Scoping Study of Off-Grid Solar PV and Captive Power Systems in the Textile Sector

Techno-economic and Environmental Analysis

Alternate Development Services (ADS),

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This research stands as a testament to what can be achieved through a shared vision and collaborative action. We hope the findings and recommendations will catalyze transformative changes and inspire continued efforts toward achieving the sustainability goals within the textile industry.

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List of Abbreviations

AEDB	Alternative Energy Development Board
ADS	Alternate Development Services
APTMA	All Pakistan Textile Mills Association
ARE Policy	Alternative & Renewable Energy Policy
CBAM	Carbon Border Adjustment Mechanism
CPGCL	Central Power Generation Company Limited
CPPA	Central Power Procurement Agency
CPP	Captive Power Plant
CPPA-G	Central Power Purchasing Agency-Guarantee Limited
CTBCM	Competitive Trading Bilateral Contract Market
DFIs	Development Finance Institutions
DG	Distributed Generation
DISCO	Distribution Company
DSO	Distribution System Operator
EE	Energy Efficiency
EPA	Environmental Protection Agency
EPP	Energy Purchase Price
ESG	Environmental, Social and Governance
EU	European Union
FESCO	Faisalabad Electric Supply Company Limited
FiT	Feed-in-Tariff
FY	Financial Year
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GM	Gross Metering
GoP	Government of Pakistan
HFO / LFO	Heavy Fuel Oil / Light Fuel Oil
IEA	International Energy Agency
IFI/IFC	International Finance Institutions/Corporations
IGCEP	Indicative Generation Capacity Expansion Plan
IPP	Independent Power Producer
IRR	Internal Rate of Return
ISMO	Independent System and Market Operator
KPI	Key performance Indicator
kWh	Kilowatt hours
LCA	Lifecycle Assessment
LCOE	Levelized Cost of Electricity
MEPCO	Multan Electric Power Company Limited
MRV	Monitoring, Reporting & Verification
MW	Megawatt
NEPRA	National Electric Power Regulatory Authority
NM	Net Metering
NPCC	National Power Control Centre
NPV	Net Present Value
NTDC	National Transmission and Dispatch Company Limited
O&M	Operation and Maintenance
PBP	Payback Period
PPA	Power Purchase Agreement
PPIB	Private Power and Infrastructure Board
RE	Renewable Energy
RLNG	Re-liquefied / Re-gasified Liquefied Natural Gas (RLNG)
ROI	Return on Investment
S1, S2	Scenario 1, Scenario 2 (proposed scoping scenarios in this study)
SBP	State Bank of Pakistan
SMEDA	Small and Medium Enterprises Development Authority
TEA	Techno-Economic Analysis
TR	Trading Rate

UoSC	Use of System Charge
VPP	Virtual Powerplants
WAPDA	Water and Power Development Authority
WR	Wheeling Rate

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Executive Summary

This study evaluates pathways for rapid, credible decarbonization of Pakistan's textile hubs through large-scale deployment of off-grid and captive solar PV under a Competitive Trading Bilateral Contracts Market (CTBCM) regime. It addresses a multi-dimensional problem: energy security and serious reliability shortfalls in textile production; the economics of distributed and centralized solar options; interaction of new market constructs (Use of System Charge (including wheeling rates), trading rates) with investor returns; and emergent trade-policy constraints (notably the EU Carbon Border Adjustment Mechanism, CBAM). The research synthesizes field mapping, GIS-based asset inventories, stakeholder viewpoints across Faisalabad and Multan, and scenario-based techno-economic modelling to produce policy-actionable guidance for regulators, industry and financiers. The need for the study is immediate and sector-specific. Pakistan's textile value chain is energy-intensive and exposed to frequent outages, costly captive generation and international market pressures to reduce embodied carbon. Existing net-metering and gross-metering rules only partially address industrial scale requirements; they leave unresolved wheeling economics, settlement visibility and standardized PPA constructs that CTBCM seeks to reform. Technical constraints; reverse power flows, voltage regulation, inadequate bidirectional/time-resolved metering and high distribution losses; amplify operational risk when solar penetration scales. Financing barriers for medium-sized mills remain a serious problem: high up-front CAPEX, short loan tenors and uncertain revenue predictability under shifting UoSC regimes impede private capital mobilization. The study demonstrated scoping of existing energy production and distribution mechanisms within selected 80 mill cluster (50 from Faisalabad, 30 from Multan). Deployment patterns indicate that hybrid and tri-hybrid arrangements are already mainstream: tri-hybrids (gas + solar + grid) represent ~20% of sites in the combined sample, while combined hybrid categories (gas + solar, solar + grid, gas + grid) account for a majority of plants; about 62% of sample mills continue to use the DISCO network as backup. These field results demonstrate both the latent solar resource and the operational preference for mixed-source resilience; a favorable starting point for CTBCM-driven bilateral PPAs and virtual aggregation, provided wheeling, metering and settlement frameworks are clarified. A concise technical snapshot: GIS mapping confirms substantial rooftop and ground-mount potential across the sampled industrial clusters Two representative system models were studied in *techno-economic perspective*: a high-renewable centralized model (≈87% renewable fraction) which minimizes system LCOE (levelized cost of electricity) but demands higher initial capital and grid reinforcement, thus slowing project overall returns, i.e. payback, aggregate Net Present Value (NPV) and internal rate of return (IRR); and a distributed, lower-CAPEX model (≈75% renewable fraction) offering superior project-level IRR and faster paybacks but delivers somewhat higher system-wide levelized costs (LCOE). Under conceivable CTBCM settings (illustrative trading rate ≈ PRK 24/kWh and wheeling ~PRK 12/kWh), CTBCM scenarios produce materially improved investor returns (IRR

