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CASE STUDY

Kohinoor Textile Mills Limited (KTML)

Industrial Decarbonization & Sustainable Textile Manufacturing in Pakistan

Driving the Transition Toward Low-Carbon Textile Manufacturing

Alternate Development Services

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About the Alternate Development Services

Alternate Development Services Pvt. Ltd. (ADS) is a distinguished policy research and training organization, registered with the Securities and Exchange Commission of Pakistan (SECP). We are dedicated to driving impactful changes through research, advocacy, and capacity-building initiatives in key areas such as renewable energy, climate action, green financing, industrial de-carbonization, sustainable development, and community resilience.

Leveraging our deep expertise, ADS is committed to supporting a just and inclusive transition to a low-carbon and sustainable future. Our work spans policy research, capacity building, impact assessments, and community development, ensuring a holistic approach to fostering sustainable progress. By developing evidence-based, actionable strategies, ADS accelerates the adoption of renewable energy and supports broader socio-economic and environmental objectives.

Chief Executive’s Message

The textile industry stands at a defining moment. As one of the most globally integrated and export-dependent sectors, textile manufacturing is increasingly influenced by changing market expectations, sustainability standards, and climate-related regulatory frameworks. Today, competitiveness is no longer determined solely by product quality, production capacity, or cost efficiency, it is increasingly shaped by environmental performance, responsible resource use, and the ability to adapt to a low-carbon global economy.

For export-oriented economies such as Pakistan, the urgency of industrial decarbonization is particularly significant. International markets are evolving rapidly, and buyers increasingly demand low-carbon products, sustainability certifications, transparent emissions reporting, and traceable production systems. Regulatory developments are gradually introducing stronger environmental compliance mechanisms that influence sourcing decisions and market access. Whether through sustainability reporting requirements, environmental due diligence expectations, carbon-related trade measures, or supply-chain disclosure frameworks, the message is clear: industries that fail to transition risk losing competitiveness in future global markets.

The textile sector, given its energy-intensive nature and extensive resource requirements, has both a responsibility and an opportunity to lead this transformation. Decarbonization should not be viewed solely as a cost or regulatory burden. Rather, it is an investment in industrial resilience, energy security, operational efficiency, innovation, and long-term competitiveness.

This case study reflects an important effort to document and understand how industrial sustainability can be operationalized within the textile sector. The study recognizes that industrial transformation does not occur in isolation. Supportive policies, enabling regulatory environments, improved financing mechanisms, infrastructure readiness, and stronger public-private collaboration are essential to accelerate the transition toward low-carbon manufacturing.

It is hoped that this publication will serve as a practical knowledge resource for industry leaders, policymakers, researchers, and practitioners seeking scalable solutions for sustainable industrial development. More importantly, it is intended to encourage dialogue, inspire replication, and demonstrate that decarbonization within Pakistan’s textile sector is not only possible, but increasingly necessary for future competitiveness and resilience.

Amjad Nazeer
June, 2026

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List of Abbreviations

AC	Alternating Current
AW	Annual Worth
BCI	Better Cotton Initiative
CHP	Combined Heat and Power
CPP	Captive Power Plant
CTBCM	Competitive Trading Bilateral Contract Market
CVC	Chief Value Cotton / Cotton-Polyester Blend
DC	Direct Current
FO	Furnace Oil
GHG	Greenhouse Gas
HFO	Heavy Fuel Oil
HOMER	Hybrid Optimization Model for Electric Renewables
IEC	International Electrotechnical Commission
IEA	International Energy Agency
IFC	International Finance Corporation
IRE	**NA** International Renewable Energy Agency
IRR	Internal Rate of Return
ISO	International Organization for Standardization
KTML	Kohinoor Textile Mills Limited
LCOE	Levelized Cost of Energy
MRV	Monitoring, Reporting, and Verification
NPC	Net Present Cost
OECD	Organization for Economic Co-operation and Development
PM	Particulate Matter
PV	Photovoltaic
PW	Present Worth
RE	Renewable Energy
ROI	Return on Investment
RO	Reverse Osmosis
SBTi	Science Based Targets initiative
SCADA	Supervisory Control and Data Acquisition
SECP	Securities and Exchange Commission of Pakistan
UHC	Unburned Hydrocarbons
UF	Ultrafiltration
UNIDO	United Nations Industrial Development Organization
WHR	Waste Heat Recovery
WWTP	Wastewater Treatment Plant

CHAPTER

01

Introduces the study, defines its aims and scope, and outlines the specific objectives it seeks to achieve.

1.1. Introduction

Kohinoor Textile Mills Limited (KTML) is one of Pakistan’s leading vertically integrated textile manufacturing companies, founded in 1953 and headquartered in Lahore. Operating across the complete textile value chain including spinning, weaving, processing, and home textiles, it produces a wide range of products such as yarn, greige fabric, dyed and printed fabrics, and finished home textile items like bed linen and curtains. Over the decades, KTML has evolved from a conventional spinning and weaving unit into a modern, export-oriented industrial enterprise with advanced manufacturing facilities in Rawalpindi, Gujar Khan, and Raiwind. The company serves international markets including the United States, Europe, and other global regions, and employs thousands of workers while maintaining a strong focus on technological innovation, quality control, and sustainability initiatives such as renewable energy adoption and water management systems.

KTML stands as a prominent example of large-scale industrial decarbonization and sustainable manufacturing within Pakistan’s textile sector. As a fully vertically integrated textile facility, KTML encompasses operations from spinning to finished fabric production, allowing comprehensive control over energy consumption, process efficiency, and environmental performance. This case study provides an in-depth examination of KTML’s transition toward a low-carbon operational model, focusing on its energy systems transformation, water and material circularity, emissions reduction strategy, and economic and policy constraints.

The integrated textile manufacturing operations and product range of KTML, covering the complete value chain from spinning to finished home textile products. KTML operates 384 weaving looms for greige fabric production and produces cotton, blended, and special fibre CVC yarn in its spinning division. Its dyeing unit has a capacity of 24 million meters of fabric per year using Thermosol dyeing with 2.8-meter-wide and 3.4-meter-wide frame dyeing systems, while the printing section includes rotary and digital printing with a capacity of 24 million meters annually. The bleaching facility adds another 8 million meters per year of processing capacity. In stitching, the company manufactures around 29 million meters annually using advanced machinery such as Brata, Quilting, Hemstitch, Embroidery, Juki, and Blind Stitch systems. KTML also produces a variety of home textile products including bed linen, fillings, curtains, decorative fabrics, and kitchen and splash items, highlighting its vertically integrated textile production capabilities. Figure 1 demonstrates the integrated textile manufacturing process and diversified product range of KTML, illustrating its vertically integrated operations from spinning and weaving to processing, stitching, and home textile production.

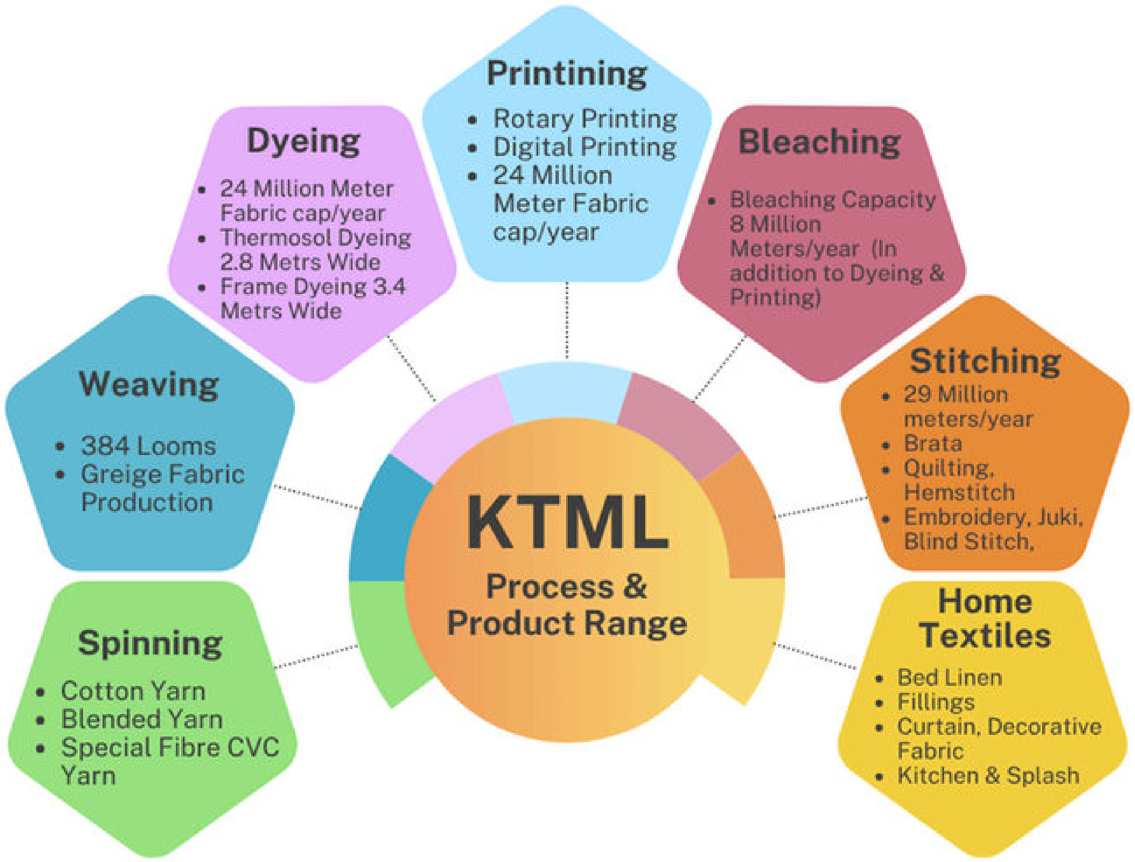


Figure 1: Process Flow and Product Range of KTML Operations

The production activity and manufacturing capacity of KTML (Kohinoor Textile Mills Limited) across its key textile operations. In the weaving section, the company operates 384 looms used for fabric production. The spinning division has a capacity of 181,000 spindles, highlighting large-scale yarn manufacturing capability, along with 3,648 spinning rotors that support rotor spinning operations for efficient yarn production. In fabric processing, KTML achieves an annual production capacity of 42 million meters per year, covering activities such as dyeing, finishing, and treatment of fabrics. The stitching division has a production capacity of 29 million made-ups per year, reflecting the company's large-scale garment and home textile manufacturing operations. The lower section of the figure further visualizes these capacities through bar charts: the machinery capacity chart compares the quantities of looms, spindles, and spinning rotors, while the production output chart illustrates the yearly output of processing and stitching operations measured in millions of meters. Furthermore, Figure 2 illustrates the overview of KTML production capacity and annual manufacturing output.

