Optimization of Industrial Hybrid Renewable Energy System using HOMER

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THESIS ACCEPTANCE CERTIFICATE

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Dedication

To my beloved parents (Mr. Khalid Javed and Ms. Nighat Naheed) who has always believed in me and inspired me to follow my dreams, and without their constant motivation, this work would not have been possible.

Abstract

The current steep rise in energy demand by industrialization and urbanization has pushed human civilization towards renewable energy technologies. Pakistan, an underdeveloped country, has a shortfall of 6,997 MW of electricity. Being an agricultural country, Pakistan has the benefit of producing energy requirements from solar and biomass. The geological position of Pakistan has much potential for harnessing solar power. Layyah, a city in Punjab province, was used as a case study area. Solar radiation and rice husk as a biomass resource were found to be unstoppable electricity production. Homer software was used for the techno-economic analysis of the PV/Biomass hybrid system. Off-grid (PV-BM-DG-B) and On-grid (PV-BM-G) models were designed, where 300 kW configuration of biomass generator was feasible for Off-grid and 200 kW configuration of biomass generator for On-grid power generation, respectively. The techno-economic analysis revealed that Off grid with 300 kW biomass generator is feasible as it shows NPC, LCOE, and renewable penetration of 5.91 M$, 0.125 $/kWh and 99.8%, respectively, whereas, in On-grid system with 200kW biomass generator showed 3.51 M$, 0.0503 $/kWh and 97.9%, respectively. Environmental analysis revealed that these models would help to reduce carbon emissions compared to grid emissions. Off grid model with 400 kW is the most feasible model as it will need only 68 trees to absorb the 1305 kg CO_2 in a year.

Keywords: Solar energy, Biomass, Rice husk, Renewable resources, HOMER.

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List of Abbreviations

Photovoltaic	PV
Biomass	BM
Diesel Generator	DG
Batteries	B
Grid	G
Net present cost	NPC
Levelized cost of energy	LCOE
Cost of energy	COE
Biomass sources	BS
Kilowatt hour	kWh
International energy agency	IEA
Renewable source	RS
Municipal solid waste	MSW
Renewable energy resource	RES
Greenhouse gases	GHG
Transmission and distribution	T&D
Combined heat and power	CHP
Concentrated solar power	CSP
System advisor model	SAM
Power-technology tower	PTC
Gross domestic product	GDP
Wind turbine	WT
Hybrid renewable energy system	HRES
Remote radio head	RRH

American society for testing and materials……..…………………..……... ASTM

Carbon, hydrogen, nitrogen and sulphur analyser……………..……....... CHNS

Proportional integral derivative……………………………….………… PID

National renewable energy laboratory………………………………….. NREL

Hybrid optimization of multiple energy resources……………………... HOMER

Direct current…………………………………………………………… DC

Alternative current……………………………………………………… AC

Voltage……………………………………………..…………………… V

Operational and maintenance………………………………………….. O&M

Initial capital…………………………………………………...……… IC

Cycle charging………………………………………………………… CC

Internal rate of return………………………………………………….. IRR

Return on investment………………………………………………….. ROI

Payback period………………………………………………………… PBP

Total cash inflow for a time…………………………………………… C_t

Total initial investment cost……………….…………………………. Co

Total annual energy production……………………………….……… E_{total}

Life cycle cost…………………………….…………………………… LCC

Capital cost……………………………..……………………………… C_{cap}

Replacement cost………………………………………………………. C_{rep}

Operation and maintenance cost...……………………….…………….. C_{OM}

Fuel cost…………………………...…………………………………. C_{fuel}

Salvage cost……………………..……………………………………… $C_{salvage}$

Discount rate……………………..……………………………………... DR

Gross calorific value……………………………………………………..……… GCV

Low heating value…………………………………………………………… LHV

Chapter 1

Introduction

1.1. Energy

The capacity to do work is how scientists characterise energy. Energy is converted from one form to another and then used to do work, and this ability is what makes modern society possible. Everything from getting about (on foot, by bike, in a car, on a boat, etc.) to providing for one's fundamental needs (lighting, cooking, product production, ice making, etc.) requires energy [1].

1.2. Non-renewable energy

Primary sources of energy, such as the sun or wind, may be utilised to generate heat, while secondary energy sources, such as electricity or hydrogen, can be generated from primary energy sources. Their availability is limited by what can be gleaned from the ground or mined. Over millions of years, marine organisms and plants died and were buried, giving rise to coal, natural gas, and petroleum. For this reason, these fuels are known as fossil fuels.

The uranium used to generate nuclear power is a non-renewable resource that undergoes atomic splitting (a process known as nuclear fission) to release heat and, ultimately, electricity. Experts believe that uranium was first produced while stars formed billions of years ago. The uranium fuel cycle is inefficient because most of the uranium in the earth's crust is either too difficult to extract or too costly to process [2].

1.3. Renewable energy

Renewable energy (RE) encompasses a wide range of resources that can replenish themselves over time, such as solar, wind, hydroelectric, geothermal, and biomass sources (BS). These assets may provide power for the whole economy, gasoline for vehicles, and thermal energy for construction and manufacturing [3]. Compared to traditional energy sources, renewable energy technologies have significant advantages [4]. There is no shortage of renewable energy sources; in fact, the intensity at which the sunrays hit Earth's crust is one thousand times greater than the energy generated by all of humanity's current use of fossil fuels.

Acid rain, air pollution, forest degradation, ozone depletion and radioactive emissions are all interconnected with problems in the energy industry and the way its consumers use and manage their resources. All these things must be considered simultaneously if humanity is to achieve a bright energy future with minimal environmental impacts. Plenty of evidence suggests negative consequences due to human activities in changing environments.

The energy sector and the public have begun prioritizing environmental factors beyond carbon emissions. There has been widespread acceptance of the idea that individuals bear some of the financial burdens of pollution. The energy cost has grown in the last decade to two in certain regions, reflecting the higher expenses associated with protecting the environment. By the middle of the 21st century, global population growth is projected to have doubled, and economic growth will probably continue. By 2050, primary-energy needs are predicted to grow by 1.5–3 times, while the demand for energy services might increase by as much as an order of magnitude [5]. At the same time, issues like acid rain, ozone depletion in the stratosphere, and climate change will get more attention since they are directly tied to energy use and production.

1.4. Solar Energy

Renewable energy sources such as wind, hydro, geothermal and solar must be seriously considered [7]. Nevertheless, solar power may be the greatest hope for the future: Earth absorbs only 1.8×10^{14} kW of solar energy; however, the energy reached on earth is 3.8×10^{23} kW [8]. This makes solar energy the most plentiful form of renewable energy. Solar energy is received on Earth in several ways, including light, heat, and electricity. A significant amount of this energy is dissipated as it travels due to dispersion, reflection, and absorption by clouds. Solar energy has effectively been shown to meet the energy requirements [9] because it is naturally cost-free, infinite, and stable [10]. The effectiveness of the solar PV sector is heavily dependent on the geographic distribution and intensity of solar radiation. These two factors vary worldwide. As shown in, due to their longer sunlight hours each year, Asian states have the most significant potential to benefit from solar radiation. Much of solar energy is lost because it is not harnessed [11]. There are numerous places, especially those in development, where solar radiation is abundant and may be used widely [12].

In 2020, compared to neighboring India, Pakistan had a much lower per capita energy usage of 448 kWh [6]. Increasing dependence on renewable energy resources, especially solar energy, may help raise Pakistan's relatively low per capita energy consumption. In terms of both geography and climate, the region of Punjab in Pakistan has great promise as a site for solar power. The majority of the country, except the northern regions, enjoys an average of 8-10 hours of sunlight per day throughout the year; this number drops to seven to eight hours during the winter months (starting from December till February) and rises in summer nine to ten hours (starting from May to August) [7]. Pakistan has an average of 5 to 7 kWh/m^2 daily sun irradiation [8]. Punjab is a significant province with 53 percent [9] of the population. South Punjab has high solar insulation and a rising need for electricity. In 1994–1995, residents of Punjab used 23,635 GWh of electricity. In 2016–2017, this quantity of energy was 60,940 GWh. In only 24 years, the growth is more than two folds [10]. There is a large body of research, both domestic and international, that places heavy emphasis on renewable energy sources, particularly solar power for a variety of applications. Openshaw claims that the use of solar energy may curb tree-cutting [6] as shown in **Fig. 1.*1***

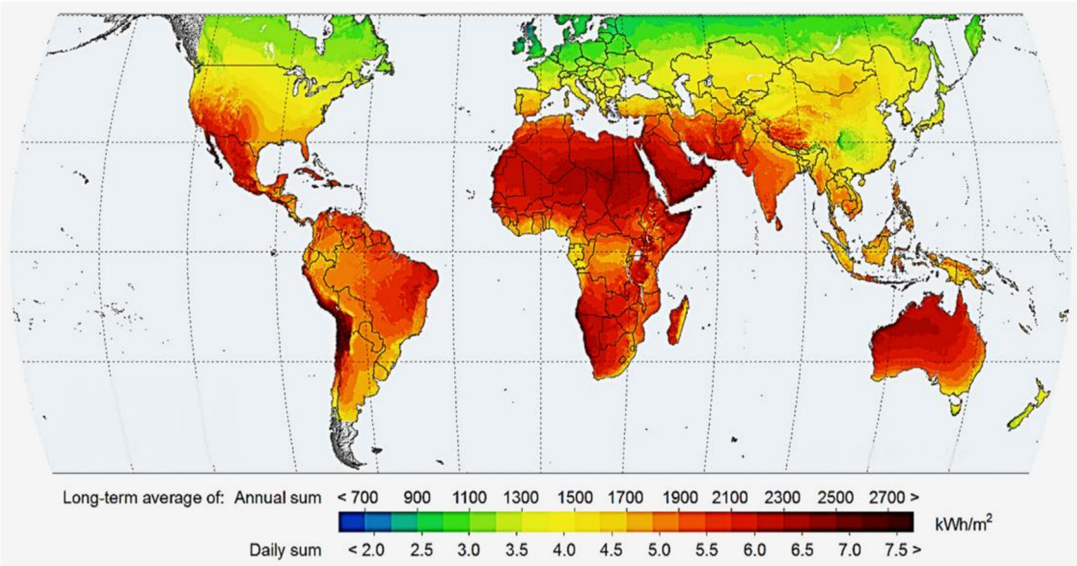


Fig. 1.1 Global irradiation on Map

Given its location in the sunbelt in Southwestern Asia, Pakistan has much potential for harnessing solar power. Three hundred sunny days and 1500–3000 annual sunlight hours provide an estimated 200–250 Watt/m^2 daily average worldwide horizontal radiation. Pakistani solar radiation map is seen in **Fig.1.*2***

Located in the southern area of Pakistan, Punjab Province, Layyah is a backwater surrounded by deserts. The Layyah power grid is under tremendous strain to meet the increasing energy demands of the city's residents while also coping with the consequences of policymakers' indifference. The sun shines for a longer time, and there are few possibilities of overcast or wet weather throughout the year, indicating the most significant potential for solar energy.

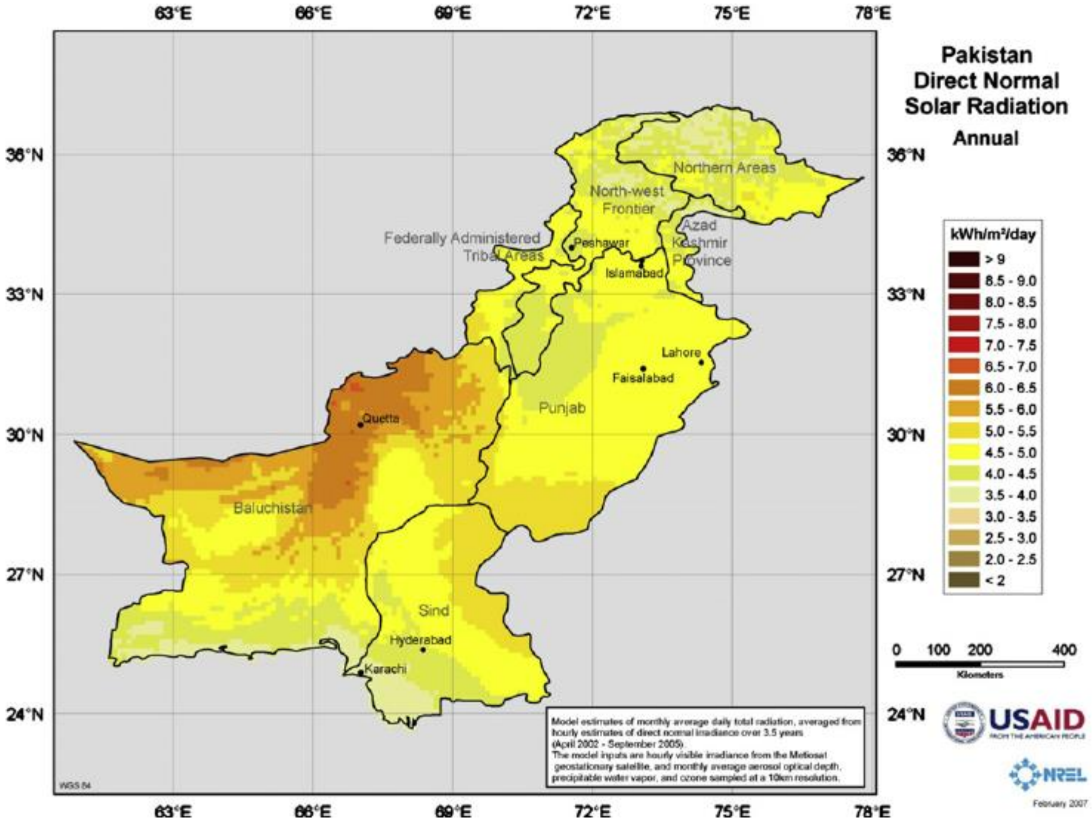


Fig.1.2 Solar Map of Pakistan

1.4.1. Photovoltaic technology

This technique directly transforms solar energy into electricity. Therefore, these panels are purposefully made to be as easy to use as possible so that everyone may benefit from them [11]. More than that, they may provide more remarkable results with less input. Therefore, they have many uses all around the globe. However, the method might need some tweaks to provide better results. Silicon is a typical semiconductor material used in photovoltaic (PV) systems because of its ability to induce electricity. PV panels rely on extra energy being supplied to stimulate electrons. The working principle is that solar energy transfers electrons from low-stated energy to higher when solar energy. Due to this activation, free electrons and holes will be created in the semiconductor, and electricity will be produced [12].

Semiconductors, including silicon (mono-, poly-, and micro-), Cd Se, and Cd Te, are often utilized in PV systems. Many considerations go into making a final decision on which materials to choose [13]. A PV system has multiple parts, including cells, modules, and arrays. To ensure optimal performance, structures, electronics, mechanical devices, and electrical connections are subject to various controls and regulations. A PV system will produce maximum electrical power on sunny days, measured in peak kilowatts [14]. From the dawn of time, scientists have been working to increase PV panels efficiency, and now, the sector is believed to be expanding rapidly, with annual growth rates of 50% (or more) since 2002 [15].

