ENERGY AND CLIMATE
PANORAMA

ASSESSMENT OF BIOMASS-BASED BOILER OPERATION FEASIBILITY IN TEXTILE INDUSTRY

About Us

Who we are

We are a dedicated team of researchers and experts who recognize the urgent need for action in addressing climate resilience and energy transition in Pakistan. Our mission is to develop and implement effective policies for cleaner, renewable energy sources like solar and wind, aligning with Pakistan's 2030 goal of 30% renewable energy in its electricity mix. As a multidisciplinary team, we leverage expertise in three key disciplines of study—Energy Systems Engineering, Thermal Energy Engineering, and Electrical Power Engineering—to drive our mission forward. We are united by a shared vision of creating a sustainable and resilient future for Pakistan, where cleaner energy sources play a pivotal role in reducing the nation's vulnerability to climate-related challenges.

What we do

We conduct in-depth, evidence-based research to analyze and improve energy policies in Pakistan. Our focus is on advancing renewable energy solutions and engaging stakeholders to ensure effective policy implementation. Our methodology involves a critical examination of current energy policies to pinpoint areas of improvement and formulate strategies for the widespread adoption of renewable energy sources across various levels.

In line with our commitment to fostering sustainable practices, we have established a fellowship program as part of our broader initiatives that aims to facilitate evidence-based research for promoting energy transition in Pakistan. Through research studies, surveys, and forecasting, we plan to assess various aspects of energy transition, including the adoption of renewable energy technologies and their impact on climate change. Our approach involves active engagement with stakeholders to address their concerns and facilitate the effective implementation of policies, fostering the growth of renewable energy manufacturing and marketing facilities.

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Executive Summary

Industrial production remains dependent upon fossil fuels, which is the main source of greenhouse gas (GHG) emissions worldwide. Over the past two decades, fossil fuels have largely failed to resolve the persistent energy crisis in developing countries like Pakistan. Therefore, the commercialization of renewable energy sources for industrial applications is required to mitigate the adverse impacts of climate change and ensure the affordable and clean energy supply (SDG 07, 13).

The textile sector, a large contributor to world energy consumption, is facing the challenge of lowering its carbon footprint while retaining operational effectiveness in an era characterized by environmental awareness and the pursuit of sustainable industrial practices. The project, titled "Assessment of Biomass-Based Boilers Feasibility in the Textile Industry," launches a thorough investigation into the viability and possible advantages of biomass-based boiler technology within the framework of Pakistani textile production. For this purpose, three textile facilities: KOHINOOR Textile (Pvt) Ltd. Islamabad, Master Textile (Pvt) Ltd. Lahore and Packages Industries (Pvt) Ltd. Lahore are studied from the perspective of biomass utilization in boilers to cater the process heat demand.

A comprehensive techno-economic feasibility assessment is carried out using the energy management tool RETScreen®, that how well the biomass boilers may be adapted to different textile industries' thermal load considering the capital expenditure, operating expenses, and prospective financial incentives. Feasibility of different biomass fuels such as rice husk, wheat, wood chips, corncob, bagasse, etc. in target industries, is analyzed in terms of economic indices such as fuel saving, Benefit-Cost ratio (BCR), payback period and Net present value (NPV). Furthermore, environmental impact of biomass-based boilers is analyzed in terms of GHG emission reduction emphasizing the advantages of sustainability and the reduction of carbon emissions.

1. Introduction

Pakistan is the 9th largest exporter of textile products and is 5th largest producer of cotton in the world [1]. Textile is the most important manufacturing sector of Pakistan and has the complete value chain available in Pakistan from cotton to ginning, spinning, fabric, dyeing and finishing, made ups and garments. The textile sector contributes nearly 1/4th of industrial value-added products and provides employment to about 40% of the industrial workforce [2]. Additionally, textile has an average share of about 60% in national exports [3]. The industry comprises of 13.41 million spindles, 198,801 rotors, 375,000 power looms and 28,500 shuttle less looms. Industry is mainly located in Lahore, Faisalabad, and Karachi. The global textile market was estimated at $1 trillion in 2020 which is expected to reach $1.5 trillion by 2027 at a compound annual growth rate (CAGR) of 4.3% from 2020 to 2027 [4]. Textile industries use boilers to cook slurry, and printing & dyeing mills use boilers to heat and dry textiles, processes carried out by hand.

The role of boilers in the textile industry is very important. However, with the advancement of technology, machinery and equipment were born [5]. The appearance of the boiler brought great convenience to the plant. It not only brings high efficiency, saves manpower and time, but also is better than manual finishing. The steam quality of the boiler in the textile industry has a decisive influence on the product quality of the dyeing & drying process of the textile industry. On the other hand, the In developing countries such as Pakistan, due to the low cost of biomass, coal and relatively low environmental protection requirements, more textile industries are willing to choose coal/biomass fired boilers with low fuel costs [7]. Compared with a gas-fired boiler, its fuel cost is higher but with the advantages of gas-fired boilers, full automation in operation and only one pipeline for transportation and installation, the boiler has become the preferred type of boiler for many textile industries [8]. One of the industries that uses the most energy worldwide is the textile sector, which mostly relies on fossil fuels. However, there is growing interest in alternative and renewable energy sources because of rising environmental sustainability concerns and the requirement to minimize greenhouse gas emissions [9]. Boilers powered by biomass hold promise to lessen the negative effects of the textile industry's energy use on the environment.

Various investigations have been led to survey the achievability of biomass-based boilers in different modern applications. Numerous studies have investigated the potential advantages and disadvantages of using biomass-based boilers in the textile industry. Notable investigations include those by [10], which confirmed the fuel-switching method in present coal-fired boilers to decrease operating costs, foster renewable energy usage, and improve the energy security. Cofiring with coal in currently operating coal-fired boilers is one of the most appealing and simple biomass energy methods. Up to 20% of the boiler's coal usage can be replaced by biomass in cofiring [11]. Both the biomass and the coal are burned at the same time. Biomass can offer the advantages when it is utilized as an additional fuel in a coal boiler already in use such as lower fuel prices, a reduction in SOx, NOx and greenhouse gas emissions, and an evasion of landfills and their associated expenditures [12].

Flue gas opacity reductions are just one of the known advantages. Putra et al. (2023) demonstrated hypothetical and investigational study of ash-related challenges during coal co-firing with various types of biomasses in existing coal fired boilers [13]. Saleem et al. (2015) demonstrated the quest for alternative fuel in the wake of energy crisis as well as steam generation in US Denim Mills [14]. The economic feasibility of biomass boiler integration in textile industries particularly supply chain integration and sustainable boiler operation to synergize the energy system of textile industry have been extensively studied [15, 16]. Additionally, the environmental advantages of biomass-based boilers have been underlined in studies [17, 18], which accentuated the decrease in carbon emissions and the overall environmental footprint of textile industry by using biomass as a primary energy source.