uplift and positive NPVs) compared with business-as-usual, though sensitivity to UoSC is critical: wheeling above recognized critical rated (~Rs 15–20/kWh) erodes distributed project viability and materially lengthens payback periods. Incorporating conservative CBAM value (i.e., $15/t$CO_2$) further strengthens the business case for renewables, raising adjusted NPVs and IRRs and increasing the attractiveness of large, centralized deployments avoiding greater absolute CO_2. Policy implications are definitive and prescriptive. First, CTBCM can help with the scaling of renewable projects and distribution network and offer impressive financial gains but must be implemented with transitional protections for small/medium prosumers: predictable, phased UoSC schedules, differentiated intra-cluster wheeling discounts, and transition of existing net-metered assets to competitive trading models. Second, wheeling must be kept free from non-network legacy charges (stranded costs / cross-subsidies) during a defined transition window to preserve distributed deployment economics and to mobilize SME investment. Third, standardized PPA templates, measuring, reporting and verification (MRV) rules for emissions (to qualify CBAM credits), and fast-track metering/interconnection procedures will lower transaction costs and economic hurdles. Finally, blended public finance (green finance lines, concessional credit), targeted tax incentives and capacity-building for energy managers are essential to convert technical feasibility into scalable deployment. In short, the report argues for a well-crafted dual-track strategy: accelerate centralized, large-scale renewable builds (to minimize system LCOE and aggregate emissions) while protecting and incentivizing distributed, behind-the-meter solar growth (to mobilize private capital quickly and improve operational resilience). CTBCM is an enabling platform only if its tariff architecture, market governance and MRV systems are designed to be investment-friendly, predictable and aligned with international carbon compliance regimes. If these design conditions are satisfied, Pakistan’s textile sector can secure both near-term competitiveness and long-term market access in a low-carbon global economy.

Chapter 1: Introduction and Roadmap for Off-grid Solar Adoption in Pakistan

1.1 Background and contextual development

1.1.1 Energy challenges faced by textile mills and implications

The textile sector in Pakistan is one of the largest consumers of energy in the country, while also serving as a backbone for exports, employment, and industrial value addition. Pakistan's large textile export sector contributes approximately 8.5% to national gross domestic product (GDP), supplies about 60% of exports, and employs nearly 30% of the industrial workforce [1,2]. Textile mills require continuous power for spinning, weaving, dyeing, printing, and finishing; with critical tolerances for voltage, frequency, steam supply, and uptime; and with lowest possible supply losses. However, the energy supply from grid is unstable: frequent outages, load-shedding, and voltage fluctuations leading to disruption of operations, reduction in throughput, damage to machinery, and product quality degradation. These disruptions transform into heavy financial losses, both from interrupted production and from waste of raw material and labor time. For instance, one recent grid failure in January 2023 resulted in losses estimated around US$70 million for the textile sector in a single day [3]. Thus, the intensive energy utilization by textile sector of Pakistan (estimated at 7.8 TWh/year in Punjab's Faisalabad and Multan hubs) exposes it to both supply disruptions and escalating tariffs [4]. **Figure 1** shows sector-wise energy consumption in Fiscal Year (FY) 2022 [5].

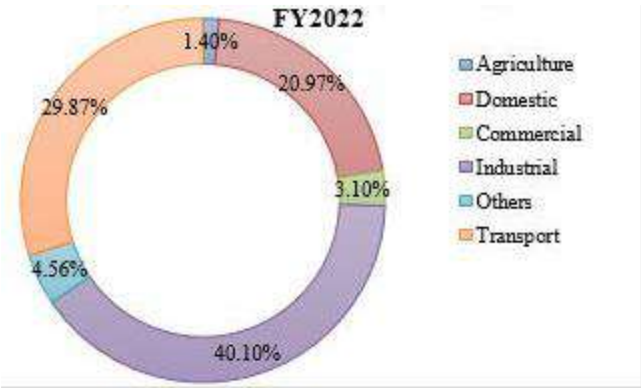

Figure 1: Sectoral Energy Consumption FY 2022

Thus, it can be stated that Pakistan's textile sector is suffering enormous challenges in terms of power production and supply chains. Compounding these reliability challenges, textile firms face high tariffs and unfavorable supply-cost structures. Power rates for industrial users have risen sharply; for many export-oriented firms tariffs have increased to 40 PKR/kWh, compared to earlier, lower benchmark "regionally competitive" rates of around 26 PKR/kWh [6]. These higher energy costs burden textile industry characterized by low margins and high input costs. Network inefficiencies also exacerbate the problem: transmission and distribution losses add to supply cost, while captive power plants (CPPs) using gas or RLNG have been essential for many mills to maintain power when the grid fails but have become more expensive due to fuel price hikes, gas supply constraints, and rising tariff regimes [7].