At the core of KTML's sustainability strategy lies a multi-layered hybrid energy system that integrates renewable and conventional energy sources to ensure reliability, efficiency, and reduced carbon intensity. The system includes:

1. Solar photovoltaic (PV) generation,
2. Biomass-based thermal energy production,
3. Grid electricity, and
4. Backup captive generation based on gas and furnace oil.

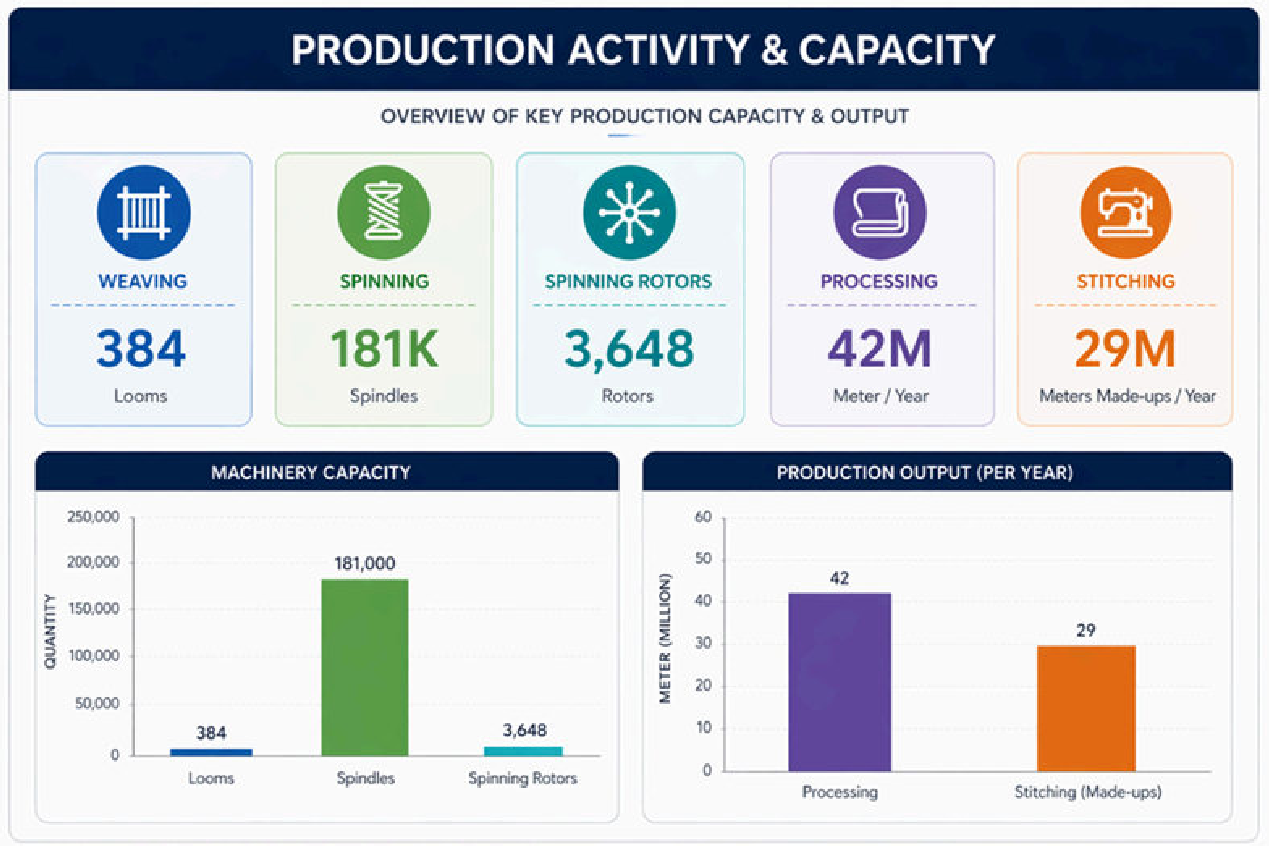


Figure 2: The overview of KTML's Production Capacity and Annual Manufacturing Output

KTML has deployed 18.2 MW of solar PV capacity at its Rawalpindi site, contributing to a total installed capacity of 31.38 MW across three facilities. Real-time operational observations during the site visit indicated solar generation levels of 11–11.2 MW, meeting nearly 90% of the facility's instantaneous electricity demand. This demonstrates a high level of renewable penetration during daytime operations. However, despite this strong performance, solar curtailment of approximately 250 kW was observed. This curtailment is not due to technical limitations but rather restricted grid export capacity and absence of supportive policies such as net metering, indicating a critical disconnect between infrastructure capability and regulatory frameworks.

Table 1: Solar Energy Capacity, Performance, and Economic Indicators

Parameter	*Value*	*Remarks*
Solar PV (Rawalpindi)	*18.2 MW*	*Onsite installed capacity*
Solar PV (Total – 3 sites)	*31.38 MW*	*Group-wide deployment*
Observed Solar Generation	*11–11.2 MW*	*Midday peak*
Curtailment	*~250 kW*	*Policy/infrastructure constrain*
Solar Cost	*26–27 PKR/kWh*	*Favorable case*
Payback Period	*3.5–4 years*	*Ideal scenario*

In parallel with renewable electricity adoption, KTML has significantly transformed its thermal energy systems, which are critical for textile processing operations such as dyeing and finishing. The facility operates a 20-ton/hour biomass boiler, producing approximately 20,000 kg/hour of saturated steam. This system utilizes rice and wheat husk as the primary fuel, representing a shift toward low-carbon and locally available biomass resources. Supporting systems include: waste heat recovery (WHR), which enhances overall efficiency by capturing and reusing residual heat, and dual-fuel boilers using gas and furnace oil to ensure operational flexibility and backup capacity, and coal usage has been reduced to very limited levels and is effectively phased out, reflecting a clear transition toward cleaner thermal energy sources.

Table 2: Thermal Energy Systems and Fuel Utilization

Parameter	***Value***	***Remarks***
Biomass Boiler Capacity	*20 ton/hr*	*Saturated steam*
Steam Output	*~20,000 kg/hr*	*Continuous production*
Primary Fuel	*Rice/Wheat Husk*	*Decarbonization driver*
Backup Fuels	*Gas / Furnace Oil*	*Dual-fuel system*
Boiler Pressure	*1.87 bar*	*Recorded*
Boiler Pressure	*Very limited*	*Nearly phased out*
WHR System	*Installed*	*Nearly phased out*

KTML's operational model is characterized by real-time energy balancing across multiple sources. Solar energy dominates daytime operations, while grid supply with a capacity of 20 MW and backup systems ensure continuity during variability or peak demand conditions. During the visit, grid reliance was minimal, observed between 250–500 kW, further reinforcing the effectiveness of renewable integration. However, maintaining system stability requires advanced monitoring systems, including SCADA-based energy management, enabling precise tracking of load distribution and energy intensity.

Table 3: Energy System Integration and Grid Interaction

Component	***Capacity / Value***	***Operational Role***
Solar PV	*18.2 MW (onsite)*	*Primary supply*
Grid Capacity	*20 MW*	*Reliability support*
Grid Usage (observed)	*250–500 kW*	*Minimal daytime dependence*
Gas Engines	*9 MW*	*Rarely used backup*
Furnace Oil Backup	*14 MW*	*Standby reserve*
Furnace Oil Backup	*~250 kW*	*Export limitation*

KTML demonstrates a strong emphasis on energy monitoring and efficiency optimization, supported by SCADA systems that track consumption across production processes. Observed energy intensity ranges from 118 to 262.75 kWh per unit, reflecting variability across operational stages. Electricity cost dynamics reveal significant variation, with solar energy costing 26–27 PKR/kWh, grid electricity costing 32.75 PKR/kWh during off-peak hours and 42–43 PKR/kWh during on-peak hours, and captive generation reaching up to 48–54 PKR/kWh in worst-case scenarios. Despite the strong economic case for solar, policy barriers such as lack of net metering and high-capacity charges limit financial optimization and discourage further expansion.

Table 4: Electricity Consumption and Cost Structure

Parameter	***Value***	***Remarks***
Monthly Consumption	*150,000–300,000 units*	*Variable*
Energy Intensity	*118–262.75 kWh/unit*	*Process-dependent*
Solar Cost	*26–27 PKR/kWh*	*Lowest*
Grid Cost (off-peak)	*32.75 PKR/kWh*	*Moderate*
Grid Cost (on-peak)	*42–43 PKR/kWh*	*High*
Captive Cost	*48–54 PKR/kWh*	*Worst case*

KTML has implemented a comprehensive water sustainability framework that integrates treatment, recycling, and storage systems. The facility operates a wastewater treatment plant (WWTP) with an input capacity of 185 m³/hour (equivalent to 4,440 m³/day) and an observed operational throughput of 1,611 m³/day. The system achieves a high-water recycling rate of 80–85%, with treated water being reused in dyeing and washing processes, significantly reducing freshwater demand. Water resilience is further strengthened through a large rainwater reservoir with a capacity of 62,000 m³ and a secondary pond with a capacity of 70,000 gallons, which manages colony wastewater.

Table 5: Water Management and Recycling Performance

Parameter	***Value***	***Remarks***
WWTP Capacity	*4,440 m³/day*	*High capacity*
Operational Throughput	*1,611 m³/day*	*Observed*
Recycling Rate	*80–85%*	*Efficient reuse*
Rainwater Storage	*62,000 m³*	*Major reservoir*
Secondary Pond	*70,000 gallons*	*Auxiliary system*

Material circularity is embedded within KTML's operations through the implementation of industrial circular economy practices. The facility operates three recycling plants with a combined capacity of 24 tons per day, enabling mechanical recycling of textile waste into reusable material streams. In addition, waste by-products are effectively valorized through external reuse pathways, where sludge is utilized in brick manufacturing and ash is repurposed for bricks and packaging materials. Treated water from reverse osmosis and ultrafiltration systems is also reused within production processes, reinforcing closed-loop resource utilization

Table 6: Circularity and Waste Utilization Systems

Parameter	***Value***	***Remarks***
Recycling Capacity	*24 tons/day*	*Mechanical recycling*
Recycling Units	*3 plants*	*Onsite*
Sludge Utilization	*Bricks*	*Third-party use*
Ash Utilization	*Bricks/Packaging*	*External reuse*
Water Reuse	*RO/UF systems*	*Process integration*

From an environmental performance perspective, KTML has established a 2021 emissions baseline and achieved a 45% reduction in greenhouse gas emissions as of March 2026. This progress is primarily driven by large-scale solar deployment, biomass fuel substitution, and reduced coal dependency. Solar installations alone contribute to an annual avoidance of approximately 29,834.3 tCO_2 across three plants. The company has set forward-looking targets of achieving a 50% emissions reduction by 2030, aligned with Science-Based Targets Initiative principles, and reaching Net Zero emissions by 2050. While these measures are largely driven by operational efficiency and cost optimization, they also demonstrate the significant co-benefits of emissions reduction as an industrial strategy. This creates important opportunities to advocate for stronger policy alignment, incentivize low-carbon transitions, and support the scaling of such practices beyond individual firms toward sector-wide climate action.