Numerous biomass-based boilers have been reported to generate heat and steam for various industrial processes including textile industry [19]. Biomass-based boilers are becoming increasingly popular in the textile industry as a more sustainable and eco-friendlier alternative to traditional fossil fuel-based boilers [20]. The use of biomass as a fuel source reduces the industry's reliance on non-renewable energy sources and helps to reduce greenhouse gas emissions. Biomass-based boilers in the textile industry can be used for a variety of applications, including the production of steam for textile processing, dyeing, and finishing [21]. They can also be used to generate electricity, which can be used on-site or sold back to the grid. There are several different types of biomass-based boilers that are being used in the textile industry, including: Stoker boilers [22], these boilers (shown in Figure 1) use a mechanical stoker to feed the fuel into the combustion chamber, where it is burned to generate heat and steam.

Figure 1. Chain Grate Stoker Biomass-based Steam Boiler

Fluidized bed boilers [23], these boilers (shown in Figure 2) use a bed of sand or other inert material to suspend and burn the fuel, resulting in a more efficient and cleaner combustion process.

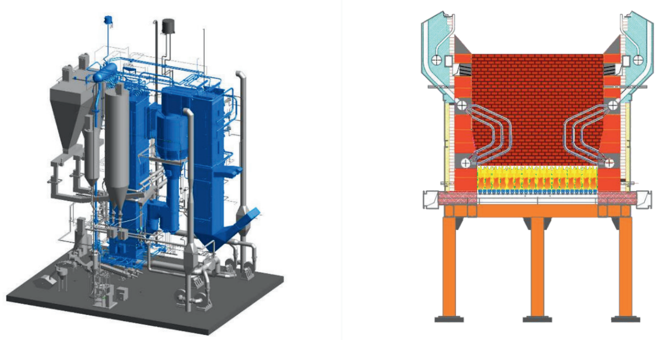

Figure 2. Fluidized Bed Biomass-based Steam Boiler

Bubbling fluidized bed boilers [24], these boilers (shown in Figure 3) use a bed of sand or other inert material with a stream of air bubbles to create a turbulent combustion process that results in more efficient heat transfer.

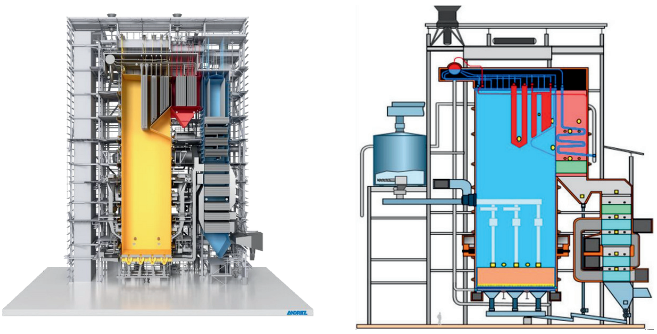

Figure 3. Bubbling Fluidized Bed Biomass-based Steam Boilers

The analysis shows that switching to alternative fuels from those normally utilized in this industry has many benefits, particularly in areas like improving an internal resource while helping to cut down on energy imports [25]. Adopting eco-friendly practices and assisting in the reduction of greenhouse gas emissions, the lower energy expenses brought on using a less expensive fuel and promoting domestic renewable natural resources as a strategy of achieving energy independence from foreign sources. Up to 36% less energy is needed to produce the necessary steam for an industrial operation when biomass is used, which is a very significant energy cost saving [26]. This benefit might make it possible to increase this industry's competitiveness. In fact, using biomass energy as the primary source for producing steam encourages the usage of a domestic product.

Major sources of biomass in Pakistan include agricultural crops, municipal solid wastes, and animal manure. The annual production of about 150.785 Mt of agricultural crops residues, 417.3 Mt of animal manure, 49.6 Mt of municipal solid waste in Pakistan offer a variety of bioenergy options ranging from biofuels to bio-electricity production [27]. owing to the huge agricultural sector, Pakistan produces several agricultural residues including wheat husks, rice husks, cotton sticks and sugar cane residues [26]. In addition to non-woody agricultural residues, the woody portion also contributes a great share to the production of energy.

As per press release from press information department in Ministry of information and broadcasting, The output of wheat (27.5 million mt), rice (8.4 million mt), maize (8.5 million mt), mung beans (0.275 million mt), onions (2.3 million mt), and potatoes (5.7 million mt) in Pakistan has reached record highs. The second-highest production was attained by sugarcane (81 million mt). Production of sugarcane is anticipated to reach 87.67 million tons in 2021–22, an 8% increase from the previous year. 8.84 million tons of rice are expected to be produced, which is an increase of 5% over the previous year. 9.0 million tons of maize are expected to be produced, an increase of 8.5% over the previous year. As of 01 November 2021, cotton output was 6.2 million bales, an increase of 82% from 3.4 million bales at the same time last year. The maximum portion of produced biomass is consumed domestically for heat and cooking purposes and a small portion is utilized in industrial and commercial sectors as shown in Figure 4. The domestic sector is the largest consumer of biomass in Pakistan. It accounts for an estimated 80% of the total biomass consumption in the country [28].

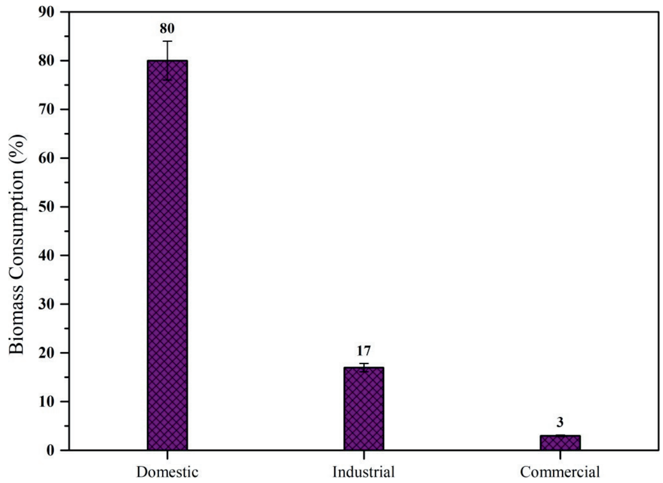

Figure 4. Biomass Consumption by Sectors

Biomass is primarily used for cooking and heating in rural areas, where access to modern energy sources is limited. The industrial sector is the second-largest consumer of biomass in Pakistan. It accounts for an estimated 17% of the total biomass consumption in the country. Biomass is used as a fuel for boilers and other industrial processes in sectors such as textiles, sugar, pulp, and paper [29]. The commercial sector accounts for an estimated 3% of the total biomass consumption in Pakistan. Biomass is used for heating and cooking in small businesses such as tea stalls and bakeries. The transport sector accounts for a negligible share of the total biomass consumption in Pakistan. Biomass is not used as a fuel for transportation in the country. The total estimated biomass consumption in Pakistan is around 58 million tons per year, according to a study by the United Nations Development Program (UNDP). This represents a significant opportunity for the development of sustainable biomass energy systems in the country, including for use in the textile industry. It's worth noting that Pakistan is heavily dependent on imported oil and gas, which makes up a significant portion of its energy mix [30]. The country has been investing in renewable energy sources in recent years to diversify its energy mix and reduce its dependence on fossil fuels [31]. Pakistan's energy share by fuel based on the latest data available from the International Energy Agency for 2019 is given below in Figure 5.