Power supply disruptions, considerable grid losses and high tariffs combined compelled textile mills to critically assess energy demand and supply structures putting serious pressures regarding energy crisis across industry. In response to these pressures, many textile mills have adopted mixed power sourcing strategies. At the technical and operational level, textile mills in major industrial hubs (Faisalabad and Multan) have historically relied on captive generation using natural gas, diesel and furnace oil because the national grid has suffered from transmission losses, peak shortfalls and variable power quality. Thus, whether industries rely on grid or captive generation, the sector's competitiveness is at risk due to an unstable power supply, volatile fossil fuel prices, lower efficiencies of CPPs (only around 30–40%) and high operational costs. Additionally, transmission and distribution (T&D) losses through national grid were accounted for around 17 – 18% for FY24 – 25, which increase energy bills [8]. Thus, mills are investing increasingly in solar PV rooftop or ground-mount systems to displace daytime fuel-based generation and reduce peak grid demand exposure. For example, several large mills are installing multi-megawatt solar PV systems (e.g. a 7.2 MW project by Kohinoor Mills) as cost projections improve for solar power generation amid rising grid tariffs [9]. Solar, however, remains mostly a supplementary supply source; most mills retain captive or grid sources for evenings, nights, and periods of weak solar, to meet their full load demands and ensure process continuity [10,11].

The growing importance of solarization (and hybridization) is not only economic but environmental. Textile production, powered largely by fossil fuels contributes significantly to greenhouse gas (GHG) emissions. Adopting solar PV and integrating renewables helps reduce *Scope-2 emissions* (from purchased electricity) and fossil fuel combustion in captive generation, improves energy efficiency, and potentially gives textile exports a competitive edge under futuristic carbon-adjustment schemes like carbon border adjustment mechanism (CBAM). The European Union's (EU) CBAM is an EU based emissions accounting mechanism designed to put a fair price on carbon emitted during the production of carbon-intensive goods that are entering the EU, and to encourage cleaner industrial production in non-EU countries. This is putting carbon intensity of industrial supply chains under inspection; for textile industries which are export-oriented, decarbonization is now as much a *commercial necessity* as an environmental goal. Thus, all these factors increasingly demand sustainable supply chains and as Pakistan seeks to meet its nationally determined contributions (NDCs), the textile industry's transition to low-carbon, hybrid energy systems are need of the hour as a policy priority and optimizing economic gains [12]. Moreover, a cleaner *energy production profile* can help firms hedge against future fuel supply disruptions and regulatory risks. **Figure 2** shows opportunities for renewable adoption in textile sector of Pakistan [13].

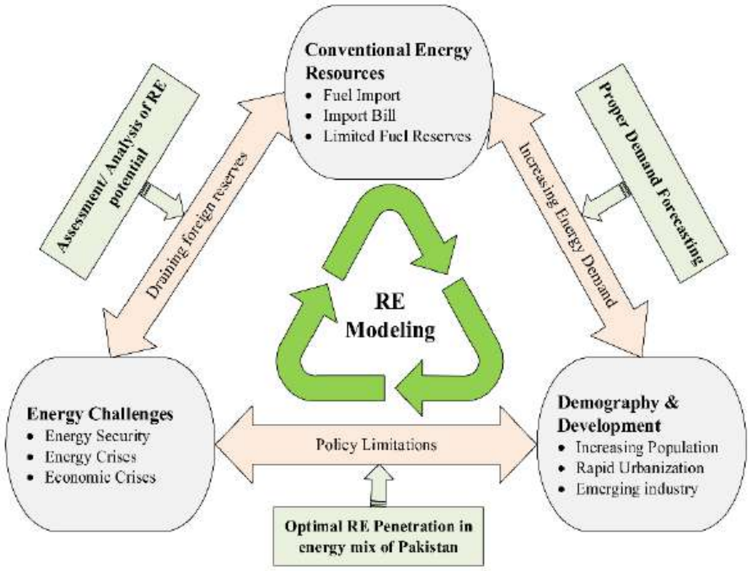

Figure 2: Opportunities for renewable adoption in textile sector of Pakistan

1.1.2 Energy Supply Chains through Grid in Textile's perspective

Coming towards *energy supply* models being adopted by industry or implemented by regulatory authorities like NEPRA; historically since the adoption of solar PVs, the grid regulatory mechanism relies majorly upon net metering (NM). *Net-metering (NM) or Reverse metering (RM)* is the process of running an energy meter in reverse, when a user adds energy to the system instead of taking it out. The electric grid is used by utilities, through an electric billing program, to "sell" extra energy generated by solar panels [14]. Since its formalization under NEPRA in 2015, it has been the primary regulatory mechanism enabling rooftop and small-scale solar uptake across Pakistan; and textile mills have been early and visible adopters. By mid-2025, cumulative NM capacity exceeded ~5.3 GW with over 42,000 installations, and prominent textile players (e.g., Nishat) now use on-site PV to offset energy-intensive processes such as spinning, weaving and finishing [15]. For the textile sector NM delivers clear, practical benefits: it reduces retail energy bills, lowers dependence on expensive and non-ecofriendly onsite diesel/LFO generation, relieves distribution load during daylight hours, improves operational resilience (behind-the-meter generation and hybrid islanding during outages), and yields environmental and foreign-exchange savings by cutting imported fuel use [16–20]. As of mid-2025, buyback rate for existing net-metering users stands at PKR 27 per kWh, but proposed reforms aim to reduce this to ~PKR 10 per kWh; a ~60% cut; to alleviate grid cost burdens.