Table 7: Emissions Performance and Targets

Parameter	***Value***	***Remarks***
Baseline Year	*2021*	*Reference*
Reduction Achieved	*45%*	*As of 2026*
Solar CO_2 Avoidance	*29,834.3 tCO_2/year*	*3 plants*
2030 Target	*50% reduction*	*Interim goal*
2050 Target	*Net Zero*	*Long-term*

KTML operates within a highly export-oriented business model, with 64–70% of its exports directed toward the United States and 15–25% toward Europe, alongside additional shares to the United Kingdom (10%) and the United Arab Emirates (5%). International buyers increasingly demand sustainability compliance, including low-carbon production and traceability. However, limited financial support or cost-sharing mechanisms from buyers place the burden of decarbonization investments on the manufacturer, creating economic pressure despite strong environmental performance. Additionally, Figure 3 illustrates the key export markets of KTML.

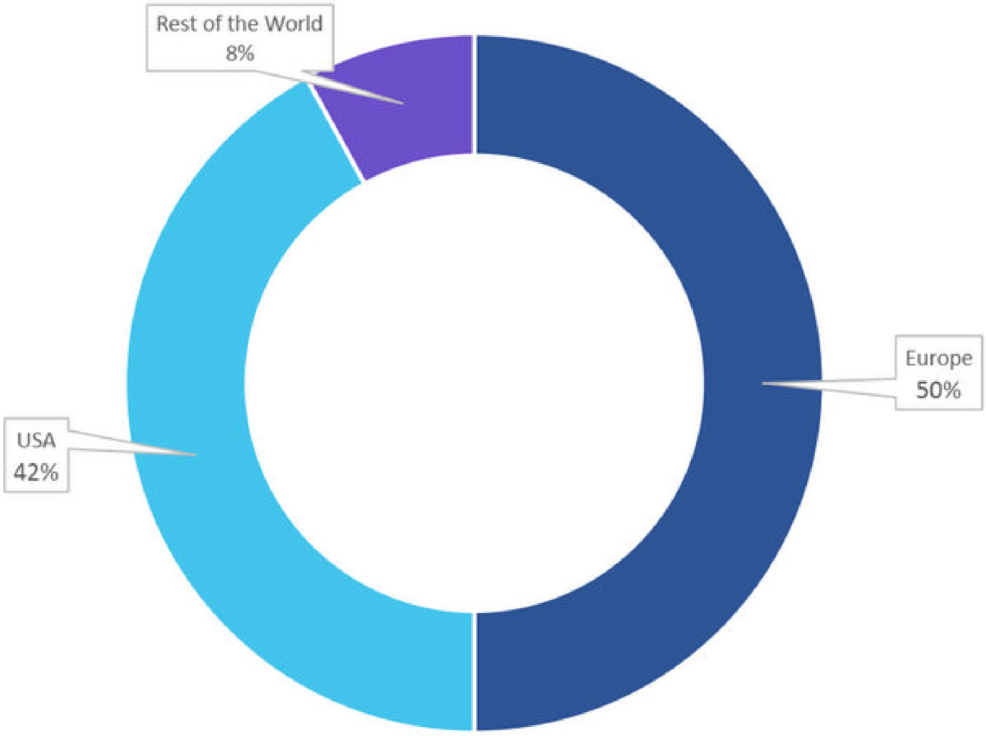


Figure 3: Key Export Markets of Kohinoor Textile Mills

KTML is positioned at an advanced stage of industrial decarbonization, with well-established systems across energy, water, and materials. Nevertheless, several systemic constraints remain, including policy limitations such as lack of net metering and high-capacity charges, grid integration barriers that restrict export capability, market challenges due to limited buyer participation in sustainability costs, and the need for robust data verification and monitoring systems.

This case study provides a comprehensive analysis of KTML as a model for industrial sustainability in emerging economies, focusing on integrated renewable and hybrid energy systems, thermal decarbonization through biomass, advanced water recycling and circularity practices, emissions reduction pathways and targets, and the economic, regulatory, and market constraints shaping its transition. KTML demonstrates that deep decarbonization in energy-intensive industries is technically feasible and operationally viable, even within constrained policy environments. However, scaling such models requires coordinated policy reforms, improved grid infrastructure, and stronger alignment between global market incentives and local industrial realities.

1.2. Aims and Scope of the Case Study

The primary aim of this study is to analyze the integrated decarbonization and resource efficiency practices implemented at KTML, with a focus on understanding how large-scale textile industries in developing economies can transition toward sustainable and low-carbon operations. The study encompasses a comprehensive evaluation of KTML's hybrid energy systems, including solar photovoltaic generation, biomass-based thermal energy, and conventional backup systems, along with their operational performance, cost dynamics, and system integration.

The scope of this study further extends to assessing water management strategies, including wastewater treatment, recycling, and rainwater harvesting, as well as material circularity practices such as textile waste recycling and by-product utilization. In addition, the study examines KTML's emissions reduction trajectory, climate targets, and alignment with global sustainability frameworks. It also considers external factors such as policy constraints, grid limitations, and international market pressures that influence the effectiveness and scalability of these sustainability initiatives. Overall, the study aims to provide a holistic understanding of industrial sustainability practices within the textile sector. While the findings are grounded in the textile sector, the applicability of such practices may vary across industries depending on factors such as production processes, export orientation, industrial classification, and spatial or infrastructural constraints. Overall, the study aims to provide a holistic understanding of industrial sustainability practices within the textile sector.

1.3. Objectives

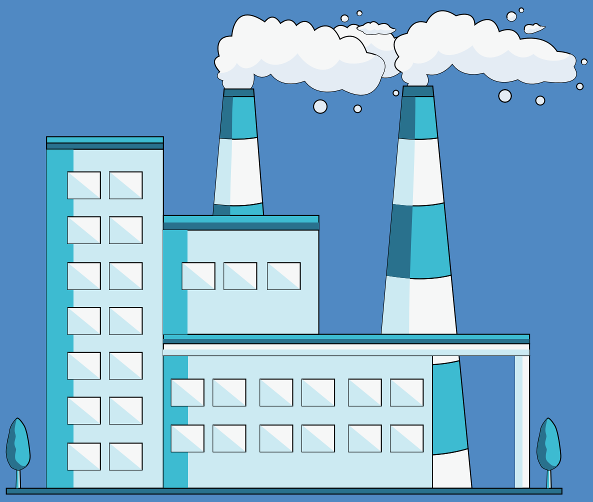
The key objectives of this case study are as follows:

1. Utilize KTML as a benchmark case model for industrial decarbonization, focusing on its adoption of solar energy, biomass-based thermal systems, and integrated hybrid energy architecture to reduce fossil fuel dependency and improve energy efficiency.
2. To evaluate KTML's resource efficiency and sustainability practices, including water recycling, wastewater treatment, and material circularity, in order to understand how these integrated systems support low-carbon and environmentally sustainable textile production.
3. To derive scalable insights and practical lessons from KTML's experience, considering technical performance, economic feasibility, and policy constraints, to provide a roadmap for other textile industries aiming to adopt solar energy, achieve decarbonization, and reduce emissions.

CHAPTER

02

Describes the research methods, tools, and procedures used to conduct the study.