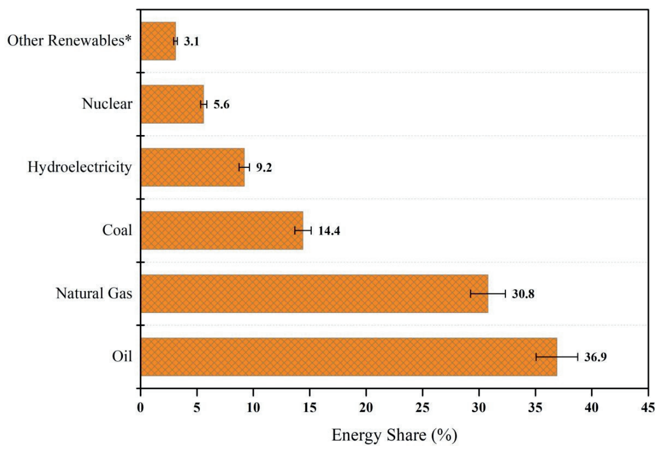

Figure 5. Energy Share by Fuel Source

*Other Renewables include wind, solar and biofuels.

1.1. Scope of the Study

This study's scope includes a thorough evaluation of the viability of biomass-based boilers in the textile sector. It will include:

- A technical feasibility study that considers how well biomass boilers may be adapted to different textile industry processes.
- An evaluation of the economy's viability, considering capital expenditure, operating expenses, and prospective financial incentives.
- Assessment of the environmental impact, emphasizing the advantages of sustainability and the reduction of carbon emissions.
- A comparison with traditional boilers powered by fossil fuels is made to show

the benefits and drawbacks.
- Case studies and actual instances of textile companies utilizing biomass-based boilers successfully.

1.2. Limitations

- Depending on the availability of sufficient biomass resources in particular places, the viability of biomass-based boilers may vary.
- The installation of biomass boilers may necessitate upgrading the current infrastructure and overcoming any technical difficulties.
- Changing government incentives and varying biomass prices may have an impact on economic viability.
- Differences in biomass feedstock types and sourcing methods may affect the environmental advantages.
- The viability and incentives of biomass-based boilers may be impacted by changes in environmental laws or governmental policy.

1.3. Assumptions

- The study presupposes a basic familiarity with biomass-based boiler technology and its possible advantages.
- It presupposes access to historical data and information on energy usage and textile manufacturing processes.
- Though prospective changes will be considered, the study assumes a stable policy and regulatory environment at the time of analysis.
- Economic evaluations will be based on the current state of the market and the cost of biomass at the time of the study.

2. Approach and Methodology

The investigation starts by carefully going over important technical documents, industry reports, and academic literature that has undergone rigorous peer review. The methodical collection of important knowledge about the application of biomass-based boiler technology within the textile industry is the main goal of this foundational phase. This literature review serves as the theoretical foundation for the study, providing it with a comprehensive overview of previous research, current problems, and prospective directions for future study in the area of biomass-based boilers used in the textile industry.

Meanwhile, a careful site selection procedure is carried out, guided by a thoughtful evaluation of a variety of variables, such as geographical diversity, boiler capacity, and the interest of Pakistani textile manufacturing companies in participating in the research project. The site selection procedure follows strict guidelines to guarantee the thorough depiction of elements that influence the adoption of biomass boilers, supporting the assurance of the research's validity and applicability across a range of textile industry settings. Surveys are rigorously planned and carried out to methodically accumulate quantitative data from KOHINOOR Textile (Pvt) Ltd. Islamabad, Master Textile (Pvt) Ltd. Lahore, Packages Industries (Pvt) Ltd. Lahore.

These studies include a wide range of topics, such as boiler specifications, biomass procurement procedures, performance criteria for assessing operating efficiency, and the complex web of energy consumption patterns.

Figure 6. Chain Grate Boiler Installed in KOHINOOR Textiles (Pvt) Ltd. Islamabad

Figure 7. Boiler section Survey of KOHINOOR Textiles (Pvt) Ltd. Islamabad

In parallel, a semi-structured interview strategy is employed, involving key participants like plant managers and technical specialists. These in-depth interviews have been carefully planned to elicit qualitative insights that provide light on the complexity of decision-making procedures, how hurdles were overcome, and the many different elements that contributed to the successful integration of biomass-based boilers. Concurrently, in-depth interviews offer a layer of qualitative richness by delving into nuanced viewpoints and providing a thorough understanding of the complexities controlling the uptake and efficacy of biomass-based boilers within the textile industry.

Figure 8. Fluidized Bed Boiler Installed in MASTER Textiles (Pvt) Ltd. Lahore

Figure 9. Coal/Biomass Cofired Boiler Installed in PACKAGES Industries (Pvt) Ltd. Lahore

2.1. RETScreen Expert Modeling

Together with the factual information collected through surveys and interviews, the powerful analytical capabilities of the RETScreen Expert software are leveraged. The precise boiler specifications, properties of the biomass feedstock, and measurements of energy use are all included in this extensive dataset, which is painstakingly incorporated into the computational architecture of RETScreen Expert. With careful calibration to reflect the current energy consumption and emissions profiles of each textile production plant under consideration, this symbiotic fusion produces exact and comprehensive models. These calibrated models serve as an accurate reflection of the nuanced details that underlie real-world operations. They were created with a keen awareness of both the current landscape of biomass-based boiler utilization and an alternative conjectural scenario featuring traditional fossil fuel-based counterparts. The calibration procedure gives these models the necessary fidelity for scenario-based analysis, a crucial weapon in the toolbox of well-informed decision-making.

2.2. Economic Analysis

Economic factors, including capital expenditures, continuing operating costs, and the attractiveness of prospective financial incentives, are distilled via the astute lens of RETScreen Expert. The financial viability of biomass-based boiler projects is precisely assessed within this analytical crucible, acting as a compass in the maze of financial choices.

2.3. Environmental Impact Assessment

Additionally, RETScreen Expert examines the ecological effects of the deployment of biomass-based boilers in its capacity as an environmental litmus test, calculating the reduction in carbon emissions and related environmental benefits. The reduction of carbon emissions and the ensuing ecological benefits brought about by the use of biomass-based boilers serve as the main focus of this study and serve as a solid basis for environmental impact assessments.

