via net metering.

2.4 Literature on Solar PV Systems

Several studies have examined and reported solar PV systems' technical and economic feasibility in different world regions. Chandel et al. [10] analyzed the techno-economic feasibility of a 2.5-MW solar PV plant to meet a garment zone's energy requirements at Jaipur (India), considering both on-site and off-site systems. The on-site PV plant had an internal rate of return (IRR) of 11.88% and a net present value (NPV) of 119.52 million INR with a simple payback period of 7.73 years. In contrast, the off-site powerplant had an IRR of 15.10%, NPV of 249.78 million INR, and a simple payback period of 6.29 years. Financial analysis suggested that an off-site PV installation is better due to the high cost and land scarcity near the city. Mukisa et al. [11] analyzed the feasibility of grid-integrated rooftop solar PV systems using the System Advisor Model (SAM) for 36 industries located in Uganda. A method was proposed to determine the rooftop area suitable for installing PV modules using Google Earth and Azimuth tools.

The results indicated that the proposed PV systems are economically feasible, with an LCOE of 5.75 US cent/kWh and an IRR of 7%. Owolabi et al. [12] analyzed the techno-economic feasibility of a 6-MW grid-tied solar PV project in Nigeria's six northeastern states using RETScreen Expert software. All the selected locations were found suitable for PV installations. Still, Yobe state was deemed the best site because of its highest yearly solar radiation and the greatest capacity factor of 21.7%, with an annual electricity generation of 11,385 MWh. This has the potential to eliminate 5,452.5 tons of CO_2. The payback period for this system was estimated to be 13.6 years. Azerefegn et al. [13] examined the techno-economic performance of grid-connected PV/wind power plants using HOMER Pro Software considering unscheduled grid outages for the industrial load in three different climate regions Ethiopia. It was concluded that the grid/diesel/PV/battery systems are technically and economically viable with excellent environmental performance for all three regions with a cost of 0.044 $/kWh, 0.049 $/kWh, and 0.048 $/kWh, respectively. Compared to the existing systems, these systems can reduce CO2 emissions by 45%, 44%, and 42%. Catawbas et al. [14] analyzed photovoltaic-green roofs' performance in one of the leading industrial zones in Turkey. The results showed that the installation of PV and green roof systems in conjunction could enhance the energy yield of the system by 3% as well as increasing the efficiency of the PV system. The PV system can reduce carbon emissions by 42.25 kgCO_2 per year, and it has a payback period of about 7 years.

2.5 Studies conducted for Biomass Systems in Pakistan

Most of the published literature related to the use of biomass in Pakistan focuses on quantifying the potential of bioenergy and technological assessment of energy generation through biomass with an emphasis on agricultural residues [15]–[18]. There is limited literature regarding the techno-economic feasibility of using biomass-based boilers for industrial applications. Ali et al. [19] evaluated the potential of risk husk combined with poultry waste to generate renewable energy via anaerobic fermentation. The cost-benefit analysis showed that biogas' production using rice husk with poultry waste is viable in Pakistan. Awan et al. [20] conducted a thermodynamic evaluation to optimize operational conditions of a rice husk-based industrial boiler of a 4-MW cogeneration plant in Muridke, Pakistan. The effect of excess air percentage and flue gas temperature on the boiler performance was analyzed. It was found that the recommended improvements can result in a 3–4% increase in boiler efficiency with predicted savings of 150,000 USD per year.

2.6 Studies conducted for Solar PV Systems in Pakistan

As indicated in the literature, numerous techno-economic feasibility studies are performed for PV systems in Pakistan, especially on stand-alone and hybrid systems for applications in rural areas with no access to electricity [21]–[24]. However, no detailed feasibility study is conducted for PV systems in industrial facilities that incorporate the technical and financial aspects and the emission reduction potential. Sadati et al. [25] evaluated the energy and economic performance of a 10-MW PV system for Multan, Pakistan. Results indicated the PV system's capacity factor to be 19.85% with a Levelized energy cost (LCOE) of 0.192 USD/kWh. Share and Abbas [26] assessed the economic feasibility of a grid-connected PV system in Muzaffargarh, Pakistan, using HOMER software. The cost of energy for the system was 0.159 USD/kWh, which is significantly less than purchasing electricity from the grid. It can potentially eliminate 2,425 $kgCO_2$ of emissions per year. Bhutto et al. [27] analyzed the performance of the 5-kW PV system in different cities of Pakistan using RETScreen software. The results show that the annual electricity generation of such a system in Quetta, Sukkur, Bahawalpur, and Karachi is 9327 kWh, 8743 kWh, 8516 kWh 8638 kWh, respectively. These systems have the cumulative capacity to reduce 14.41 tCO_2 of greenhouse gas emissions per year. Financial analysis indicated that these systems' simple payback period is 7 to 7.7 years, while the equity payback period is in the range of 3.5 to 4.3 years. Ali and Khan [28] performed a techno-economic analysis of two 42-kW polycrystalline silicon (p-Si) and Copper Indium Selenide (CIS) thin-film-based PV systems in Lahore, Pakistan. The study concluded that CIS is superior as far as performance ratio is concerned because its annual energy output is more significant than p-Si. However, p-Si has a lower LCOE, making it more economically viable. Moreover, the area required to install the p-Si system is considerably less than the CIS system, making it a good choice for areas with limited space.

Summary

This chapter gives a brief overview of international studies conducted on techno-economic assessments of biomass-based industrial boilers and solar PV systems for industrial facilities. Literature related to biomass and solar PV systems in different regions of Pakistan is also reviewed.

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Chapter 03

Methodology

3.1 Industry Sustainability Assessment

Many organizational facets of an enterprise are covered by sustainability, such as reducing electricity usage, fuel use, and expense by applying proactive policies to meet targets in all fields of existing technologies. This research aims to find a techno-economic and environmentally sustainable solution for Iqbal Rice Mills (Pvt) Limited to achieve its sustainability goals.

3.2 RETScreen International Software application

The RET Screen Renewable Energy Management Platform (commonly abbreviated as RET Screen) is a clean energy software package established by the Ministry of Natural Resources Canada (Government of Canada) to determine the financial and environmental risks and benefits of different green energy technologies for every position on the earth. Visual Basic and C are the operating systems for this application. The RETScreen has a global climate data repository of over 6000 field stations (monthly solar irradiation and temperature data during the year), energy resource maps (e.g., wind maps), hydrology data, and commodity data, including solar photovoltaic panels and wind turbine power curves. It also has a connection to NASA's climate database. It facilitates the systematic exploration, assessment, and enhancement of potential renewable energy and energy conservation programs [1]. The study of various forms of energy efficiency and sustainable technologies (RETS) focuses on electricity generation, lifecycle prices, and eliminating greenhouse gas emissions. RETScreen Plus is a Windows-based energy monitoring analysis platform for analyzing electricity use [2].

3.3 Standard steps for RETScreen Modeling

RETScreen was created to address some of the challenges that come with evaluating clean energy sources quickly. These involve a lack of customer understanding and familiarity with green energy and the unreliability of previous sustainable energy solutions compared to newly developed technologies [3]. Figure 3-1 provides a flow map with a condensed description of the methodology applied by the program.

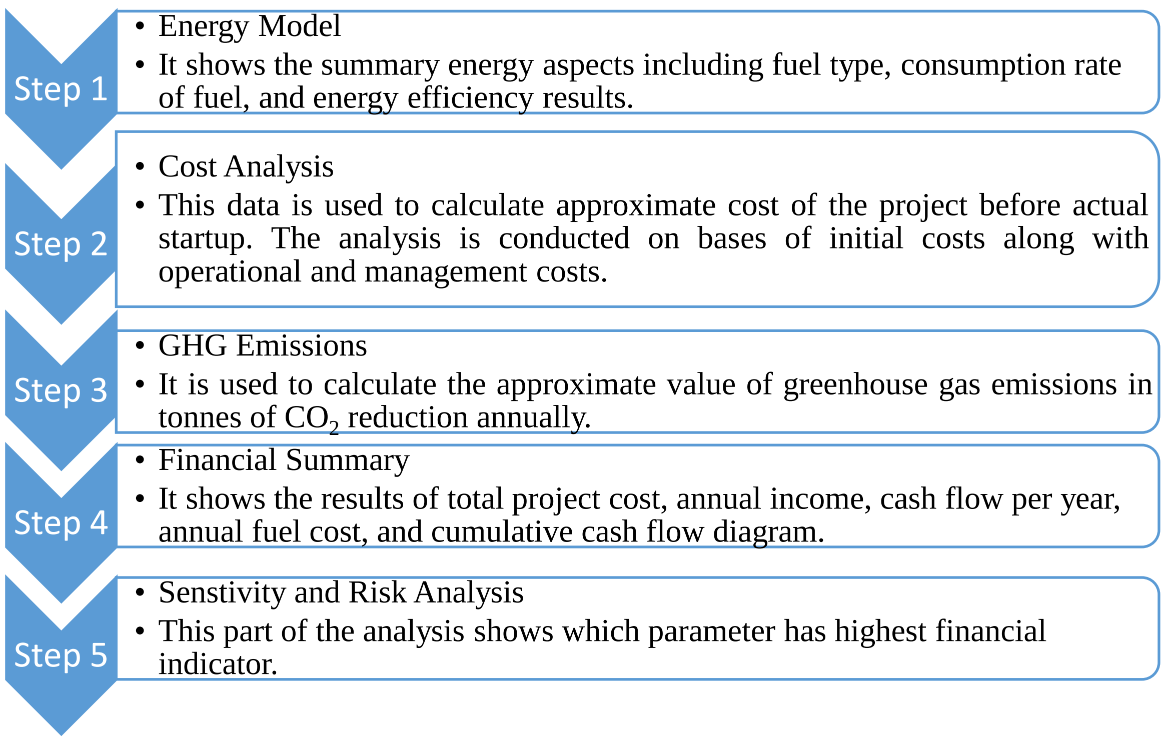

Figure 3- 1 Steps for standard analysis in RETScreen software

Experts and decision-makers can use these modeling analysis steps to define and assess renewable energy initiatives' technological and financial feasibility and test the current and continuing energy efficiency projects. This process helps to evaluate the lifecycle costs, greenhouse gas emission reductions, and energy production. Figure 3-2 depicts the flowchart used in the simulation function.

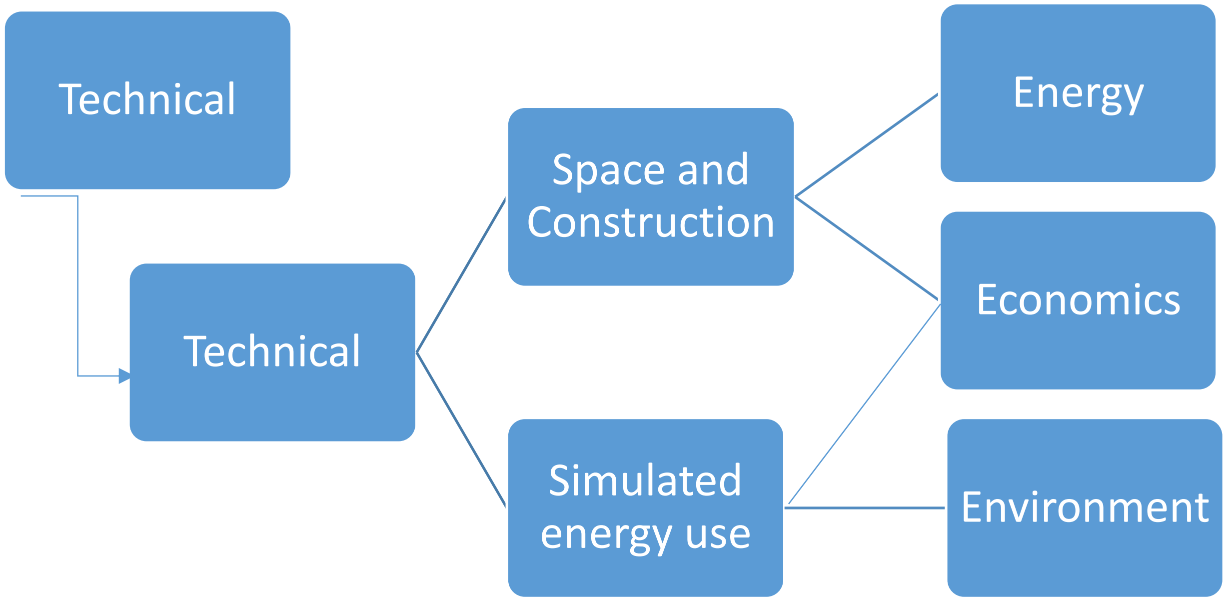

Figure 3- 2 RETScreen technical evaluation structure flowchart [2]

3.4 Modeling of system

3.4.1 Data Collection

It's essential to use reliable forecast details that a credible world agency can't be disputed and checked. RETScreen has permission to obtain accurate data from the National Aeronautics and Space Administration (NASA). Table 3-1 indicate the geographical position and climatic conditions that relate to that location.

Table 3- 1 Geographical information of study site [4]

Ambient data/Location	Climate information of the location
Climate data location	Pakistan - Punjab – Faisalabad
Latitude	31.4
Longitude	73.1
Climate zone	0B-Extremely hot-dry
Heating design temperature	5.2 (°C)
Cooling design temperature	38.6 (°C)
Earth temperature amplitude	25.8 (°C)

Monthly climate conditions of air temperature, relative humidity, daily solar radiation-horizontal, earth temperature, and wind speed have been shown in Table 3-2. From the data obtained by NASA, it can be observed that daily solar radiation-horizontal is maximum for May and is least for December.