2.1 Methodology

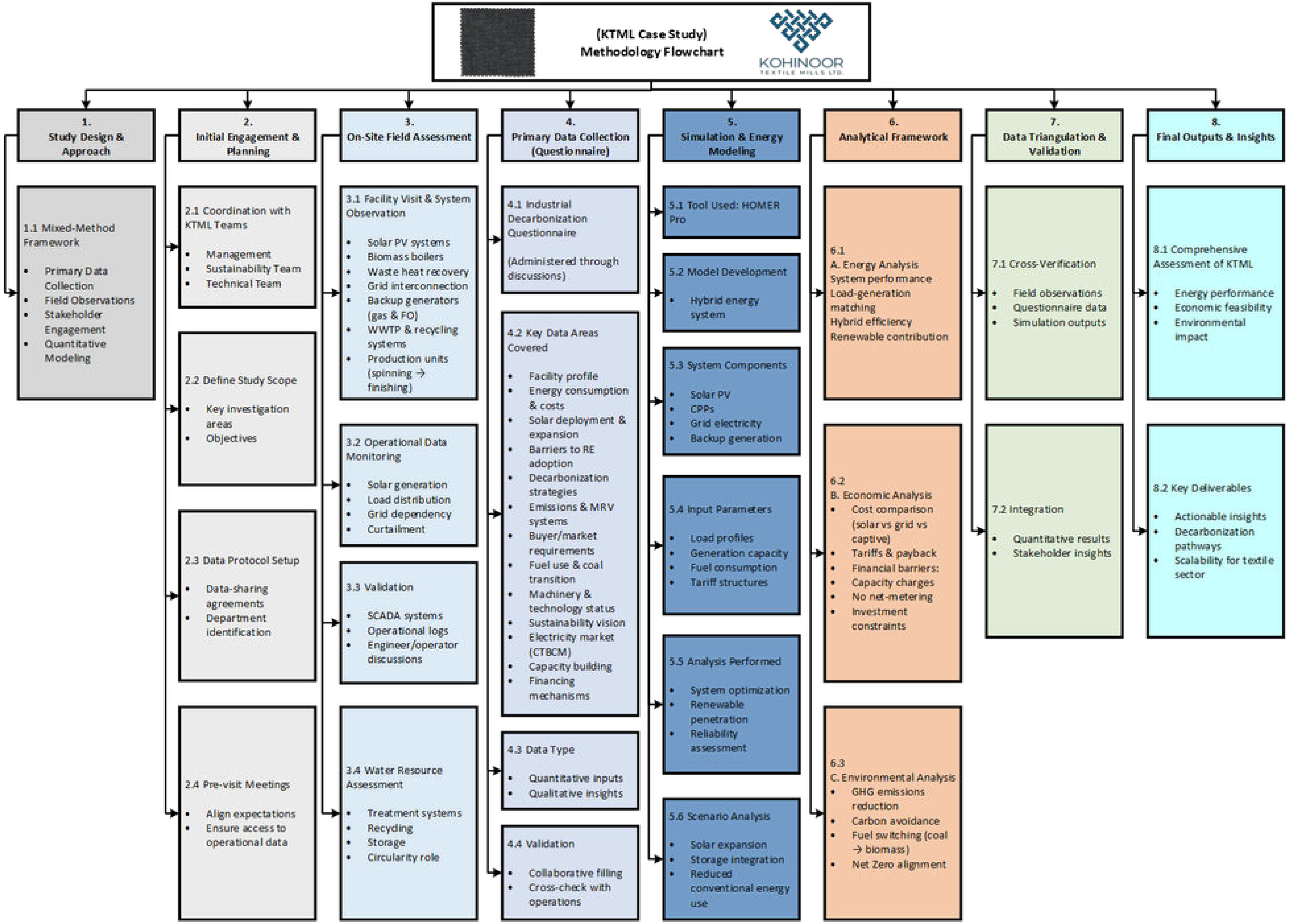
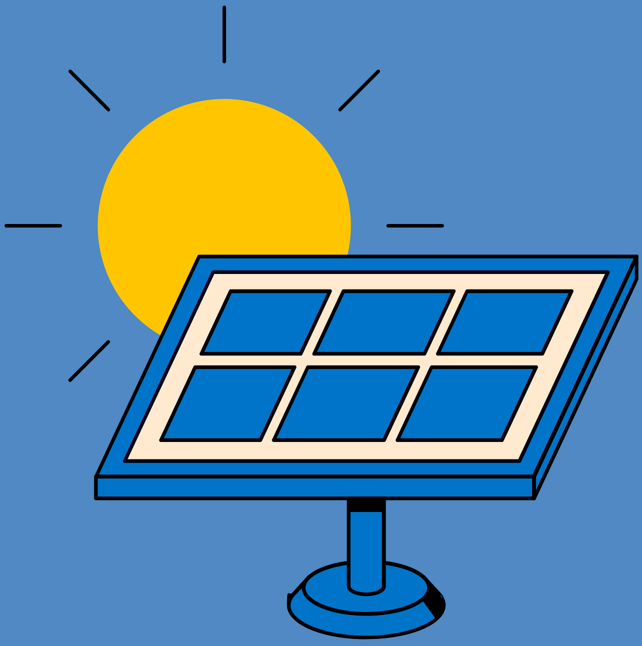


Figure 4: Flow chart of the proposed work

CHAPTER

03

Examines KTML's industrial energy systems, covering solar and biomass-based generation, waste heat recovery, grid integration, and monitoring and load management within its overall system architecture.



3.1. Industrial Products and Processes at KTML

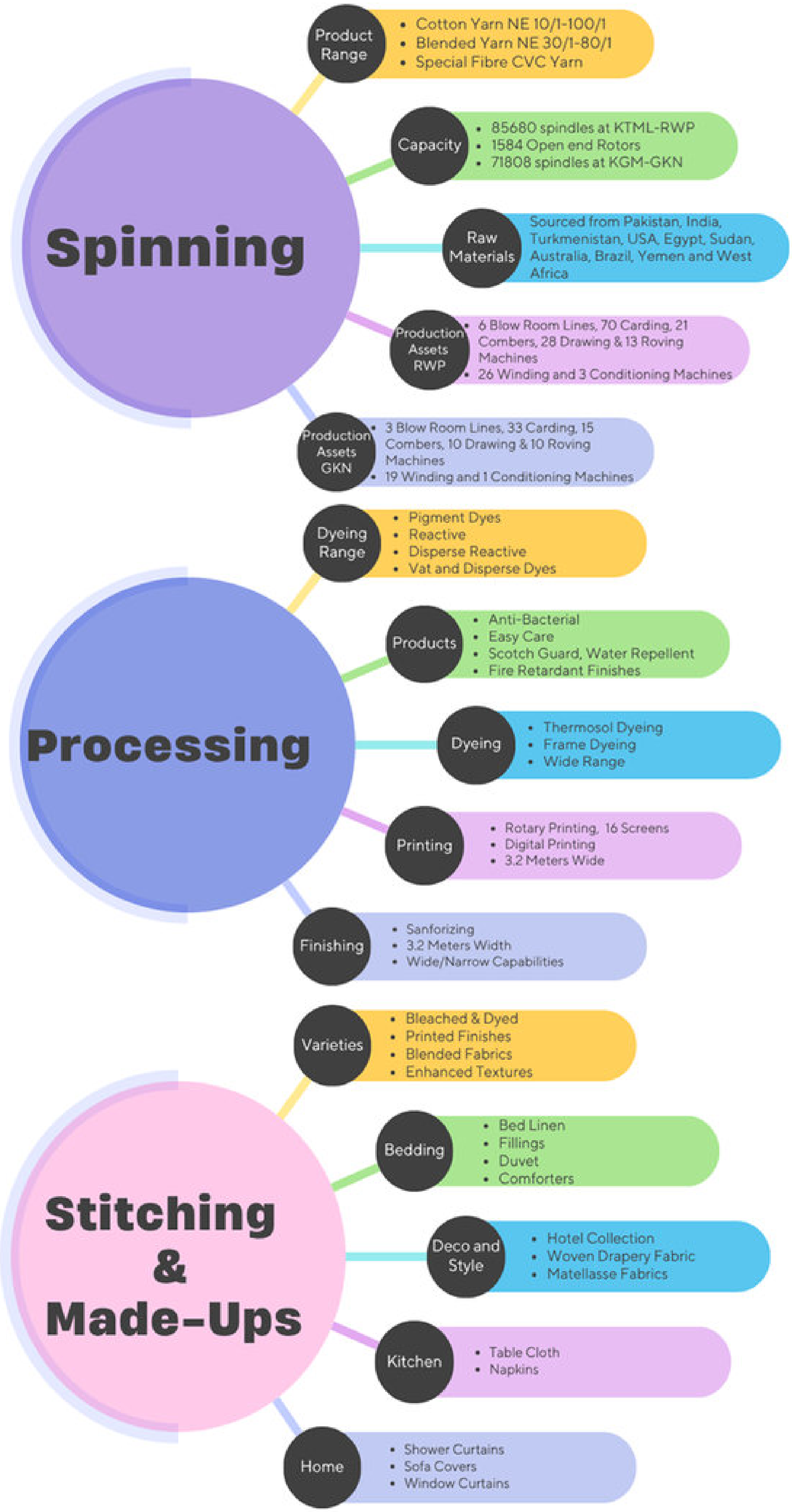


Figure 5: The Vertically Integrated Setup of KTML

3.2. Energy Management

Energy systems at KTML are designed to support continuous industrial operations while minimizing environmental impact. The facility operates a hybrid and integrated energy system, combining renewable energy sources with conventional and backup systems to ensure reliability, efficiency, and cost optimization. This system is dynamically managed to balance generation and demand in real time, making it a strong model for industrial decarbonization.

3.3. System Architecture

KTML's energy system follows a multi-source hybrid model, integrating solar photovoltaic (PV), biomass-based thermal energy, grid electricity, and backup captive generation. Solar energy serves as the primary electricity source during daytime operations, contributing up to 90% of the facility load during the visit and even higher during certain processing operations. Biomass is the dominant thermal energy source, replacing conventional fossil fuels for steam generation.

The overall energy mix is structured to prioritize low-cost and low-carbon sources, with solar and biomass forming the base load, while grid electricity and captive systems act as balancing and reliability components. This integrated configuration allows KTML to reduce dependence on expensive and carbon-intensive grid electricity while maintaining operational stability.

3.4. Solar Power Generation System

Solar photovoltaic systems play a central role in KTML's energy strategy, generating a significant portion of the facility's electricity during daytime operations. The installed capacity enables substantial on-site generation, directly supplying production loads and reducing reliance on external electricity sources. The system operates in synchronization with plant demand, ensuring efficient utilization of generated power.

However, operational observations indicate instances of solar curtailment, primarily due to limited grid export options and regulatory constraints such as the absence of effective net-metering mechanisms. Despite these limitations, solar energy significantly lowers operational costs and contributes to emissions reduction, making it the most economically favorable energy source within the system.

3.5. Biomass-Based Thermal Energy System

Thermal energy requirements are met through biomass-based boilers, which use agricultural residues such as rice and wheat husk to produce steam. This system provides a sustainable alternative to fossil fuels, supporting energy-intensive processes such as dyeing, washing, and finishing. The biomass boiler operates continuously, generating high volumes of steam required for industrial operations.

This approach not only reduces carbon emissions but also utilizes locally available resources, enhancing energy security and cost stability. The transition from coal to biomass represents a key decarbonization measure within KTML's energy system, significantly lowering the overall carbon footprint of thermal operations.

3.6. Waste Heat Recovery and Energy Efficiency

Waste heat recovery (WHR) systems are integrated into the energy infrastructure to capture excess heat from boilers and process units. This recovered heat is reused within the system, reducing the need for additional fuel consumption and improving overall energy efficiency.

In addition to WHR, energy efficiency measures such as optimized process control, efficient machinery, and thermal insulation are implemented across the facility. These measures collectively reduce energy losses and enhance the performance of both electrical and thermal systems.

3.7. Grid Integration for Backup and Fluctuations Balancing

To ensure reliability, grid electricity and backup generation systems, including gas engines and furnace oil units, are integrated into the energy mix. The grid connection provides additional support during periods of low renewable generation or peak demand, while captive generation systems act as contingency solutions.

Backup systems are typically used minimally, as the primary reliance is on solar and biomass. However, their presence is critical for maintaining uninterrupted operations, particularly in scenarios involving grid instability or renewable variability. The system is designed to switch seamlessly between energy sources as required.

For handling fluctuations, the integrated system incorporates load management strategies and real-time monitoring to balance supply and demand dynamically. Variations in solar generation—due to cloud cover or diurnal cycles—and inconsistencies in biomass fuel supply are managed through a combination of grid support, demand-side adjustments, and automated control systems. This coordinated approach ensures voltage and frequency stability, optimizes energy utilization, and enhances overall system resilience.