2.4. Comparison and Evaluation

Comparing the empirical information gathered from surveys and interviews with the results produced by the RETScreen Expert models allows for validation and thorough examination. This comparison protects against model errors while providing a vantage point from which to identify discrepancies and obtain important insights that call for more investigation. In order to ensure that the models accurately reflect real-world verities and that any discrepancies or notable results are submitted to extensive inspection and correction, comparison analysis serves as an essential quality control method.

2.5. Recommendations

At the end of this thorough analysis process, discriminating and useful recommendations are painstakingly crafted for each textile production plant. These suggestions cover aspects of the integration of biomass-based boilers' viability, economic viability, and potential improvements. Each institution is given a practical path for the installation of biomass-based boilers by the compilation of these suggestions, which aggregates actionable information and places a clear emphasis on environmental and economic imperatives.

2.6. Report Compilation

In the end, the research's extensive results, astute conclusions, and forward-thinking suggestions combine to form a magnum opus—an exhaustive project report. This paper, an example of synthesis, captures the whole scope of the investigation and provides a broad overview of the findings. This study takes on the role of an irreplaceable resource by serving the needs of the stakeholders and decision-makers who determine the direction of the textile industry.

3. Major Findings / Results

The variety of biomass sources, which include agricultural wastes like wheat and rice straw as well as wood-based alternatives like wood pellets and sawdust, emphasizes how adaptable and flexible biomass-based boilers are. Due to this diversity, the textile industry is able to choose feedstocks based on local circumstances and availability. Since biomass sources constantly emit fewer emissions and have smaller carbon footprints than coal, the initiative emphasizes the dedication to environmental responsibility. This supports the goals of tackling climate change and global sustainability. When compared to coal, a traditional fuel source, biomass fuels have clear benefits in terms of sustainability and emissions reduction. From an environmental and economical point of view, biomass sources are far superior to coal in terms of decreasing emissions and provide competitive financial returns.

According to the RETScreen modeling results, biomass-based boilers present a strong argument for Pakistan's textile sector. They provide a win-win situation that combines favorable environmental effects, significant fuel cost reductions, and alluring cash gains. The results of this study highlight the crucial significance of biomass sources in enhancing sustainability and commercial viability within the textile industry while also promoting more general socio-environmental goals. The choice of fuel is of the utmost importance.

These findings show that biomass-based boilers have a number of advantages, including lower emissions, lower costs, and positive cash flow. For textile producers looking to lessen their impact on the environment, maximize their budgets, and guarantee a steady supply of energy, these issues are crucial. The textile industry's energy environment has the potential to be completely transformed by biomass sources because of their sustainability and financial benefits.

3.1. Benefit-Cost ratio (BCR)

The BCR of 1359 in bagasse is unusually high as shown in Figure 10. This means that a biomass-based boiler using bagasse has a predicted return of 1359 units for every unit invested in it. A BCR of this magnitude is remarkably positive and demonstrates the great economic feasibility and potential profitability of bagasse as a fuel source. Bagasse-using textile businesses should expect huge financial gains and considerable carbon savings. The BCR of corn cob is a decent 1005. Even if it isn't as high as bagasse, its value still represents a wise investment. It suggests that a return of 1005 units may be anticipated for every unit invested. The BCR of corncob highlights their value as a biomass fuel for textile businesses looking for affordable and sustainable energy sources. The BCR of forest residue is 1352, which is comparable to bagasse. This demonstrates the appeal of using forest waste as a fuel source for boilers that run on biomass.

It implies that businesses using forest residue may anticipate a sizable return on their investment, making it an appealing option from both a financial and environmental standpoint. Municipal solid waste (MSW) displays a BCR of 1355, which is comparable to bagasse and forest residue. This highlights MSW's potential as a renewable fuel source. Businesses who choose MSW may expect impressive returns on their investments as well as the additional advantage of waste management, helping to create a cleaner environment. The BCR for rice straw is an outstanding 1334. This suggests that making investments in rice straw-based biomass boilers might result in significant financial advantages.

The BCR shows that rice straw is both economical and capable of cutting carbon emissions considerably, which is in line with sustainability objectives. The economic feasibility of wood pellets is demonstrated by their BCR of 1173. This BCR still shows excellent returns on investment while being a little lower than some other biomass sources. For the textile industry, wood pellets offer a trustworthy and sustainable energy choice that supports both commercial and environmental goals. The BCR of mixed wood waste is 1181, which is comparable to that of wood pellets. This proves that it is a biomass feedstock that is competitive and provides good returns on investment. A flexible option, mixed wood waste has the ability to improve the economic and environmental performance of textile companies. Sawdust stands out as a cost-effective solution for biomass-based boilers with a BCR of 783.

Despite having a lower BCR than some other biomass sources, it nevertheless represents a wise economical choice. Sawdust provides dependable and effective energy generation, promoting sustainability and financial success. Wheat straw has a significant economic attraction as seen by its remarkable BCR of 1399. Wheat straw is a biomass feedstock that offers considerable returns on investment for textile businesses. This makes wheat straw an appealing option, especially when combined with emissions reduction. A traditional fuel source, coal, is used as a benchmark. As opposed to biomass sources, its BCR is significantly lower, highlighting the better economic and environmental benefits of biomass-based boilers. Coal has a lower BCR because of its high cost and negative environmental effects.

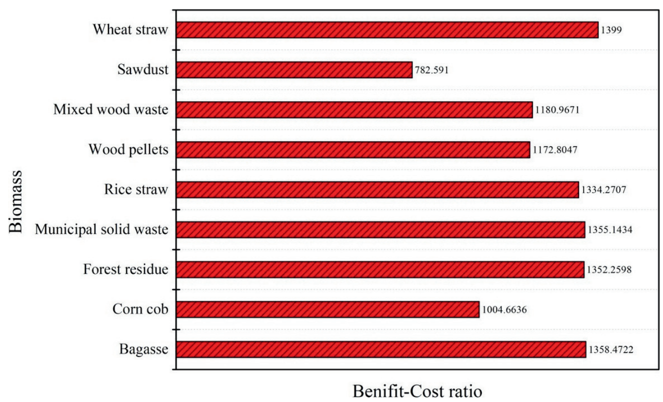

Figure 10. Comparison of Benefit-Cost Ratio of Various Biomasses

The benefit-cost ratios obtained by RETScreen modeling highlight how economically appealing biomass-based boilers using a variety of feedstocks are. Other biomass sources such as bagasse, forest residue, municipal solid waste, and others have BCRs that show sustainability as well as profitability. These findings highlight the possibility for the textile industry to switch to more cost-effective and environmentally friendly energy sources, in line with both their financial goals and wider social and environmental obligations.

3.2. Payback Period

Bagasse has a payback time of only 0.04 years, or a few weeks, which is incredibly quick as shown in Figure 11. This indicates an incredibly quick return on investment for textile firms who decide to use bagasse-based biomass burners. This biomass source's economic viability and rapid financial benefits are well demonstrated by its short payback period. Corncob has a payback period of 0.05 years which is slightly higher than bagasse but is still considerable. Forest residue also exhibits a quick return on investment, with a payback period of 0.04 years (about one to two months). This is consistent with the economic allure of using forest waste as a fuel source for biomass-based boilers, making textile firms looking for immediate financial advantages a good fit.