Figure 3: Properties of current Distributed Generation (DG) and NM regulations 2015, NEPRA [20]

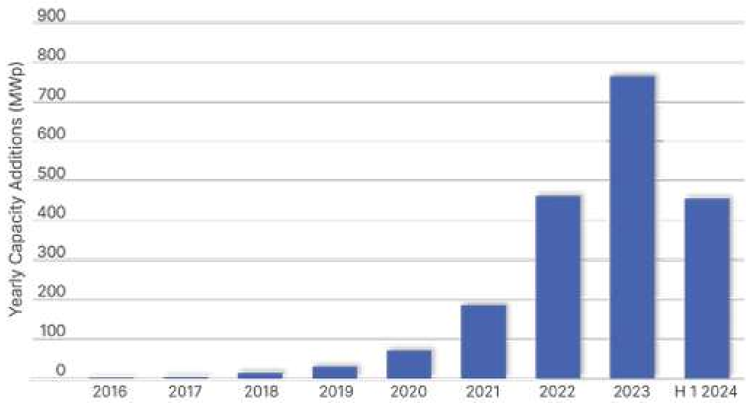

Figure 4: Yearly Net-metered Solar PV capacity licensed with NEPRA [21]

Gross metering is another grid metering method in Pakistan's landscape. Under gross metering, *all* solar generation is regulated so as to be sold to the grid at a fixed *feed-in tariff (FiT)*, while mills purchase grid power at *retail rates*. This typically decouples generation from consumption. Thus, gross metering grid regulated systems extract all the electricity produced by a solar PV system and feed it directly into the grid, without direct consumption at the site [17]. In Pakistan's textile sector, where energy intensity is high and daytime process loads (spinning, weaving, finishing) are substantial, its role is very limited. Under the recently proposed framework new rooftop exports would be bought back at roughly one-third of NEPRA's base tariff (≈PKR11–14/kWh for Financial Year (FY) 2025–26), while existing net-metered installations are being metered at ~PKR27/kWh; this creates a unambiguous dual-rate reality in which mills pay ~PKR30/kWh for grid power but receive only ~PKR12–15/kWh for solar exports [22,23]. For large, land-rich textile sites or dedicated solar parks; more common outside dense mill clusters; GM can deliver predictable cash flows and easier scheduling for DISCOs, and it simplifies billing. But for the bulk of Pakistani mills (Faisalabad, Multan and similar clusters) GM sacrifices the primary commercial benefits of behind-the-meter solar; direct bill reductions, resilience during outages, and peak-offset value; making it often less attractive than net-metering or hybrid approaches.

As Pakistan's net-metering (NM) and gross-metering (GM) schemes have matured, the limitations of these traditional supply models are becoming increasingly evident; especially for large industrial consumers in the textile sector. Under NM/GM, solar producers are constrained by fixed buyback rates, capacity caps tied to sanctioned load, separate export-import accounting, and policies which often reduce incentives (for example, recently the buy-back rate for surplus solar under net-metering was proposed to be cut significantly to PKR 10/unit, and contract durations were shortened for new users) [24–26]. Thus, there is a critical need to move towards a new electricity supply market, which addresses all these shortcomings for energy-intensive textile clusters. In fact, the solution has arrived, but due to various challenges, not fully developed; i.e. **privatization of electricity markets** under competitive market mechanism.

The *Competitive Trading Bilateral Contract Market (CTBCM)* regime presents a timely and transformative opportunity for the deployment of such decentralized energy systems. It is proposed convincingly in NEPRA's 2020 "CTBCM Implementation Roadmap" and aims to regulate generation, transmission, and distribution through open channels, while giving foundational access to private players [27,28]. It directly addresses the pain points enlisted above for textile operators by enabling bilateral contracts, wheeling and wholesale trading. It aims to liberalize the electricity market by enabling *bilateral power purchase agreements (PPAs)* between generators and bulk power consumers, thereby allowing large industrial units, such as those in the textile sector, to procure electricity directly from producers at competitive rates [13,29]. This regulatory transition lays a strong foundation for *behind-the-meter renewable generation*, captive PPAs, and self-consumption models, making off-grid and captive PV solutions highly relevant and economically viable under the evolving energy framework [30].