Table 3- 2 Reference Site Conditions [4]

Month	Air Temperature (ºC)	Relative Humidity (%)	Daily Solar Radiation-Horizontal (KWh/m²/d)	Earth Temperature (ºC)	Wind Speed (m/s)
January	13.0	37.5	3.25	11.7	2.2
February	15.9	37.3	4.19	15.2	2.4
March	22.2	31	5.10	22.1	2.5
April	28.8	23.7	6.01	29.5	2.6
May	35	17.2	6.71	36.7	2.8
June	38	23.6	6.65	40.5	2.9
July	36.4	39.8	5.99	38.7	2.8
August	34.7	45	5.60	36.5	2.5
September	32.2	38.5	5.37	33.4	2.2
October	26.9	26.2	4.65	26.6	2.0
November	20.6	24.5	3.73	19.3	2.1
December	15.1	31.3	3.14	13.5	2.1

3.5 Photovoltaic Array

RETScreen international software has the characteristics to simulate PV systems of different technologies, including poly-Si, mono-Si, CIS, CdTe, spherical Si, and a-Si. The software database contains several PV models made by various manufacturers and their characteristic parameters such as nominal output temperature, solar collector location, and optimum performance. All PV models in RETScreen international software are based on Evans's work [5], and their optimum efficiency parameter is calculated by equation 1.

$$\eta_p = \eta_r[1 - \beta(T_c - T_r)] \quad (1)$$

Where $\eta_p$optimum efficiency of PV array is, η_r is array efficiency at T_c=T_r, β is temperature coefficient for solar cell efficiency, T_c is monthly average solar cell temperature, and T_r Is reference temperature for solar cell efficiency. The value of T_c can be calculated by using equation (2).

$$T_c = \left[(219 + 832K_t)\left\{\frac{NOCT-20}{800}\right\}\right] - T_a \quad (2)$$

Where NOCT is Nominal Operating Cell Temperature, and K_t is clearance index. A mono-Si PV model array has been selected for installation on the proposed site, and PV analysis is done using the mono-Si PV model array. Its characteristics are given in Table 3-3.

Table 3- 3 Characteristics of selected solar PV array model [6]

Parameters	Values
PV model type	Mono PERC (158.75×158.75mm)
Module	JKM440M-78H
Manufacturer	China-JINKO Solar
Capacity	440 W
Power tolerance	0~+3%
Module efficiency	20.27 %
Nominal operating temperature	45±2 ^oC
Temperature coefficient of P_{max}	-0.35%/^oC
Maximum power voltage (V_{mp}) at STC	43.65 V
Maximum power current (I_{mp}) at STC	10.08 A
Open circuit voltage (V_{oc}) at STC	51.70 V
Short circuit current (I_{sc})	10.77 A
Nominal Operating Cell Temperature (NOCT)	45±2^oC

Inverters have been used to convert DC voltage to AC voltage. The power generated by the solar PV array is in DC voltage which needs to be converted to AC voltage before penetration to the power load. For this purpose, an inverter of 60KW with 98.9-98.7% efficiency has been proposed for the solar PV array. The specifications are given in Table 3-4.

Table 3- 4 Specifications of the proposed inverter [7]

Parameters	Values
Model	SUN2000-60KTL-M0
Manufacturer	HUAWEI
Output power	60 KW
Maximum input voltage	1,100 V
Rated output voltage	220 V / 380 V, 230 V / 400 V
DC connecter	Amphenol Helios H4
AC connecter	Waterproof PG Terminal + Terminal Clamp
Cooling method	Natural convection
Protection degree	IP65
Efficiency	98.9% @480 V; 98.7% @380 V / 400 V

3.6 Installed fire tube boiler

A fire-tube boiler is in which hot gases travel through tube channels, and water flows through the sealed water container. The thermal conduction mode of heat transfer converts heat from hot gases to flowing water via the tube walls. It raises the temperature of the stream, resulting in the production of steam for process heating. For process steam production, three boilers with capacities of 10 tones/hour, 8 tones/hour, and 4 tones/hour have been installed on the site. Another boiler with a 4 ton/hour generating capability has also been established for waste heat recovery. Still, it only operates while an energy crisis and industry shift their power capacity to on-site electricity generators. For the case of this study, boiler capacity has been assumed to be 10 tons per hour as the average daily requirement of steam for process heat is 5.4 tons per hour. Further details of boilers and process steam generation are given in Table 3-5.

Table 3- 5 Details about boiler and process heat

Parameters	Values
Boiler type	Fire tube steam boilers
Total generation capacity	10 tones/hour
Steam Discharge Pressure	10 bar
Furnace Temperature	180 ^oC
Exhaust Temperature	110- 120 ^oC
Condensate return	50%
Makeup water temperature	20 ^oC
Condensate temperature	80 ^oC
Operating hours	7500 hours/year

The condensate return is estimated to be 50%, and the base case of fuel usage is dependent on coal consumption, which is then transferred to rice husk, wood, or a mixture of all fuels to be used as fuel for process steam production.

3.7 Proposed PV-Biomass Hybrid System

The proposed scenarios are DC electric load, solar PV array modules, biomass combustion in the boiler, and inverters. The planned scheme is not intended to eliminate energy demand from the national grid but rather replace some of it with the presented case at the site's boiler section. For improved environmental performance, the planned device incorporates the advantages of solar PV and biomass systems. Biomass, which comprises organic materials such as crop wastes, woods, animal, and human waste, is abundant on the site. Its use for power and electricity generation is widespread due to its abundance in nature. Rice husk and wood have been used instead of coal in the proposed case to achieve a physically viable and environmentally sustainable alternative.

3.8 Data measurement plan

First, electricity usage was measured by electricity bills, and then walk-through audits were performed to gather details regarding the built facilities. For the planned location, level-1 (walk-through) and level-2 (equipment-based) energy audits have been completed.

Level 1 energy audits recognize low-cost or no-cost energy conservation options, followed by a level 2 energy survey utilizing energy audit equipment to identify places with potential energy upgrades for energy savings. Data about utility bills, production, process flow, installed equipment details, operation schedule, number of shifts, and sub-metering data on-site has been gathered during energy audits for further assessment and energy opportunities identification.

Summary

The chapter describes the analysis methods used in this study. A brief introduction to the component is presented in the study are presented. The proposed research PV-biomass hybrid, as well as the energy assessment strategy, is extensively discussed.

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CHAPTER 04

Case Study of Iqbal Rice Mills (PVT) Limited

4.1 Company overview

IRM currently has four rice reprocessing units with a capacity of 20 tones/hour, four drying units having thirteen dryers with a total of 55 tones/hour of paddy rice drying capacity. There are three boilers at the plant with a capacity of 22 tones/hour. Mills and warehouse facilities are on 65 acres of freehold property, with a total of 75000 tons of rice stored in warehouses built on international standards.

4.2 Production data

The industry has provided data of 15 months (July 2018 to September 2019), and data of 12 months has been used for analysis purposes. The highest rice production was 4463.3 tons in July 2019, while the lowest production was in November 2018, which was 1984.2 tons. Twelve months of data analysis has also shown that Iqbal Rice Mills (Pvt.) Limited is 3140.8 tons of rice. The monthly rice production at Iqbal Rice Mills (Pvt.), limited with their monthly production in percentage, has been shown in graphical form in Figure 4-1. As the data is not in complete form every year, it is impossible to identify year-to-year production trends. However, data has indicated production scale and peak values almost identical for the year's corresponding months.

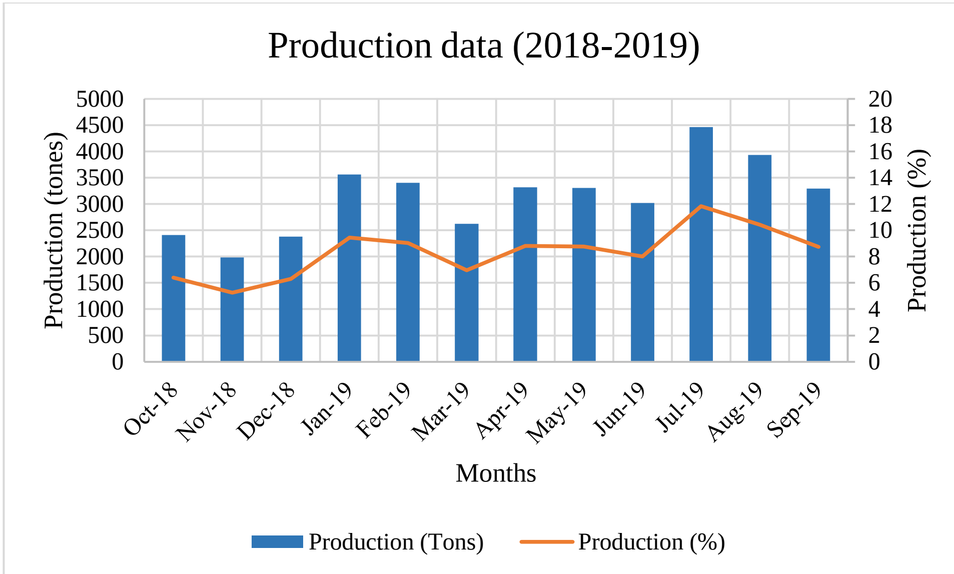


Figure 4- 1 Production data of Iqbal Rice Mills (Pvt.) Limited

Production data, monthly electricity consumption, and specific energy consumption parameters have been tabulated in Table 4-1.

Table 4- 1 Production & Electricity consumption of IRM (Pvt.) Limited

Month and Year	Production (Tons)	Electricity Consumption (units + dryers) (KWh)	Specific Energy Consumption(S.E.C) (KWh/tons)
Oct-18	2408	246801	102.5
Nov-18	1984.2	339422	171.1
Dec-18	2380	444280	186.7
Jan-19	3563.2	625624	175.6
Feb-19	3404.4	549941	161.5
Mar-19	2622.8	456353	174.0
Apr-19	3318.9	463922	139.8
May-19	3302.9	282075	85.4
Jun-19	3017.9	193330	64.1
Jul-19	4463.3	370815	83.1
Aug-19	3930.9	263111	66.9

Sep-19	3292.7	243273	73.9
Total	37689.2	4478947	

4.3 Electricity consumption

Four rice reprocessing, four paddy rice drying, and two husking units with a capacity of 20 tons/hours, 55 tons/hours, and 20 tones/hours, respectively, are significant consumers of electricity at Iqbal rice mills (Pvt.) limited. The average monthly electricity consumption is 373.2 MWh, while the annual consumption of electricity is 4479 MWh. Electricity consumption of production unit at Iqbal rice mills (Pvt.) Limited has been shown in Figure 4-2. The highest electricity consumer is unit#7 with a total share of 20%, followed by unit#2 having 19% of the total electricity consumption. The lowest electricity consumption has been noted for unit#8, which is 0.4%.

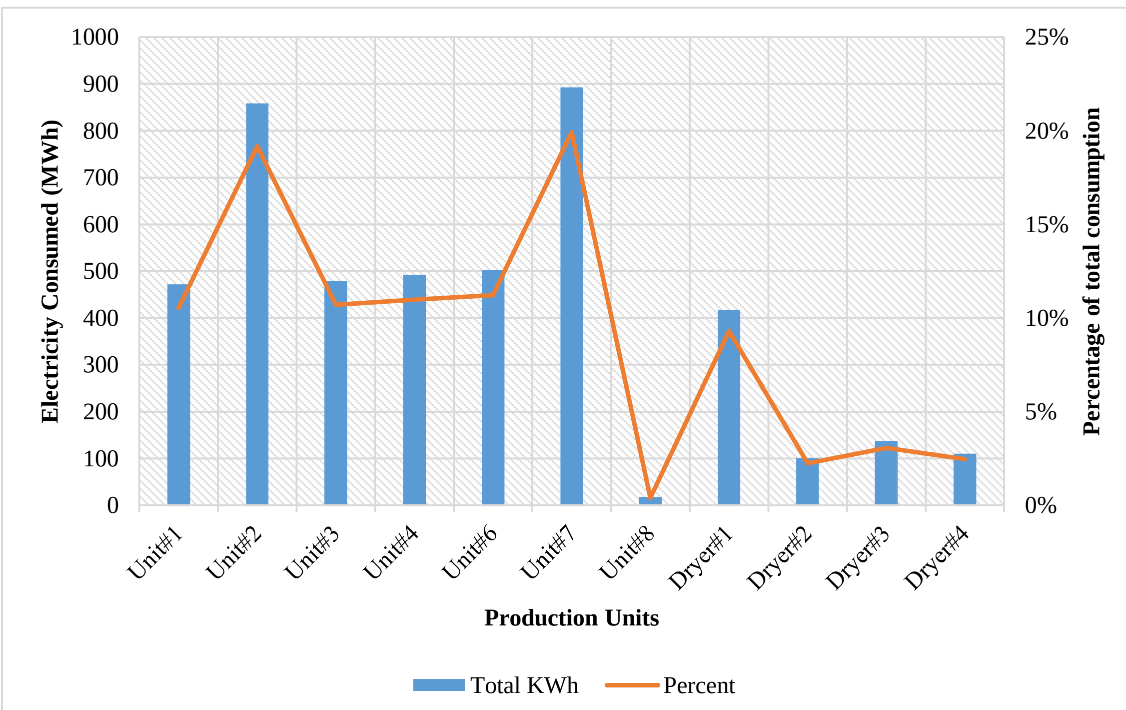


Figure 4- 2 Electricity consumption of production units

The electricity in MWh and plant production in metric tons for 2018-2019 data is shown in Figure 4-3.

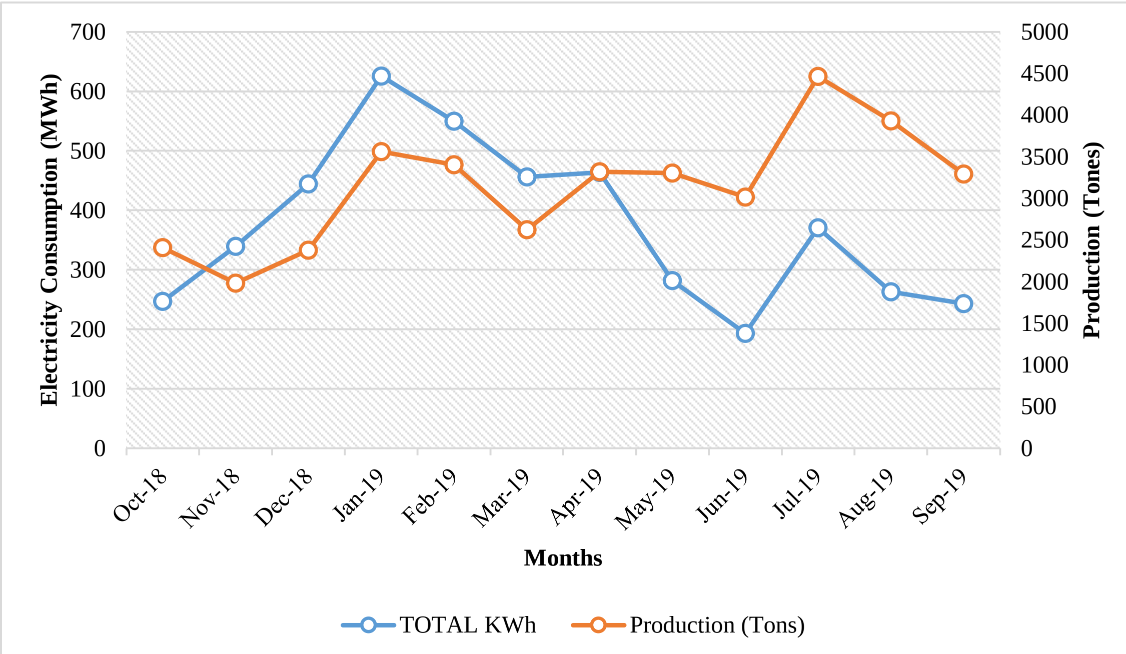


Figure 4- 3 Production vs. Electricity Consumption

4.4 Specific Energy Consumption

For a 12-month study cycle starting from October 2018 and ending in September 2019, specific energy consumption (SEC) varies from 64 KWh/ton to 187KWh/ton of rice processing. Specific energy consumption for the whole year is shown in Figure 4-4. The broad variation in SEC is due to the operational variables of the rice drying plant. All the rice is first passed through and processed through the drying process in paddy, but not all the paddy is shifted to the husking unit for processing and rice production. From the annual production data analysis, the average value of SEC has been calculated to be 124 KWh.