Municipal solid waste (MSW) has a payback period of 0.04 years, which is comparable to that of forest residue and denotes a quick return on investment. In addition to providing financial benefits, MSW supports sustainable environmental practices and waste management. The payback period for rice straw, MSW, and forest residue is all 0.04 years. This illustrates that the textile industry may expect quick financial gains while also pursuing environmental goals by choosing rice straw as a biomass fuel. With a payback period of 0.04 years, wood pellets further highlight how affordable this biomass source is. Given the short payback time, firms should be able to swiftly recoup their early expenditures and begin reaping large financial rewards. Several additional biomass sources also have a payback period of 0.04 years, including mixed wood waste. This enhances the fuel's economic appeal as a viable option for biomass-based boilers, providing quick returns and sustainability benefits. The payback period for sawdust is 0.06 years, which is still only a little over a year. When compared to other biomass sources, sawdust may take a few extra weeks to make back the original expenditure, but it is still a sensible financial and environmental choice. The payback period for wheat straw, at 0.04 years, is comparable to the other biomass fuels' brisk returns on investment. The use of wheat straw by the textile industry can result in quick cash returns while encouraging environmentally friendly energy methods.

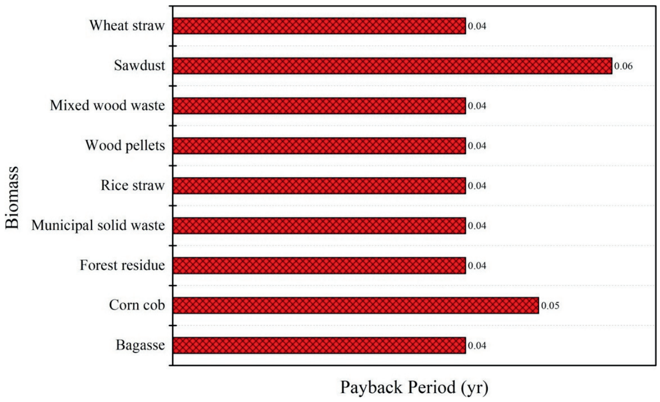

Figure 11. Comparison of Payback Period for Various Fuel Types

The RETScreen modeling findings for payback periods illustrate the quick financial gains connected to different biomass sources for biomass-based boilers. The short payback periods of bagasse, forest residue, municipal solid waste, rice straw, wood pellets, mixed wood waste, and wheat straw all show their high economic feasibility. Even though sawdust has a somewhat longer payback period, it is still a desirable alternative. These results highlight the opportunity for the textile industry to switch to biomass-based boilers and achieve both short-term financial gains and long-term environmental goals.

3.3. GHG Emissions

Bagasse comes up as an exceptional option for being ecologically friendly, producing just 1040 tCO2 as shown in Figure 12. This low amount of carbon emissions is consistent with international initiatives to cut greenhouse gas emissions and prevent climate change. Utilizing bagasse, the textile industry may considerably lower its carbon impact. Compared to most other biomass sources, corn cob emits 1040 tCO2, which is same CO2 than they do. Despite the fact that it is a renewable fuel source, its emissions are noticeably same as those of bagasse and other biomass alternatives. Similar to bagasse, forest residue emits just 1040 tCO2, demonstrating its promise as a low-carbon and sustainable fuel source. By employing forest leftovers, industries may satisfy their energy demands while reducing emissions. Municipal solid waste (MSW) also exhibits 1040 tCO2 emissions, reflecting the environmental responsibility connected to this biomass source. MSW not only promotes energy but also waste management and carbon emissions reduction. The CO2 emissions from rice straw, bagasse, and forest residue total 1040 tCO2. This highlights its function as a low-emission fuel source and highlights how advantageous it is for lowering the carbon footprint of the textile industry. Additionally, the 1040 tCO2 emissions from wood pellets add to their environmental friendliness. Because the emissions levels across different biomass sources are stable, using wood pellets to cut carbon emissions is a dependable and sustainable solution. Mixed wood waste produces 1040 tCO2, which is comparable to other biomass sources. This confirms its potential to serve as a low-carbon energy source that can help achieve the aim of reducing emissions. With 1040 tCO2, sawdust emits the same amount of CO2 as a number of different biomass sources. This constancy underlines how ecologically friendly sawdust is as a fuel option. Like its predecessors, wheat straw emits 1040 tCO2. Its emissions profile is consistent with the goals of sustainability, which call for a reduction in carbon emissions from industrial activities. The amount of CO2 emissions from coal, a traditional fuel source, is substantially greater, coming to 183,224 tCO2. The advantages of biomass over coal for the environment are shown by this striking contrast. Textile businesses may significantly contribute to minimizing climate change and their environmental effect by switching to biomass-based boilers.

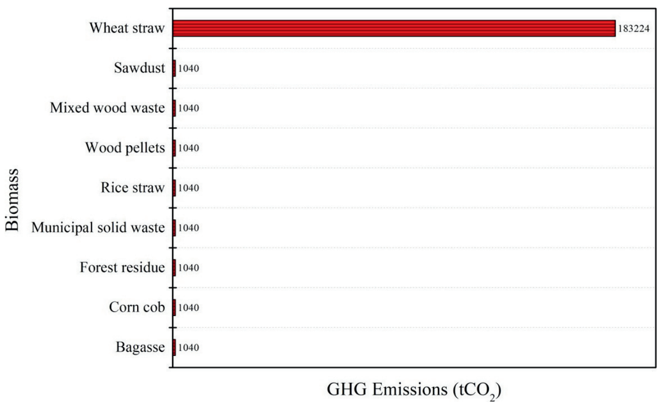

Figure 12. Comparison of CO2 Emissions from Various Fuels

The RETScreen modellings CO2 emissions findings demonstrate the environmental advantages of using different biomass sources for biomass-based boilers. Bagasse, wood pellets, mixed wood waste, sawdust, and wheat straw are only a few examples of materials that consistently generate low carbon emissions. This demonstrates their potential to assist the textile industry in lowering its carbon footprint and achieving sustainability objectives.