1.5. Biomass

Since households and the local power sector use natural gas and furnace oil to produce heat and electricity in Pakistan, their high prices significantly contribute to the country's energy problem [16]. Biomass is a possible resource for resolving such problems in developing nations like Pakistan. Renewable energy is widespread in developing and developed countries because it can be a sustainable option with minimum environmental impact. Nearly 71% of European Union (EU) power comes from renewable sources [17, 18].

Biomass, a versatile renewable energy source, may significantly meet the varying demand profiles across the world's electrical, construction, and transportation sectors. Globally, Biomass is a primary source, accounting for 14% of the 18% of RE in the energy mix [19]. In 2012, biomass was the source of 370 TW/h of electricity or about 10% (50 EJ) of the global production primary energy source [20]. A variety of liquid biofuels in the Americas; poly-generation of biofuels, heat, and power production in Europe; wood fuel and charcoal for domestic heating and fuel in small-scale industries in Asia and Africa are just a few instances of the intriguing regional variations within finished product from bioconversion. Bioenergy accounts for a larger percentage of the entire energy mix in places where biomass resources are plentiful. **Fig.1.** shows how different types of biomasses are distributed all over the globe to serve as the primary energy source, based on data collected from around the world.

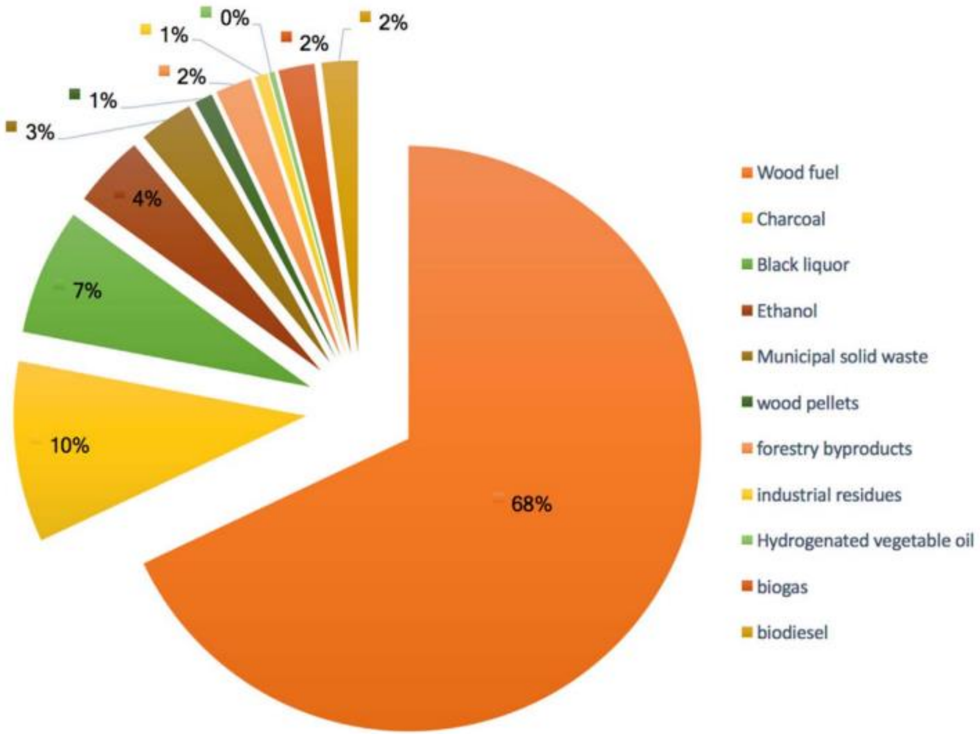


Fig.1.3 Distribution of biomass globally as the primary source.

By 2050, biofuels may provide as much as 27% of the world's transportation fuel consumption by IEA, indicating a great deal of room for the expansion of biofuels for future sustainability. 1.5% of global electricity production is through biomass. Global electricity production from biomass in 2014, 2015, and 2016 (projected generation through 2020) [21] is shown in Fig. 1.4.

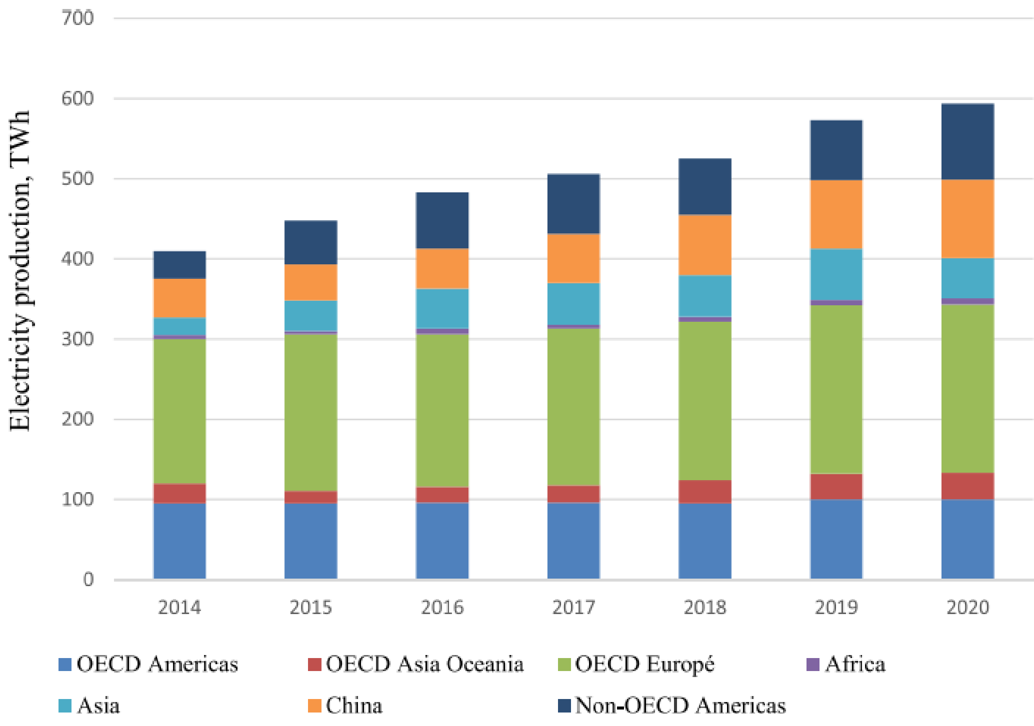


Fig. 1.4 Regional-based electricity production through biomass from 2014 to 2020

The industrialized world uses energy waste streams as a renewable source (RS) of fuel. However, properly implementing biomass as an alternative renewable energy supply is still lacking in developing states like Pakistan. RS, such as biomass, hydropower, solar, and wind, account for around 18% of global energy production [22]. A severe energy crisis is causing social and long-term economic concerns [23-25], and Pakistan is one of them. However, to satisfy expanding energy requirements, the state is tapping into its abundant indigenous sources, such as hydro-power, wind energy, solar, and biomass potential. The proportion of yearly energy consumption from different hydro, oil, coal, nuclear, and gas sources is shown in **Fig. 1.** from the 2010-2016 Pakistan Year Economic Book [26].

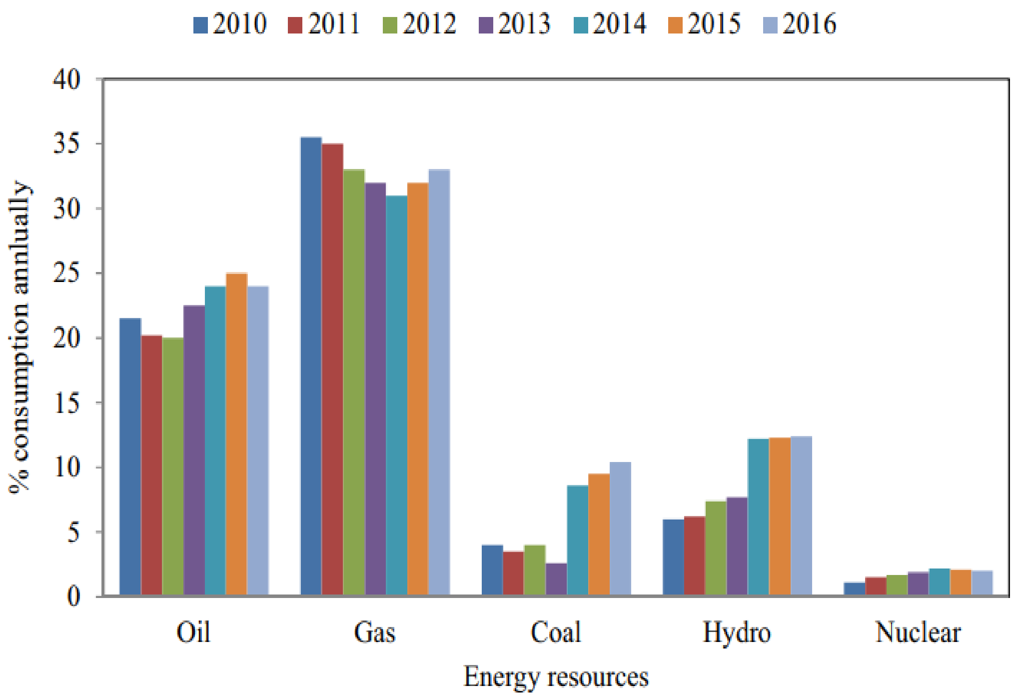


Fig. 1.5 Energy utilization from different sources in Pakistan (2010 to 2016).

1.6. Types of Biomasses

1.6.1. Agriculture crops waste

In Pakistan, since most of the economy is based on agriculture, a great deal of agricultural waste might be used in electricity generation by biomass fuel. Rice husk, Wheat straw, cane trash, rice straw, cotton sticks, and bagasse are all examples of agricultural residues as shown in **Fig.1.** that result from the cultivation and by-product of numerous crops [27]. According to World Bank figures [28], 62% population of Pakistan [29] live in a remote communities, while 26,280,000 hectares of land are used for agriculture. People in rural areas often use agricultural waste as a direct energy source for cooking and other household purposes.

Fig.1.6 Agriculture base waste

1.6.2. Forest wood residues

Wood is used for both cooking and heating purposes. People preserve enough wooden sticks to use as fuel in their stoves [30]. Biomass resources (BS) provide for over 80% of estimated energy consumption in Pakistan [16]. Forest residue is ecologically favorable and may produce a considerable proportion of total bioenergy. Different forest residue has been shown in Fig. 1.

Fig. 1.7 Forest wood waste as biomass

1.6.3. Animal waste

Animal manure is another source of energy used for burning or cooking alongside agricultural crops left over. Manure, which describes animal waste, includes organic stuff that may be easily transformed into biogas with little further processing [20].Different kinds of Animal waste has been shown in **Fig. 1.**

Fig. 1.8 Animal waste as a source of biomass

1.6.4. Municipal solid waste

Environmental health concerns due to improper waste management are a problem in many countries, and Pakistan is no exception. Municipal solid waste (MSW) includes both organic material and inorganic metals and may be treated in several ways to be used for energy production [20]. Different kinds of Municipal waste have been shown in **Fig.1.**

Fig.1.9 Municipal solid waste

1.7. Problem statement

Biomass energy is obtained from various sources, such as wood and wood waste, agricultural crops and residues, food waste, animal manure, algae, municipal solid waste (MSW), and landfill gas. In Pakistan, which is primarily an agricultural country, agriculture plays a crucial role in the economy, providing employment to a significant portion of the population and contributing to the GDP. The country cultivates major crops like wheat, rice, cotton, sugarcane, maize, as well as a variety of fruits and vegetables. Consequently, Pakistan has abundant availability of biomass energy in the form of agricultural crops and residues.

One specific biomass resource of importance is rice husk, which is the outer protective covering of rice grains separated during the milling process. Rice husk possesses significant potential for energy generation. However, it is worth noting that currently, rice husk in Pakistan is commonly burned as a waste material. Existing literature suggests that there is a lack of sufficient evidence to fully explore and support the potential of rice husk as a viable biomass energy source in the country.

1. In Pakistan, a predominantly agricultural country, biomass energy derived from various sources such as agricultural crops, residues, and rice husk remains largely untapped, with the majority of rice husk being burned as waste instead of being utilized for energy generation.

2. The potential of rice husk as a valuable biomass resource for energy generation in Pakistan has not been fully explored or supported by evidence, indicating a need to investigate and develop efficient technologies s to harness this renewable energy source effectively.

1.8. Research Objectives

The following are the research goals:

- To assess the potential and feasibility analysis of the rice factory to produce electricity using Rice Husk.
- To provide a detailed analysis of how low-cost clean energy can be obtained from biomass and solar energy near the load center in Layyah, Punjab.

1.9. Scope and limitations

1.9.1. Scope

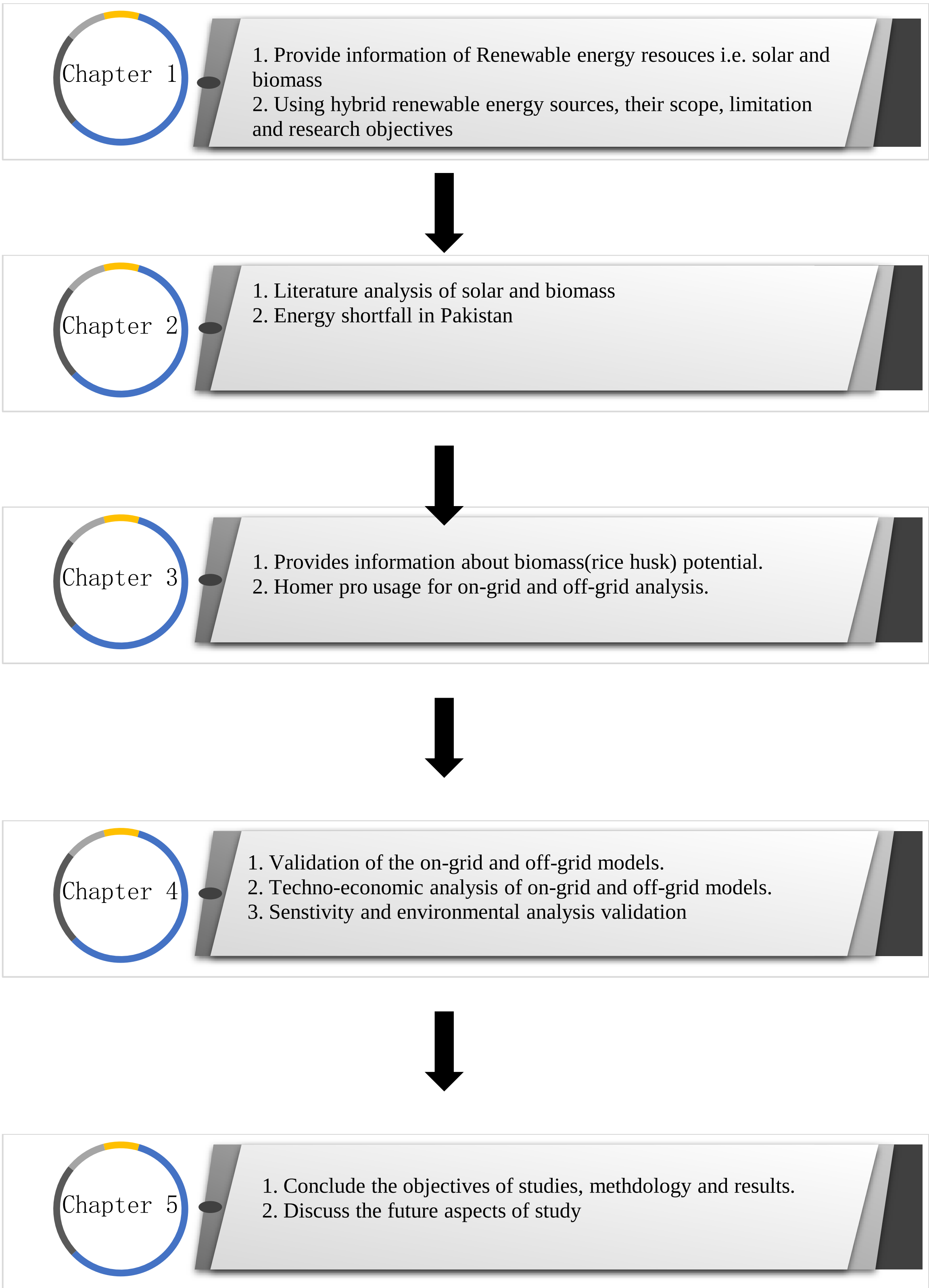
The scope of the study is to have a hybrid system that can cover energy demand from available renewable resources. Solar and biomass resources are used for energy production, having on-grid and off-grid models. Different aspects are considered, including LCOE, NPC and Payback period etc., so the model will be authentic for investment and generate the required energy demand.