3.8. Energy Monitoring, Control, and Load Management

Advanced SCADA (Supervisory Control and Data Acquisition) systems are deployed to monitor energy generation, consumption, and distribution in real time. These systems provide detailed insights into load profiles, system performance, and energy flows across different processes.

Real-time monitoring enables efficient load management, allowing operators to balance supply and demand, minimize energy losses, and optimize system performance. It also supports data-driven decision-making for future energy planning, system expansion, and efficiency improvements. This level of integration and control is essential for managing a complex hybrid energy system and achieving long-term sustainability goals.

3.9. Certification as a Tool to Commercial Advantage

Figure 6: KTML's Social and Environmental Certifications

Kohinoor Textile Mills Limited (KTML) demonstrates how aligning with internationally recognized frameworks such as ISO, OEKO-TEX, Better Cotton Initiative (BCI) etc. can deliver quantifiable operational and commercial value. Evidence from the International Organization for Standardization (ISO) and United Nations Industrial Development Organization (UNIDO) indicates that environmental management systems can reduce energy and resource consumption by approximately 10–25%, while studies by the World Bank and International Finance Corporation (IFC) show that process optimization and waste reduction can lower operating costs by 5–15%. On the revenue side, sustainability-linked certifications increasingly function as a market access requirement. Analysis by the Organization for Economic Co-operation and Development (OECD) and International Trade Centre suggests certified products can achieve price premiums in the range of 2–10% and secure longer-term sourcing agreements. Furthermore, compliance systems such as those embedded in OEKO-TEX significantly reduce the risk of shipment rejections and costly recalls, strengthening reliability with global buyers. For example, a mill producing $100 million in annual exports could conservatively realize $5–8 million in incremental value through improved margins, reduced rejection rates, and preferred supplier status. When complemented by renewable energy investments, data from the International Renewable Energy Agency (IRENA) and International Energy Agency (IEA) indicate typical payback periods of 3–6 years, after which firms benefit from stabilized and lower energy costs. In effect, adopting such certifications is not just a compliance exercise, it is a strategic investment that strengthens export competitiveness, enhances brand value, and positions the business for sustainable, future-ready growth in global supply chains.

CHAPTER

04

Presents simulation modelling of KTML's energy systems, evaluating their performance and conducting an economic analysis of the results.

4.1. Simulation Modelling

The table presents a comparative analysis of two energy system configurations designed for Kohinoor Textile Mills Limited (KTML): a base system representing the current setup and a proposed system that introduces optimization through hybridization. Both systems are modeled to meet the high and continuous energy demand of KTML's integrated textile operations, which include spinning, processing, and finishing.

In the base system, the primary energy source is solar photovoltaic (PV) generation with a capacity of 18.2 MW, which aligns with the actual installed capacity at KTML's Rawalpindi site. This solar system plays a dominant role during daytime operations, often supplying a significant portion of the load. The system is supported by a 14 MW conventional generator, likely representing furnace oil-based captive generation, which acts as a backup during peak demand or solar unavailability. Additionally, the grid is modeled as an unlimited source (represented as 999,999 kW), allowing flexibility in meeting demand shortfalls. A 6 MW converter is included to manage the conversion of solar DC power to usable AC power and to ensure proper synchronization across the system.

The proposed system builds upon this configuration by integrating a 9 MW reciprocating gas generator, which reflects KTML's existing gas engine capacity. This addition enhances system flexibility by introducing a relatively cleaner and more cost-effective alternative to furnace oil-based generation. The gas generator helps balance the intermittency of solar power, particularly during non-daylight hours or periods of reduced solar output, and reduces dependence on both the grid and high-cost backup generators. As a result, the proposed system represents a more diversified and resilient energy mix, combining solar, gas, and backup generation sources.

From an economic perspective, the comparison highlights a trade-off between initial investment and long-term cost efficiency. The base system has a lower initial capital cost of $14.9 million, whereas the proposed system requires a significantly higher upfront investment of $28.4 million due to the addition of gas-based infrastructure. However, despite this increase in capital cost, the proposed system achieves a lower net present cost (NPC) of $12.7 million compared to $16.9 million for the base system. This indicates that over the project lifecycle, the proposed configuration is more economical, primarily due to improved fuel utilization, reduced reliance on expensive energy sources, and better system optimization.

In the context of KTML's operational and policy environment, the proposed system aligns well with ongoing decarbonization efforts by maximizing solar utilization and incorporating relatively cleaner gas-based generation. However, practical challenges such as gas price volatility, supply constraints, and regulatory issues related to grid interaction (e.g., net-metering limitations and capacity charges) may influence real-world performance and decision-making. Overall, the proposed hybrid system offers a balanced approach, improving reliability, reducing long-term costs, and supporting KTML's transition toward a more sustainable and efficient energy system.

Table 8: All main components in the system architecture

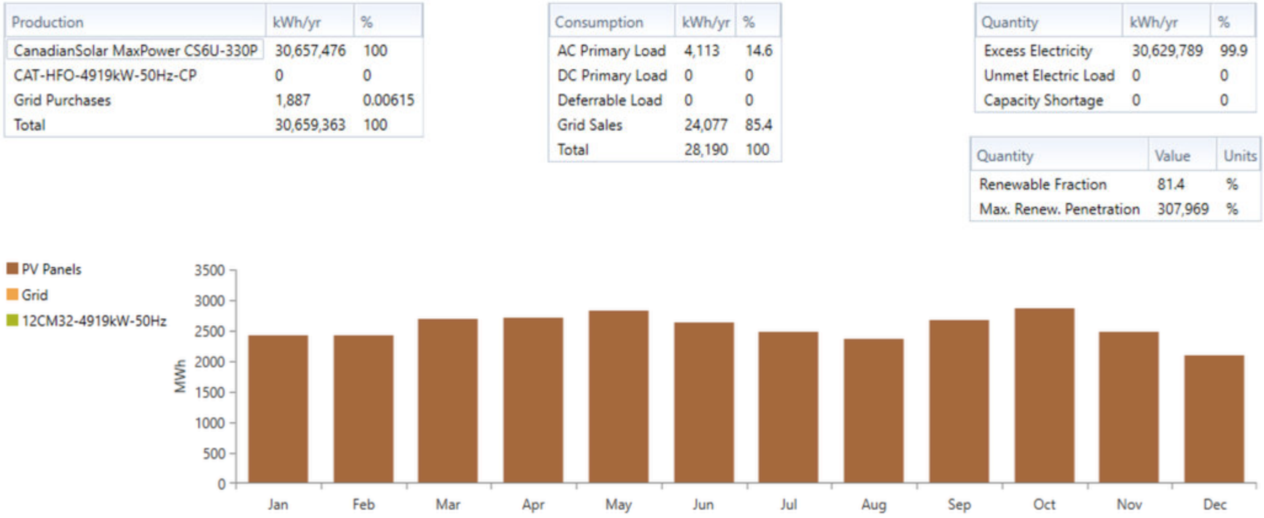
	Architecture														Cost	
								PV Panels (kW)	RecipGas (kW)	12CM32-4919kW-50Hz (kW)	1kWh LI	Grid (kW)	Converter (kW)		NPC ($)	Initial capital ($)
Base system	●		●		●	●	●	18,200		14,000		999,999	6.00		$16.9M	$14.9M
Proposed system	●	●	●		●	●	●	18,200	9,000	14,000		999,999	6.00		$12.7M	$28.4M

4.1.1. Energy Performance

A comprehensive annual energy system overview for KTML demonstrates the integration of solar power generation, grid interaction, and industrial load management within a hybrid renewable energy configuration. The system combines annual energy balances with a monthly electricity production profile to evaluate generation, utilization, and export performance throughout the year.

The production side is dominated by the Canadian Solar MaxPower CS6U-330P PV system, generating approximately 30,657,476 kWh/year and contributing almost 100% of total electricity production. Grid purchases are minimal at about 1,887 kWh/year, while the CAT-HFO-4919 kW-50Hz-CP unit remains inactive under the simulated conditions. Total annual electricity production is approximately 30,659,363 kWh/year, indicating a highly solar-driven energy system. On the consumption side, the AC primary load is around 4,113 kWh/year, while grid sales account for nearly 24,077 kWh/year, showing that a significant portion of generated electricity is exported to the utility grid. The system records no unmet electric load or capacity shortage, confirming reliable operational performance. However, excess electricity remains very high at approximately 30,629,789 kWh/year, reflecting substantial surplus solar generation beyond local demand requirements. The renewable fraction is reported at 81.4%, with maximum renewable penetration reaching nearly 307,969%.

The monthly electricity production profile shows relatively stable PV generation throughout the year with slight seasonal variation, peaking around October and decreasing slightly during December. Overall, the results in Figure 7 indicate that KTML's modeled energy system is strongly renewable-oriented, with solar energy acting as the primary electricity source and the grid mainly serving as an export channel for surplus power.



Production	kWh/yr	%
CanadianSolar MaxPower CS6U-330P	30,657,476	100
CAT-HFO-4919kW-50Hz-CP	0	0
Grid Purchases	1,887	0.00615
Total	30,659,363	100

Consumption	kWh/yr	%
AC Primary Load	4,113	14.6
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	24,077	85.4
Total	28,190	100

Quantity	kWh/yr	%
Excess Electricity	30,629,789	99.9
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	81.4	%
Max. Renew. Penetration	307,969	%

Figure 7: Electrical profile of KTML's existing system architecture

Figure 8 presents the thermal energy balance for KTML, showing thermal production, consumption, and monthly heat generation trends. The system is entirely supported by a Generic Boiler, producing approximately 4,109 kWh/year and supplying 100% of the thermal load demand. No contribution from the 12CM32-4919 kW-50Hz unit is observed under the simulated conditions. The consumption section indicates a total thermal load of about 4,109 kWh/year, fully matching the produced thermal energy. The model records zero excess thermal energy, demonstrating a balanced thermal system without overproduction or shortage. The monthly thermal production profile remains relatively stable throughout the year, with only minor variations between months. Slightly higher production is observed during March and August, while February shows comparatively lower output. Overall, the figure reflects a simple and balanced thermal energy configuration for KTML, where boiler-based heat generation consistently satisfies the modeled thermal demand.