3.4. Fuel Cost Year-1

The fuel cost of 101970355 PKR for forest waste is fair. Forest waste is now a commercially feasible fuel source for the textile industry because to its cost efficiency, which raises operational profitability. With an annual fuel cost of only 94092959 PKR, bagasse stands out as a financially appealing option as shown in Figure 13. Bagasse is a viable financial option as a biomass fuel for the textile industry because of its cheap cost. Comparing it to traditional fuels like coal results in considerable cost reductions. The fuel cost of 542722241 PKR for corncob is a bit higher than the bagasse but is still considerable for its high heat capacity. Municipal solid waste (MSW) has a fuel cost of 98313965 PKR for first year of the project. Because MSW is so reasonably priced, it appeals to enterprises looking to maximize their budgets while cutting carbon emissions. The yearly fuel cost for rice straw is slightly higher at 124780523 PKR. Rice straw is slightly more expensive than some other biomass sources, but its price is still reasonable and justified given its sustainability advantages. A higher yearly fuel cost of 329724164 PKR is shown for wood pellets. It's important to remember that this cost is still far lower than that of coal, though. Wood pellets are a desirable option for the textile industry because they strike a compromise between affordability and sustainability. Similar to the price of wood pellets, mixed wood waste has an annual fuel cost of 319374268 PKR. This strengthens its position as a biomass feedstock that strikes a compromise between cost and environmental concerns. The yearly fuel cost for sawdust is greater, coming up around 824310410 PKR. Sawdust is a more expensive option, but its accessibility and high energy density make it a viable option, especially for sectors with specialized operating needs. A suitable yearly fuel cost of 43009128 PKR is provided by wheat straw. This mid-range price places wheat straw as an economical biomass source that supports sustainability goals. The yearly fuel expenses for coal, a traditional fuel source, are 1818596860 PKR greater. This high price highlights the superior economics of biomass versus coal. For the textile industry, switching to biomass-based boilers might result in significant fuel cost reductions.

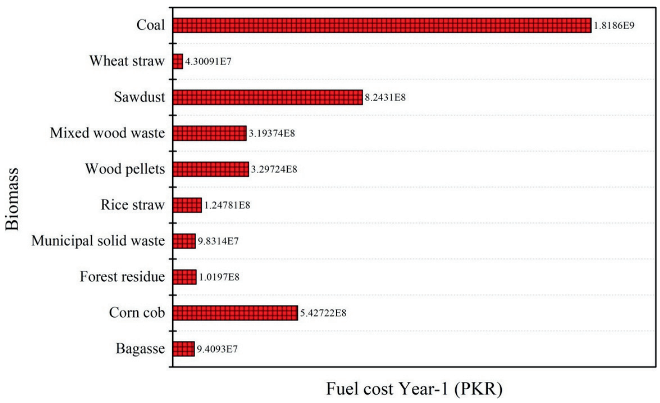

Figure 13. Comparison of Fuel Cost for Year-1 for Different Solid Fuels

The cost-effectiveness of various biomass sources for biomass-based boilers is highlighted by RETScreen modeling findings. The competitive yearly fuel prices offered by bagasse, forest residue, municipal solid waste, rice straw, and wheat straw all contribute to financial effectiveness. A balance between price and ecology is offered by wood pellets and mixed wood waste. Sawdust is a reasonable option despite its greater cost due to its advantages. These results highlight the opportunity for the textile industry to lower fuel costs while implementing more eco-friendly energy sources.

3.5. Annual Energy Savings

Bagasse has a 1310932 million BTU of energy savings per year, which makes it suitable for supplying the textile industries' heating needs as shown in Figure 14. Bagasse is a sensible option for biomass-based boilers since its degree of heating capacity fits with operational requirements well. With a greater yearly energy savings of 1153620 million BTU, corn cob has the ability to meet sizable heating demands. Despite having a larger load, its bulkier form may necessitate careful consideration of storage and logistics. Bagasse and forest residue both provide 1310932 million BTU to the yearly energy savings. This steady load demonstrates its capability for supplying the required warmth in the activities of the textile sector. Additionally, municipal solid waste (MSW) has an annual energy savings of 1310932 million BTU, which strengthens its capacity to supply heat. The demands of the industry are well-matched by MSW's heating capability. The yearly energy savings for rice straw is 1310932 million BTU, matching the textile industries' heating requirements. Rice straw is a desirable option because to its durability and load capacity. To meet the heating requirements of textile businesses, wood pellets maintain an annual energy savings of 1310932 million BTU. Due to their uniformity in load capacity, wood pellets are positioned as a dependable and effective fuel source. Mixed wood waste and other biomass sources contribute to the same 1310932 million BTU yearly energy savings. This shows that it can deliver reliable heating performance in the textile industry. Additionally, sawdust has an annual energy savings of 1310932 million BTU, highlighting its capability for supplying needed heat. Its availability as a byproduct of several wood processing businesses complements its load capacity. A significantly lower yearly energy savings of 1153620 million BTU is provided by wheat straw. Even though it has slightly lower heating requirements than some other biomass sources, it is still a feasible alternative for textile operations. This shows coal's significant heating capability while simultaneously highlighting its economic and environmental disadvantages in comparison to biomass choices.

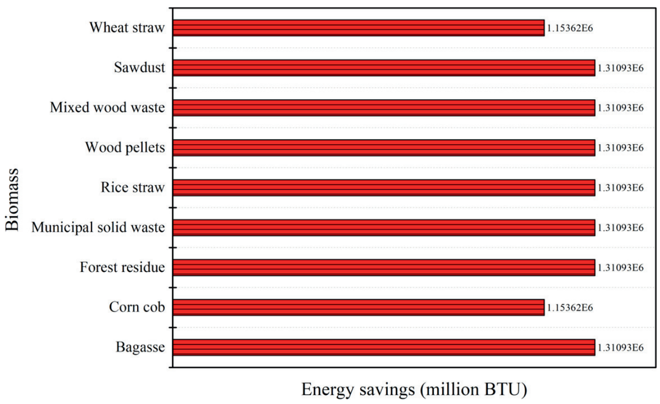

Figure 14. Comparison of Annual Energy Savings for Various Solid Fuels

The RETScreen modeling's yearly heating demand findings highlight the suitability of several biomass sources for supplying the textile sectors' heating needs. The steady and appropriate load capacities offered by bagasse, forest residue, municipal solid waste, rice straw, wood pellets, mixed wood waste, sawdust, and wheat straw all provide dependable heating performance. These results highlight the possibility for the textile sector to switch to biomass-based boilers while preserving operational effectiveness and sustainability.

3.6. Net Present Value (NPV)

Bagasse has a 43031869511 PKR positive NPV, suggesting a successful financial outcome. This means that textile businesses may anticipate a sizeable return on investment throughout the course of the project if they choose bagasse as a biomass feedstock. The NPV for corn cob is at 31816137464 PKR as shown in Figure 15. This suggests that employing maize cob as a biomass source in this context may be economically feasible for textile manufacturers. Understanding the variables behind this low NPV will require more research. The positive NPV of 42834934619 PKR for forest residue is consistent with the biomass source's promising financial prospects. Forest residue use by textile manufacturers can result in significant financial gains. Additionally, municipal solid waste (MSW) displays a favourable NPV of 42926344353 PKR. This shows that MSW is a financially appealing option since it provides both environmental benefits and significant cash rewards. With a positive NPV of 42264680419 PKR, rice straw is economically viable as a biomass feedstock. If the textile industry chooses rice straw, they should expect to see a sizable return on their investment. The positive NPV of

37146210532 PKR offered by wood pellets demonstrates its financial allure. Wood pellets have a minor advantage in terms of price compared to certain other biomass sources, but they are still quite profitable. Additionally, mixed wood waste has a positive NPV of 37404957929 PKR, supporting its economic feasibility. Mixed wood waste can yield good results for the textile industry. Although significantly less than some other biomass sources, sawdust has a positive NPV of 24776433223 PKR. It is still a financially sound option for biomass-based boilers, though. A positive NPV of 44308965284 PKR is provided by wheat straw, matching its viability from a financial standpoint. This biomass source contributes to sustainability objectives while offering excellent financial returns.