1.9.2. Limitation

The study uses Homer software for the simulation of assumed models. Homer uses the data from different integrated databases to calculate the provided data.

1.10. Organization of thesis

The following flow chart shows the structure of the thesis:



Summary

This chapter focused on the different terminologies and available renewable resources in Pakistan with the current condition of utilizing renewable resources, especially solar energy, and biomass. It includes the average solar irradiation in Pakistan and its utilization. Moreover, types of biomasses and their energy production utilization are also discussed. This chapter also provides information on research objectives, scope, and limitations of this study.

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Chapter 2

Literature Review

The risks of global warming and pollution are increased through fossil fuel usage. Advancements in the development and research of RES that can replace conventional energy or fossil fuels are essential for establishing green economy energy. However, the main drawbacks of energy from fossil fuels are their rapid decline and GHG emissions [1, 2]. Fossil fuels cannot meet demand because of their high price and limited supply [3, 4]. This has led to increasing research looking at RES generation [5]. According to Wilkins et al. (2017), the top nations generating renewable energy in the present day are Spain (10.17%), Italy (8.8%), United Kingdom (11.94%), Germany (12. 74%), Turkey (5.25%), Brazil (7.35%), Sweden (10.96%), United States (4.75%), Australia (4.75%), and Japan (5.30%) [6]. Solar, wind, biomass, and geothermal energies are just a few renewable energy options that might help Pakistan to reduce its energy security and supply gap [7]. Renewable energy is the greatest bet for Pakistan at this time to help it prosper economically and sustainably. Biomass [8], coal [9], partial oxidation of hydro-carbons [8], and steam methane reforming [8] are only some of the renewable energy options that have been discussed in the past as potential complements to wind, hydro, and photovoltaic power [10]. Moreover, they indicated that combining renewable energy sources is the cleanest and most effective option for policy execution of economic development in Pakistan. In addition, they discovered that power generated from nuclear sources is the most efficient. Additionally, renewable energy sources are becoming increasingly important for globalisation and long-term economic prosperity. Because RES ought to be produced at low cost and utilised to meet society's demand in a way that doesn't have a detrimental impact on the environment, on society, or on the economy [11, 12]. Pakistan, like many other developing nations, has little fossil fuel reserves, but renewable energy sources are gradually becoming more accessible [13]. Since this is the case, all countries, whether developing or developed, are moving toward RES to meet their growing electrical demands [14, 15].

2.1. Pakistan Energy demand

Over 5,000 MW of electricity is needed to power the country, but Pakistan is struggling to use its energy resources because of several obstacles [16]. Among the most pressing issues facing emerging states like Pakistan today is ensuring a reliable and affordable energy supply for the future [17]. The state's economic growth is primarily attributed to its ability to provide people with a consistent and cost-effective energy supply [18]. Because it allows for more long-term, sustainable solutions to be implemented in the electrical network, operation, and energy resource management, long-term electricity planning has grown in favour in recent years [19]. Meeting the demand and supply imbalance is urgent, especially for developing states such as Pakistan, which is experiencing one of its worst power outages in recent memory and calls for careful long-term energy planning [20]. Every country's economy and progress depend on a reliable source of energy. It is fast advancing to the top of the list of national concerns [20]. The energy crisis and environmental deterioration are the most pressing problems in Pakistan [21]. Sustainable development is accomplished when domestic energy resources are used effectively for power generation [22]. Pakistan is experiencing an energy crisis due to the ageing power plants, which produce too little energy, and the country's inadequate Transmission and Distribution (T&D) network, which is hampered by a lack of resources [23]. Therefore, load shedding is widely used across Pakistan, leading to 8–12 hour daily (urban) and 16–18 hours daily (rural) forced outages of power [24]. Large-scale hydroelectric and coal projects have been unable to be implemented due to a shortage of significant investments in these sectors and long-term political unrest at national and provincial levels, increasing the dependency on costly fossil fuels that must be imported [25]. In addition, corruption in the power industry is facilitated by the inadequate collection of energy bills [26]. Power plans issued by the Government of Pakistan (GoP) in the 1990s are also significantly tied to other major technical components of energy problems [27]. GoP has often implemented its electricity policy without engaging in adequate energy planning or using appropriate energy modelling technologies [16]. Countries worldwide, including Turkey, India, South Africa, Syria, Malaysia, Portugal, Iran, and China, are already using sophisticated energy modelling techniques to inform their energy planning and, ultimately, their energy and power policies.

Pakistan is amid an energy crisis due to two factors: Lack of proper electricity generation and domestic resources assessment:

1. Natural gas, geothermal, solar, tidal, oil, coal, and wind are a few energy sources. A significant gap exists between energy demand and supply due to ineffective policy and planning of the energy, a lack of understanding of energy modelling methods, unfavourable governance difficulties, and a heavy reliance on imported fossil fuels.

2. In 2018, the electricity capacity was 33,433 MW; this is expected to expand to 34,282 MW in 2019 (a 2.57 percent increase). In this tenure, electricity production climbed from 85,522 GWh to 87,324 GWh, a 2.1% rise. Power consumption was still greater than electricity generation, at 120,392 GWh.

2.2. Pollution problem in Pakistan

GHG emissions and climate change are mainly attributable to today's predominant usage of fossil fuels for energy production. A 93% increase in global net energy production by 2040 is projected [28], which, if achieved via the exclusive use of fossil fuels, would significantly exacerbate existing environmental issues. A rise in the need for energy directly results from growing populations, expanding economies, and more industries that cause rapid industrial, municipal, animal, and agricultural waste accumulation. One of the world's most rising concerns is how to properly manage garbage, which is particularly acute in developing nations. The need for effective solutions is urgent and affordable means of trash disposal, and one viable option is to convert various types of garbage into usable energy [29].

2.3. GHG emissions from electricity generation

Burning fossil fuels for electricity generation and transportation accounts for the vast majority of GHG emissions in Pakistan (151.6 mmt in 2010) [30]. Carbon dioxide, however, was the primary component of GHGs [31]. Pakistan's 2011 electric power fuel sources showed that 35% of energy production is based on expensive fuel oil [32]. Gas, hydro, and nuclear are the three primary energy sources. Currently, neither biomass nor coal is being used significantly to produce power. It is estimated that during 2011-2012, the United States imported 19.2 million metric tonnes (mmt) of products of petroleum at a value of 15.2 $ billion [33]. Renewably sourced electrical sources, such as biomass, have received less attention. Pakistan's government is looking into RES, particularly energy that are bio-based sources, as its dwindling supply of fossil fuels becomes a greater concern.

As in the latest emission forecasts, energy will be the most significant contributor to global warming gases by 2030. Electrical power generation from thermal sources accounts for a disproportionate amount of the country's overall energy output. Using thermal sources of energy has been on the rise over the last decade (from 65% in 2008 to 67% in 2018; see Fig. 3). The majority of Pakistan's greenhouse gas emissions come from the country's gas and oil-fired power facilities [34]. As seen in Fig. 4 from a study by the European Commission, GHG emissions in Pakistan have risen over the last several decades. For example, the number of tonnes of CO_2 increased from 63,081.14 levels to 174,843.37 levels from 1990 to 2015. The only way to prevent severe environmental degradation is to use RE sources on a vast scale. The population of Pakistan, now the world's sixth biggest, is growing at a pace of 2.4%/year and is projected to touch 0.3331 billion by 2050 [35]. Also, by 2025, urbanisation is anticipated to have reached 52% of the population [36]. The average yearly increase in Pakistan's electricity consumption is around 8 percent [16]. There was a 30% deficit in 2018's total energy production in Pakistan, which was 120,785 GWh [37]. To close the demand-supply imbalance for that year, an extra 51,765 GWh of electricity production was needed.

2.4. Pakistan Biomass Energy Potential

Amur and Bhattacharya [38] calculated biomass and its by-products in Pakistan for several purposes. Over eighty-six percent of all biomass energy is used on domestic scale. Currently, a majority in Pakistan of biomass energy is used via old-style cooking stoves used in rural regions. Most Pakistanis (over 64%) cook at home using biomass as an energy source. [39]. The research conducted by Mirza et al. [40] found that biomass has the potential to provide a large amount of energy in Pakistan. They claimed cutting-edge co-generation (power and heat) technology might improve biomass energy efficiency. The promotion of CHP is unsuitable in Pakistan since the country's building heating demand is far lower than its building cooling demand, and to achieve its maximum total thermal efficiency of around 80%, CHP needs a heating load greater than the demand for electric power. It was proposed by Mirza et al. [40] that human waste and animal manure may be used to generate electricity. Though the technology to convert municipal garbage into energy already exists, new plant construction and landfill diversion rates need financial backing. Farmers must gather animal faeces from various locations to use them as fuel. Similar problems arise with the exploitation of agricultural wastes since the transport cost to foreign power-producing units is not practical. The same plants that can combust biomass from farms may also handle dried animal excrement. Wood and agricultural waste in Pakistan constitute a substantially larger reserve than that mentioned by Mirza et al. [40]. Since biomass calorific value is lower and burns more slowly than coal or hydrocarbon fuels, deploying it as a significant renewable energy source presents considerable challenges, as proven by Bhutto et al. [41]. They showed some numbers on how much biomass contributes to energy production overall. Multiple routes for the biomass's potential transit were outlined. With anticipated electric efficient conversions, the P.E. conversion of various biomasses was assessed, which varied by biomass type and technology/pathway. Bhutto et al. [41] addressed ongoing and planned programmes for producing biogas from animal faeces. Biogas may be produced from animal manure by anaerobic digestion; however, this answer to the energy dilemma requires considerable time and money. The current price tag is about £5B/GW of producing capability, similar to the price tag for generating power using offshore wind. In addition, the procedure is more expensive on a small scale, costing over £100K for 10 kW electric for a 100-cow farm. This is over ten times more expensive than solar electricity is now. It is counterproductive to advocate costly solutions to Pakistan's energy crisis. Though the local production of energy approach that is recommended here— small-scale power plants that use biomass fuel to generate steam and electricity—is believed alternative low cost, it would still need assistance from Government to operate it in a wide number of regions.

2.5. Energy production through Biomass in Pakistan

2.5.1. Agriculture crops waste

Sugarcane cultivation in Pakistan is at number four worldwide [57], and the country's massive sugarcane plantations create much waste during harvesting season in the form of cane trash and bagasse. About 63,920,000 m/t sugarcane was cultivated in 2010–11, and about 5,752,800 metric tonnes of rubbish was produced that same year, giving rise to estimates of potential annual bioenergy production of about 9475 GWh [58]. Sugar mills in Pakistan are permitted to use bagasse as fuel to generate about 2000 MW of electricity for sugar mill operations [59]. In addition to cane waste and bagasse, cotton crop by-products like cotton sticks might be used to generate bioenergy in Pakistan. About 11 percent of the world's farmland is set aside for growing cotton to supply the global textile industry. There were an estimated 1,474,693 metric tonnes of cotton stick waste in 2011 [60].

More than 75 countries grow rice for their people to eat every day. The rice milling business produces a significant amount of rice husk yearly as the primary waste product. India harvests over 145 x 10^6 metric tonnes of rice each year. Assuming a rice husk recovery rate of 20% from rice grains, yearly rice husk production in India is about 29 X 10^6 tonnes [42]. The interior regions of Sindh and Punjab are the primary rice producers in Pakistan. Rice grain is extracted from bran during the rice milling process, and rice husk is the by-product of rice grains. The rice husk that is produced as a by-product is not used and is instead discarded in large numbers, which may lead to landfill overflows and methane emissions. Some of the rice husk's particle nature makes it a potential carcinogen and cardiovascular risk factor if ingested. Incorrect disposal of rice husk may be avoided if it were instead utilised to create energy. In order to meet the energy needs of mills, rice husks should be exploited and turned into helpful energy forms [43]. The calorific value of around 15 MJ/kg of rice husk is, making its heating value 41% lower than coal but its price 36% lower.

In China, where the population and rice output are enormous, about 70 million tonnes of rice husk is generated yearly [44]. Ash from rice husks has silica (95%), making it a very low-density energy source. There have been prior investigations into the use of silica from rice husks in manufacturing of catalyst-supporting material [14], ceramics [45], solar-grade silicon [46], and zeolite [47-49]. Rice husk is often used as a filler, compost, and install mats. Many academics are looking into methods to utilise rice husk as fuel in response to the rising need for more waste-to-energy conversion. Gasification [50], pyrolysis [51], and combustion [51, 52] have all been studied to determine their potential for converting rice husks into hydrogen, liquid fuel, heat, and power. In order to maximise hydrogen output, Li et al. investigated a gasification catalyst-based process [53].

Because of its low energy density and widespread distribution, biomass presents challenges in transport and collection costs. Rice husk is consistently produced yearly, guaranteeing a supply of this essential raw material. To use biomass, like wood, it is crucial to undergo pre-treatment processing, including drying and grinding. However, rice husk particles do not need a pre-treatment procedure, thus saving on equipment and energy. Since rice husk particles are consistent in shape and chemical content, they may quickly come into contact with oxygen and burn efficiently [54]. Furthermore, rice husk particles have nearly the same heating value, making it simple to regulate the temperature of a process.

2.5.2. Forest wood residues

For now, at least, the people of Pakistan's northern regions must depend on forest-sourced wood for their heating and cooking needs. Small limbs, trees, tops, and useless timber are all part of the forest residue that remains after forests are cleared. About 4.224 million ha (5.2%) of the land area is forested [57]. Nearly 80% of Pakistan's consumption of total energy comes from biomass [58], and one biomass source, forest residue, is ecologically advantageous and may produce a large proportion of total bioenergy.

2.5.3. Animal waste

Manure, which describes animal excrement, often includes organic material that may be used to produce biogas without further processing. The literature review in Pakistan estimates the yearly manure production at 368,434,650 metric tonnes [57]. Animal manure is converted to biogas for home and commercial use on a small scale in several rural areas of Pakistan. Numerous livestock ranches in Pakistan's metropolitan areas generate a great deal of manure that is used as fertiliser in the agricultural sector to boost soil fertility [58, 59].