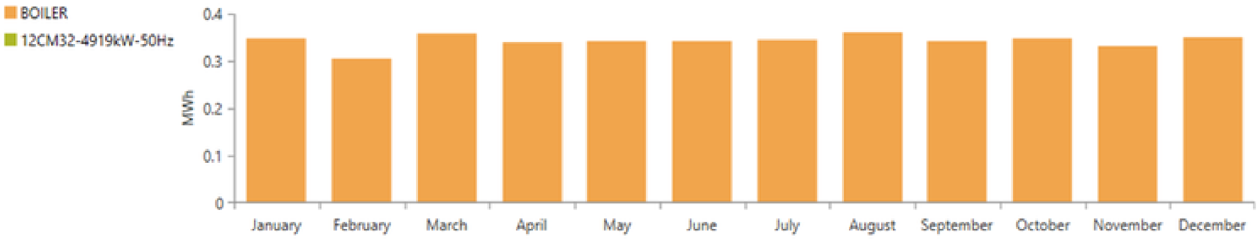


Figure 8: Thermal production and consumption in all processes of KTML

Figure 9 represents the natural gas consumption profile of KTML. The figure clearly shows that natural gas usage is almost negligible throughout the year, indicating that the CHP or backup fuel-based system is either inactive or only rarely operated. The “Fuel Consumption” heatmap remains completely black across all hours of the day and all days of the year, which corresponds to nearly 0 L/hr fuel consumption. No visible peaks, fluctuations, or operating periods are observed, confirming that there is effectively no continuous natural gas demand in the modeled system.

This profile suggests that KTML primarily relies on alternative energy sources within the integrated energy system, while natural gas is retained only as a standby or emergency-support fuel. Unlike a baseload CHP operation with constant fuel demand, the provided figure indicates that the generators are either shut down for most of the year or operated only during exceptional conditions such as backup operation, maintenance support, or temporary load balancing.

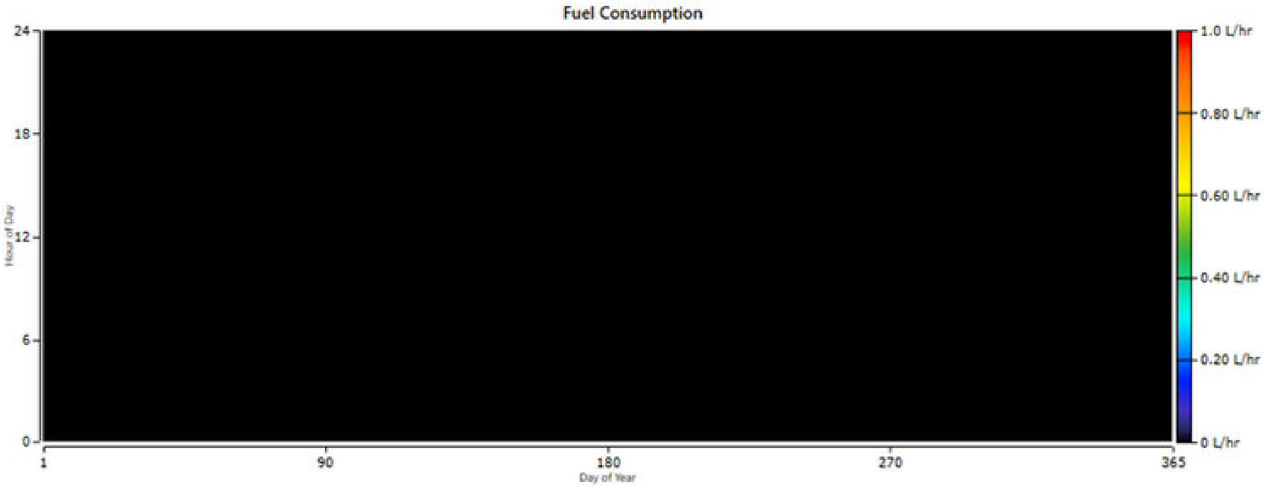


Figure 9: Natural gas consumption profile of KTML

Now Figure 10 represents the performance and operational characteristics of the Captive Power Plant (CPP) at KTML (Kohinoor Textile Mills Limited), which is operated solely for steam generation rather than electricity production. The plant operates continuously for 8,760 hours per year with only one start, indicating stable baseload operation throughout the year. The capacity factor is 100%, showing full utilization of the installed system for thermal energy supply. In this configuration, the CPP does not export or generate usable electrical power, and the entire fuel input is utilized to produce steam for industrial processes. The system generates approximately 77.4 million kWh/year of thermal energy, equivalent to an average thermal output of about 8,838 kW. This recovered thermal energy is used directly to meet KTML's process steam demand. The plant consumes around 21,050,280 m³ of natural gas annually, with a total fuel energy input of nearly 207.9 million kWh/year. Since the setup is dedicated to steam production, the operational performance mainly reflects thermal recovery and fuel utilization efficiency rather than electrical efficiency. The heatmap also indicates uniform year-round operation, confirming that the CPP runs continuously at a constant thermal output to ensure uninterrupted steam supply for textile manufacturing processes at KTML.

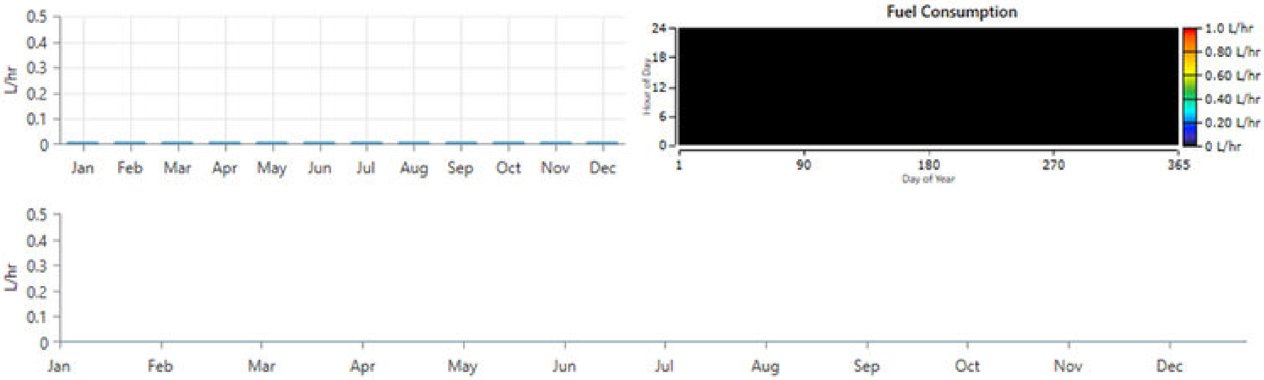
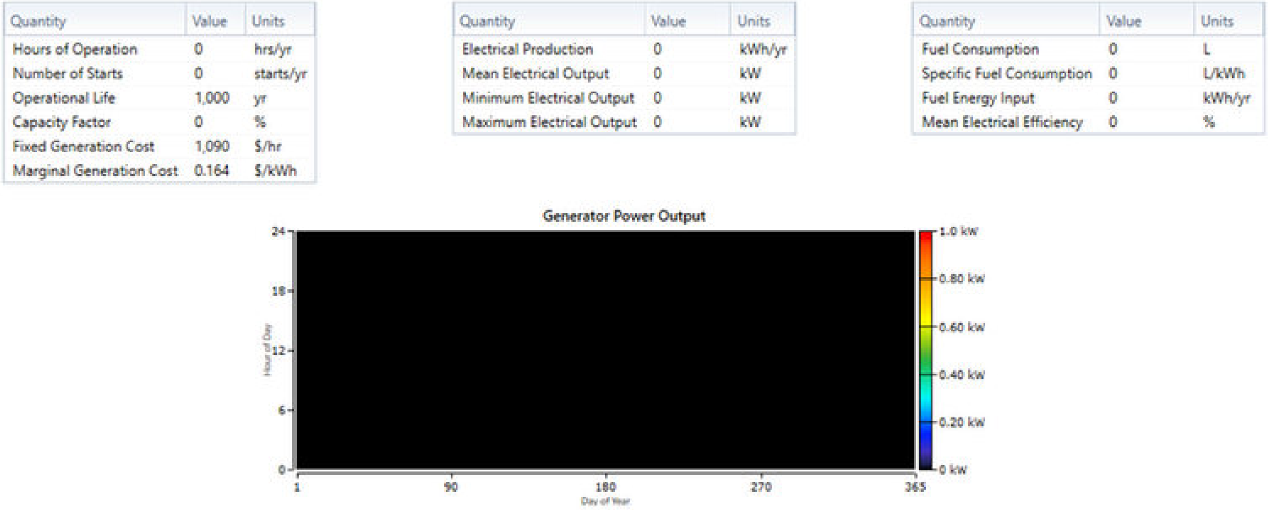


Figure 10: Captive Power Plant with no power output.

Figure 11 presents the operational and fuel performance of the HFO (Heavy Fuel Oil) generator at KTML, showing that the unit remains completely inactive throughout the year. The generator records 0 operating hours, 0 starts, 0 kWh/year electricity production, and 0 liters of HFO consumption, confirming that it is never dispatched during the simulation. Although the system assigns high fixed and marginal generation costs to the unit, its capacity factor remains 0%, indicating that it only exists as a backup source. The completely black "Generator Power Output" heatmap further confirms zero operation across all hours and days of the year. Overall, the findings show that KTML's primary energy system is sufficient to meet the required demand, eliminating the need for HFO-based generation and avoiding associated fuel consumption and emissions.