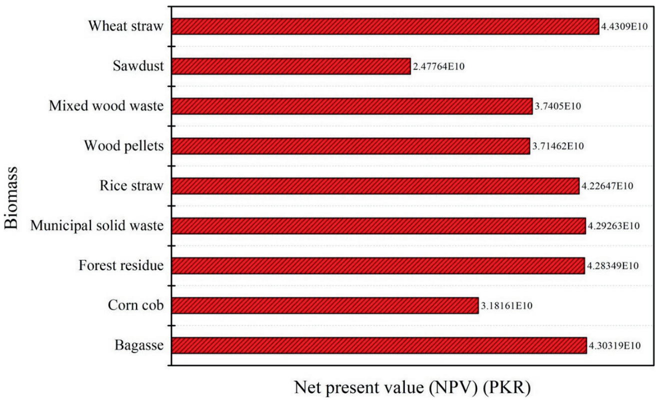

Figure 15. Comparison of Net Present Values for Different Solid Fuel Types

The RETScreen modeling's NPV findings demonstrate the various biomass sources' financial feasibility for biomass-based boilers. Positive NPVs, or substantial financial returns on investment, are offered by bagasse, forest residue, municipal solid waste, rice straw, wood pellets, mixed wood waste, sawdust, wheat straw, and corncob. These results highlight the potential for the textile industry to use biomass-based boilers and not only lessen their environmental impact but also reap large financial rewards.

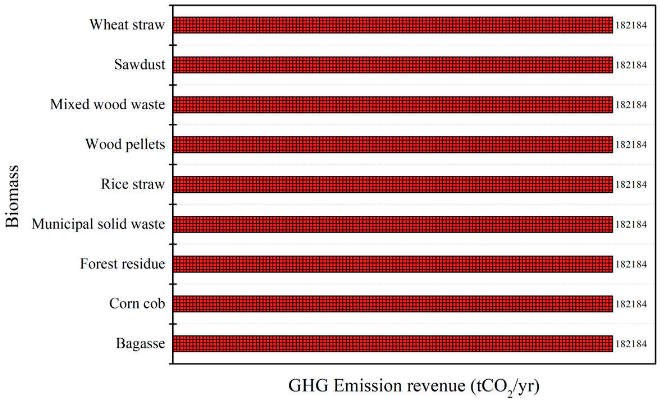

Figure 16. GHG Emissions Revenue Generated via Different Biomasses

3.7. Yearly Cash Flow-Year-1

Bagasse exhibits a positive 1717244964 PKR annual cash flow. This healthy cash flow shows that businesses in the textile industry who use bagasse as a biomass feedstock should anticipate steady financial growth over time, which will support their long-term financial viability. Whereas maize cob has an annual cash flow of 1.27E+09 PKR. This suggests that corn cob could yield the anticipated financial benefits as compared to bagasse. With a healthy cash flow of 1709367568 PKR for first year, forest residue is in line with its promising financial future as shown in Figure 17. Over time, this biomass source provides constant financial advantages. Additionally, municipal solid waste (MSW) has a positive annual cash flow of 1713023957 PKR, highlighting its financial allure. Industries that choose MSW might expect consistent financial advantages. A positive 1686557400 PKR cash flow for rice straw attests to its viability financially. This biomass source offers reliable financial returns that support sustainability goals. A positive annual cash flow of 1482215287 PKR from wood pellets demonstrates its feasibility financially. Despite being a little less abundant than some other biomass sources, wood pellets continue to bring in a consistent income. A positive yearly cash flow of 1492565183 PKR furthers mixed wood waste's desirability from a financial standpoint. Consistent financial advantages can result from using mixed wood waste. Sawdust has a positive cash flow of 987027512 PKR for first year. It is still a financially sound option for biomass-based boilers, although being a little less expensive than certain other biomass sources. The annual positive cash flow from wheat straw is 1768328794 PKR, which is consistent with its viability financially. This biomass source contributes to sustainability objectives while offering excellent financial returns. Sadly, the statistics presented does not include the annual cash flow for coal. The fact that coal has more long-term financial and environmental risks than biomass sources must be considered.

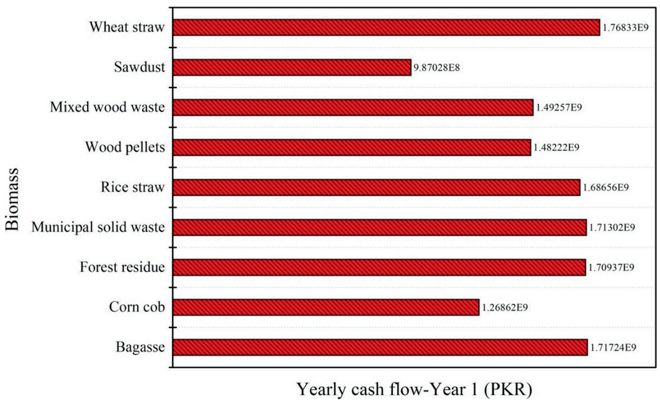

Figure 17. Yearly Cash Flow of Various Biomasses

3.8. Contribution Towards SDGs

The project, "Assessment of Biomass-Based Boilers Feasibility in the Textile Industry," significantly advances a number of Sustainable Development Goals (SDGs) in the unique Pakistani environment. These contributions serve as a good example of how the project is boosting socioeconomic growth, environmental protection, and sustainable development in the nation. This initiative acts as a key catalyst for bringing industrial practices in Pakistan in line with SDGs, where sustainable development is a critical need. It illustrates how cutting-edge and ethically sound technology, including biomass-based boilers, may help the country move toward a more sustainable and affluent future while tackling pressing developmental issues. The project's emphasis on rural development and potential revenue creation for localities engaged in the production of biomass feedstock has implications for decreasing poverty and resolving inequality which covers the SDG 1. The initiative supports the use of biomass-based boilers, which act as a clean and sustainable energy source, directly supporting SDG 7. This change improves Pakistan's textile industry's access to cost-effective, sustainable energy options while reducing dependency on fossil fuels and increasing energy efficiency. SDG 8 is aided by the project's capacity to provide employment, especially in rural regions where biomass feedstock is produced. It encourages the establishment of respectable employment opportunities and supports long-term economic expansion.