2.5.4. Municipal solid waste

Environmental health risks related to improper management of municipal solid waste are a problem in many nations, and Pakistan is no exception (MSW). Municipal solid waste (MSW) contains both organic material and inorganic metals, and it may be treated in a number of ways to be used for energy production [57]. A review of the relevant literature in Pakistan indicates that municipal solid waste (MSW) has a value of calorific around 6.89 MJ/kg/year and may be used to generate electricity at a rate of roughly 13,900 GW h. Pakistan's most significant urban cities, including Islamabad, Lahore, Karachi, and Multan, all have industrial zones that generate a considerable deal of municipal solid waste (MSW) that might be used to generate electricity [55].

Wastes from all types of businesses and households are included in the definition of MSW. However, this possibility is lost because of improper collecting practices and the spread of various illnesses rather than the creation of electricity.

2.6. Biomass Conversion Technologies

Several biochemical and thermal methods, such as anaerobic digestion, gasification, and pyrolysis, efficiently transform biomass waste into bioenergy and biofuels. It is a smart strategy for dealing with trash and making something useful out of it. The Fischer-Tropsch process is a technique for transforming biomass into electricity and valuable compounds. Municipal solid waste (MSW) biomass is gaining attention as a viable energy resource in many parts of the globe. Additionally, waste management that incorporates biomass conversion to bioenergy is a powerful method of protecting the environment.

2.7. Thermal transformation technologies

Biomass is converted by thermal conversion processes to bioenergy, which involves heating the biomass at varying temperatures to produce solid fuels, liquid fuels, and gases. Small- and large-scale decomposition activities generate enough bioenergy to meet or exceed electricity needs.

2.7.1. Pyrolysis

Whether or not biomass has pyrolytic characteristics depends on its chemical makeup, which includes components like cellulose, hemicellulose, and lignin. After a chain of reactions, they emerge with a wide range of new substances. The reaction conditions determine how the products are distributed as shown in Fig. 2.1 Other waste and Biomass products provide 10% of the world's energy [56]. By pyrolyzing it at temperatures lower than 300 °C, cellulose loses molecular mass, generates less water, produces less CO, CO_2, and char, and gains these properties. When biomass is heated to between 300 and 500 degrees Celsius, molecules depolymerize into anhydrous glucose, which is then transformed to tarry-pyrosulfate. High temperatures cause the sugar (anhydrous) to undergo dehydration, fission, decarboxylation, and disproportionation processes, producing volatile and lightweight gases. In Asia, pyrolysis is often done using agricultural and organic waste [57-59]. Biofuels, biogas, and char-like products are created by the thermal breakdown of biomass feedstock at 500-800 °C temperatures without oxygen [60]. In other words, the quantity of the producing product is temperature dependent.

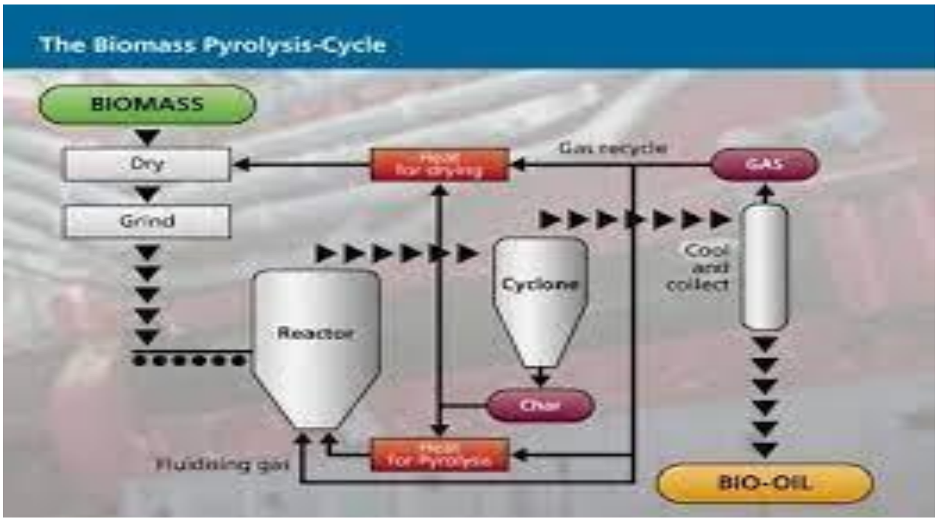

Fig. 2.1 Pyrolysis Process of Biomass

High heat produces biogas, whereas low heat favours a liquid medium [61]. Among the several by-products of pyrolysis, biofuel makes up about 40-75%, according to the available literature [62-65].

2.7.2. Combustion

Combustion is the process where biomass feedstock is directly heated to 800-1000 °C [66], resulting in a hot gas flue. Steam is produced from gas flue to power turbines to generate electricity [67] as shown in **Fig.2.*2***. Biomass combustion, although the oldest type of combustion utilised by humans, is among the most difficult to control because it uses solid sources in various reaction phases with significant relation between mass fluxes and heat. Effective combustion systems have been developed using these methods after thorough analysis and modelling.

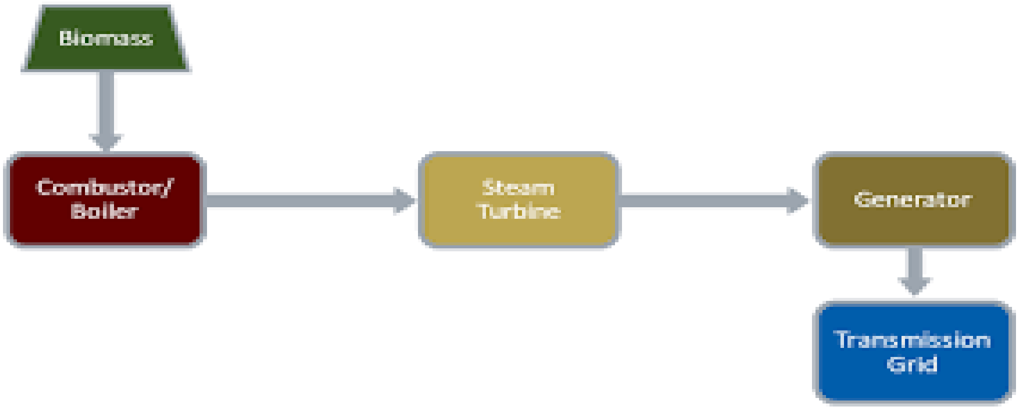

Fig.2.2 Combustion process of Biomass

2.7.3. Gasification

Process of gasification by which broken down biomass into its component gases. In this procedure, biomass is thermally decomposed by combustion (incomplete), producing a gas mixture that is combustible (consisting of H, CH_4, CO, CO_2, N, and $H_2O_{(Vap.)}$) [68]. A little gas is created by gasification, but what little there is may be used in fuel engines at home or in the lab for various chemical reactions [69]. A process related to pyrolysis, gasification is performed at high temperatures to regulate gas output [70]. The produced gas is a combination of H, CH_4, CO, CO_2 and N; it is called producer gas as shown in **Fig.2.3** .Gas turbine technology has been used for biomass with the purpose of increasing process efficiency and decreasing input cost. Combined-cycle gas turbine systems may reach efficiencies of up to 50%.

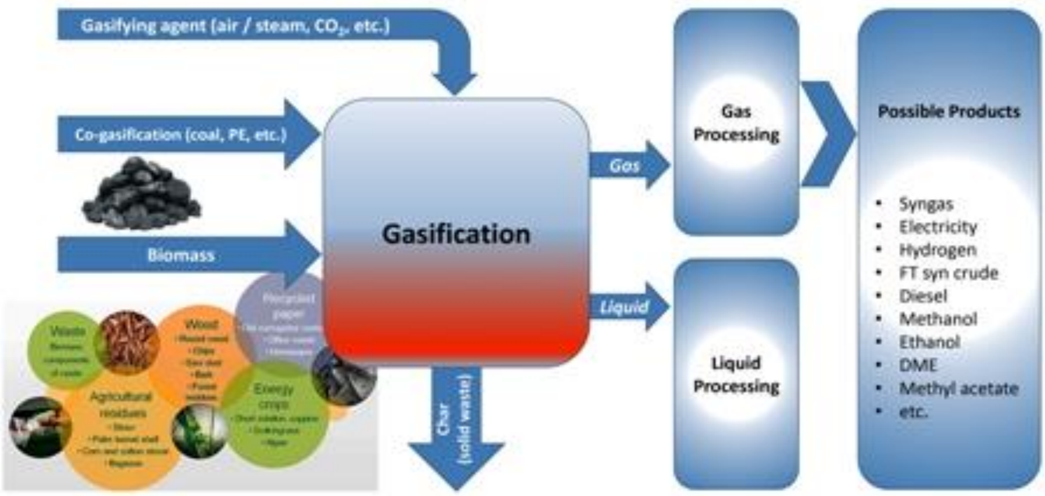

Fig.2.3 Gasification process of Biomass

2.7.3.1. Fixed-type bed gasifier

Gas formation devices (Gasifiers), whether of the moving or fixed bed kind, consist of solid-to-gas conversion bed particles where gasifier substances (such as O_2, air, steam, and gas) move either upwards or downwards. These gasifiers consist of fuel vessels (cylindrical) and agents for gasification, a feeding device, an ash collecting unit, and an outlet for the gas. These gasifiers function well in low to medium-pressure (25-30atm) environments. Dry filtering, cyclone, and wet scrubbing are the usual gas cleaning and cooling components in a bed-fixed gasifier. These gasifiers (Fixed bed) gently travel along the reactor as the gasification process progresses. These gasifiers are often operated at low gas velocity, high carbon conversion, and extended solid residence time due to their simple design, materials, and general operating parameters. While the development of tar contents has a significant impact on them, advances in tar management measures have provided viable alternatives. It has been observed that this gasifier works well for producing heat and electricity on a modest scale [71-73]. Downdraft gasifiers, updraft gasifiers, and cross-draft gasifiers are all subsets of the fixed bed type of gasifiers [73-76].

2.7.3.2. Fluidized-type bed gasifier

This design of the gasifier is grounded on fluidization theory, which holds that fuel and bed-inserted material may be treated as a single fluid. When medium fluidized, such as steam, air, O_2, or a combination thereof, is allowed to push its way from solid storage to the reactor [77, 78]. Such gasifiers utilize back mixing to efficiently blend the feed and gasifier particle mass. Although these gasifiers have typically employed silica as their bed material that is inert, there have been new tendencies toward using alternative bulk materials, such as dolomite, glass beads, olivine, sand, etc., which display catalysis properties, so to tar reduction concerns. For more efficient utilisation of the char produced, when it comes to ash and design configurations conditions, such as agglomerated or dry ash, these gasifiers differ from fixed bed gasifiers.

To improve gasification process, fluidized beds are used because of their ability to function under almost isothermal circumstances by increasing heat transmission between fuel particles. Due to the reactor of fluidized-bed low operating temperature (often between 800 and 900 °C, depending on bed material melting point), gasification processes do not achieve chemical equilibrium under these circumstances. One such reason for chemical equilibrium to be avoided is a short gas residence period. As a result of these considerations, the fluidized bed reactor's production gas hydrocarbon contents are within fixed-bed's range. However, it has been observed that gasifiers' capacity to convert “C” may reach up to 95%. Due to their design and outstanding mixing qualities, these gasifiers are well-suited for industrial-scale production and can process various fuel particle sizes [79].

Additives may be used in fluidized bed gasifiers to speed up the tar conversion process. Even after silica presence, either fuel ash or bed materials, eutectics may be formed from biomass materials, including the almond husk, wheat straws, rice, canes and grasses that have high amounts of alkali metals and ash. As a result, particles become sticky and form larger lumps, leading to de fluidization and, finally, the shutdown of the reactor for periodic cleaning [80, 81]. To address such issues, appropriate remedial actions need to be developed. For instance, calcined limestone added to bed-fluidized that raise eutectics melting point, allowing for prolonged gas formation at extreme temperatures. However, this method is not particularly effective until the proportion of limestone in bed-fluidized is sustained for a prolonged time. Additionally, gasification at higher temperatures (above 900 °C) for longer time intervals may be possible using carbonised limestone, which lowers the risk of aggregation and eliminates the need for regular bed replacement. Because of char tarring and sticking, it is predicted that these are 20% and 4%, respectively, inaccuracies in measurement and collection of C-removed by thimble filters and cyclone [82-85].

Fluidized bed gasifiers have numerous advantages, including their adaptability high thermal rates, low medium requirements, homogeneous extreme heat within gasifier, and outstanding cold gas efficiencies, including fuel and load. However, as previously stated, the quality of the fuel gas generated by these gasifiers is negatively impacted because of tar and the production of dust particles by a wide variety of biomass almond husk, wheat straws, rice, canes and grasses) [86, 87]. Additionally, fluidization bed reactors have been classified as either bubbling or circulating fluidized bed reactors based on the fluidization level and bed height, respectively.

2.7.4. Biochemical decomposition

Biogas (Eq. (1)) is produced when microorganisms break down the organic matter in biomass, which may occur with or without oxygen. Through a straightforward chemical conversion, microorganisms are very effective in breaking down the chemistry of organic materials and biogas production.

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \text{ --------- } (1)$$

Utilizing large quantities of lignocellulose and manure and its possible transformation into various products, such as fine chemicals, biofuels, and affordable sources of energy for bioconversion and enzyme synthesis has been the subject of extensive study in Pakistan in recent decades [70, 88].

2.7.5. Anaerobic digestion

Biogas is produced by microbial activity in oxygen absence on biomass feedstock. Biogas, a combination of CO_2, CH_4, H_2, and traces of additional gases, is produced by processing biomass waste on both the household and industrial levels. Microorganisms in a digester break down the biomass into biogas, which may be utilised with large-scale industrial gas engines or for direct use in the kitchen [89, 90].

2.7.6. Fermentation

The biological process known as fermentation converts glucose into ethanol via the action of microbes, most often bacteria. Fermentation is performed on an industrial scale to produce bioethanol worldwide as fuel for vehicles. 60-70% of the world's maize starch is utilised for ethanol synthesis [91]; hence, the main biomass utilised within this method is derived from starch crops and sugar. However, the utilisation of lignocellulosic biomass is preferred to prevent the needless dichotomy between fuel and food.

2.7.7. Transesterification

Catalytic transesterification of bio-oil yields biodiesel. Biodiesel is manufactured using animal fat and a wide range of vegetable oils such as rapeseed, palm oil, soya bean, hemp, sunflower, and mustard [61]. A catalyst is a substance used to speed up a chemical reaction; it might be an enzyme, a base, or an acid that has been immobilised on a substrate.