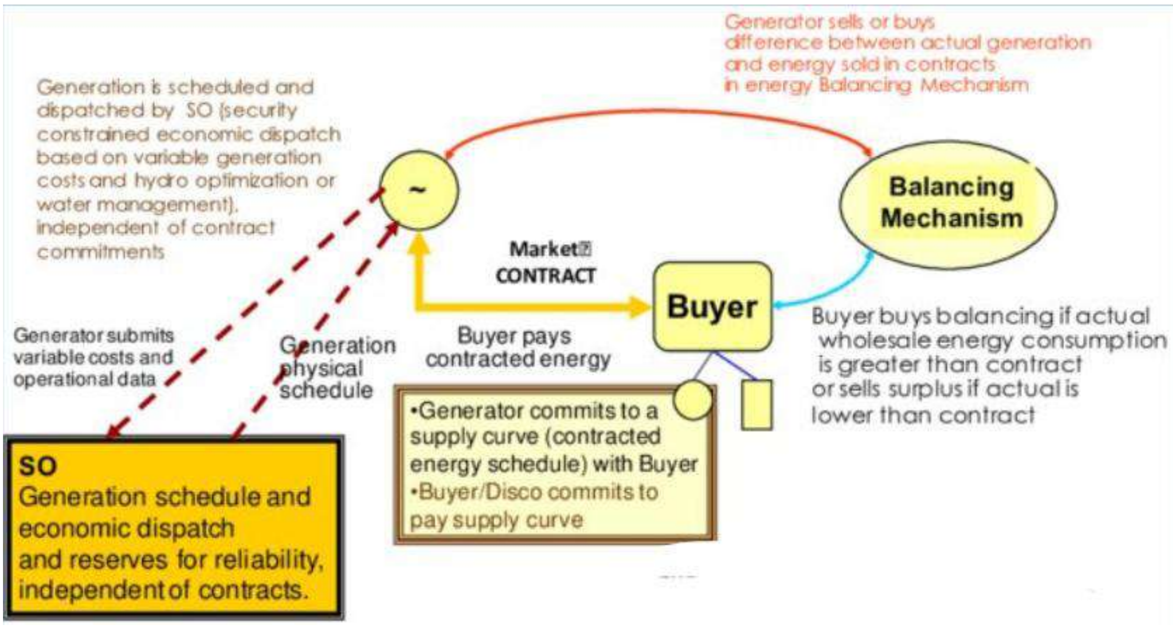

Figure 5: Mechanism of CTBCM implementation [29]

Mills can procure competitively priced solar via third parties or sell surplus under negotiated terms, better match daytime solar profiles with shift-based industrial demand and share the cost of necessary grid upgrades and storage; making CTBCM a more flexible, scalable and value-accretive route for decarbonising Pakistan's textile clusters. **Table 1** lists comparative analysis of various grid integration mechanisms.

Table 1: Comparative Analysis of Electricity Distribution schemes

Feature	Net Metering	Gross Metering	CTBCM
Consumer Benefit	High	Moderate	Very High
System Size Suitability	≤1 MW	≤1 MW	≥1 MW to multi-MW
Regulatory Complexity	Low	Moderate	High
Open Market Access	×	×	☑
Group Captive Allowed	×	×	☑
Environmental Compliance Support (CBAM etc.)	Partial	Limited	Full
Long-Term PPA Option	×	☑ (limited)	☑

1.2 Problem Statement

Pakistan's textile sector is a building block of national economy but remains highly exposed to energy risk and transition pressure. Textile manufacturing is energy-intensive, and mills have historically relied on captive thermal generation (diesel, heavy fuel oil, and gas) and on-site CPPs to manage unreliable grid supply and maintain continuous production. Captive plants provide stable and firm capacity but at the expense of *high operating cost* and relatively *low thermal efficiency* compared with modern centralized power-plants; along with exposing mills to fuel price volatility, supply interruptions and high localized environmental footprint, increasing production costs and export vulnerability [2,31]. At the same time the national policy landscape is pressing for rapid renewable uptake: Pakistan's Alternative & Renewable Energy (ARE) Policy 2019 and Indicative General Capacity Expansion Plan (IGCEP) set ambitious renewable targets while NEPRA's distributed generation and market-reform programs (including the design of CTBCM) aim to open bilateral contracts directly between power producers and buyers neutralizing default practices through wheeling caps, enabling private solar and third-party supply to industrial customers [27,32]. Solarization; through pragmatic rooftop, ground-mounted and captive PV combined with hybrid dispatch and trading in competitive electricity market; offers mills a realistic way to cut fuel imports, lower operating costs and improve daytime resilience, while creating tradable surplus that can be monetized under reformed market arrangements. The policy intent is clear, but the transition path is obstructed by a combination of *regulatory, technical, financing, implementation (policy) and organizational* barriers that this study seeks to map and quantify.

Despite the clear benefits, several barriers hinder large-scale solar PV and hybrid CPP adoption in the textile sector [27,33,34]:

- Fluctuating net-metering rates (with lower incentives to power producers while DISCOs being the major beneficiaries in single-buyer model) and unclear wheeling-charge frameworks under CTBCM discourage long-term investments and cause *regulatory uncertainty*.
- Increasing distribution assets limit hosting capacity for behind-the-meter generation and can destabilize the grid if remain unchecked, thus causing *infrastructure constraints*.
- High upfront capital costs and limited access to concessional financing with no proper devised financing mechanisms impede project viability, particularly for mid-sized mills, cause *financing challenges*.
- Current ARE and net-metering policies prioritize residential rooftop PV, covering industrial installations at 1 MW and failing to address hybridization incentives for >1 MW systems, and larger power producers suffer from economic losses due to net metering and gross metering policies, as well as *policy gaps* in widespread CTBCM adoption.

1.3 Objectives of the Study

This scoping study aims to address critical gaps and explore viable pathways for integrating off-grid solar PV and hybrid captive power systems within Pakistan's textile industry under the emerging CTBCM framework. The main objectives of this scoping study are as follows:

1. Scoping of *existing energy practices* prevalent in textile sector of Pakistan's selected industrial hubs and exploring the potential for off-grid Solar PV adoption.
2. Potential *mapping* of Solar PV systems currently installed in textile sector of those hubs along with proposing a scheme for widespread Solar PV adoption.
3. Proposing s*cenarios* for analyzing critical factors in adoption of renewable systems based on off-grid PV by independent power producers and buyers based on bilateral contracts under *CTBCM model* and performing comprehensive techno-economic analysis for those scenarios including off-grid configurations, grid-connected self-consumption, and CTBCM-enabled bilateral trading setups, evaluating metrics such as levelized cost of energy (LCOE), payback periods, internal rate of return (IRR), and net present value (NPV).
4. Evaluation of *economic and environmental feasibility* of proposed systems (off-grid solar PV and hybrid CPP) compared with 'business as usual' case and comparative analysis of benefits of CTBCM adoption with existing grid management schemes like Net metering or gross metering.
5. Conducting sensitivity analyses for proposing the regulatory factors (wheeling charges, trading tariffs, grid losses etc.) enabling optimized energy setup in selected hubs under bilateral trading contracts to evaluate operating framework benefiting all the stakeholders concerned.