Quantity	Value	Units
Hours of Operation	0	hrs/yr
Number of Starts	0	starts/yr
Operational Life	1,000	yr
Capacity Factor	0	%
Fixed Generation Cost	1,090	$/hr
Marginal Generation Cost	0.164	$/kWh

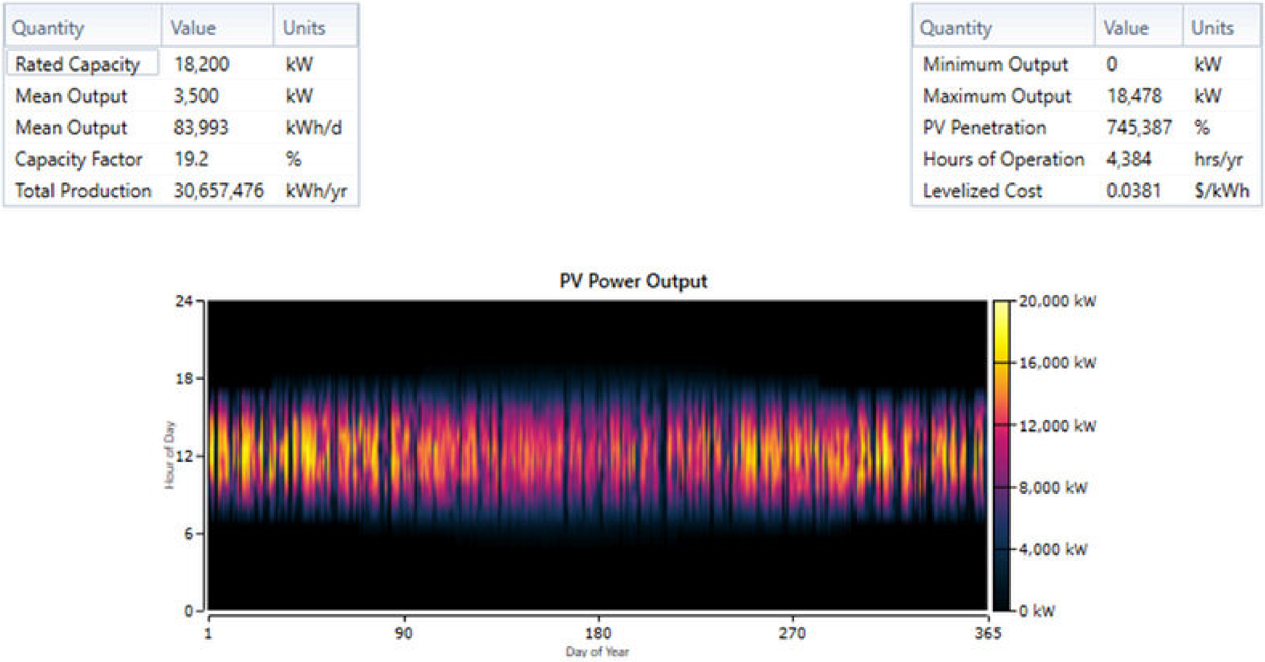
Quantity	Value	Units
Electrical Production	0	kWh/yr
Mean Electrical Output	0	kW
Minimum Electrical Output	0	kW
Maximum Electrical Output	0	kW

Quantity	Value	Units
Fuel Consumption	0	L
Specific Fuel Consumption	0	L/kWh
Fuel Energy Input	0	kWh/yr
Mean Electrical Efficiency	0	%

Figure 11: No HFO utilization but can be used as a backup

Figure 12 presents the performance and contribution of the solar photovoltaic (PV) system within the KTML energy setup, and in clear contrast to the HFO generator, the PV system is actively generating a significant amount of power throughout the year. Initially, in the left panel, the system's capacity and production statistics are summarized. The PV array has a rated capacity of 18,200 kW, indicating a large-scale installation. The mean output is 3,500 kW, which corresponds to an average daily energy production of 83,993 kWh/day. Over the course of a year, this results in a total production of 30,657,476 kWh/year, showing that solar is a major energy contributor. The capacity factor is 19.2%, which is typical for solar systems and reflects the variability of sunlight due to day-night cycles and weather conditions. Secondly, the right panel provides operational and economic indicators. The PV system operates for 4,384 hours per year, meaning it produces power during daylight hours across most days. The maximum output reaches 18,478 kW, slightly exceeding the rated capacity, which can happen under optimal irradiance and temperature conditions. The minimum output is 0 kW, as expected during nighttime. Notably, the levelized cost of energy (LCOE) is 0.0381 $/kWh, which is relatively low, making solar economically attractive. The PV penetration is extremely high (745,387%), which indicates that solar production far exceeds the local load demand at many times, this suggests either excess generation, curtailment, or export to other parts of the system. Thirdly, the bottom heatmap labeled "PV Power Output" visually illustrates how solar generation varies over time. Along the horizontal axis are the days of the year (1–365), and along the vertical axis are the hours of the day (0–24). The color scale ranges up to 20,000 kW, with brighter colors (yellow/white) representing higher output. The plot clearly shows that power is generated only during daylight hours, typically between approximately 6:00 and 18:00, with peak production around midday. The intensity and spread of colors vary across the year, reflecting seasonal changes in solar irradiance—stronger and longer production periods occur during sunnier months, while weaker and shorter periods appear in less sunny seasons.

The solar PV system is the dominant and primary energy source in the KTML system. Its high production and low cost explain why the HFO generator remains unused, as the system can reliably meet demand using solar energy alone for most, if not all, of the year.



Quantity	Value	Units
Rated Capacity	18,200	kW
Mean Output	3,500	kW
Mean Output	83,993	kWh/d
Capacity Factor	19.2	%
Total Production	30,657,476	kWh/yr

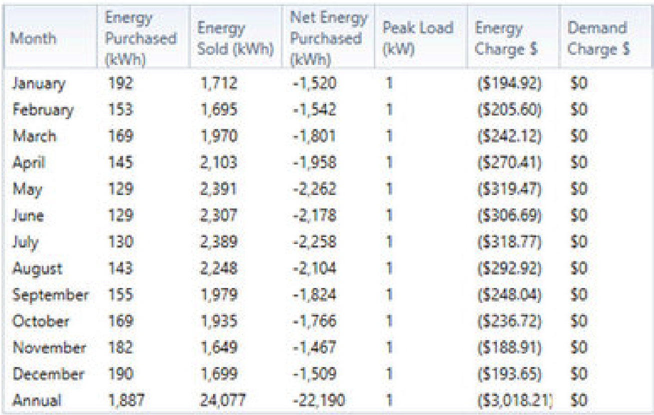
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	18,478	kW
PV Penetration	745,387	%
Hours of Operation	4,384	hrs/yr
Levelized Cost	0.0381	$/kWh

Figure 12: Solar photovoltaic (PV) generation system within the KTML energy setup

Figure 13 illustrates the interaction between the KTML system and the electrical grid, showing that the system predominantly exports energy to the grid while importing only a very small amount of electricity. At the top, the monthly summary table provides detailed numerical information regarding the grid exchange. The energy purchased from the grid remains very low throughout the year, ranging between 129 kWh and 192 kWh per month, with an annual total of only 1,887 kWh. In contrast, the energy sold to the grid is substantially higher in every month, varying from 1,649 kWh to 2,391 kWh monthly, resulting in a total annual export of 24,077 kWh. Consequently, the "Net Energy Purchased" values are negative for all months, ranging from approximately −1,467 kWh to −2,262 kWh, indicating continuous net export to the utility grid. Overall, the system achieves an annual net export of approximately 22,190 kWh.

Financially, this strong export performance produces negative values under "Energy Charge $," representing revenue or savings due to electricity export. Monthly energy charges vary from approximately ($188.91) to ($319.47), leading to an annual total of about ($3,018.21). In addition, the demand charge remains $0 throughout the entire year, while the peak load is maintained at only 1 kW each month. These results confirm that the grid is minimally utilized for consumption purposes and primarily serves as a destination for surplus generated electricity. The bottom-left heatmap, labeled "Energy Purchased from Grid," shows only limited and scattered colored regions throughout the year, with most periods remaining dark. This indicates that grid import occurs only occasionally and at very low power levels, generally below 1.0 kW according to the color scale. The imports appear more noticeable during nighttime and low-generation periods, particularly in some seasonal intervals, but they remain insignificant overall. Conversely, the bottom-right heatmap, labeled "Energy Sold to Grid," displays a strong and continuous colored band throughout most days and hours of the year. This confirms that the KTML system exports electricity consistently to the grid over extended daily periods.

The color intensity, reaching values close to 6.0 kW, suggests stable and substantial surplus power injection into the utility network. Minor seasonal variations are visible, reflecting changes in solar generation conditions across the year; however, the overall pattern clearly demonstrates persistent net energy export and effective renewable energy utilization.



Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
January	192	1,712	-1,520	1	($194.92)	$0
February	153	1,695	-1,542	1	($205.60)	$0
March	169	1,970	-1,801	1	($242.12)	$0
April	145	2,103	-1,958	1	($270.41)	$0
May	129	2,391	-2,262	1	($319.47)	$0
June	129	2,307	-2,178	1	($306.69)	$0
July	130	2,389	-2,258	1	($318.77)	$0
August	143	2,248	-2,104	1	($292.92)	$0
September	155	1,979	-1,824	1	($248.04)	$0
October	169	1,935	-1,766	1	($236.72)	$0
November	182	1,649	-1,467	1	($188.91)	$0
December	190	1,699	-1,509	1	($193.65)	$0
Annual	1,887	24,077	-22,190	1	($3,018.21)	$0

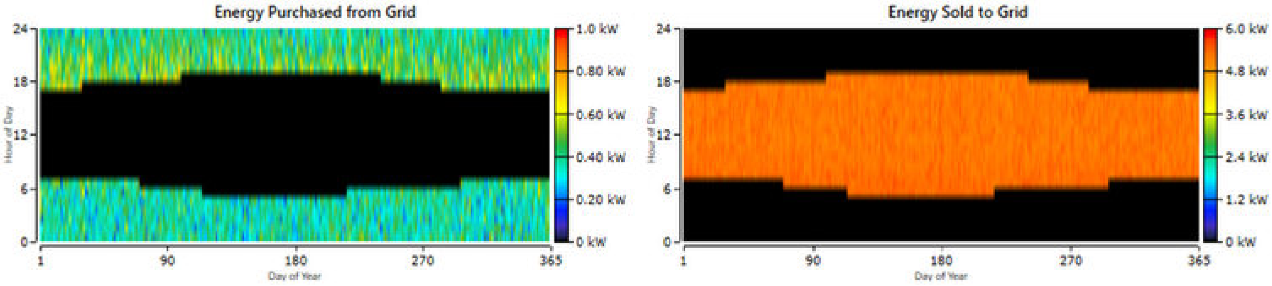


Figure 13: Grid purchases and sales throughout the year at KTML.

4.1.2. Economic Analysis

The financial performance of the KTML energy project (likely a solar or energy-efficiency investment based on the LCOE, which is 0.0125$/kWh. Each metric helps assess profitability, risk, and investment attractiveness from a different angle. The present Worth (PW = $4,192,183) represents the total value of all future cash flows (revenues minus costs), discounted back to today's terms. A positive and large present worth means the project is financially viable and creates substantial value over its lifetime. For KTML, a PW of over $4.19 million indicates strong long-term economic benefit after accounting for the time value of money. The annual Worth (AW = $324,284/year) converts that total value into an equivalent uniform yearly benefit. This makes it easier to compare with other projects or annual financial targets. In KTML's case, the project effectively generates about $324k per year in net economic benefit, which is a steady and meaningful contribution to operational savings or revenue.

Most importantly, the return on Investment (ROI = 6.4%) shows the percentage gain relative to the initial investment, typically on an annual basis. This is a simple profitability indicator. A 6.4% ROI suggests moderate returns—financially acceptable, though not extremely high—especially when compared with low-risk investments or energy-sector benchmarks. Secondly, the Internal Rate of Return (IRR = 10.2%) is one of the most important indicators. It represents the discount rate at which the project's net present value becomes zero.