2.8. Solar energy

The average daily solar radiation received by a square metre of land in Pakistan is between 4.45-5.83 kW h/m^2 [92]. The average daily worldwide output is 3.61 kW h/m2 [93]. Unfortunately, Pakistan's power production industry relies significantly on imported fossil fuels despite having ideal sites for implementing CSP technology. The government was unable to import the required amount of oil due to fluctuations in oil prices [94], resulting in a 7,000 MW peak power shortage in 2015 [24]. Pakistan's energy industry is also a source of environmental danger. The expected high emission rate of 185.97 mt of CO_2 in 2030, due to the overuse of fossil fuels in electricity generation, will heighten worries about the current and future impacts of climate change. To cut back on oil imports and ensure a sustainable, environmentally friendly energy supply, Pakistan needs to explore alternative sources such as CSP technology. Since 2006, the Government of Pakistan (GoP) has established a plan to speed up the progress in the renewable energy industry. This strategy covers the years 2006-2008 (in the short term), 2008-2012 (in the medium term), and 2012-present (soon) (long term). Despite this, the Government of Pakistan has only achieved some of its goals. Projects are more expensive due to the high import prices. Potential investors are discouraged by the ongoing political unrest and security concerns. Additionally, the difficulties are exacerbated by the absence of high-quality digital maps of potential regions. The import cost rises not just because of a lack of domestic production but also because of a lack of trained workers and training facilities. Recently, Pakistan has made some steps to partially meet its energy needs via renewable energy projects. Solar energy, the largest RES, contributes 400 MW [95]. In Pakistan, PV power plants are the primary source of this kind of energy production, and although an MoU was signed between the two countries to establish a 300 MW CSP facility, further significant steps toward generating power using CSP technology have not been taken. [22, 96]. CSP technology development is proceeding steadily in Pakistan's surrounding nations, many of which have Pakistan's metrological and infrastructural characteristics. The CSP potential of India's 591 districts was calculated by Purohit and Purohit (2017) [97]. Using the System Advisor Model (SAM) programme, the technical merits of CSP solutions were assessed. Based on their projections, it seems that India may be able to use more than 2700 GW of solar electricity using CSP in the future. However, the optimization of parameters of CSP for various sites is missing in India from the research. The CSP techno-economic feasibility in Bangladesh was analysed by Lipu and Jamal (2013) [98]. To do this, they analysed two previous projects as examples: PS-10 (which used power-technology tower) and PTC technology-based ANDASOL-Thirty different sites in Bangladesh. They discovered that some produce more electricity annually than the Spanish locations used as a baseline. The study's conclusions are likely skewed since they were modelled after the operational circumstances of Spanish reference sites. The production of solar thermal power in Pakistan has not been the subject due to low research [92, 99, 100], and published research has not provided a comprehensive techno-economic assessment. Soomro et al. (2019) newly released work is the only one to compare the techno-economic efficiency of four distinct Pakistani locations for focussed thermal-solar power plants [101].

2.9. Factors affecting the electrical system of Pakistan

The electrical system of Pakistan is mainly powered by coal, natural gas, and oil. Pakistan's electricity industry might benefit from increased use of RES. It is possible to meet the state's current and future needs for energy using its stockpile of practical, renewable energy resources. Renewable energy sources are abundant, affordable, and ecologically sound in Pakistan. Even yet, the government has not been able to tap into its potential fully. Possible hurdles impeding the efficacy of RE in the state's power infrastructure account for the lack of renewable energy utilisation so far [102]. Literature on the challenges of RE in Pakistan is already accessible [103, 104]. Studies have identified six obstacles to the expansion of RES: (1) public, (2) political, (3) economic, (4) inadequate infrastructure, (5) market restrictions, and (6) institutions.

2.10. Politics stumbling blocks for RE

There would be significant political hurdles to using renewable energy sources. Every nation must have a clear political goal in place for its renewable energy infrastructure if it is to compete with fossil fuels. There must be no impediments in the form of regulations, policies, or incentives that prevent people from implementing renewable energy systems [105]. The World Future Council claims weak political will is a significant obstacle to implementing renewable energy programmes worldwide. Only 5% of political choices on renewable energy in 2030 are intended to combine subsidies for electricity produced from fuel [106]. This poses severe problems for Pakistan's potential renewable energy since it shifts to using domestic coal to provide a large portion of the country's electrical needs.

2.10.1. Public consciousness barriers to renewable energy

Most individuals in developed states pay a higher price for renewable energy, but the situation is quite different in Pakistan. People are increasingly turning to solar photovoltaic systems as a quick fix for their severe 8- to 10-h power outages [107-109]. Therefore, solar photovoltaics will lose appeal unless the government can solve the energy issue. Pakistanis do not perceive RES as a long-term solution as they lack the education and information necessary to understand the technology behind them [108, 109]. Most people live in rural and urban do not realise renewable energy's positive social and environmental impacts and think it is too expensive [110-112].

2.10.2. Economic barriers to renewable energy

Pakistan is making rapid scientific and economic advances in renewable energy, with costs reducing while positioning rising. Most people believe that renewable energy sources are prohibitively expensive, unreliable, and inefficient [113]. This is what happens when you think about old-fashioned expectations. The quick success of renewable energy and these expectations provide a significant barrier to the widespread adoption of renewable technology in developing nations like Pakistan. A greater proportion of GDP in emerging economies goes toward renewable energy as a fossil fuel substitute than in developing economies [114, 115].

2.10.3. Poor infrastructure barriers to renewable energy

Additionally, renewable energy integration is facilitated by inadequate and unattainable technologies. Pakistan still struggles to provide a reliable energy supply. The transmission and distribution networks can only transfer and disperse the necessary half of power. Also, during periods of high demand, the system will fail at any load larger than that [114] in three parts [110-112].

2.10.4. Institutional barriers to renewable energy

The energy issue in Pakistan may be attributed in large part to a lack of communication and collaboration between key government entities. The Pakistan Council for Sustainable Energy Technologies has as one of its main objectives boosting the share of RE in the government's total energy consumption [113]. However, they seem to be working apart from one another. The lack of clarity in assigning roles and duties across departments has slowed progress and sapped productivity. A lack of money from the organisations also impacted research and development [4].

2.10.5. Markets’ barrier to renewable energy

It promotes residents to adopt renewable energy, particularly photovoltaic solar, for transportation infrastructure, especially in rural areas of Pakistan. [102]. However, adopting these new technologies is still minimal because the government supports the economic advantages and the expense of maintaining traditional technology [116].

2.11. Hybrid power generation through Homer

For scenario 1, with the use of animal manure, Khan et al. (2018) found that Wind/Bio, PV/Wind/Biomass and PV/Biomass hybrid schemes are practical, with COE of about 0.06$ for all models and over fifty percent of energy produced by the On-grid system is surplus and may sell back to the grid. In Case 1 hybrid System, the PV/Wind/Biomass generates an annual total of 89,226 kWh (67.5%) from biomass, 15,503 kWh (11.7%) from solar, and 27,365 kWh (20.7%) from the wind. In scenario 2, when crop residue is used, the hybrid system provides 32.9% (57,153 kWh) from solar, 63.1% (173,540 kWh) of its annual power needs from wind and 3.99% (6,925 kWh) from biomass. The availability of animal dung for biogas generation resulted in a further decrease in COE, since its use as a fuel source had no cost compared to crop leftovers. A biogas generator may be fed animal waste to produce biogas and slurry as by-product [117].

Using Senamat Ulu plantation data from 2018, including 58,305 tonnes of palm oil production, Syawal et al. (2021) estimated that the biomass plant at Senamat Ulu could generate 6,113.65 kW of electric power from shells and palm fibre 3,924.57 kW, for a total annual electrical energy output of 53,555,549.9 kWh. Simulation I (PV, Biomass, and Micro-Hydro) has the lowest NPC and COE costs at $ 275,091 and 0.0768 $/kWh, respectively, with the contribution of biomass 49,946 kWh/year at an electricity price of $ 0.0271/kWh, PV contributing 26,681 kWh/year at 0.107 $/kWh electricity cost, Micro-hydro contributing 0.00992 $/kWh cost of electricity price with 156.025 kWh/year, Storage During that time, 5.8 years passed before any payback was realised [118].

With a hybrid off-grid system, the power production cost is reduced, as stated by Rajbongshi et al. (2017). Thus, it is essential to schedule the load well (increase the load factor) or manage it properly (reduce the peak load) to lower COE production. Both stable and unstable grid conditions must be considered when analysing a hybrid system linked to the grid. For equivalent load profiles, grid-connected hybrid systems are shown to have lower energy costs than off-grid hybrid systems. With plan A, the price of producing electricity drops from $0.145/kWh to $0.064. This is because the energy demand in the village is high, and power is purchased from the grid, while in the opposite case, if the hybrid system generates more electricity than it needs, the surplus is sent to grid. The breakeven distance among off-grid grid expansion and hybrid systems reduces with increasing load demand. For energy needs of 169, 178, and 286 kWh/d, the breakeven lengths are 7.50, 6.53, and 1.48 km, respectively, thus grid expansion is favoured over the village [119].

As a summary, Jahangir et al. (2020) included the following:

- Results from the sensitivity analysis indicate that the BG's capacity and energy output have dropped as biomass prices have risen and wind turbines and solar photovoltaics meet the remaining energy needs. Furthermore, the input rates of biomass are larger than the needs of system power.
- The power cost for the system is proportional to the inflation rate and the price of biomass. So, when both inflation and the cost of biomass grow, so does the price of power.
- Biogas power generation drops 86% when biomass price rises from $20 to $60 per tonne, with PVs and WTs making up the difference. However, WTs are only used by the best system when biomass costs between $40 and $60 per tonne.
- The optimal system consists of PV (80.7 kW), BG (150 kW), converter, and 27 batteries in the first sensitivity analysis (inflation rate of 15%). 67.9% of the necessary energy comes from BG, while 32.1 % comes from PV. The estimated electricity cost is $0.128/kW h, while the net present value is $904513.
- The optimal system (at a 10% inflation rate) from the second sensitivity analysis consists of PV (1.14 kW), BG (100 kW), converter, and 36 batteries. BG can meet 99.5% of annual electricity needs with its annual output of 428,835 kW h.
- The environmental impact study found that HRESs produce significantly less carbon dioxide than the grid. CO_2 in HERS output is proportional to their BG output. For this reason, increasing the proportion of BG in the necessary energy supply would result in higher CO_2 emissions.
- The proposed system would result in a 99 percent reduction in CO_2 emissions compared to coal-based power plants. Utilizing this project will, therefore, result in cost savings of up to $8444 [120].

Homer Pro was used to maximise the efficiency of a fifty MW hybrid power plant by using the available biomass, PV, and wind resources in a specific area (Kallar Kahar) in the state of Punjab was studied by Ahmad et al. (2018). Wind, PV, and biomass power facilities may share the load, and the surplus might sell to grid. Variations in grid availability, energy demand patterns, and peak load significantly impact final COE. Grid-connected hybrid systems with 73.6 MW peak load incur an energy cost of 180 million USD, with LCOE of 0.0574 $/kWh. However, on-grid hybrid system has a lower COE than off-grid one with identical load profiles. [121].

A hybrid system meets 88 kWh/day in energy needs for the research site with a gasifier presented by Malik et al. (2020), which includes 1 kW PV array, 5 kW wind turbine, 10 kW converter, 17 kW gasifier biomass and ten batteries. The total annual electricity production from the planned price for the hybrid model, including storage, was around 33,873 kWh at the cost of 0.222$/unit [122].

Compared to the biomass-wind hybrid system, the biomass-PV design developed by Mishra et al. (2016) is superior in terms of reliability, cost, and environmental friendliness. Total NPC $15,611, LCOE 0.174 $/kWh, and $811/year operating cost continue to favour the PV-biomass hybrid system for a given demand [123].

If enough energy storage devices are made available, the renewable energy-focused supply system presented by Hossain et al. (2020) is both technically possible and sustainable in the long term. The macro-BS can run off the battery pack for up to 162 hours, giving you plenty of time to make repairs. The hybrid supply system's surplus of around 2,094 kWh of electricity guarantees a zero per cent energy outage. In addition, switching from a conventional DG system to BG/PV hybrid system can reduce both NPC and GHG by as much as 33.86 percent and 99.9 percent, respectively. In addition, the performance metrics reveal that the proposed system provides a higher standard of wireless performance. A green mobile communication system that uses BG/PV hybrid system enabled by macro with RRH is an excellent option [124].

Malik et al. (2020) looked into the western Himalayan territory to find spots with low profile of wind, suggesting wind turbines; smaller, micro, Pico, and nanoscale with a lower cut-in speed (1–1.5 m/sec) could be effective at producing electricity there. To meet the 88 kWh/day energy demand at the study site, the simulations determined that a configuration with 11 kW of PV, biomass gasification 5 kW, converter 7 kW, and

18 kW of the grid would be optimal. From a financial perspective, the optimal design has an LCOE of $0.102 per kWh, which is 29% and 7% cheaper than Case-2 and -3, and an estimated TNPC of $42,081. This is in addition to a renewable component of 83%. The optimal design generates 59.7 MWh/year of electricity, with 61% coming from the biomass gasifier, 22% from the PV, and 17% from the grid. Likewise, the proposed system reduces annual CO_2 emissions by 27.8 Mt compared to a diesel-only system, as shown by examining the emissions data [125].

A study published in 2021 by Vendoti and co-workers, it was evaluated and contrasted four distinct configurations of HRES, including PV, biomass (BM), fuel cell (FC), wind (W) and battery (B) systems. An operational system plan is developed after several criteria, including but not limited to estimated energy consumption, distribution of energy sources, monthly power production, cost analysis, and system-generated emissions, are taken into account. Additionally, the Homer Pro programme has been used to plan and assess the performance of four different hybrid energy system configurations. Combination-1 had the lowest NPC at $8,90,013 and COE at 0.214 $/kWh with 0% capacity shortfall as compared to the other configurations. This configuration is economically viable and capable of meeting the assessed region's vital energy needs. Compared to other system configurations, the wind/PV/biogas/battery/ biomass/fuel cell configuration has the lowest NPC and COE and is thus the best option for satisfying the load needs in the examined region. As a result, this research has presented the optimal configuration (wind/PV/biogas/battery/ biomass/fuel cell) of resources. 50 kW biomass, 60 kW biogas, 100 kW solar, 50 kW wind, 80 kW converters, and 323 kWh battery are all part of the proposed systems [126].

2.12. Research Gap

- A lot of work has been done in the potential analysis of solar and other renewables, but none of them relates them with the distributed generation which can be used for addressing the energy crisis of country.
- There is little or no work done is the potential analysis of Biomass (Rice Husk) as a potential source for distributed generation near the load centers.
- No work is done specifically on the usage of rice husk as biomass for electricity production for Rice mills.

Different models were proposed for the generation of electricity using renewable sources. Different papers target various combinations of renewable energy sources such as wind, solar, biomass and hydropower. Different configurations were proposed according to the regional feasibility. This study targets the Layyah district of Punjab, using Solar and Biomass configuration where rice husk was used as biomass source and investigate the model feasibility in off-grid and on-grid scenarios.

Summary

This chapter provides the details of energy generation from solar and different types of biomasses. Moreover, its emphasis is on different method used to convert biomass into various beneficial products. It also shed light on Pakistan energy demand, pollution problem due to using fossil fuels and emission of greenhouse gasses. Various models or configurations of renewable energy resources were presented in literature review and conclude the solar and biomass can be used as potential source for energy generation and can also be used as alternative resources. Therefore, the research aims to find out the best model or system using solar and biomass (rice husk) to provide sustainable energy.

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Chapter 3

Methodology

3.1. Sample collection and preparation

The rice husk was taken from a reputed rice mill in Layyah, Punjab, as shown in **Fig. 3.*1*** where rice husk was not a valuable by-product. About 2kg of rice husk powdered were collected, which were passed through 1mm sieve for further characterization and testing.