The initiative contributes to SDG 9 by supporting the implementation of cutting-edge biomass-based boiler technology inside Pakistan's textile industry. The textile sector will become more competitive and ecologically conscious as a result of this, which also encourages industrial diversification, technical advancement, and the creation of sustainable infrastructure. The initiative may improve air quality and lessen environmental effects in areas with textile industries, which indirectly supports SDG 11.

Communities who live close to these sites benefit from cleaner, more sustainable industrial operations. Boilers powered by biomass support wise use of renewable resources and are consistent with SDG 12's goals for effective and sustainable resource management. The use of biomass-based boilers greatly lowers carbon emissions and lessens the textile industry's impact on global warming. The goals of SDG 13 to tackle climate change and its effects are in line with this. By promoting responsible land resource management, particularly in the acquisition of biomass feedstock, the initiative indirectly advances SDG 15. This helps to protect terrestrial ecosystems and biodiversity. The collaborative attitude of the initiative, which involves the textile industry, research facilities, and perhaps even government organizations, embodies SDG 17. To meet common goals for sustainable development, it promotes collaborations.

4. Socio-Economic Significance of the Study

Socioeconomic relevance comes from its capacity to advance the textile sector, promote environmental responsibility, promote economic growth, and enhance the standard of living in areas impacted by textile manufacture. It serves as an example of the wider trend of sectors shifting toward environmentally friendly and sustainable methods, helping to create a future that is more resilient and affluent. The study titled "Assessment of Biomass-Based Boilers Feasibility in the Textile Industry" has a significant and wide-ranging socioeconomic impact. It includes a wide range of advantages and effects that go beyond the research's immediate area and have an impact on several stakeholders and society at large.

In the textile sector, the use of biomass-based boilers may greatly reduce greenhouse gas emissions and the carbon footprint of textile production. This supports global sustainability objectives and aids in reducing climate change. Boilers powered by biomass can improve energy effectiveness in the textile industry by lowering energy prices and usage. The increase in productivity aids textile businesses in maintaining their viability and competitiveness. The study encourages the appropriate use of renewable resources, such as agricultural waste and wood waste, by using biomass as a source of energy. As a result, the demand for fossil fuels is lessened, helping resource conservation. The study's economic feasibility analysis offers insightful advice for textile firms thinking about switching to biomass-based boilers. They can possibly save money and increase profitability by using it to assist them make educated investment decisions. When using biomass-based boilers, professional personnel may be needed for installation, upkeep, and biomass procurement. This may lead to the creation of jobs in the nearby towns of textile mills. Compared to the burning of fossil fuels, biomass often results in lower air pollution levels. This might result in better air quality in places with textile manufacturers, which would be good for the health and wellbeing of locals.

By adopting biomass-based boilers, the nation may minimize its reliance on imported fossil fuels while increasing energy security for the textile industry and the country. The study's conclusions and recommendations can make it easier to apply biomass-based boiler technology to other industrial fields, promoting sustainability and creativity in a variety of fields outside textiles. Rural communities frequently participate in the acquisition of biomass feedstock, giving them access to an extra source of income. This may help rural communities' socioeconomic growth. Policymakers may be informed by the research on the viability and advantages of biomass-based boilers, which might result in the creation of favourable regulations and financial incentives for the use of renewable energy in the industrial sector. The findings could persuade textile producers to build sustainable supply chains for biomass fuel, encouraging ethical sourcing methods and aiding neighbourhood farmers and forestry groups. By adhering to international sustainability requirements and customer expectations, textile businesses that use environmentally friendly and sustainable techniques, such as biomass-based boilers, are expected to increase their worldwide competitiveness.

5. Conclusions

The study's conclusions highlight the tremendous potential for biomass-based boilers to spur progress in the textile sector. Textile producers may simultaneously lessen their environmental impact, increase their commercial competitiveness, and support broader socioeconomic development by adopting this sustainable energy option. The future suggestions presented here provide stakeholders a road map for navigating the route toward a more competitive and sustainable textile sector.

5.1. Value Addition / Impactful Outcomes

This study indisputably proves that biomass-based boilers are a viable option for the textile industry's need for sustainable energy. Unambiguously, rigorous scientific and economic analyses show that switching to biomass can significantly reduce carbon emissions while simultaneously preserving or even increasing operating efficiency. This study is significant because it has the potential to have a significant positive environmental impact on the textile industry.

Our research emphasizes how important it is to advance sustainability goals and reduce carbon emissions in industrial operations, notably in the textile manufacturing industry. This study has eloquently shown via careful economic analysis that biomass-based boilers may provide textile industries with both strong economic viability and environmental benefits. Our study presents a convincing argument for the economic viability of switching to biomass by carefully weighing capital costs, operational costs, and potential incentives. Responsible resource management is best exemplified by the careful use of biomass as the main energy source.

Textile companies may demonstrate a strong commitment to resource conservation while reducing their reliance on limited fossil fuels by embracing agricultural wastes, wood waste, and other biomass feedstocks. This study clarifies the possible socio-economic benefits of using biomass-based boilers, including the chances for rural development and the creation of employment opportunities. The production of biomass feedstock by local populations stands to gain greatly from improved economic possibilities. The need of carefully thought-out rules and incentives in accelerating the adoption of biomass-based boilers within the textile sector is a key finding of this study. Policymakers must take note of the findings and think about putting policies in place that support the use of renewable energy sources and environmentally friendly business practices. The effective use of biomass-based boilers in the textile industry has the potential to spur more extensive technical advancement and technology transfer between sectors. This study draws attention to the possibilities for promoting sustainability and innovation across the industrial environment.

5.2. Future Recommendations

To evaluate the accessibility, affordability, and sustainability of biomass feedstock sources across a range of areas, we advise undertaking thorough market evaluations. The textile industry will benefit from having this information when choosing where to get feedstock. To create and execute supporting policies, such as tax incentives and subsidies, aimed at promoting the use of biomass-based boilers, collaboration with policymakers is essential.

Governments should proactively set goals for industry's use of renewable energy. Allocate funds for research and development projects aimed at improving the effectiveness and emissions performance of boiler technology based on biomass. Collaborations with key industry players can promote innovation and increase competitiveness. In order to create sustainable supply chains and ensure ethical sourcing procedures and fair pay for feedstock sources, form strategic collaborations with biomass suppliers support regional biomass-producing communities. Promote thorough education and training programs designed specifically for textile industry experts to improve their competency in biomass boiler operation, maintenance, and safety.
The key to successful implementation is having trained personnel. Implement reliable reporting and monitoring systems to carefully monitor the economic and environmental performance of biomass-based boilers in the textile industry. Effective knowledge distribution requires the exchange of best practices and lessons learned.

Allocate funds and assistance for ongoing studies into the use of biomass energy and its potential uses in the textile sector. Explore new trends and technologies as they emerge since they may help to improve operational effectiveness and sustainability.

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