In simpler terms, it's the project's effective annual return. For KTML, an IRR of 10.2% means the project yields about 10% annually over its lifetime. If this exceeds the company's cost of capital or required rate of return, the project is considered financially attractive—which is likely the case here.

Simple Payback Period 8.25 years of complete system, tells how long it takes to recover the initial investment from cash inflows, without considering discounting. For KTML, it takes a little over 8 years to break even in nominal terms. This is reasonable for infrastructure or energy projects, though not very fast. However, the discounted Payback Period (14.85 years) improves on the simple payback by accounting for the time value of money. Because future cash flows are worth less than present ones, it takes nearly 15 years to recover the investment in real terms. The large gap between simple and discounted payback suggests that much of the benefit occurs later in the project life. Finally, LCOE (Levelized Cost of Energy = $0.0125/kWh) is extremely significant. It represents the average cost of generating one unit of electricity over the system's lifetime. At just 1.25 cents per kWh, this is exceptionally low—far below grid tariffs or fossil-fuel-based generation in Pakistan. This indicates that KTML's energy solution is highly cost-competitive and likely a major driver of the positive financial outcomes shown above. Furthermore, the economic analysis is presented in Table 9 as follows:

Table 9: The main technical parameters of economic analysis

Metric	*Value*	*Units*
Return on investment (ROI)	*6.4*	*%*
Simple payback	*825%*	*yr*
Discounted payback	*14.85*	*yr*

4.1.3 Environmental Analysis

The comparative emissions data in Table 11 reveals that the proposed system is significantly more environmentally friendly than both the natural gas–based and HFO-based systems. Carbon dioxide (CO_2) emissions from the proposed system are only 2,142 kg/yr, which is extremely low compared to 1,911,535 kg/yr from the natural gas system and 2,390,721 kg/yr from the HFO system, highlighting a substantial reduction in greenhouse gas emissions. The proposed system also completely eliminates carbon monoxide (CO), unburned hydrocarbons (UHC), and particulate matter (PM), whereas the natural gas system emits 13,516 kg/yr of CO, 717 kg/yr of UHC, and 116 kg/yr of PM, while the HFO system emits 1,360 kg/yr of CO, 126 kg/yr of UHC, and 111 kg/yr of PM. These pollutants are major contributors to air pollution, health hazards, and reduced combustion efficiency. In terms of sulfur dioxide (SO_2),he proposed system emits only 5.17 kg/yr, which is negligible compared to the 5,800 kg/yr emitted by the HFO-based system, demonstrating the proposed system's effectiveness in minimizing sulfur-related environmental impacts such as acid rain. Although the natural gas system produces nearly zero SO_2 emissions, it still emits considerably higher levels of other pollutants than the proposed system.

Nitrogen oxides (NO_x) emissions are also drastically reduced in the proposed system, recorded at only 2.53 kg/yr compared to 2,590 kg/yr for the natural gas system and 10,491 kg/yr for the HFO-based system. Since NO_x emissions contribute to smog formation, acid rain, and respiratory diseases, this reduction represents a major environmental advantage. Overall, the analysis confirms that the proposed system provides a highly sustainable and cleaner energy solution with near-zero emissions, offering superior environmental performance compared with conventional natural gas and HFO-based energy systems.

Table 10: Emissions Analysis of the existing proposed energy system at KTML

Quantity	*Quantity*	*Emissions with CP*	*Total Emissions*	*Units*
Carbon Dioxide	*2142*	*40,639,172*	*40,641,314*	*kg/yr*
Carbon Monoxide	*0%*	*135,143*	*135,143*	*kg/yr*
Unburned Hydrocarbons	*0*	*0*	*0*	*kg/yr*
Particulate Matter	*0*	*3,810*	*3,810*	*kg/yr*
Sulfur Dioxide	*5.17*	*0*	*5.17*	*kg/yr*
Nitrogen Oxides	*2.53*	*283,545*	*283,547.53*	*kg/yr*

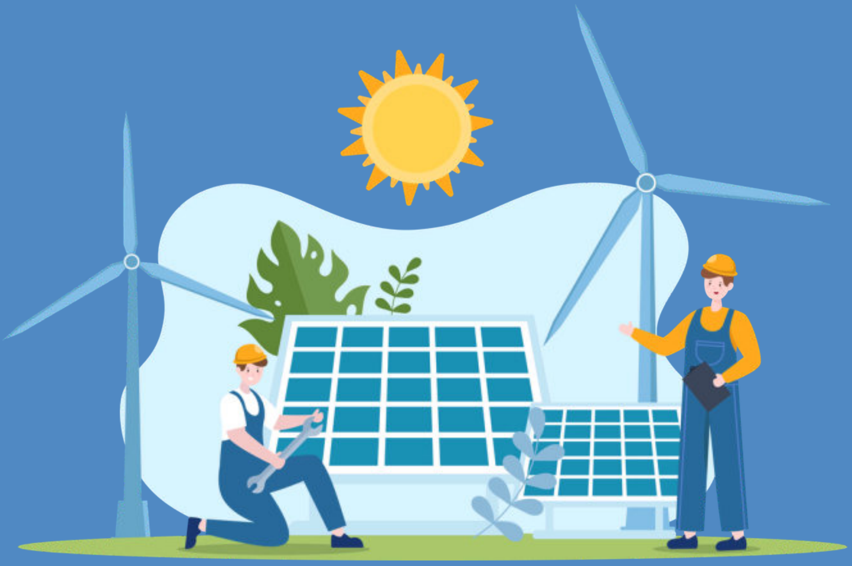
Table 11: Emissions comparative analysis of existing system Vs. alternative fuel-based electricity systems

Quantity	*Proposed system*	*Natural gas-basec*	*HFO-based systen*	*Units*
Carbon Dioxide	*2,142*	*1,911,535*	*2,390,721*	*kg/yr*
Carbon Monoxide	*0%*	*13,516*	*1,360*	*kg/yr*
Unburned Hydrocarbons	*0*	*717*	*126*	*kg/yr*
Particulate Matter	*0*	*116*	*111*	*kg/yr*
Sulfur Dioxide	*5.17*	*0*	*5,800*	*kg/yr*
Sulfur Dioxide	*2.53*	*2,590*	*10,491*	*kg/yr*

CHAPTER

05

Summarizes the key findings and draws final conclusions from the study.



5.1. Conclusion

The case study of Kohinoor Textile Mills Limited (KTML) demonstrates that large-scale industrial decarbonization within the textile sector is not only technically feasible but also economically viable and commercially strategic. Through a vertically integrated sustainability model combining renewable energy, biomass-based thermal systems, circular resource management, and internationally recognized certifications, KTML has established itself as a benchmark for sustainable textile manufacturing in emerging economies.

KTML has achieved substantial environmental and operational improvements through its integrated hybrid energy system. The company deployed 31.38 MW of solar photovoltaic capacity across three facilities, including 18.2 MW at its Rawalpindi site alone. Solar energy now supplies nearly 90% of daytime electricity demand, significantly reducing dependence on expensive grid electricity and fossil-fuel-based captive generation. The company has also transitioned its thermal operations toward cleaner fuels through a 20-ton/hour biomass boiler utilizing rice and wheat husk, while coal usage has been almost completely phased out.

These interventions have delivered significant cost savings. Solar electricity generation costs approximately 26–27 PKR/kWh compared to 32.75–43 PKR/kWh for grid electricity and 48–54 PKR/kWh for captive generation. The project achieved a positive Present Worth of approximately USD 4.19 million, an Internal Rate of Return (IRR) of 10.2%, and a simple payback period of 8.25 years. Furthermore, the Levelized Cost of Energy (LCOE) of only USD 0.0125/kWh highlights the long-term competitiveness of renewable energy investments in the textile sector.

From an environmental perspective, KTML has reduced greenhouse gas emissions by approximately 45% from its 2021 baseline as of 2026 and has established ambitious targets of 50% emissions reduction by 2030 and Net Zero emissions by 2050. Solar installations alone avoid nearly 29,834 tCO_2 annually across the company's three plants. Comparative emissions analysis also shows that KTML's proposed hybrid energy system drastically lowers pollutants such as CO_2, NO_x, SO_2, particulate matter, and carbon monoxide compared with conventional natural gas and HFO-based systems. These results clearly demonstrate that renewable integration and thermal decarbonization can significantly reduce the environmental footprint of energy-intensive textile operations.

Beyond energy transition, KTML's sustainability model also integrates advanced water management and circular economy practices. The facility recycles 80–85% of treated wastewater through its high-capacity wastewater treatment plant and operates textile recycling systems capable of processing 24 tons/day of waste material. By-products such as sludge and ash are repurposed into construction materials, reinforcing industrial circularity and resource efficiency.

Importantly, KTML highlights how sustainability certifications can become a major commercial advantage. Certifications such as ISO, OEKO-TEX, and Better Cotton Initiative (BCI) strengthen buyer confidence, improve export competitiveness, reduce shipment rejection risks, and support access to premium international markets. Studies referenced within the case study suggest that sustainability certifications can reduce operational costs by 5–15%, improve resource efficiency.

by 10–25%, and generate export-related value enhancements of USD 5–8 million annually for large exporters through preferred supplier status and improved market access.

For large textile industries that have not yet initiated decarbonization or sustainability interventions, KTML provides a practical and scalable roadmap. The first step should involve conducting a comprehensive energy, water, and emissions baseline assessment to identify major inefficiencies and carbon-intensive processes. Industries should then prioritize “low-hanging fruit” interventions such as energy monitoring systems, waste heat recovery, efficient motors, water recycling, and rooftop solar installations. Simultaneously, companies should begin transitioning thermal systems from coal and furnace oil toward biomass or cleaner fuels while developing long-term renewable energy integration plans.

Establishing sustainability governance structures, digital monitoring systems such as SCADA, and internationally recognized certifications should follow as strategic enablers for export competitiveness and compliance with evolving global supply chain requirements. Finally, companies should adopt measurable decarbonization targets aligned with international frameworks such as the Science Based Targets initiative (SBTi), ensuring long-term alignment with global climate expectations and buyer requirements.

Overall, KTML demonstrates that sustainability is no longer solely an environmental obligation; it is a strategic industrial transformation pathway that enhances cost competitiveness, strengthens energy security, improves operational resilience, reduces emissions, and secures long-term access to global textile markets.

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