Fig. 3.1 Sampling of biomass (rice husk) from rice mill

3.2. Characterization of rice husk

Proximate analysis and ultimate analysis were both parts of the characterization process. The experiment repeated each variable three times, and the average was recorded. The quality of rice husk predicted after the experiments and various tests are given below to analyze:

3.2.1. Proximate analysis

The proximate analysis of rice husk included the fixed carbon, volatile matter, ash content and moisture are given below:

3.2.2. Moisture content

The moisture content was determined by ASTM: D3173-17a method. The weight of the sample was taken and then oven it. It will remove all the moisture within the sample. The difference in weight allows us to calculate the moisture content.

3.2.3. Volatile matter, fixed carbon, and ash content

To find out volatile matter, the rice husk was treated according to D-3175-17 where 2g of rice husk was heated in an enclosed crucible of 900 ºC in a muffle furnace and maintained at that temperature for 7 minutes. The crucible containing the sample was removed from the furnace after 7 minutes of heating without air exchange. Loss of mass is proportional to the number of volatile substances present.

According to the D-3174-18 standard, 10 g of rice husk was heated in crucible and progressively in muffle heater to the ignition temperature of 600 C for 2 hours to estimate the ash content. Measurements were taken every 2 hours until a steady weight was established. Ash content was calculated by subtracting the initial and final weight using the thermo-gravimetric analyser's built-in integrated software (TGA).

The amount of fixed carbon (D-3172-13) was calculated by adding both the %age volatile matter and %age of ash content in the sample and difference the value with 100 as shown in equation (1) below:

$$\text{Fixed carbon} = 100 - [\%\text{age VM} + \%\text{age ash}] \qquad (1)$$

The proximate analysis includes the moisture, ash content, volatile matter and fixed carbon were performed against rice husk and the air-dry base values were 7.00, 18.42, 55.85 and 18.73, respectively, following the American Society for Testing and Material Standards (ASTM). The values of proximate analysis were also provided in the **Table 3.*1***

Table 3.1 Proximate analysis of rice husk

Rice Husk	Percentage %
Moisture	7
Fixed Carbon	18.42
Volatile Matter	55.85
Ash	18.73

3.3. Ultimate Analysis

CHNS-analyser performed a conclusive analysis to identify the rice husk's chemical make-up. Hydrogen (H), carbon (C), sulphur (S), and nitrogen (N) were the key elements to identify through this procedure. Sulphur %age was identified by ASTM D4239 Method A, Oxygen (by difference) %age followed ASTM D3176 protocol. ASTM D5373 protocol was followed to identify the percentage of carbon, hydrogen and nitrogen and their values are given in **Table 3.*2***

Table 3.2 Ultimate analysis of rice husk

Rice Husk	**Dry basis Percentage**
Carbon	41.63 %
Nitrogen	1.259
Sulphur	0.19
Hydrogen	5.65%
Oxygen	36.24

3.4. Gasification Method

The gasification procedure was done as already proposed by Loha et al. [1]. The top screw feeder was run for five minutes at a particular frequency to evaluate the rate of flow of rice husk, and final product was then collected using an output chute. By weighing the biomass as it was collected, we could calculate the biomass flow rate at that frequency. Subsequent iterations of the procedure use a range of distinct frequencies of operation. At first, 100 mm of silica sand was used to fill the gasifier. Because rice husk is non-granular, an inert bed material like silica sand was employed to facilitate fluidization. The PID controller is used to determine the ideal temperature for material of bed, which then heated and fluidized in an electronic furnace. The gasifier's bottom was opened and steam and air which were compressed injected after desired temperature was attained and maintained. Before entering the gasifier, air was warmed to 60 degrees Celsius and steam is superheated to 200 degrees Celsius. Steam and air flow were monitored by employing steam flow metre and rotameter. Through the side port, the biomass was introduced. Gas samples were collected after operations have stabilised and examined using a Gas Chromatograph. Multiple conditions, including temperature, equivalency ratio, and steam-to-biomass ratio, were tested in the tests. Only one of the operational parameters is changed at a time. Both the steam-to-biomass ratio (S/B) and ER may be determined. The gasifier was operated long enough under each setting to achieve a steady state, and then three samples are obtained and examined at 5-minute intervals. As the flow rate of biomass was too low in this experimental investigation, the tar content of the generated gas was not quantified; instead, the average value from five independent experiments under each operating condition is utilised for data analysis. During operation, the gasifier is pressurised to a level just above atmospheric pressure [1].

3.5. Case study area

Rice factory is in Layyah, Punjab. It is between longitudes 70-44 and 71-50 degrees east and latitudes 30-45 to 31-24 degrees north. In Sindh Sagar Doab, the region is composed of a quasi-patch of sandy terrain between the Chenab and Indus rivers. The district's total area is 6,291 km^2, measuring 88 km in breadth from east to west and 72 km in length from north to south. The city serves as the district and tehsil headquarters for Layyah. The rice mill in the Layyah produced rice husk which is the outer covering of rice Paddy. The average solar irradiation is around 5 kWh/m^2/day.

3.6. HOMER Pro software

In the United States, the HOMER program was designed by Dr. Peter Lilienthal at the NREL [2]. In October 2014, a new version of the Homer program called Homer Pro was launched [3]. Hybrid power systems that rely primarily on renewable sources may be designed, optimized, and analyzed with the help of HOMER Pro® software. HOMER may be used in both off- and on-grid model designs and analysis [4].

3.6.1. Load assessment

The load assessment was done by Homer as seen in **Fig. 3.2** Load profile taken from Homer. as it has an embedded database and calculated the data in months. It also provided the variable load demand in different months. The load profile from the rice mill was also taken, and calculated their monthly consumed electricity units which are present in **Fig.3.**

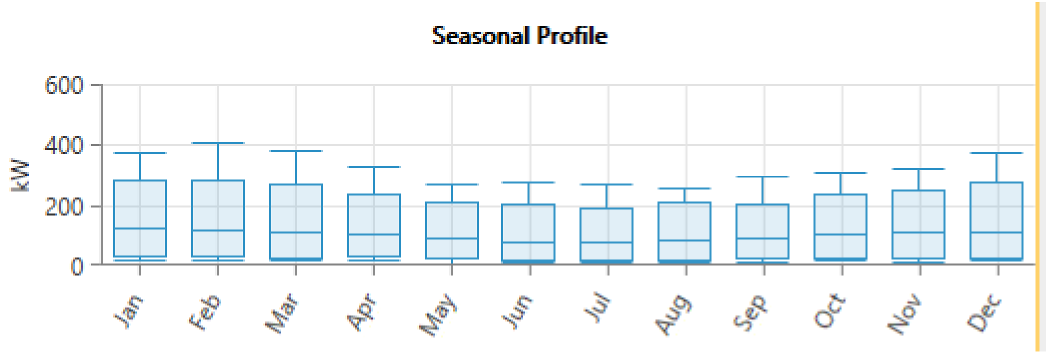

Fig. 3.2 Load profile taken from Homer.

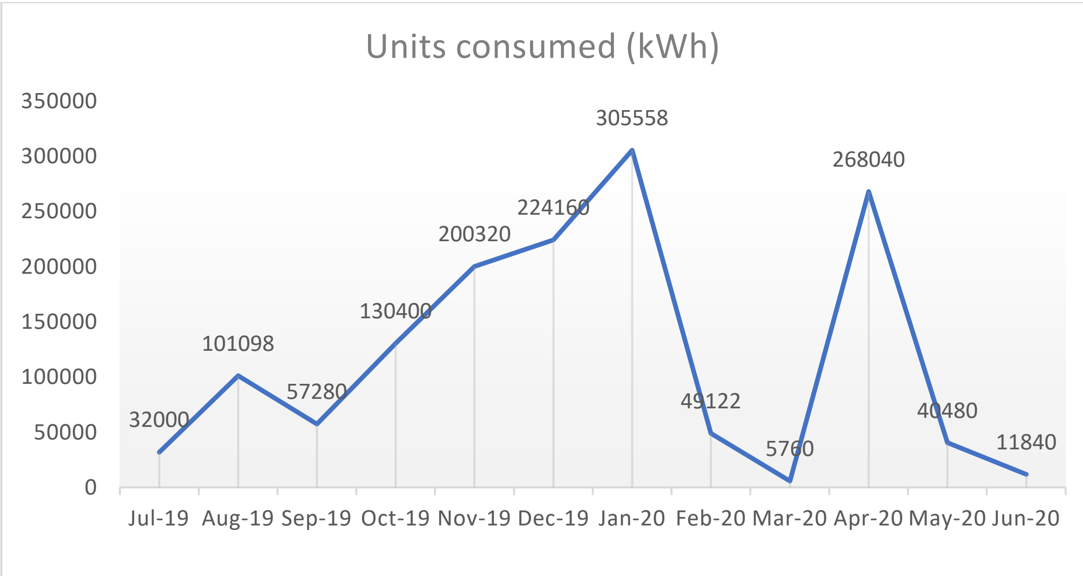

Fig.3.3 Scaled load profile of the rice factory.

3.6.2. Resources assessment:

3.6.2.1. Solar Resource:

Real-time hourly irradiance data are required for accurately modelling a hybrid system utilizing the solar energy module. The on-ground data for solar is not available for the selected site. Therefore, the monthly average clearness index and solar irradiance will be synthesized into hourly data using the built-in algorithm of V.A. Graham in HOMER Pro, as shown in **Fig.3.**

Fig.3.4 Solar resource assessment through Homer.

3.6.2.2. Biomass Resource:

Paddy Purchased by the rice factory was 19493580Kg, for the fiscal year 2021-2022 annually. Rice husk produced by raw material 3891.71 tons annually, as one ton of paddy gives approx. 8 kg of rice husk. The information was collected from the site area visit and the production of rice husk by different factories. **Fig.3.** presented the monthly production of rice husk. A laboratory tested the rice husk sample, where proximate and ultimate analysis was done. The gross Calorific value was calculated by Bomb Calorimeter testing. Lowest Heating Values calculated by using equation [5]:

GCV= 16.82MJ/kg

LHV of Rice Husk= GCV- Hv (9H/100 +M/100)

=15.52 MJ/kg

Where Hv is the latent heat of vaporization of water at 25 degrees Celsius which is 2260KJ/Kg and H is the Hydrogen value, and M is the moisture content.

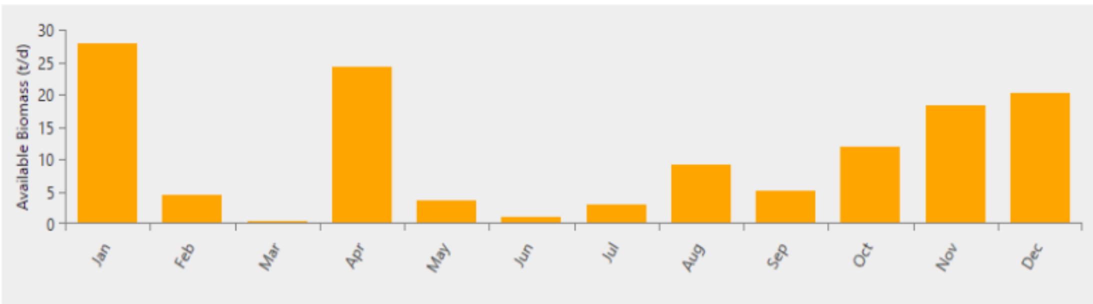

Fig.3.5 Month-wise rice husk production

3.6.3. Unit Sizing and Micro-grid configuration

Different schemes of attachments of various components required for on-grid (Grid, biogas system, solar panels, and converter) and off-grid (Biogas, Solar panels, Diesel Generator, battery storage and converter) are present in **Fig.3.**

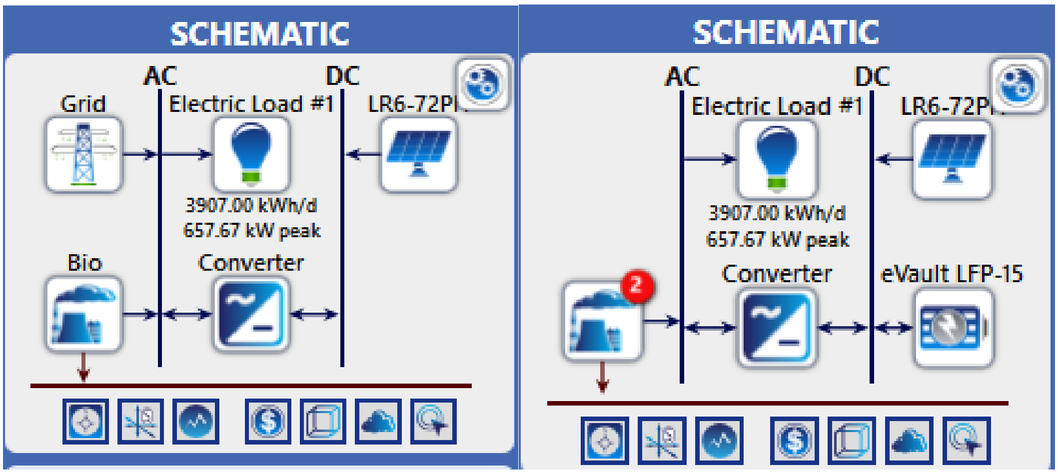

Fig.3.6 Micro-grid components of on-grid (left) and off-grid (right) connect scheme.

Following are micro-grid components:

3.6.3.1. Solar panels

Longie Solar LR6-72PE with a rated capacity 370W. Fixed azimuth and optimal slope. These solar panels are of interest due to cost competitiveness and easy availability in the local market. Seventy-two monocrystalline solar cells – hold their suitability for commercial-scale projects. Technical and other parameters of the solar panels are provided in **Table3.*3***

Table3.3 Cost and technical parameters of solar penal.

Capital	Replacement cost	O&M Cost	Temp. Effect	NOCT	Efficiency	Life Period	Derating Factor
$/kW	($/kW)	$/Year	%/ °C	°C	%	Years	%
470.9	185	2	−0.38	47	19.1	25	80

3.6.3.2. Biogas System

In the absence of oxygen, it is a combination of (CO_2), (H) and methane (CH_4). Only rice husk is taken. Custom-sized generic biogas genset is used. 100kW, 200kW, 300kW and 400kW Genset are used separately. The biomass resource (rice husk) is locally available, and the biogas fuel price ($/kg) is zero. The fixed carbon content of rice husk is taken from the sample testing result. The different cost parameters have shown in **Table 3.*4***. LHV of Biomass gas, specifically using rice husk, is 6.02MJ/kg [1].