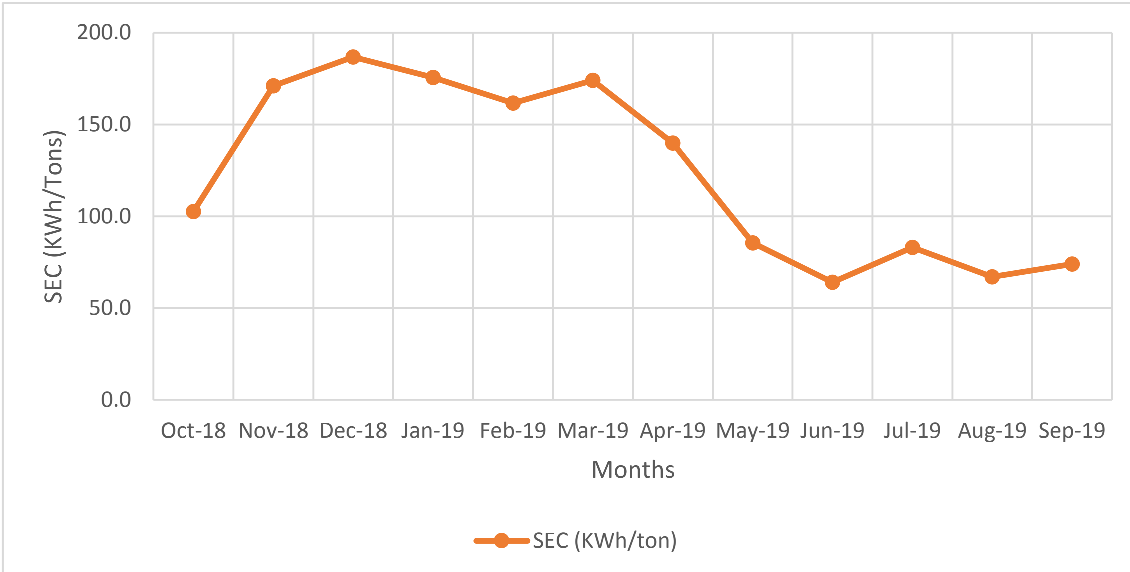


Figure 4- 4 Specific Energy Consumption (SEC) of the production plant

Summary

This chapter covers energy consumption, specific (SEC), and production data of Iqbal rice mills (Pvt.) limited located at Faisalabad Rd, Chiniot, and Punjab 35400. The data has been then shown in graphical form to show the maximum production and energy consumption for the selected site.

CHAPTER 05

Results and Discussion

The findings of the research are presented in this chapter. This chapter covers the graphical interpretation of the gathered data and the simulation results after analyzing the data obtained from the industry and literature.

5.1 Results

The feasibility of biomass use and energy generation by solar PV array at an industrial site (Iqbal rice mills (Pvt.) limited, Pakistan) was assessed using RETScreen international software. RETScreen uses climate data from the National Aeronautics and Space Administration (NASA) to determine the selected site's climatic conditions. The planned installed solar PV generated electricity and proposed cases of biomass system have been analyzed in terms of energy (number of PV units used and corresponding power generated), economics (NPV, IRR, simple payback period, equity payback period), environment (GHG reduction), and sensitivity/risk parameters including greenhouse gas (GHG) emissions, and power production of electricity.

Simulation results are based on two scenarios; the first concerns biomass-based fuels' input, which shifts from coal-based power in the base case to 100% rice husk, 100% wood, and a 50-50 mix of both rice husk and wood barks. Simultaneously, the second part is concerned with the penetration of a 1,000KW solar PV plant. Since it is assumed that a total capacity of 10 metric tons for steam generation, it is presumed that two 5 metric tons boilers have been built on-site for process steam generation at 10 bar pressure and $190^{o}C$ temperature using rice, wood, or coal as fuel. The primary benefit of replacing traditional fossil fuels with biomass-based fuels is reducing greenhouse gas pollution, resulting in an environmentally sustainable approach that often saves money. The RETScreen multinational program is used to analyze techno-economic solutions that are ecologically sustainable.

5.2 Rice Husk as biomass fuel

Since Pakistan is an agricultural region, there is a lot of biomass production. The chosen position is near the rural areas of central Punjab, Pakistan, where agricultural fields are ample. Using rice husk as a byproduct during paddy rice production, the industry can meet its own needs. Rice husk, a potential renewable energy source, is a cost-effective, locally produced, and environmentally friendly energy source. However, rice husk-generated energy's financial and environmental profiles should be evaluated to ensure positive cash flow and lower greenhouse gas (GHG) emissions than conventional/fossil fuel power plants [1]. Every year, a large amount of rice husk is generated as agricultural waste and residue. In 2010, 672 million rice grains were made [2], and agricultural waste produced during rice processing is estimated to be 3,758 million tons per year [3].

5.2.1 Annual energy yield estimation

Interestingly, with every ton of rice grown, 1.5 tons of rice straws and 200 kg of rice husk are produced as a byproduct. Rice husk is a layer of raw rice extracted during paddy rice processing by a rice milling machine. It is a mixture of cellulose, lignin, and hemicellulose with a high ash content of approximately 20%[4], with the ash containing 80-90 percent silica [5], making it a strong co-product of energy production when rice husk is used as a fuel feedstock in the boiler steam generation process. The annual energy yield was based on the mean ambient temperature, monitoring process, power capacity, steam flow, steam pressure, superheated temperature, inverter performance, PV solar array efficiency, boiler efficiency, economic restrictions, and financial inputs determined using RETScreen international software. Figures 5-1 & 5-2 depicts the energy component of RETScreen simulations and their outcomes, respectively.

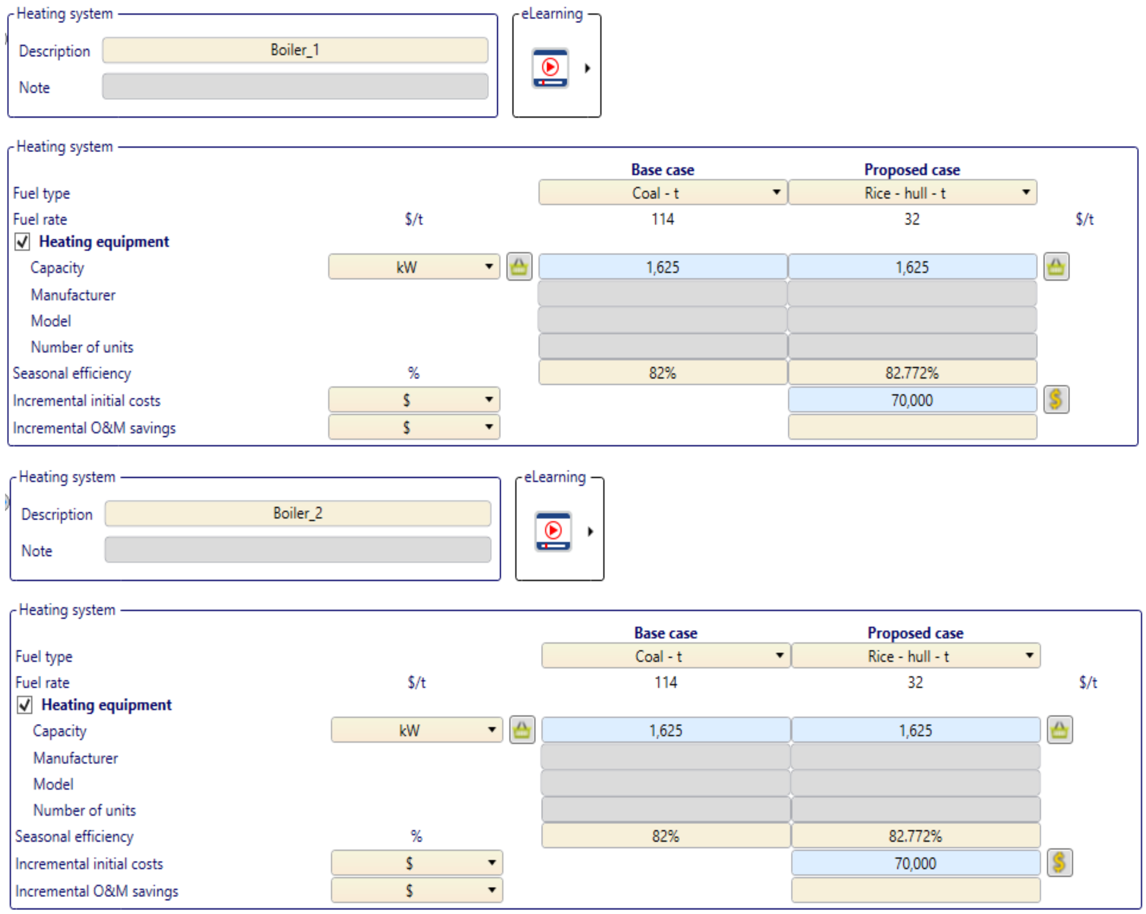


Figure 5- 1 Boiler fuel rates and retrofitting cost for rice husk

The fuel prices used in the simulation model were based on industry data. A coal-fired boiler's seasonal efficiency has been set at 82 percent, while it rises to 82.772 percent, while rice husk is used as fuel in the proposed scenario. The industry provided all process steam generation parameters, while the solar PV array and inverter parameters were obtained from literature as mentioned in Tables 3-3 & 3-4 in the methodology chapter.

Process steam

Description	Process steam_1
Note	

Process steam

		Base case	Proposed case	Energy saved
Steam flow	kg/h	2,708.33	2,708.33	
Operating hours	h/yr	7,500	7,500	
Steam demand	kg	20,312,475	20,312,475	
Steam pressure	bar	10	10	
Saturation temperature	°C	180	180	
Superheated temperature	°C	180	180	
Condensate return	%	50%	50%	
Condensate temperature	°C	90	90	
Makeup water temperature	°C	20	20	
Makeup water reduction	L		0	
Incremental initial costs	$			
Incremental O&M savings	$			
Heating system		Boiler_1	Boiler_1	
Number of units		1	1	
Heating	MWh	14,371	14,371	0 0%

Process steam

Description	Process steam_2
Note	

Process steam

		Base case	Proposed case	Energy saved
Steam flow	kg/h	2,708.33	2,708.33	
Operating hours	h/yr	7,500	7,500	
Steam demand	kg	20,312,475	20,312,475	
Steam pressure	bar	10	10	
Saturation temperature	°C	180	180	
Superheated temperature	°C	180	180	
Condensate return	%	50%	50%	
Condensate temperature	°C	90	90	
Makeup water temperature	°C	20	20	
Makeup water reduction	L		0	
Incremental initial costs	$			
Incremental O&M savings	$			
Heating system		Boiler_2	Boiler_2	
Number of units		1	1	
Heating	MWh	14,371	14,371	0 0%

Figure 5- 2 Process steam parameters for RETScreen model

RETScreen model results show that 35.05GWh of electricity equivalent fuel has been consumed in the base case to generate 5.4 tons/hour of steam for the industry while 34.7

GWh of electricity equivalent fuel consumption the proposed case by changing the fuel type. The results are shown in Table 5-1 and graphically represented in Figure 5-3.

Table 5- 1 Fuel-saving summary

Fuel consumption	Heating (MWh)	Cooling (MWh)	Electricity (MWh)	Total MWh
Base case	35,050	0	0	35,050
Proposed case	34,723	0	0	34,723
Fuel saved	326,9	0	0	326,9
Fuel saved-percent	0.93%	0%	0%	0.93%

A fuel shift of coal to 100% rice husk resulted in a 0.93 % reduction in fuel consumption. Fuel cost in the base case has been noted to be $ 427,075 while in the proposed case to be $ 346,035 by saving 19% of fuel cost as shown in Figure 5-4.