6. Identifying policy and regulatory gaps inhibiting renewable integration under CTBCM and evaluating existing policies prevalent in industrial sector regarding renewable adoption and giving policy recommendations from the perspective of various stakeholders.
7. Evaluation of proposed systems in vision of environmental CBAM setups and consequent economic and environmental gains for achieving sustainable production and consumption and consequently analyzing environmental impacts by estimating GHG abatement potential and incorporating CBAM cost factors.
8. To present the findings into **actionable recommendations** for policymakers, DISCOs, CPPA-G, and textile industry stakeholders, promoting scalable industrial solar deployment under CTBCM.

1.4 Desired Perspective

This scoping study addresses a critical gap in Pakistan's energy transition strategy: the absence of a sector-specific roadmap for renewable integration within the textile industry, aligned with the transformative CTBCM framework. Our vision reframes energy from an operational menace into a commercial advantage for textile mills in Faisalabad and Multan: act fast to capture the immediate gains from solar and hybrid systems; lower bills, cleaner inputs, and better uptime; then use those proven savings and operating experience to push for deeper market reforms unlocking scale and value. In practice this means a two-stage path: a rapid, risk-aware rollout of on-site PV, storage and efficiency measures to attain resilience and reduce fuel exposure; followed by careful privatization of supply and transparent access rules so clusters can pool demand, secure competitive contracts and monetize surplus. Only after those foundations are in place does a restructured wholesale framework (CTBCM) make sense as a multiplier; it rewards scale, enables bilateral deals and carbon revenues (from solarization), and converts energy from a cost to a strategic asset. Textile leaders who initiate the early steps and insist on predictable market rules will find themselves best positioned to turn energy into a durable competitive edge.

This study was written with those practical aims in mind and closely follows a well-drafted direction: it builds a verified mapping of grid, captive, and gas connections within the textile hubs of Faisalabad and Multan; validates rooftop and ground PV through field surveys and GIS mapping; runs realistic dispatch-aware techno-economic scenarios including backup, curtailment, and CTBCM settlement logic; quantifies growth potential through solarization and liberalization of power markets and avoided CO_2 with MRV-ready CBAM calculations; and maps concrete privatization and market entry pathways (wheeling, settlement, legacy-PPA solutions) together with developing templates and stakeholder engagement policy roadmaps. The result is not academic theory but a compact, action-oriented blueprint; grounded in local data and legal realities; designed so industry, financiers, and regulators can move from isolated solar projects to coordinated market participation without sacrificing competitiveness or export credibility. It envisions a future in which textile mills in Faisalabad and Multan become energy-efficient and low-emission units, not only through solar and hybrid systems but by becoming active players in Pakistan's restructured electricity market: a future where electricity is not simply a utility bill, but a strategic decision that determines export competitiveness, carbon compliance, and investor confidence.

1.5 Stakeholder Identification

Transitioning to renewable adoption under modified power purchasing (i.e. CTBCM) model in Pakistan's power sector redefines the stakeholder's perspectives by decentralizing generation and enabling new key energy players. In context of industrial-scale renewable integration; particularly off-grid or grid-optional Solar PV systems; stakeholders are no longer limited to only utilities and consumers. Instead, the CTBCM framework broadens this framework to include multiple active participants, each playing a strategic role in supporting the development and operationalization of renewable energy within the industrial sector, specifically the textile hubs of Faisalabad and Multan. The system is thus evolving under a newly *licensed independent system and market operator (ISMO)* in place since May 2025 to facilitate this transition [27,30,35].

The core stakeholders of this framework are the **industrial consumers (load-serving entities)**, who not only consume electricity but under CTBCM can act as *prosumer-aggregators*, i.e. investing in solar PV infrastructure, selling or buying electricity through bilateral contracts, or using distribution system operator (DSO)-enabled platforms like DISCOs to manage trades. The textile sector; as a major consumer with predictable, high load profiles; becomes a strong candidate and beneficiary likely to be of bilateral trading, contract negotiation, and solar PV investment under this scheme [32,36].

Distributed Generators (DGs) such as rooftop solar PV plant operators, microgrid developers, and third-party engineering, procurement and construction (EPC) firms form another pivotal group. With the proposed CTBCM rules enabling them to sell power directly to consumers or aggregators, these stakeholders are no longer consigned to being auxiliary suppliers. Their strategic placement and operation in off-grid or partly grid-connected areas helps cut transmission losses, strengthen local energy supply, and support cleaner energy plans [33].