Table 3.4 Multiple parameters of the biogas system

Sr. No	Parameters	Units	Values of 100kW	Values of 200kW	Values of 300 kW	Value of 400kW
1	Capital cost	($)	58403.3	84685.4	148929.1	198572.2
2	Replacement cost	($)	58403.3	84685.4	148929.1	198572.2
3	O&M cost per kW	($/op. hr)	0.010	0.010	0.010	0.010
4	Minimum load ratio	(%)	10.00	10.0	10.0	10.0
5	Lifetime	Hours	20,000	20,000	20,000	20,000
6	Lower heating value	MJ/kg	6.02	6.02	6.02	6.02
7	Gasification Ratio	Kg/kg	0.7	0.7	0.7	0.7
8	Carbon content	(%)	18.42	18.42	18.42	18.42

3.6.3.3. Battery Storage

According to climatic conditions, the Lithium-ion battery model is used. The DC bus PV module is connected as an energy source with a nominal rated voltage of ~40V. To ensure 40V at DC bus, string size for generic 1kWh Li-ion is kept at 11. The autonomy hours are two, and temperature impacts on battery performance are also considered, as shown in **Table 3.*5***

Table 3.5 Technical and cost parameters of batteries storage system

Sr. No	Parameters	Units	Values
Generic 1 kWh Li-ion [ASM]			
1	Capital cost	($)	1647
2	Replacement cost	($)	1647
3	O&M cost	($)	10.00
4	Nominal capacity	kWh	1.02
5	The initial state of charge	(%)	100
6	Minimum state of charge	(%)	20
7	Degradation limit	(%)	30
8	Consider temperature effects	--	Yes

3.6.3.4. Diesel Generator and Power Converter

A diesel generator is utilized to cater to the power deficit in the winter season. In case solar panels were not able to generate electricity for the off-Grid System. The capacity of DG is 700kW. **Table 3.*6*** showed the cost and efficiency with other parameters are given below:

Table 3.6 Technical and cost parameters of diesel generator

Capital Cost	Replacement Cost	O&M Cost	Life Period	Fuel Price
($/kW)	($/kW)	$/op.hr	(hr)	($/L)
67.5	67.5	0.030	15000	1.20

The converter converts AC electrical energy into DC and vice versa. Usually, the converter rating is selected according to the power rating of energy source connected to the corresponding bus with typical converter efficiency of 85%.

$$C_{conv}\ (kW) = P_{array} \times 100/85$$

The technical parameters and cost of the power converter were provided in **Table 3.*7***

Table 3.7 Cost and technical parameters of power generator

Capital cost	Replacement cost	Life Period	Relative Capacity	Efficiency
($/kW)	($/kW)	(years)	%	%
42.5	42.5	25	100	85

Summary

This chapter provides the methodology of proximate and ultimate analysis of rice husk with the characterization of samples, its preparation, and details of the gasification process. Homer software is used for the simulation of renewable energy sources. Load assessment has been done for the models, on-grid and off-grid connections, and different micro-grid components, including solar panels, biogas gasifiers, batteries storage and the diesel generator, are discussed. All the technical parameters have been set accordingly.

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Chapter 4

Results and Discussion

4.1. Ultimate Analysis

On dry basis values of ultimate analysis of rice husk, the percentage of various elements including C, N, S, H and O are 41.363%, 1.259%, 0.19%, 5.65% and 36.24%, respectively, which were significantly deviated from the previously reported study by Maham et al. where values were 37.4%, 0.2%, 0.3% and 4.7% [1], respectively, not including the oxygen value. High carbon and hydrogen values revealed that there would be a high generation of biogas from rice husk, which will help to produce more electricity.

4.2. Techno-economic Analysis

Eight different scenarios were developed, with various combinations and electricity generation capacities. Four different combinations or cases were developed of biogas gasifiers of 100kw, 200kw, 300kw and 400kw to know the economic and optimized electricity production scenario with On-grid and Off-grid. We have optimised these models with the lowest LCOE and highest Renewable penetration. Biogas gasifiers have been used to meet the load at night. Moreover, PV will be used to meet the load during the daytime. We have designed four Off-grid models in which a diesel Generator will be used alternative production source in the uttermost condition. Furthermore, we had a grid connection for stability for the On-grid models. To analyse all parameters, it showed that Off grid with 300kw biomass gasifier was the most efficient scenario in off-grid, as provided in Table 10. The NPC, IC, LCOE were 5.91 $M, 1.87 $M and 0.125 $/kWh, respectively. In terms of investment, ROI, IRR and PBP were 31%, 37% and 2.6, respectively, with excess electricity production and renewable penetration which were 55.7% and 99.8%. In the on-grid scenario, the 200kW project (case-6) was the most optimal. In the 200kW system, initial capital was 0.76 $M, NPC 3.51 $M and LCOE 0.050 $/kWh. The financial parameter revealed that IRR was 17 %, ROI 13% and PBP 7.5. Excess electricity production was 16.5, but renewable penetration was 97.9 % which was seen most value for on grid models in **Table 4.*1***

Table 4.1 Techno-economical evaluation of proposed optimal systems configurations for each under-study site.

Cases	Biomass Generator	Proposed Configuration	Dispatch strategy	Cost and objective parameters			Financial and performance parameters			Excess Electricity	Renewable Penetration %
				NPC ($M)	Initial Capital($M)	LCOE ($/kWh)	IRR (%)	ROI (%)	PBP (y)	(%)	
OFF-Grid System with Battery Storage and Diesel Generator											
Case-01	100kW	PV-BM-DG-B	CC	5.18	1.90	0.117	36.7	31.8	2.68	58	92.8
Case-02	200kW	PV-BM-DG-B	CC	5.28	1.80	0.111	39	33	2.49	53	98
Case-03	300kW	PV-BM-DG-B	CC	5.91	1.87	0.125	37	31	2.6	55.7	99.8
Case-04	400kW	PV-BM-DG-B	CC	6.60	2.72	0.139	35.2	29.5	2.67	54	100
ON-GRID System											
Case-05	100kW	PV-BM-G	CC	3.18	0.75	0.0451	18.5	14.5	5.26	18.3	97.8
Case-06	200kW	PV-BM-G	CC	3.51	0.76	0.0503	17	13	5.21	16.5	97.9
Case-07	300kW	PV-BM-G	CC	4.21	0.82	0.0601	13.3	9.1	7.5	16.5	94.8
Case-08	400kW	PV-BM-G	CC	4.82	0.87	0.0686	10.1	6.8	8.8	16.4	97.6

4.2. Average Analysis and Proposed Cases:

According to the 8 different models, the average net percent cost (NPC) and levelized cost of energy (LCOE) for the off-Grid system were 5.74 $M and 0.123 $/kWh, respectively, but for on-Grid system configuration, the values were 3.91 $M and 0.0561 $/kWh, respectively, as shown in **Table 4.*2***

Table 4.2 Average NPC and LCOE of models.

Parameters	Net present cost (NPC)	Levelized cost of energy (LCOE)
	($M)	($/kWh)
OFF Grid System Configuration		
PV-BM-DG-B	5.74	0.123
ON Grid System Configuration		
PV-BM-G	3.91	0.0561

The off-Grid system required batteries to store power that would be used without solar energy. The main contribution to the system was solar panels of company LONGI Solar LR6-72PE with a capacity of 1848 kW generation which was 86.7% contribution and biomass (300GFM ZIBO ZACHAI Company) had 13.2 % active role of 300 kW electricity generation with 2.03-hours backup capacity of 31356 kWh Generic Lithium Ion Battery. The capacity of the converter was 580 kW. On the other hand, in case 7, which was grid connected and due to this feature, the cost of batteries was excluded; however, PV had 82.5% contribution with 1384 kW production and biomass system had 15.8% contribution with 200 kW electricity generation capacity. The converter was 555 kW, as shown in **Table 4.*3***

Table 4.3 Configuration and unit sizing of solar and biomass

Proposed System Configuration and sizing								
Sr No	Model type	PV System		Biomass System		Battery System		Converter Sizing
		(kW)	(%)	(kW)	(%)	kWh	Autonomy Hours	kW
Case-03	Off-Grid	1848	86.7	300	13.2	31356	2.03	580
Case-06	On-Grid	1348	82.5	200	15.8			555

4.4. COMPARATIVE ANALYSES and VALIDATION

Comparative analysis was done to find out the cost-effective electricity production. As in **Fig.4.*1***, the optimized case 3 (off-Grid with 300kw biomass gasifier) showed LCOE to be lower than the NEPRA tariff rate but higher than the previous related studies. In case 6 (on-Grid with 200kw biomass gasifier), the model was very feasible which showed LCOE even below the NEPRA tariff and other related studies where Malik et al. presented PV/BM/ grid with LCOE $0.102/kWh [1], Hossain et al. showed Hybrid PV/BG with $0.638/kWh [2], Mishra et al. depicted PV/BM hybrid with $0.174/kWh [3], Malik et al. manifested PV/Wind/Biomass with 0.222 $/kWh [4], Ahmad et al. proclaimed wind-PV-biomass-grid with 0.05744 $/kWh [5], Rajbongshi et al. revealed PV-biomass-diesel-grid with $0.91/kWh [6] and Syawal et al. exhibited biomass-PV-Li-ion-Converter and Micro-hydro with $0.0271/kWh [7].

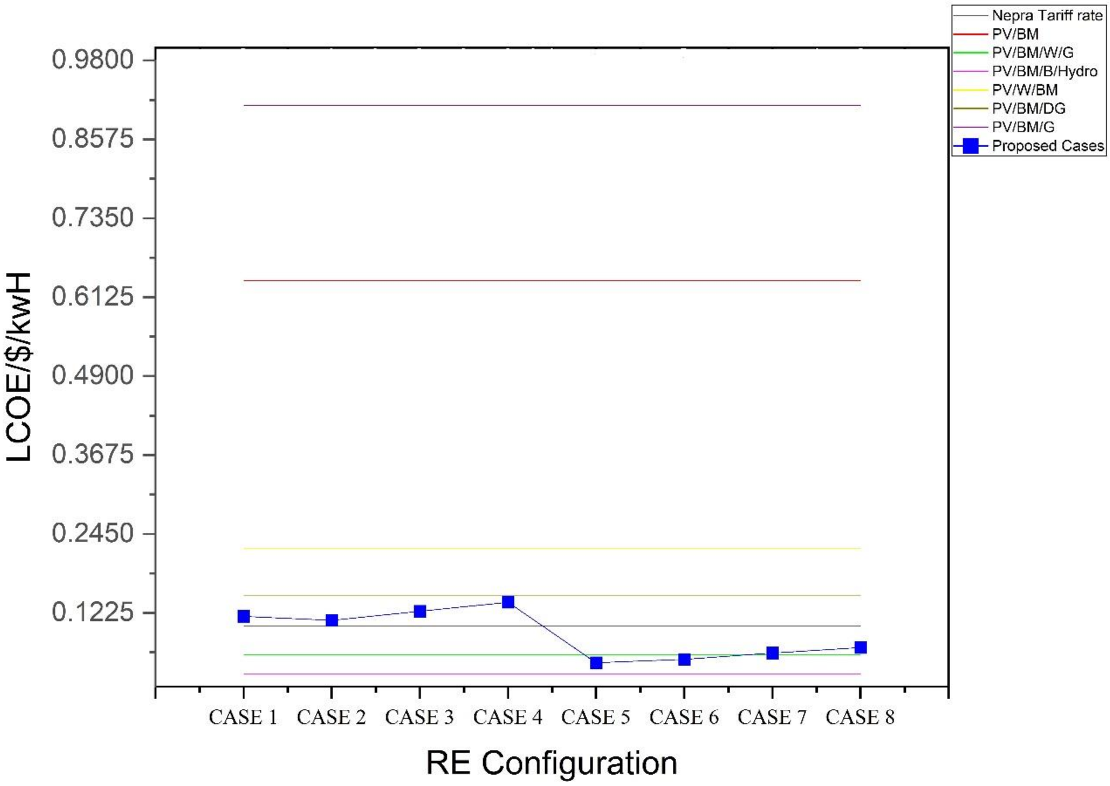

Fig.4.1 comparative cost analysis of the given model with other configurations.

4.4.1. Objective Function:

The primary objective of our study is to validate the levelized cost of energy (LCOE) and net present cost (NPC).

$$\text{Objective Function (OF)} = \min\left(NPC_{total}\right) \tag{1}$$

$$\text{NPC total} = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} - C_\circ \tag{2}$$

Similarly, the COE is calculated as,

$$COE = \frac{LCC}{\sum_{t=1}^{T} E_{total}} \tag{3}$$

$$LCC = C_{cap} + C_{rep} + C_{OM} + C_{fuel} - C_{salvage} \tag{4}$$

Total net present cost (NPC_{total}) depends upon Ct - total cash inflow during the time 't', Co- the total initial investment cost, and the discounted rate is 'r'. COE is linked to the total annual energy production (E_{total}) and life cycle cost (LCC), which includes parameters such as capital cost (C_{cap}), replacement cost (C_{rep}), operation and maintenance cost (C_{OM}), fuel cost (C_{fuel}) in case of diesel generators, and salvage cost ($C_{salvage}$) associated with the respective components [8].

4.5. Sensitivity analysis

4.5.1. Discount Rate and Inflation Rate

The various levels of uncertainty in the design parameters for off-grid and on-grid hybrid systems have been considered by HOMER. The optimal system combinations for sensitivity are displayed graphically together with the levelized cost of energy and NPC. Sensitivity analysis helps evaluate an optimal system's behaviour in the presence of different uncertainties. When sensitivity analysis was performed on the on-grid hybrid system case 6 with five different discount rates, the expected variation of ± 1.0% while taking 9.75% as a reference. When increased in discount rate, LCOE value increased from 0.0503 $/kWh to 0.0610 $/kWh, and there was a reduction in NPC price from $3.51 to $2.45 million, as shown in **Fig.4.**. Another sensitivity analysis was done on the expected 12.10 % and 1 % variation [9] for five inflation rates as a reference. NPC and LOCE showed a direct and inverse relationship with the inflation rate increase, as shown in **Fig. 4.**. The ROI and payback period in case 6 was 13% and 5.21 years, respectively. By considering this value, the model is suitable for investment.