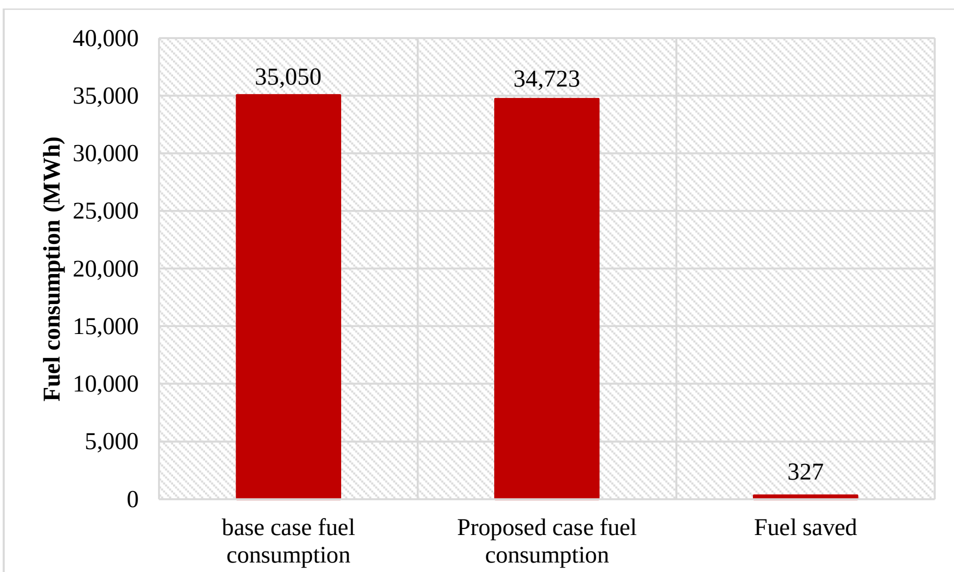


Figure 5- 3 Fuel consumption results

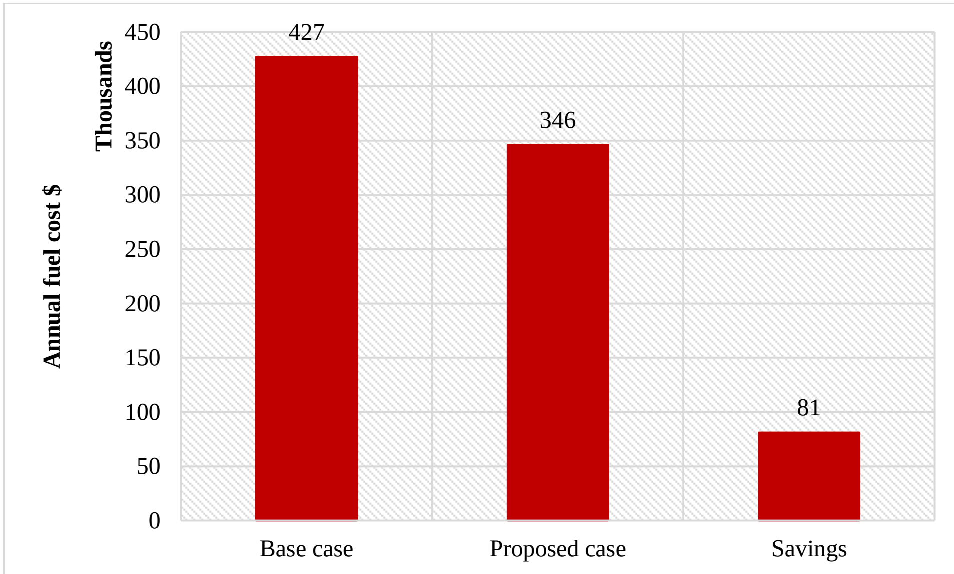


Figure 5- 4 Fuel cost savings for rice husk

5.2.2 Financial analysis

The initial financial parameters, the fuel escalation rate, inflation rate, and project life used for economic analysis of the RETScreen model have been summarized in Table 5-2. All the financial parameter values are obtained from the existing literature. Internal rate of return (IRR) on cash, internal rate of return (IRR) on equity, essential payback time, equity payback period, net present value, and benefit-to-cost ratio have all been measured using these values to determine the proposed system's economic feasibility.

Table 5- 2 Financial input parameters

Factor	Description
Fuel escalation rate	7%
Inflation rate	2.5%
Discount rate	3%
Reinvestment rate	3%
Project life	25 years
Investments and grants	0%

The initial incremental cost is calculated to be $ 140,000, with the fuel cost in the base year estimated at $ 427,075 by RETScreen simulation and the fuel cost in the proposed case at $ 346,035. The net annual savings is estimated to be $ 81,040, with a benefit-to-cost ratio of 24.7. The simple payback period is 1.7 years, while the equity payback period is 1.6 years. Based on the estimates above, it seems that retrofitting a boiler from coal to rice husk-based fire tube boilers is feasible owing to the lower initial cost and short payback period on the expenditure.

The cumulative cash flow diagram and payback period are shown in Figure 5-5, and Figure 5-6 shows a short payback period of the project and is feasible if the proposed case opts.

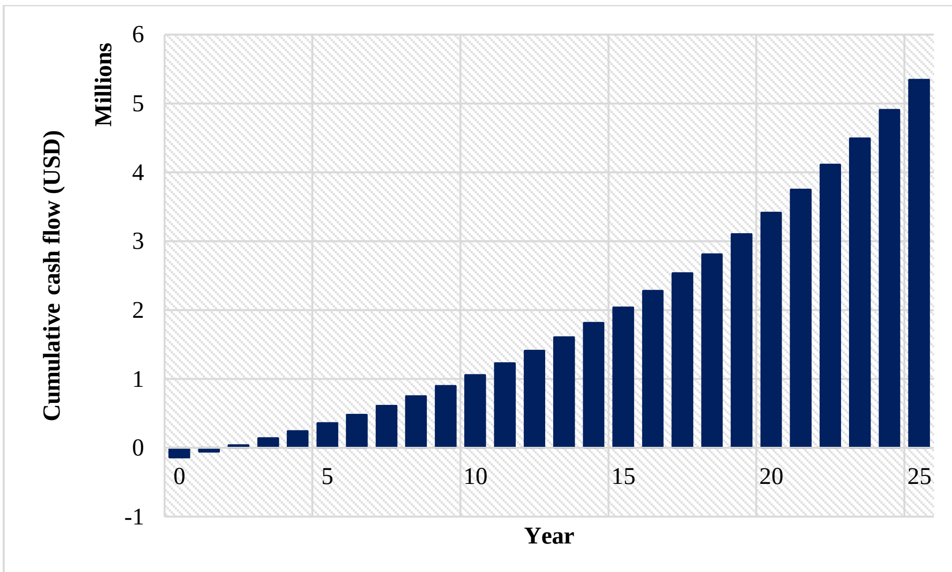


Figure 5- 5 Cumulative cash flow diagram

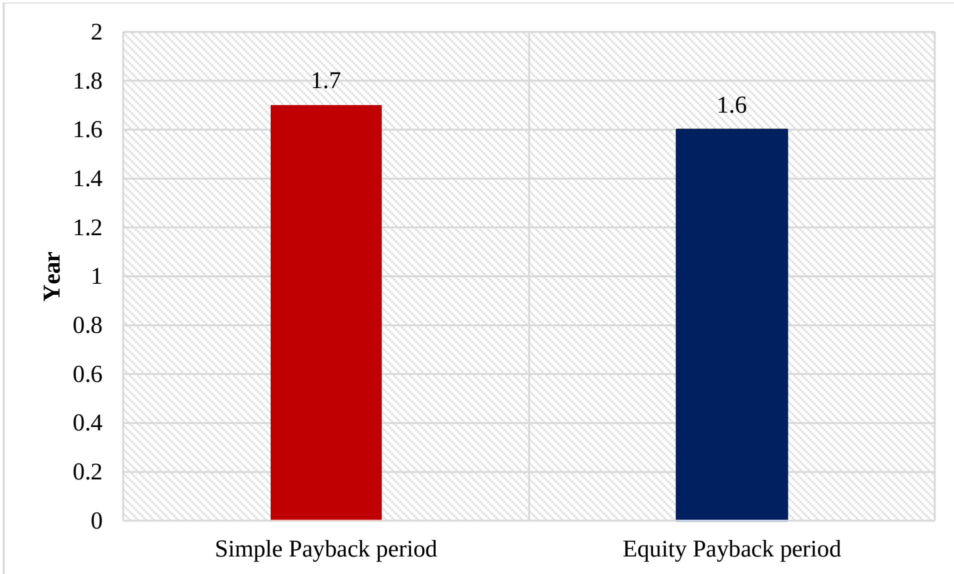


Figure 5- 6 proposed project payback period

5.2.3 GHG emission reduction analysis

When renewable energy resources are used to replace the conventional power supply, e.g., coal, natural gas, petroleum, etc., greenhouse gas emissions in the local environment are reduced. The transmission losses of 7% and GHG factor of 0.3378 tons/MWh of CO_2 equivalent for coal in the base case and 0.0066 tons/MWh of CO_2 equivalent for rice-husk based biomass fuel have been used to measure greenhouse gas emissions. The GHG emission in the base case, proposed case, and GHG emission reduction and barrels of oil not consumed have been shown in Figure 5-7.

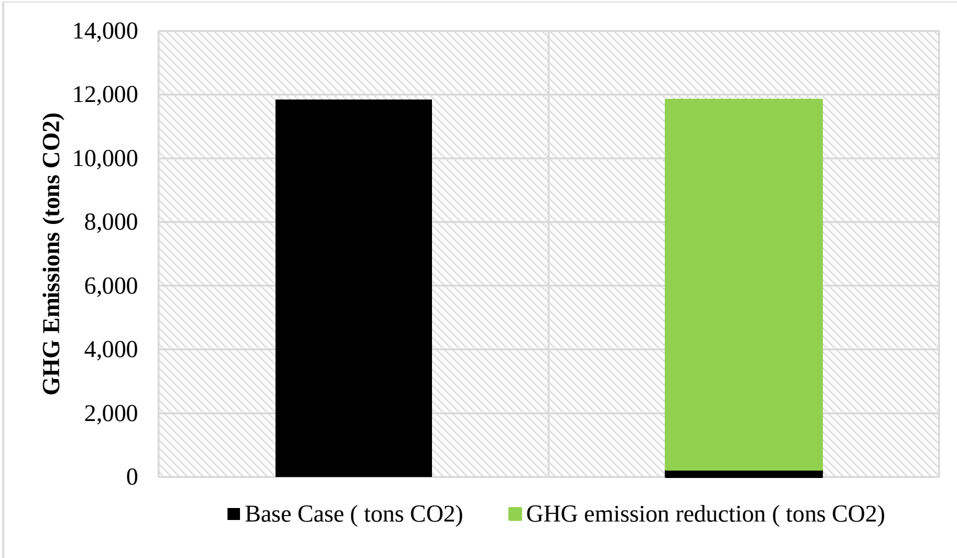


Figure 5- 7 GHG emissions in the proposed case

The results showed that shifting from the conventional method of power generation in which coal was being used to the proposed system in which rice is getting used as fuel feedstock can reduce 11,612 tons of CO_2 and 27,004.6 barrels of crude oil not consumed.

5.3 Wood as biomass fuel

The supply of electrical resources to sustain economic growth needs is one of the most complex and contemporary problems humans face [6]. Coal is not a permanent source of energy generation as Pakistan has to import almost all coal needs from abroad, which highly affects the country's economic growth rate. Purpose-grown energy crops and wastes are the two primary sources of biomass. Woody and commercial crops represent energy crops, while wood remains, garbage, urban solid waste, livestock waste, temperate and tropical crops are examples of waste. This pale wood-based renewable source can be used as biomass fuel for energy production [7]. The wood species' moisture content ranges from 41.27-70.20%; combustion efficiency ranges from 88.5-92.5%, overall thermal efficiency 21-25% [8]. Due to its high combustion efficiency, it can be used for process steam generation by burning wood as a fuel in the boiler's combustion chamber for steam generation.

In the second scenario, wood fuel is proposed for steam production in the site's boiler section. According to the site's sub-metering, 1 ton of wood can yield 3.12 tons of steam.

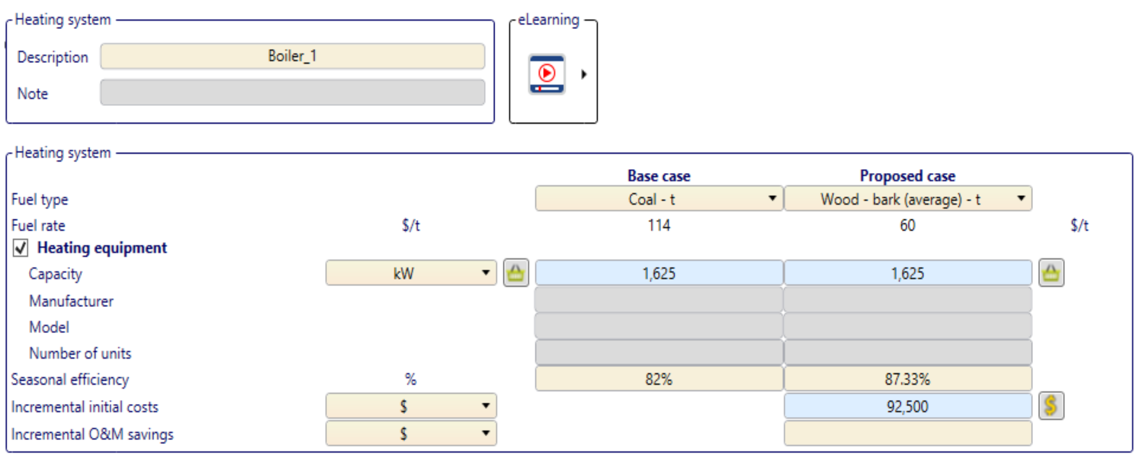
Owing to the abundance of wood in the local sector, Pakistan's wood prices are lower than coal prices. At the same period, coal in Pakistan has a higher moisture content, which prevents it from being used for energy generation until the moisture content is reduced to below the required range, allowing it to be used in coal-fired power plants. Consequently, the bulk of coal is supplied from overseas, and its price has permanently been leased.

A feasibility study was conducted based on techno-economic and environmental sustainability prospects to check the proposed scenario's energy, economics, and environmental implications. The following sections go into the topic in greater depth.

5.3.1 Energy modeling simulation results

The heating device in the proposed case study has a wood-burning thermodynamic fireplace with a capacity of 10 metric tons of steam production per hour, which was considered in the RETScreen simulations. However, the chosen site's annual average steam demand is 5.4 metric tons per hour. As a result, the steam produced is 5.4 tons per hour, while the remaining boilers portion has been left on standby mode so that the steam boilers can be turned on when a larger volume of steam is required.

There were no changes to the process steam in this proposed case as they were in the first proposed topic scenario. Figure 5-8 shows the only adjustment made to the boiler fuel class to verify the techno-economic and environmental evaluation.