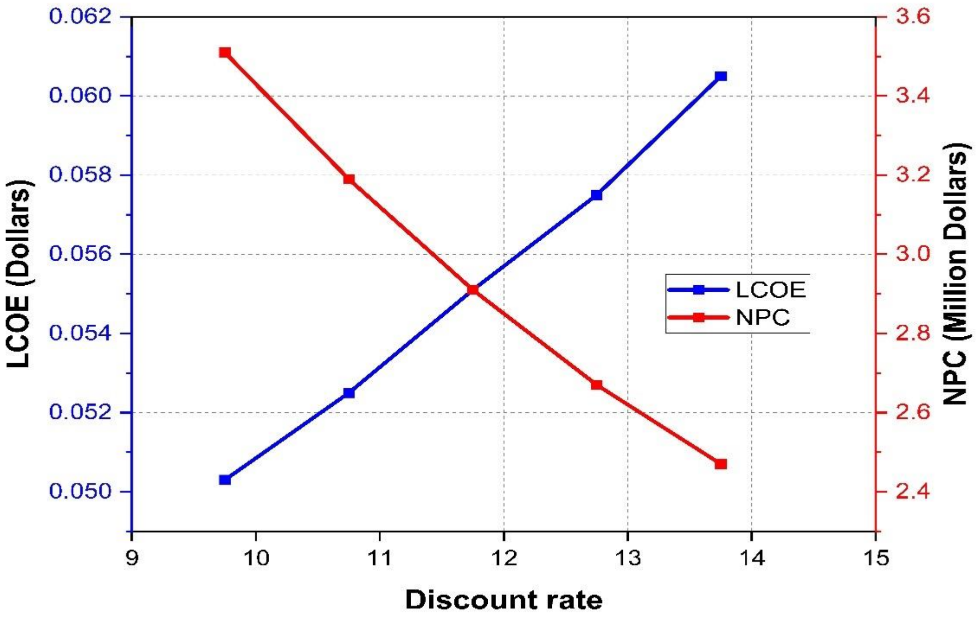

Fig.4.2 Sensitivity analysis of Discount rate

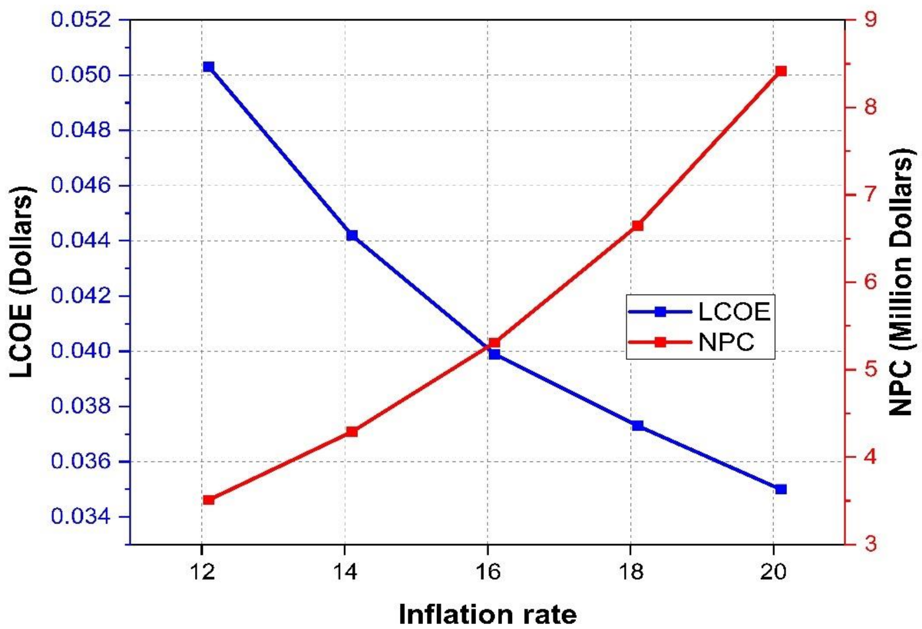

Fig. 4.3 Sensitivity analysis of Inflation Rate

4.5.2. Load Demand and Biomass Price

With the increase in population, the load demand and production cannot remain the same. Sensitivity analysis was performed by taking the expected variation of +100 kW in average load while taking 162 kW as a reference. NPC and LOCE showed a direct and inverse relation, as seen in **Fig.4.**. NPC increased from $ 3.82 to $9.91 million, while at the same time, the LCOE decreased from 0.0503 to 0.0391 $/kWh. The smaller quantity increased the per unit price of any specific commodity. However, the per-unit price was usually low for a larger quantity of the same commodity. While an increased in biomass price, while taking 40$ as a reference, showed a direct relation with both NPC and LCOE, as seen in **Fig.4.**

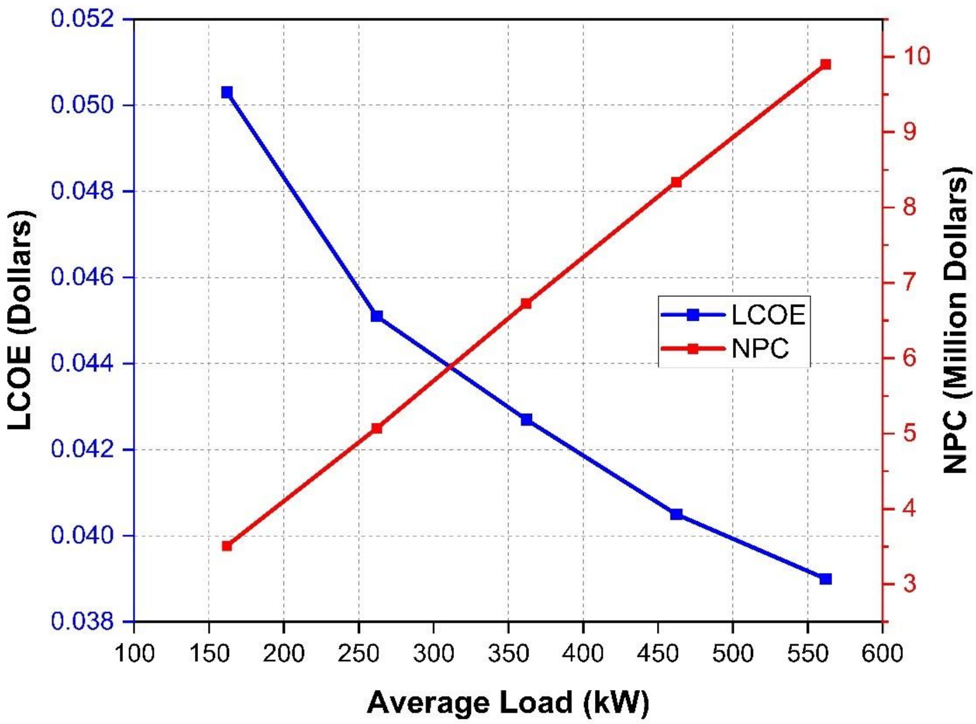

Fig.4.4 Sensitivity Analysis of Average load (kW)

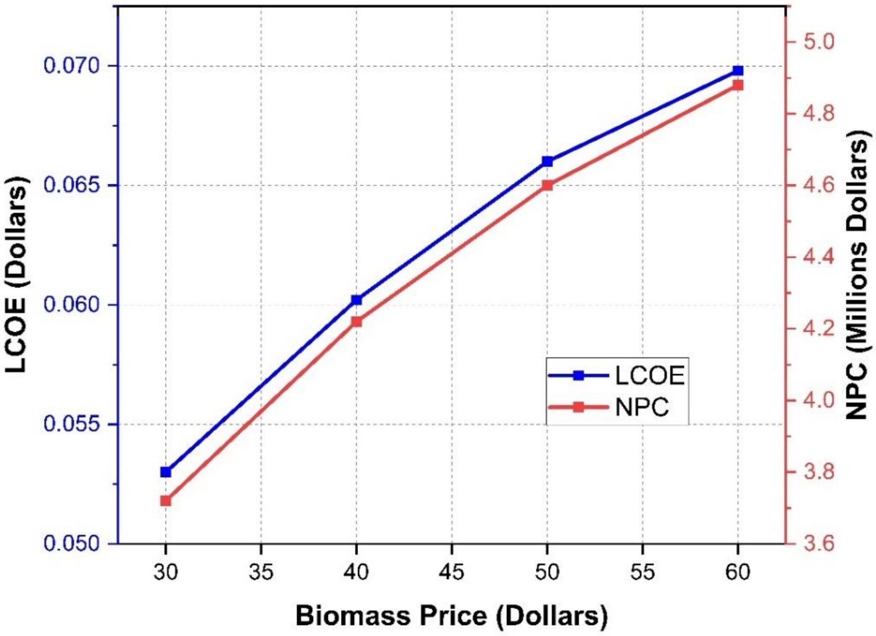

Fig.4.5 Sensitivity Analysis of Biomass Price

Environmental Analysis

Environmental analysis is performed based on GHG emissions. Only CO_2 emissions were considered because of their highest contribution to the overall emission factor. A typical 10 to 15years old tree absorbed an average of 20 kg CO_2 in a year [10]. Case 4 off grid with 400kW biomass gasifier proved to be the most feasible regarding GHG emissions, offering the least amount 1305 kg of carbon dioxide emissions and only 65 number of trees required to absorb these emissions. Case 1 off grid with 100kW biomass gasifier experienced the highest GHG emissions due to the presence of DG-based optimal configurations and its highest share as given in **Fig** . Also, comparison to overall grid and DG Emission, we can save tons of carbon emissions in a year. The cost-effective models from on-grid and off-grid were case-3 off grid with 300kW biomass gasifier and case 5 On grid with 100kW biomass gasifier, respectively. In case 3, only 168 number of trees were required to absorbed 3378 kg of CO_2. Moreover, in case 6, the carbon dioxide emission was 30517 kg which required 1525 mature trees.

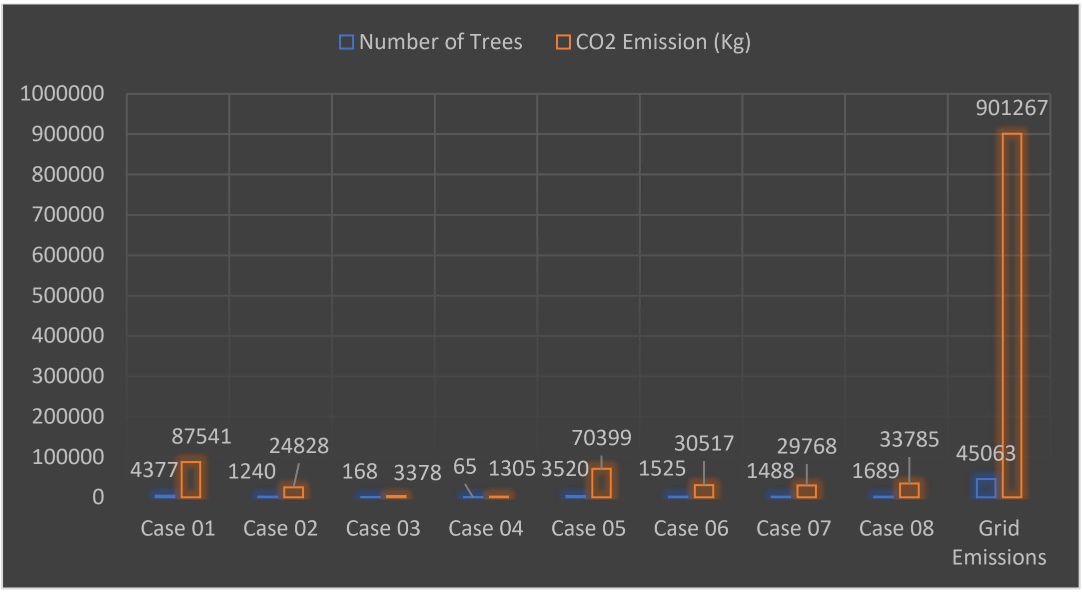

Fig 4.6 Environmental Analysis of Off Grid and On Grid Models

Summary

This chapter enlightens and validates the models and their efficiency using a simulation tool (Homer). Elemental and calorific analysis proves that rice husk can be used as a biomass resource to meet energy production requirements by converting it into biogas. Homer provides the solar radiation report due to the integrated NERL database. Rice husk is evaluated through site-visit. The techno-economic aspects of all the presented models reveal that the case-3 from on-grid and case-6 from off-grid are feasible to proceed for investors with ROI 31% and 13%, payback period of 2.6 years and 5.21 years, the initial capital of 1.87 $M and 0.76 $M with renewable penetration 99.8% and 97.9%, respectively. Sensitivity analysis with the effect of 12% inflation and 9.75% discounted rates are also determined with 5 variations. Another sensitivity analysis is done with increasing load demand and biomass price. Environmental analysis is done to check whether the models are eco-friendly, and both models from on-grid and off-grid have shown less GHG emissions, but case 4 from on-grid has the least emission.

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Chapter 5

Conclusions and Future Prospective

5.1. Conclusions

Pakistan is an agricultural country and use non-renewable energy resources to meet energy demand. Due to high prices of fossil fuels and economic crisis, Pakistan is facing energy shortfall. Solar and Biomass were identified as the best source to meet the electricity requirements in areas with little wind speed and depleted other renewable resources in Pakistan. Rice Factory in Layyah, Punjab was the case-study area, with an electricity shortfall. From the NREL report, the average solar radiation was 5.22 kWh/m^2/day. Biomass production was evaluated after the site visit, and it was calculated that 3891.71-ton rice husk was produced annually. Laboratory tested the rice husk sample, and GCV, LHV and Fixed Carbon values were found. Homer software was used for techno-economic analysis on eight developed models; four were off-grid and others were on-grid. The average NPC and LCOE of off-grid were 5.74 $M and 0.123 $/kWh, respectively, and for On-grid configuration were 3.91 $M and 0.0561 $/kWh, respectively. The models were further evaluated by comparing them with the NEPRA tariff and related studies. Both models (case-3 Off grid with 300kw biomass gasifier and case-6 On grid with 200kW biomass gasifier) showed less levelized cost as compared with the NEPRA tariff. case-3 produced 3378 kg of CO_2 emission and case-6 emitted 30517 kg. Sensitivity analysis was performed for five discount and inflation rates, showing direct and inverse relations with NPC and LCOE.

Moreover, the wind speed in Layyah is not suitable for the energy from wind, and the model is developed for a small scale but can be adoptable at a larger scale to meet energy demand. The factories that do not have the rice husk as by-product can use alternative biomass sources.

Because of the greater efficiency and dependability of these hybrid renewable systems, the government of Pakistan may play a crucial role in helping the country's rural communities to cover the current energy crisis by providing them with infrastructure. Furthermore, only tax discounts or exemptions are included in the existing law encouraging the use of such systems, which is insufficient for low-income areas to utilise such systems. A national electrification scheme may be launched if the government alters its enabling policies and provides incentives for using the system. The study's recommended hybrid renewable source-based design may be used to help off-grid rural areas become self-sufficient. This study is also helpful for other rice factories. They can adopt the same model for their factories for the lowest cost of energy. On-grid system models are more feasible and initial capital is less than Off Grid models. Moreover, for rural areas, the off-grid models are reliable and self-sufficient.

5.2. Future Prospective

The models were analysed on the software Homer Pro to find out the estimated cost and other technical aspects that will help investors (government or private) in future for investment in this plan and to meet energy demand. The factories that do not have the rice husk as a by-product can use alternative biomass sources. The large-size factories can also adopt this system by scaling them according to their load demand and production. The model can also be upgraded by adding hydro or wind energy sources where the resources are available. Those regions with good wind speeds can also adopt the model of PV-BM-Wind with favourable on-grid and off-grid connections. This model can also help in CPEC Projects.

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APPENDIX 1: Research Article

Title: Optimization of Industrial Hybrid Renewable Energy System using Homer

Abstract:

Increasing energy requirements due to population growth, urbanization, and industrialization push to adopt energy resources that will not deplete. Pakistan is among the category of those under-developing countries that are facing an electricity shortfall of 6997 MW. Pakistan is an agricultural country and has diversified sources of biomass. The geological location of Pakistan around the Sun Belt reveals that the average solar irradiation is 5 kWh/m2 /day. A case study has been done focused on a rice mill in Layyah city in Punjab province. The targeted renewable resources are rice husk (biomass) and solar energy to produce electricity. Homer Pro software is used for optimization and techno-economic analysis of the PV/Biomass hybrid systems. Eight configurations are designed against the off-grid and on-grid systems (four for each system). It is seen that the most feasible design, case-3 from the off-grid (PV-BM-DG-B) system of 300 kW configuration, shows the NPC, LCOE, and renewable penetration of 5.91 M$, 0.125 $/kWh and 99.8%, respectively, whereas, in on-grid system, case-6 (PV-BM-G) shows 3.51 M$, 0.0503 $/kWh and 97.9%, respectively. Environmental analysis reveals that these models would help in carbon emission reduction compared to grid.

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