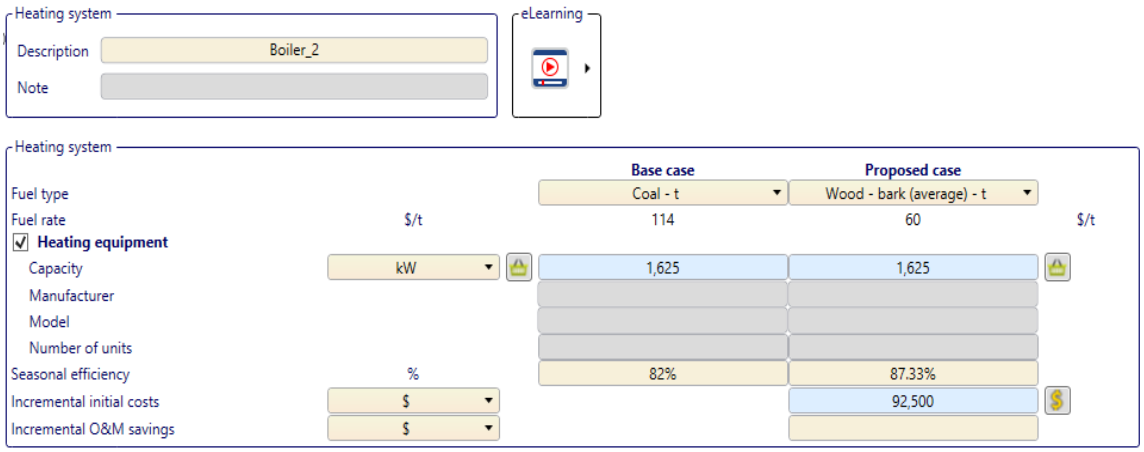


Figure 5- 8 Fuel cost and retrofitting cost for wood fuel based boiler

The fuel usage has decreased from 35,050 MWh equivalent electricity generation capacity to 32,911 MWh equal electricity generation capacity by converting coal to biomass. The proposed case fuel shift has saved 2,139 MWh of electricity production. As a result, the suggested case will save a total of 6.1% of the fuel used. Table 5-3 and Figure 5-9 show a rundown of fuel use and energy savings, respectively.

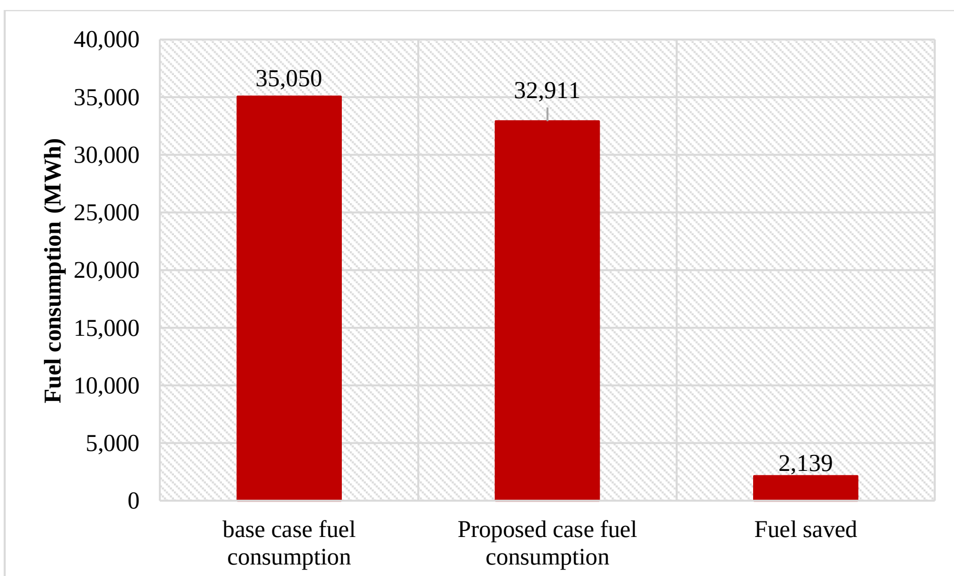


Figure 5- 9 Energy-saving results of wood-based boiler

Table 5- 3 Fuel consumption summary

Fuel consumption	Heating (MWh)	Cooling (MWh)	Electricity (MWh)	Total MWh
Base case	35,050	0	0	35,050
Proposed case	32,911	0	0	32,911
Fuel saved	2,139	0	0	2,139
Fuel saved-percent	6.1%	0%	0%	6.1%

Fuel cost in the base case scenario is $ 427,075, and it has been noted to be $ 333,113 by saving $ 93,962 annually. Fuel cost savings of the proposed scenario have been shown in Figure 5-10.

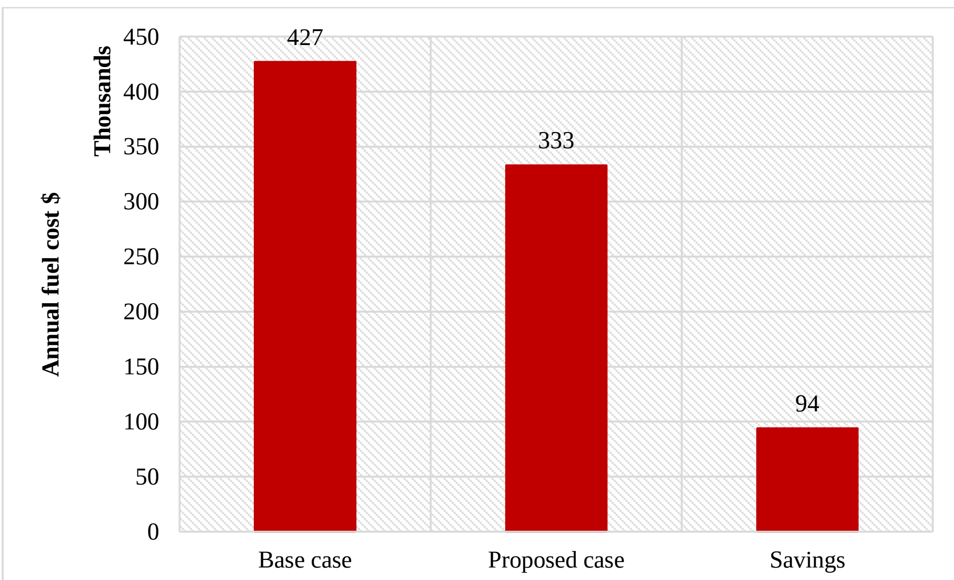


Figure 5- 10 Fuel cost savings of wood fuel feedstock

5.3.2 Financial analysis

The computed Net Present Value (NPV) of the planned biomass-based heating device is $ 3.81 Million, assuming a 25-year investment life, no subsidies, no liability from either bank, a 7% fuel escalation rate, and a 2.51% inflation rate. Cumulative cash flow for the proposed case over the years has been shown in Figure 5-11.

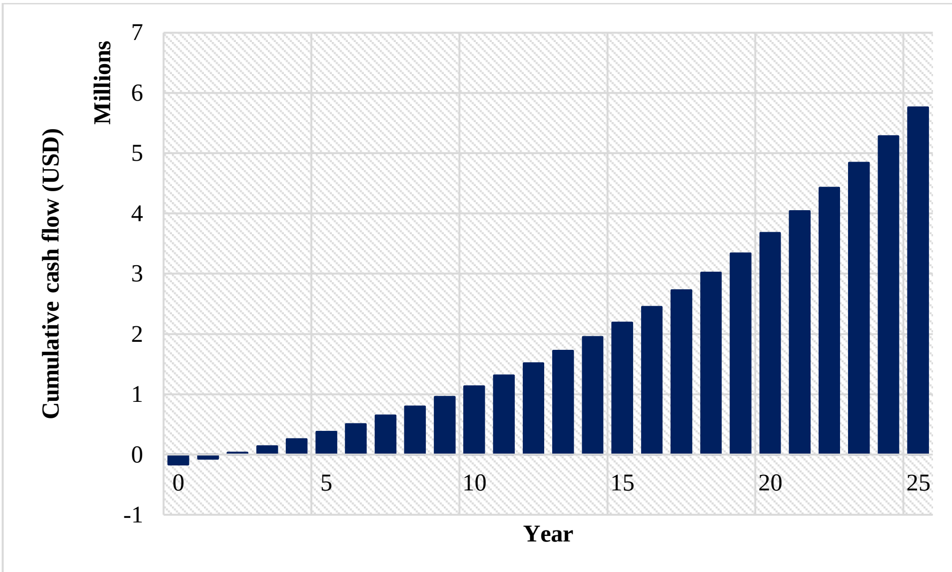


Figure 5- 11 Cumulative cash flow of the proposed case

Figure 5-12 depicts the simple and equity payback periods. It has been determined that it would take 2 years for the project to start paying off, i.e., the cumulative cash balance will be positive, and earnings will begin. As a result, the proposed project is an attractive investment due to the short payback time. The equity payback period of the system has been noted to be 1.8 years, while the benefit to cost ratio is 21.6, along with annual lifecycle savings of $/yr 219,197.

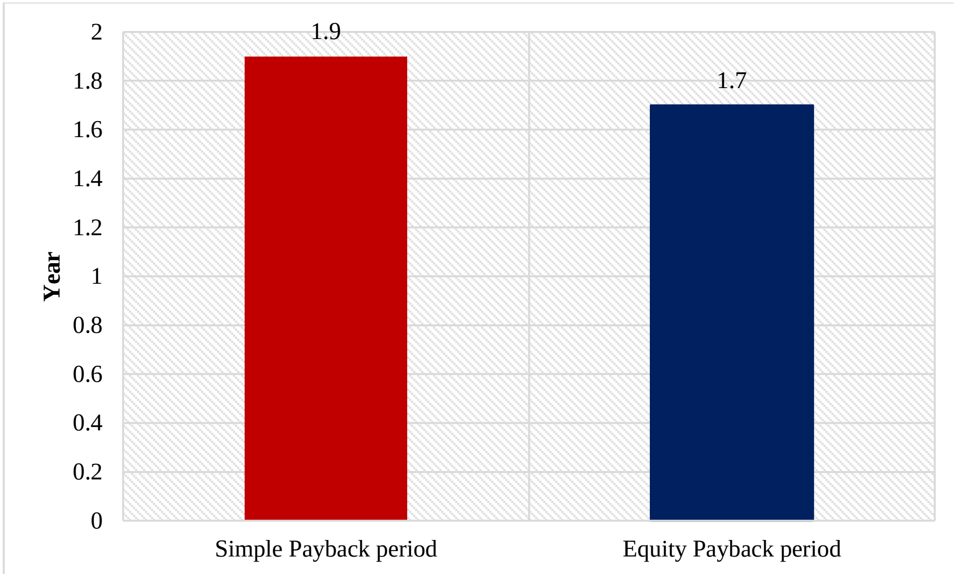


Figure 5- 12 Payback period of the proposed case

5.3.3 GHG emission reduction analysis

Using the RETScreen international software, a possible reduction of GHG emission of the proposed biomass-based model system was assessed. The baseline (coal-fired boiler) and the proposed case's GHG emissions profiles are measured (wood base boiler). RETScreen international software has used transmission losses to be 7%. Figure 5-13 depicts GHG emissions in the base and proposed cases and GHG emission reductions and barrels of oil not consumed. Switching from a traditional energy production system to a biomass-based system will save 11,623.9 tons of CO2 and 27,032.3 barrels. The GHG pollution in the base case is estimated to be 11,840.2 tons of CO_2, whereas 216.3 tons of CO_2 was released into the atmosphere, indicating a 98.2% decrease in GHG emissions.

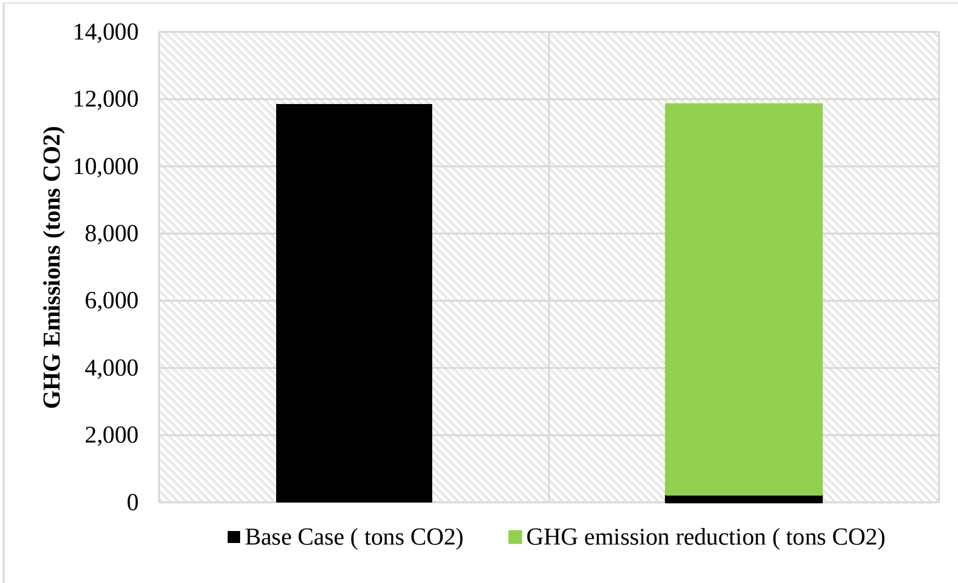


Figure 5- 13 GHG emission analysis results

The base grid's energy generation efficiency using coal as a fuel feedstock has been used to be 33.8% by energy generation totalling a GHG emission potential of 11,330.6 tons of CO_2. In the proposed scenario, energy generated by wood-based fuels is used, with GHG emission factors of 0.0066 tCO_2/MWh, resulting in 216.3 tons of CO_2 being released and 27,032.3 barrels of oil not consumed simply through changing fuel priority.

5.4 Rice-wood fuel usage

Because of the threat of climate change posed by fossil fuels, there has been a surge in interest in sustainable energies for heating and power production worldwide [9]. Since fossil fuels have been burnt and GHGs have been released into the world, clean and green energy is globally essential [10]. As a result, shifting fuel consumption targets in factories and suburban areas is critical.

5.4.1 Energy modeling results

Considering the climate change threats, it has been suggested in the project's third proposed study to use rice and wood as fuels. Rice husk to be used in one of the 5 ton/hour steam generation boilers, while wood to be used in the other. However, the actual demand for process steam is 5.4 tons per hour for the selected industry. This scenario aimed to see if combining two fuels was feasible to consider techno-economic and environmental factors before deciding. Using RETScreen tools, a simulation was conducted to determine how much energy is produced by burning 50 percent rice and 50 percent wood-based biomass fuel for the boiler's 5.4 tons of steam generation. Mean atmospheric temperature, daily solar radiation-horizontal, relative humidity, steam temperature, steam pressure, boiler efficiencies, and solar PV device efficiencies have been considered for simulation purposes. The project's lifespan has been set at 25 years.

Fuel costs, boilers specifications, process steam aspects, and solar PV parameters have been shown in Figures 5-14 to 5-16.

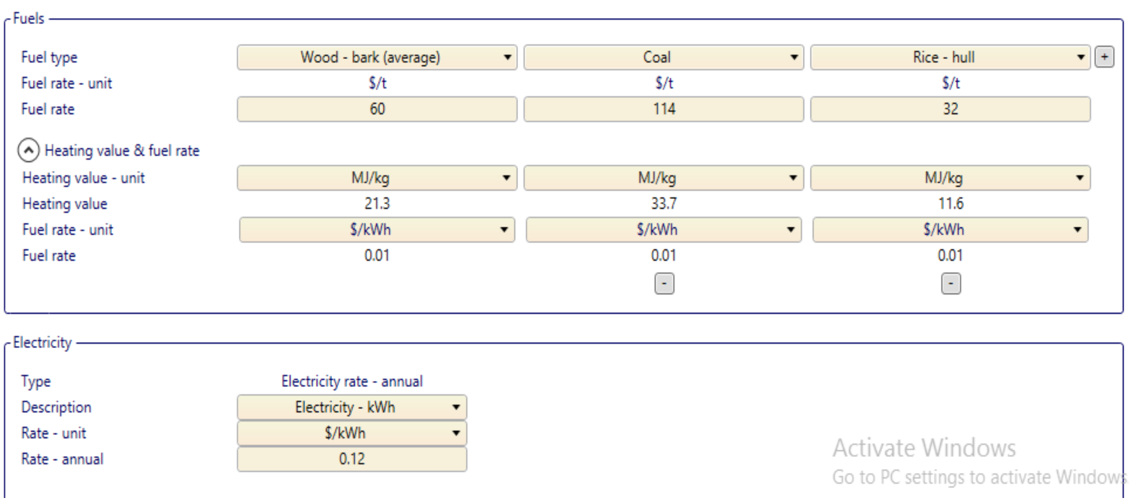


Figure 5- 14 Fuel costs and heating parameters

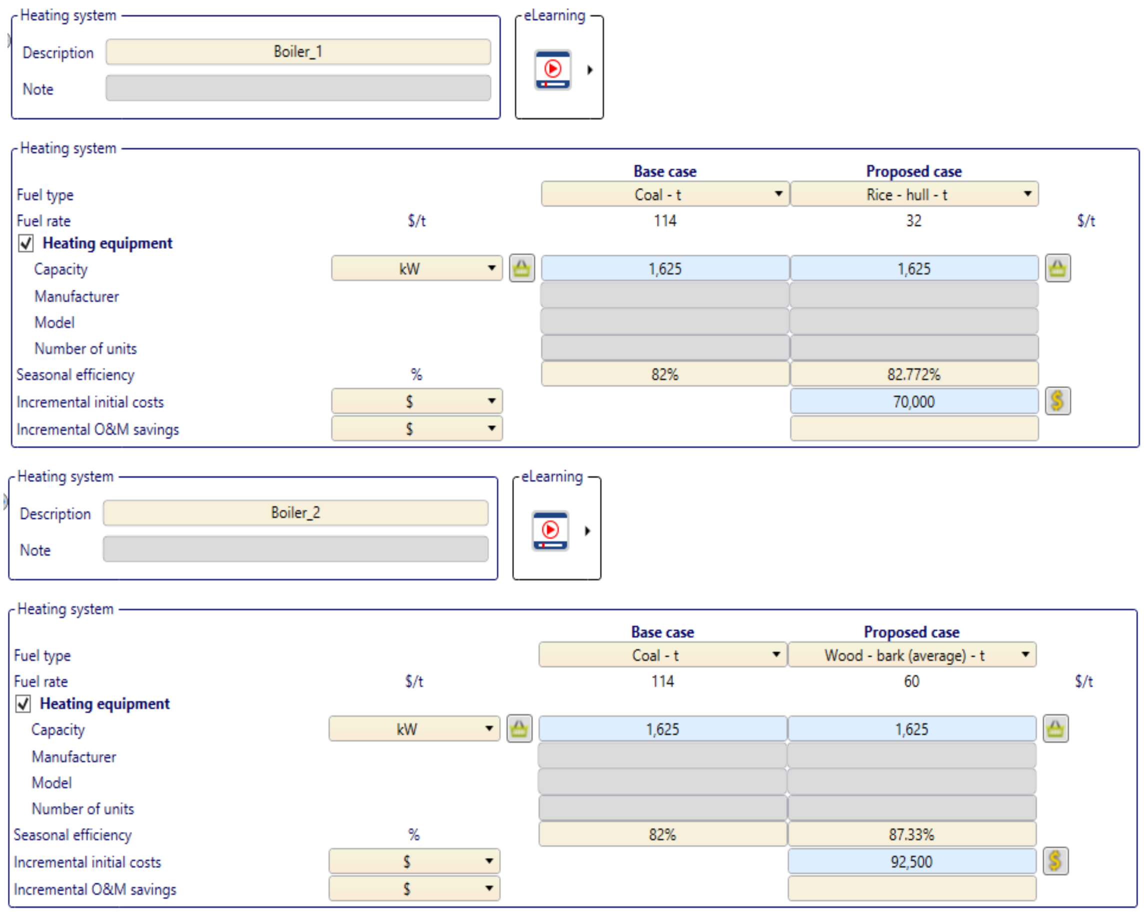


Figure 5- 15 Boiler parameters used

Boiler efficiency is 82% in the base case (coal-fired boiler), and switching from fossil fuel to biomass has also improved boiler efficiency. A wood fuel-fired boiler's efficiency has been calculated to be 87.33%, whereas a rice husk-based fire tube boiler estimated

82.772%. Coal, wood-bark, and rice-husk fuel prices are 114 USD/ton, 60 USD/ton, and 32 USD/ton, respectively.

Process steam

Description	Process steam_1
Note	

Process steam

		Base case	Proposed case	Energy saved
Steam flow	kg/h	2,708.33	2,708.33	
Operating hours	h/yr	7,500	7,500	
Steam demand	kg	20,312,475	20,312,475	
Steam pressure	bar	10	10	
Saturation temperature	°C	180	180	
Superheated temperature	°C	180	180	
Condensate return	%	50%	50%	
Condensate temperature	°C	90	90	
Makeup water temperature	°C	20	20	
Makeup water reduction	L		0	
Incremental initial costs	$			
Incremental O&M savings	$			
Heating system		Boiler_1	Boiler_1	
Number of units		1	1	
Heating	MWh	14,371	14,371	0 0%

Process steam

Description	Process steam_2
Note	

Process steam

		Base case	Proposed case	Energy saved
Steam flow	kg/h	2,708.33	2,708.33	
Operating hours	h/yr	7,500	7,500	
Steam demand	kg	20,312,475	20,312,475	
Steam pressure	bar	10	10	
Saturation temperature	°C	180	180	
Superheated temperature	°C	180	180	
Condensate return	%	50%	50%	
Condensate temperature	°C	90	90	
Makeup water temperature	°C	20	20	
Makeup water reduction	L		0	
Incremental initial costs	$			
Incremental O&M savings	$			
Heating system		Boiler_2	Boiler_2	
Number of units		1	1	
Heating	MWh	14,371	14,371	0 0%

Figure 5- 16 Process steam parameters

The fuel consumption has been reduced from 35,050 MWh of equivalent electricity generation capacity to 33,817 MWh of equal electricity generation capacity by switching from coal to rice-wood biomass fuel. According to the simulation-based results, a fuel change will save 1,233 MWh of equivalent electricity generation power. As a result, it's estimated that the suggested scenario would conserve 3.5% of the fuel used in the base case. Energy savings from the 50-50% wood and rice mix fuel feedstock has been shown in Figure 5-17 and shown in tabulated form in Table 5-4.

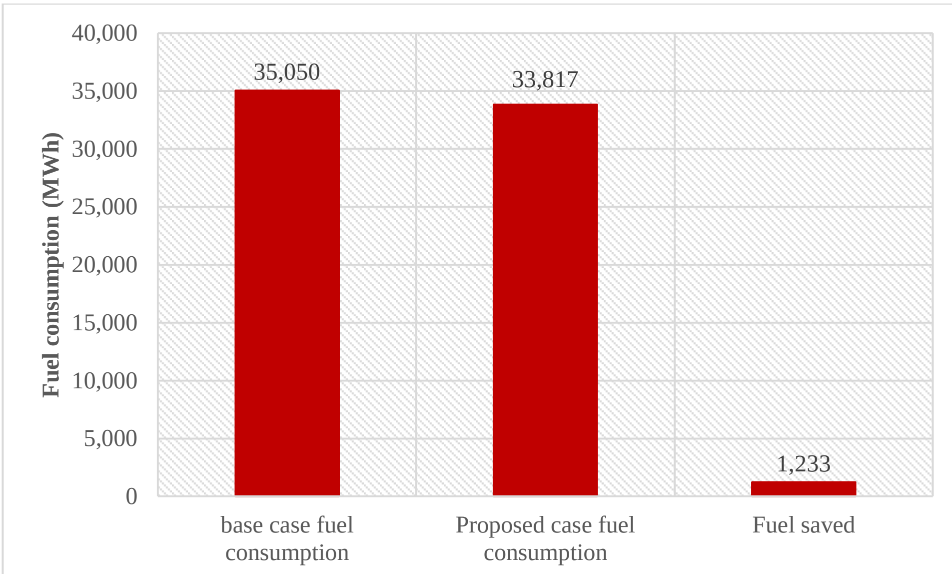


Figure 5- 17 Energy saving from the proposed case

Table 5- 4 Fuel consumption results based on the proposed case

Fuel consumption	Heating (MWh)	Cooling (MWh)	Electricity (MWh)	Total MWh
Base case	35,050	0	0	35,050
Proposed case	33,817	0	0	33,817
Fuel saved	1,233	0	0	1,233
Fuel saved-percent	3.5%	0%	0%	3.5%

The study showed that if the proposed scheme is implemented in the market, it will result in a 20.5% decrease in fuel prices since the base case fuel cost was $ 427,075and has declined to $ 339,574 if the proposed case scenario be enforced, as shown in Figure 5-18.

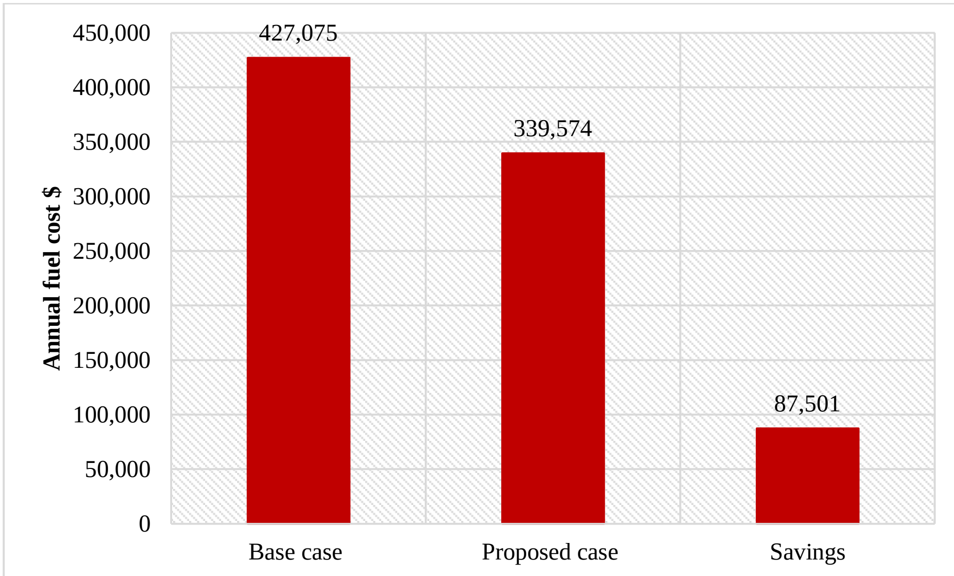


Figure 5- 18 Fuel cost savings of 50-50% rice& wood mix fuels

5.4.2 Financial analysis

Evaluating a project's financial viability based on actual, intermittent, and annual expenses and any credit that might apply to the planned scheme is critical. The economic study was conducted using the same assumptions and principles from the literature as the previous two scenarios. The initiative has earned no subsidies, debt, grants, or benefits. Image 5-19 represents a cumulative cash balance map.

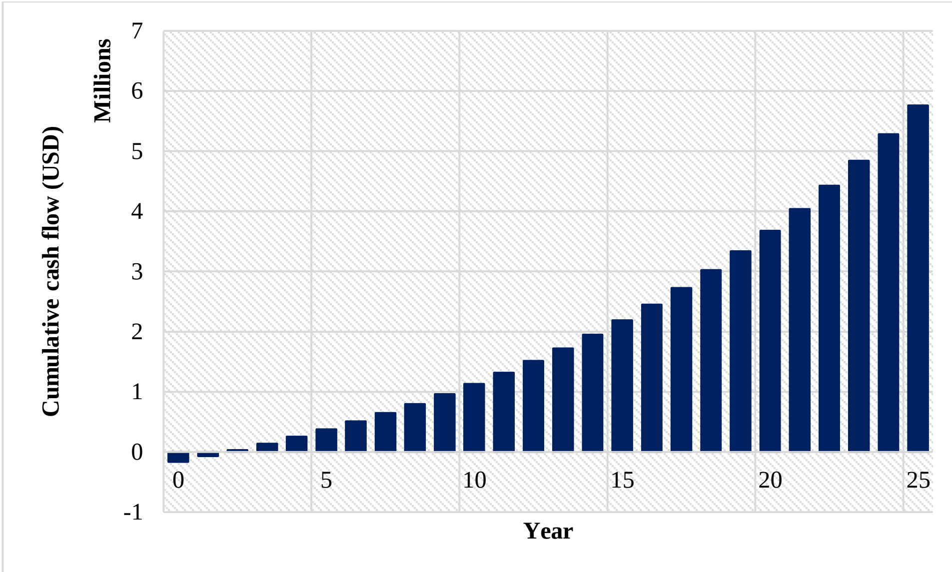


Figure 5- 19 Cumulative cash flow diagram for the proposed case

The RETScreen model holds the project life at 25 years, and a fuel escalation limit of 7% is used. The project's Net Present Value is $ 3.56 million, with a simple payback period of 1.9 years and an equity payback period of 1.7 years, respectively. Figure 5-20 depicts the simple payback period and the equity payback period. The payback period is quicker, suggesting that it is a safe investment that will produce positive cash flow in as little as 1.7 years, making it a good option for investors.

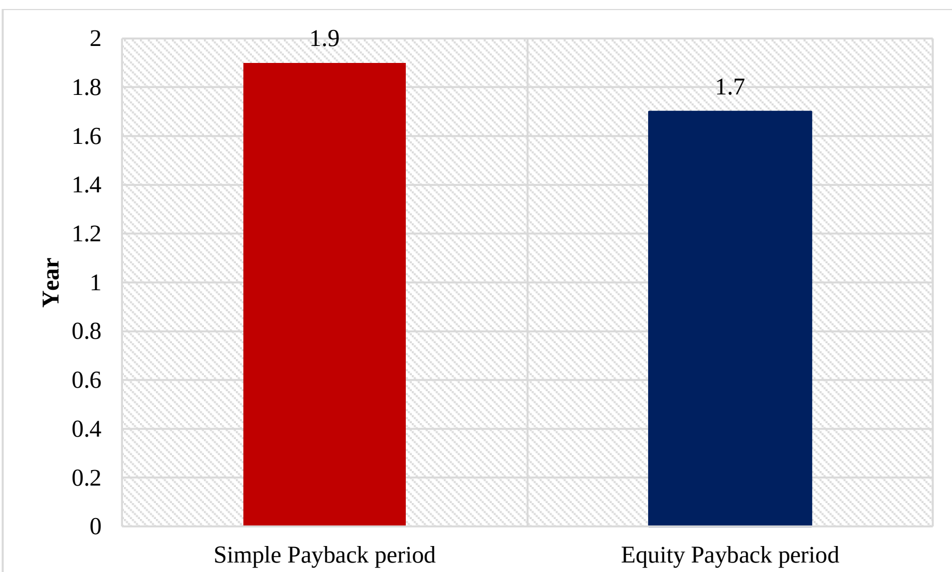


Figure 5- 20 Payback period of the proposed case

5.4.3 GHG emission reduction analysis

RETScreen international software was used to determine the base case's emission profiles (coal) and the proposed case (50% rice and 50% wood). When coal accounted for 100% of the fuel mix, transmission losses were estimated to be 7%, whereas coal-fired power generation production was 33.8%. 0.3378 tCO_2/MWh has been used as an emission factor for the base case scenario. Figure 5-21 depicts GHG emissions reduction.

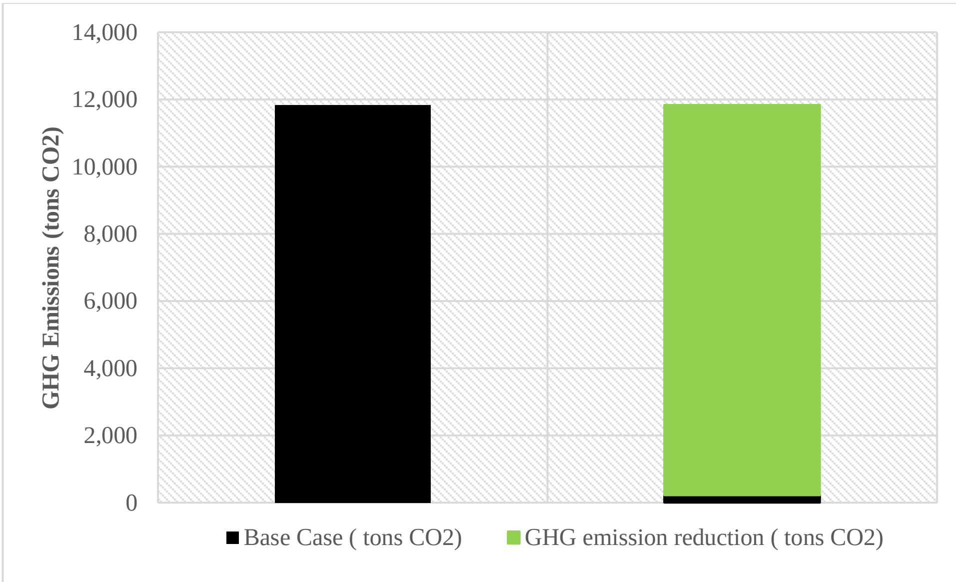


Figure 5- 21 GHG emission reduction and barrel of oil not consumed

By converting from a coal-based process heat system to the suggested case example, which uses rice and wood as a fuel feedstock source, 11,617.9 tCO_2 pollutions can be prevented. CO_2 emissions are 11,840.2 tons of CO_2 in the base case, while can be decreased to 222.3 tCO_2. This case can reduce GHG emissions by 98.1%. It is possible to save 27,018.4 barrels of crude oil by reducing CO_2 emissions by 11,617.9 tons. All of this debate demonstrates that changing the fuel feedstock is helpful to the industry's techno-economic and environmental stability.

5.5 Solar PV installation

5.5.1 Input parameters

The RETScreen international software was used to analyze various proposed solar PV device parameters, and the presented case was then compared to the base case. Tables 1, 3, and 4 of the methodology chapter provide detailed typical data included in the study to model a 1MW PV power plant. After the comparison, it is evident that the proposed case is more favourable than the current one in terms of financial feasibility, annual savings, and GHG pollution.

5.5.2 Base case power study

Electricity produced by coal and collected from the national grid was used to test the base case analysis. The base case power requirements of the proposed site are 3.07 MWh for one day as the boiler site's annual energy consumption is 4478.95 MWh. The expense of a ton of coal was used to $ 114, which the industry purchasing bills have given. The unit cost and gross electricity cost for the base case are displayed in Table 5-5. The simulations show that the base case source of power production is more expensive, financially unreliable due to volatility in coal rates, and emits more greenhouse gases.

Table 5- 5 Base case power system

Parameter	Value
Grid type	Off-grid
Fuel type	Coal
Fuel rate	114USD
Capacity	3.07MW
Heat rate	33.7 MJ/kg

5.6 Proposed case study

5.6.1 Annual energy yield estimation

The proposed case study used a mono-crystalline silicon PV solar cell with a power potential of 1,000KWp and a performance of 20.27%. This model uses fixed solar tracking mode as a control system, and miscellaneous losses are estimated at 13%. Soil losses, AC losses, DC losses, thermal losses, light-induced degradation (LID), and others contribute

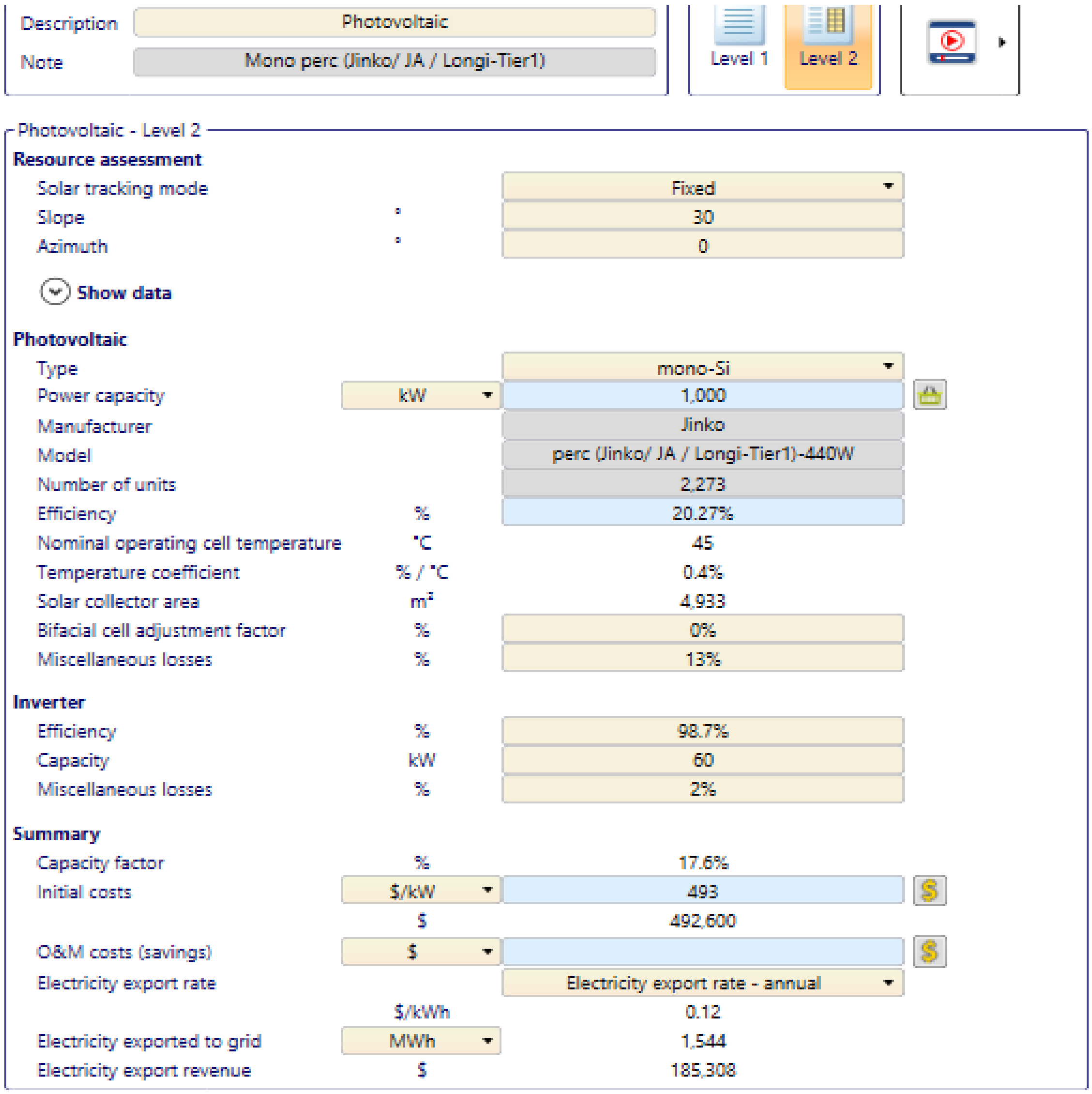


Figure 5- 22 Specifications of energy components used

to a higher miscellaneous loss. PV parameters are seen in Figure 5-22 as an input parameter to RETScreen.

As a result, gross solar PV energy supplied to the load is 1,544 MWh. In contrast to the present method, the proposed case provides a cleaner energy supply and decreases CO2 pollution by 100%, making it an attractive investment for the industry.

5.6.2 Financial analysis

The initial financial parameters were used in the RETScreen model for economic analysis of the proposed solar PV system, as seen in Table 2. Various cost items such as feasibility analysis costs, development costs, engineering costs, power system costs, the balance of system & miscellaneous expenses, operating and maintenance costs, and recurring costs were all factored into a $492,600 estimate. It is important to remember that the inverter life, estimated to be 12 years, will need to be replaced after 12 years at the cost of approximately $ 57,914. Table 5-6 illustrates the project's extensive expense estimates.

Table 5- 6 Initial cost of solar PV system

Serial No#	Item	Quantity	Unit item price (USD)	Total Price (K USD)
1	Photovoltaic	2273	286 (USD/kW)	286,000
2	String inverter	14	4136.7	57,913
3	Mounting Structure	7	6364.92	44,554
4	Balance of system	-	-	87,334
5	Civil engineering work	3032	5.41	16,403

The net present value (NPV), internal rate of return (IRR) on equity, internal rate of return (IRR) on the asset, benefit-to-cost ratio (BCR), equity payback period, and simple payback period have all been estimated based on RETScreen calculations. The project's net present value (NPV) is $ 3.27 million. According to the findings, the benefit-cost (B-C) ratio is 7.6, the annual life cycle saving is $ 187,651 a year, and the IRR on equity is 38.2%. The cumulative cash flow diagram is shown in Figure 5-23.

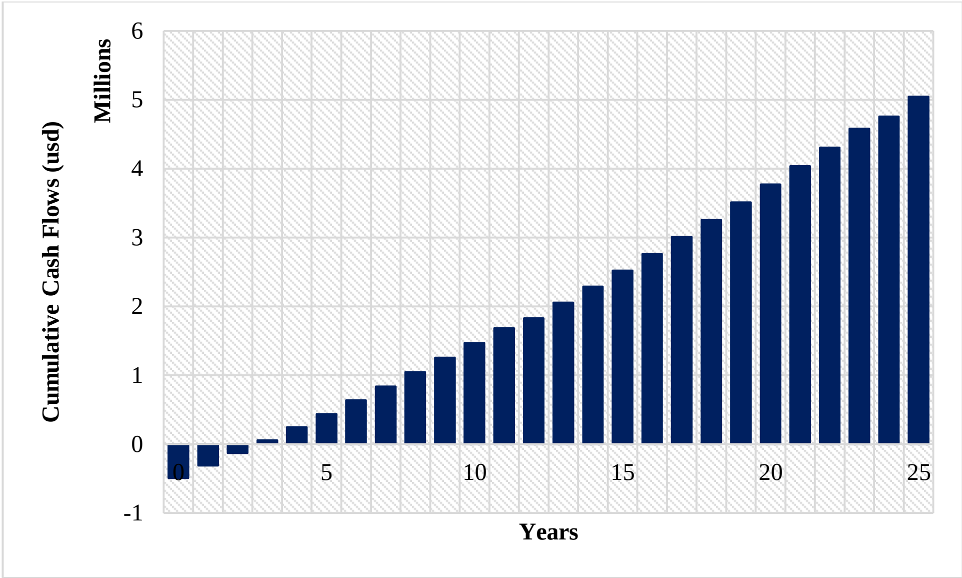


Figure 5- 23 Cumulative cash flow diagram

The project's payback duration is 2.7 years, while the equity payback period is still 2.6 years, as shown in Figure 5-24.

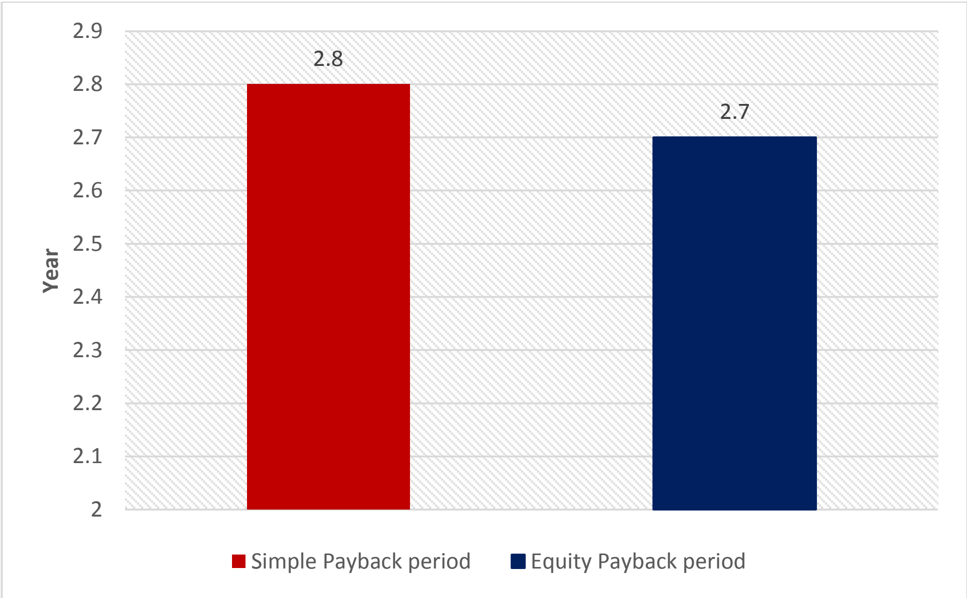


Figure 5- 24 Payback period of the proposed project

This makes the investment more popular and enticing to buyers when the return cost is greater than the project's rate of return.

5.6.3 GHG emission analysis

When renewable energy sources are used to replace conventional power production, greenhouse gas emissions are minimized. Transmission losses are estimated to be 7%, with emission factors of 0.409 tCO_2/MWh. Figure 5-25 illustrates the effects of the pollution study. In the base case scenario, all coal-based energy was used, resulting in a GHG emission of 679.3 tCO_2. Solar PV proposed system has an emission of 47.2 tCO_2 showing that a greenhouse gas emission reduction potential of 632 tCO_2 can be achieved. Figure 5-25 represents the GHG emission reduction potential of the proposed solar PV plant.

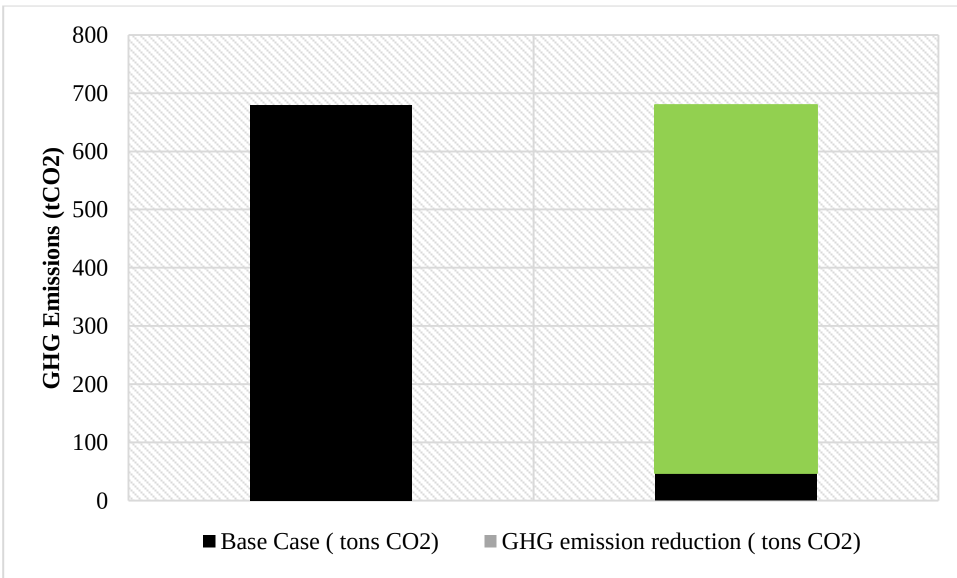


Figure 5- 25 GHG emission reduction and barrels of oil not consumed

Results show that the selected site will save 1,469.2 barrels of crude oil by shifting the electricity generation system from coal to solar-generated electricity. This is one of the most effective ways to reduce electricity development costs and provide the most potent GHG pollution mitigation strategy.

5.7 Bank-financed Solar PV system

In policymaking, comparing the operational performance of solar PV systems in companies to bank-financed systems is critical. Taking out a loan from various banks to reduce reliance on fossil fuels and change the trend toward green and clean energy production is a smart option. In this scenario, a 1 MW solar PV plant is installed with 75%

of the cost funded by the bank and 25% paid for by the industry. The payback period is 0.89 years, with a benefit to cost ratio of 26.6. The asset has a net present value (NPV) of $ 3.15 million, a 115% pre-tax IRR equity, a 30.5% pre-tax IRR on assets, and an annual lifecycle saving of $ 181,059. Figures 5-26 and 5-27 show the proposed system's cumulative cash flow diagram and payback period.

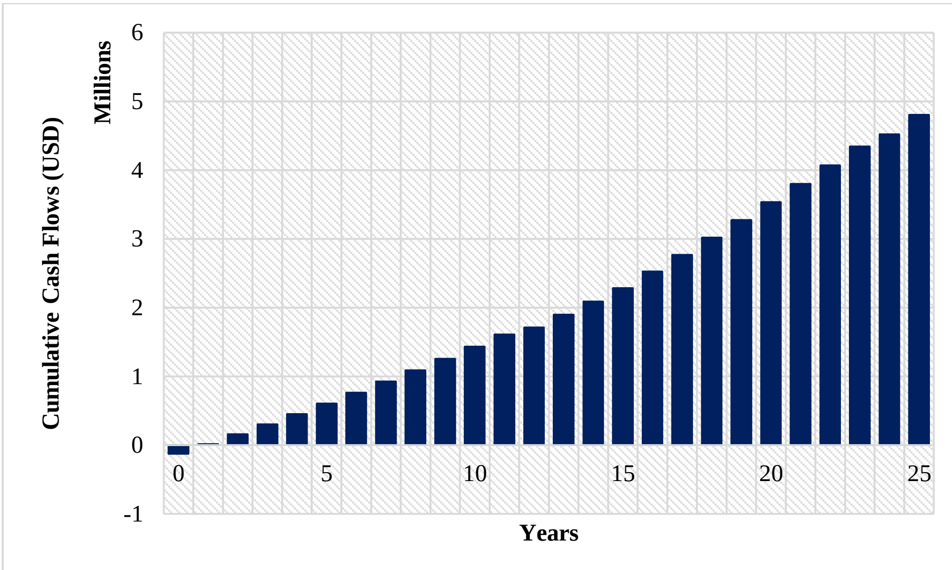


Figure 5- 26 Cumulative cash flow diagram of bank-financed solar PV system

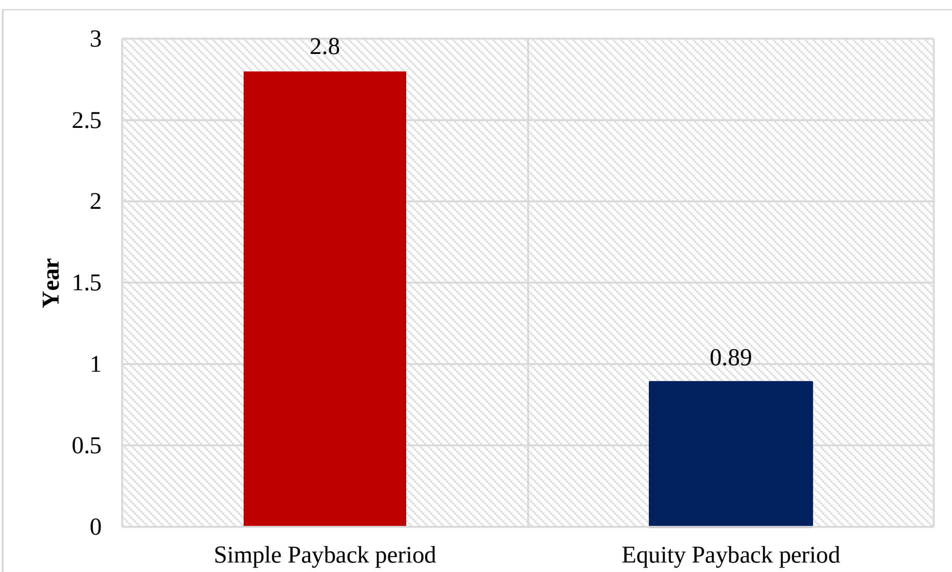


Figure 5- 27 Payback period of bank-financed solar PV system

5.8 Fixed and two-axis tracking methods

The solar irradiance determines the quantity of energy generated by a solar PV system; if the irradiance is high, so higher will the amount of energy generated, and vice versa. The positioning of solar panels and the tracking techniques employed in solar PV arrays significantly impact energy production. The suggested slope angle for a PV array when utilizing a fixed axis solar PV tracking technique is 10° to 80°, with an azimuth angle of 0°. If you're using a two-axis tracking system, the optimum slope angle is between 0° and 80°, and the best azimuth angle is between 120° and -120°. Table 5-7 summarizes the fixed and two-axis tracking techniques for company-financed and bank-financed solar PV systems.

Table 5- 7 Summary of solar PV systems

Parameters	Solar PV system (0% debt)		Solar PV system (75% Debt)	
	Single Axis Tracking	Two Axis Tracking	Single Axis Tracking	Two Axis Tracking
System Production (MWh/year)	1544	2034	1544	2034
Normalized Production (kWh/kWp/day)	4.23	5.57	4.23	5.57
Electricity export revenue ($)	185,308	244,032	185,308	244,032
Simple Payback period	2.8	2.1	2.8	2.1
Equity Payback Period (years)	2.7	2	0.89	0.62
Net Present Value (Million USD)	3.27	4.56	3.15	4.45
Annual Lifecycle Savings (Thousand USD/year)	188	262	181	255
Energy production cost (USD/kWh)	0.031	0.023	0.035	0.026

Summary

RETScreen international software biomass and solar PV model findings are presented. The techno-economic and GHG emission mitigation results for each case are presented. In this chapter, statistical details about the data are also presented.

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Chapter 6

Conclusion and Recommendations

6.1 Conclusion

The industrial sectors' energy demand is determined by their power grid, energy consumption, and work type. For Iqbal Rice Mills (PVT) Limited, located at Faisalabad Rd, Chiniot, Punjab, a Level-1 audit activity was performed for all development and utility departments inside the factory premises, with a particular emphasis on the significant energy users. The study of power bills showed past and existing energy use and field surveys to find areas where energy efficiency could be improved. For the systematic study of major energy consumers, energy audit equipment was also used.

The RETScreen international software has been used to study boiler energy efficiency calculations to find a techno-economic and environmentally safe approach for process steam generation. Based on the information gathered, two scenarios were developed. For energy, economics, and GHG emission reduction study, the biomass scenario was further subdivided into three systems: 100% rice husk, 100% wood, and 50-50% wood and rice. Fuel cost savings of 19%, 20.5%, and 22% were observed for 100% rice, 50-50% rice and wood, and 100% wood as fuel feedstocks, respectively. The benefit to cost ratio of 24.7, 22.9, 21.6 and payback periods of 1.7 years, 1.9 years, 2 years are achieved by 100% rice husk, 50-50% rice husk and wood, and 100% wood, respectively, while eliminating GHG emissions by 98%. In scenario 2, the findings indicate that a 1MW solar PV device can export 1,544 MWh of electricity to the grid while producing $185,308 of revenue for the industry while minimizing 631.8 tCO_2 pollution atmosphere with a 2.6-year payback period while for the bank-financed solar PV system, the payback period is 0.89 years along with benefit to cost ratio of 7.6. The solar PV system is also evaluated based on solar tracking methods, showing that the two-axis solar tracking method can generate more solar energy.

The findings and discussions showed that the suggested scenario of a 100% rice-husk based fuel feedstock is the most potent potential techno-economic and environmentally friendly option for boiler energy use since it saves the most money on fuel, lowers GHG emissions, and has the shortest payback time.

6.2 Recommendations

- Smart meters should be installed in the manufacturing region to allow continuous tracking and recording of electric load in real-time. This would offer an additional advantage for a better understanding of industrial energy use and, as a result, a more advanced energy demand mitigation approach.
- Boiler combustion air fans controlled by dampers can be substituted with variable speed drives to ensure that only the required air volume is delivered to the combustion chamber, lowering energy consumption.
- Based on energy audits, a boiler performance upgrade and maintenance plan should be created. The highlighted sections of the boiler are restored, retrofitted, or replaced to prevent a significant loss.
- Renewable energy, especially solar PV technology, is the most cost-effective on-site energy generation alternative. Suppose the whole industry electricity consumption moves to green energies, a cleaner energy source. It can stop electricity consumption produced by the national grid, which is mainly generated by thermal power plants that burn fossil fuels. This will assist in the reduction of carbon emissions.

Appendix

Energy, economic, and GHG emissions assessment of biomass and solar PV systems for an industrial facility

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Abstract:

Industrial sector is responsible for nearly 25% of direct and more than 35% of cumulative global, energy related GHG emissions. This study evaluates the feasibility of on-site solar PV and biomass-based boiler to reduce dependence on grid supplied electricity and coal fired boiler of a industrial plant for rice processing. The analysis includes energy, economic and GHG emissions assessments and covers the following three scenarios: (a) Solar PV system (b) Biomass fuels and (c) Co-firing of coal-biomass. Economic analysis of solar PV systems considers both company-owned and bank-financed systems. The study considers commercially available solar PV technologies of both fixed and double axis tracking for solar PV modules. Biomass fuels considered in this work include 100% wood, 100% rice husk, and a 50-50% wood-rice husk mix. Historical energy consumption shows that annual electricity demand is 4,479 MWh, costing $537,480 and producing 2,307 tCO_2 emissions. Feasibility of 1MW, company-owned, solar PV plant consisting of fixed axis panels, shows an annual electricity production of 1,544 MWh with 0.031 $/kWh levelized cost of electricity. The associated annual GHG emissions reduction is 733 tCO_2 with payback period of 2.8 years. Base case scenario for boiler operations consists of 3,746 tons of coal burning, costing $427,075 and producing 11,840 tCO_2 emissions. Biomass feedstock offers substantial reduction in GHG emissions and attractive economic benefits. Rice husk fuel study shows a 19% fuel cost savings, a 1.7-year payback period, and 11,612 tCO_2 GHG reductions. It is concluded that biomass-based rice husk fuel

feedstock is most suitable renewable energy resource for this industrial facility and can reduce 82% of cumulative annual GHG emissions. On-site Solar PV can only reduce 5.3% of cumulative GHG emissions. Furthermore, both energy efficiency improvements and off-site carbon credits provide additional opportunities for achieving net-zero GHG emissions for plant operations.

Keywords: Industrial Energy Management, Solar PV System, Biomass, Co-firing, RETScreen

Journal: Energy Reports

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