The role of *electric power traders* is also made eminent under CTBCM, which operate in Pakistan under a regulatory framework established by the National Electric Power Regulatory Authority (NEPRA). These entities serve as intermediate parties facilitating bilateral power purchase agreements (PPAs) between distributed generators and industrial consumers. With increasing volatility in power markets and the rise of variable renewable energy (VRE) generation, traders are essential for aggregating supply, hedging risk, and ensuring contractual stability for industrial clients [4]. Previously

CPPA-G (Central Power Purchasing Agency-Generation) held that role, which is now shifted in competitive market system to ISMO.

National and Regional Regulators, particularly NEPRA, WAPDA (Water and Power Development Authority), and AEDB (Alternative Energy Development Board), serve as critical enablers and supervisory bodies in this new paradigm. NEPRA's licensing reforms and CTBCM market code define the terms for market entry, balancing, and wheeling arrangements (under UoSC) for renewable energy generators [37]. Moreover, provincial energy departments play a policy management role by localizing national-level frameworks into industrial contexts. Among regulatory bodies, the *Council of Common Interests (CCI)* also holds a critical constitutional and strategic role in shaping Pakistan's power sector policy, especially for reforms crossing provincial boundaries. It has approved landmark policies, such as the National Electricity Policy 2021 and the Alternative & Renewable Energy Policy; which explicitly call for expanding renewables, competitive bidding, and transparent market frameworks [38]. For textile exporters, CCI's endorsement of clean energy targets and its authority over transmission, wheeling and tariff frameworks mean that its decisions can unlock or block the conditions needed for CTBCM and large-scale solar adoption. Its role in resolving interprovincial disputes, overseeing regulation of tariff and generation policies, and balancing provincial vs federal interests puts CCI in a unique position to ensure that market liberalization efforts are fair, enforceable, and predictable.

Distribution System Operators (DSOs) and DISCOs (Distribution Companies) such as FESCO and MEPCO, traditionally passive carriers of power, are being repositioned under the CTBCM regime. Their infrastructure facilitates both net metering and bilateral trading. They are required to ensure transparent and fair access to distribution networks, implement smart metering infrastructure, and comply with open-access principles. However, resistance from some of the DISCOs to abandon their legacy monopolies has been observed and documented, which remains a potential barrier in the implementation of full CTBCM functionalities [30,35].

The *Independent System Operator (ISO)*, currently the National Transmission and Dispatch Company (NTDC), ensures real-time power transmission and grid reliability, which becomes more challenging with high renewable penetration from solar PV systems. Their role extends to capacity planning, synchronized scheduling, and maintaining grid codes which include provisions for frequency, voltage control, and intermittent generation management [30].

Investors and Financial Institutions also emerge as stakeholders, particularly in the capital-intensive solar PV deployment. Under CTBCM, clear revenue streams via long-term PPAs and merchant market options create an environment with high investment opportunities and diverse financing mechanisms supporting both financing bodies and customers for renewable energy projects.

Instruments like green bonds, green financing schemes, risk mitigation guarantees, and viability gap funding (VGF) mechanisms are increasingly being used to support such transitions [33].

Lastly, *Environmental and Trade Policy Stakeholders*, including Ministry of Climate Change, Sustainable Development Policy Institute (SDPI), and CBAM-relevant trade authorities, interconnect with the energy transition pathway. Given that textile exports are subject to international sustainability and carbon compliance benchmarks, the renewable transition of energy inputs becomes a multi-stakeholder concern, directly influencing market access and competitiveness [39].

To sum up, the CTBCM-aligned renewable energy transition in Pakistan reconfigures traditional roles into a more independent, market-responsive, and decentralized framework. Each stakeholder's participation is integral not only to the technical and economic success of solar PV deployment but also to the strategic alignment of Pakistan's energy systems with regional and global decarbonization and trade competitiveness goals. Existing structure of power sector entities in Pakistan is presented in **Figure-6,** which are responsible for policy formulation, planning, implementation, operation, and maintenance, to provide electricity to the consumers [40]:

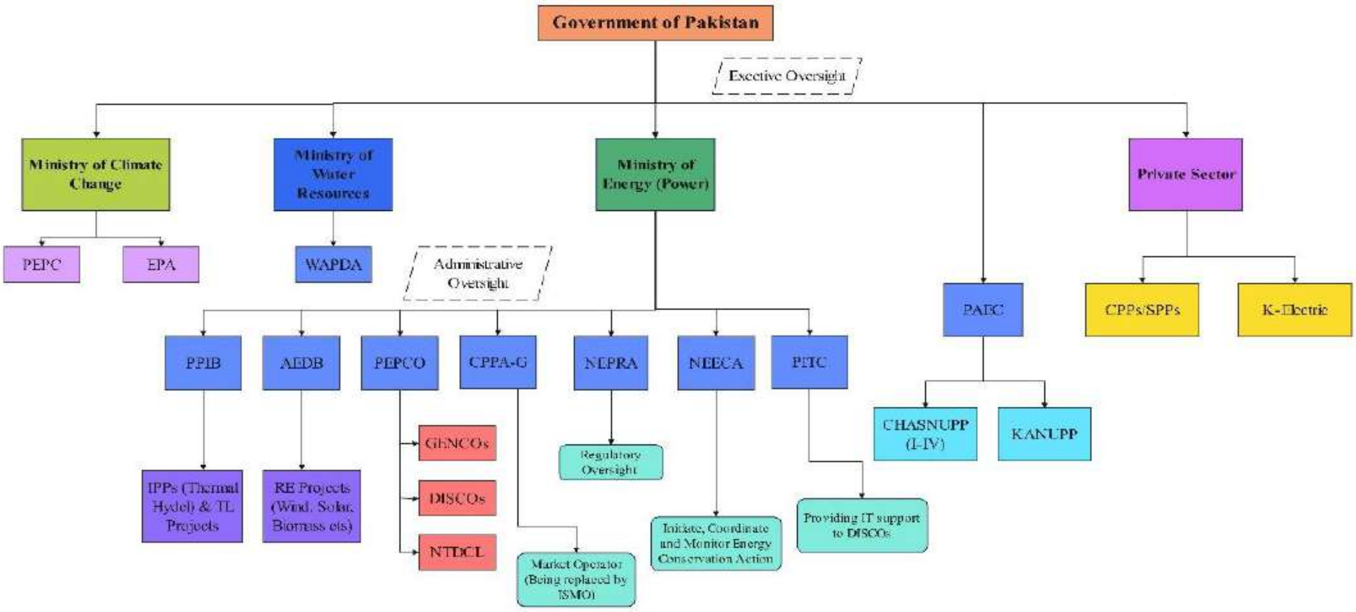

Figure 6: Power Sector's institutional Profile for development of RE projects in Pakistan (Existing Structure of Power Sector Entities in Pakistan)

Key: PEPC – Pakistan Environmental Protection Council, EPA – Environmental Protection Agency, WAPDA – Water and Power Development Authority, PPIB – Private Power and Infrastructure Board, AEDB – Alternative Energy Development Board, IPPs – Independent Power Producers, TL – Transmission Lines, RE – Renewable Energy, PEPCO – Pakistan Electric Power Company, CPPA-G – Central Power Purchasing Agency (Guarantee) Limited, GENCOs – Generation Companies, DISCOs – Distribution Companies, NTDC – National Transmission and Dispatch Company Limited, NEPRA – National Electric Power Regulatory Authority, NEECA – National Energy Efficiency and Conservation Authority, PITC – Power Information Technology Company, ISMO – Independent System and Market Operator, PAEC – Pakistan Atomic Energy Commission, CHASNUPP – Chashma Nuclear Power Plant, KANUPP – Karachi Nuclear Power Plant, CPPs – Captive Power Plants, SPPs – Small Power Producers.

1.6 Policy Frameworks supporting solarization by textile industries

1.6.1 Federal Policy Frameworks: Ambition vs. Ground Reality

Alternative & Renewable Energy (ARE) Policy 2019

- *Incentives* [41]*:*
  - **Income Tax Exemption:** 100% tax holiday for renewable projects until 2025 but withdrawn in June 2023.
  - **Customs Duty Waivers:** Zero duty on solar modules, inverters, batteries also proposed.
  - **Sales Tax Relief:** Exemption on raw materials for solar panel manufacturing / solar panel sales (2024–25 Federal Budget) but withdrawn in FY2025-26 budget [42].
- *Gaps: Vague applicability to third-party wheeling projects under CTBCM; no explicit provision for group captive models.*

1.6.2 Financial Enablers in renewable sector policies

Table 2 shows the financial incentives offered by various organization in RE adoption in Pakistan.

Table 2: Financial incentives in RE policies: Bridging the CAPEX gap [43–45]

Instrument	Textile Sector Applicability
State Bank of Pakistan (SBP) Financing Scheme	Subsidized markup (≤6%)
	Loans up to PKR 400M (≤1 MW)
	PKR 6B (1–50 MW) for 12 years
IFC/ADB Green Credit Lines	$500M pooled facility
	Tenors up to 15 years
Energy Efficiency Grants (AEDB)	50% subsidy for energy audits
	Technical assistance for hybrid retrofits

1.6.3 Punjab's Industrial Push

Punjab has been actively promoting industrial growth through infrastructure development, investment facilitation, and sector-specific energy solutions. The Punjab government is increasingly binding industrial solarization into its incentive strategy for textile hubs. The Punjab Industrial Estates Development and Management Company (PIEDMC) manages multiple industrial estates, including M-3 Industrial City in Faisalabad, with a focus on creating ready-to-operate plots, utility connections, and ease-of-business processes to attract investors. Recent initiatives have encouraged renewable energy adoption within these estates by facilitating partnerships between industrial units and solar solution providers, reducing dependence on grid electricity. In industrial estates under PIEDMC (such as Sundar Industrial Estate and Faisalabad Industrial Estate), textile mills are partnering with solar firms to shift portions of their power load to solar, reducing reliance on expensive grid electricity and improving production cost competitiveness [46]. Punjab has also struck a deal to establish a solar-panel manufacturing facility in partnership with a Chinese company, which will help lower input costs for textile mills seeking to build or retrofit solar capacity [47], and active talks are also being undergone for shifting markets from NM regulatory framework towards CTBCM roadmap.

1.7 Privatization of Electricity Markets under CTBCM – An emerging Industrial game changer; Status, Challenges, Implications and beyond

Under this proposed setup, textile mills can now:

1. Procure solar via wheeling, i.e. buy power from off-site solar farms, independent IPPs (near production site) via bilateral PPAs, utilizing DISCO grids for transport and paying use of system charge (UoSC).
2. Sell surplus, i.e. export excess captive solar to other CTBCM licensees through mutually agreed "trading tariffs".
3. Optimize hybrid portfolios, i.e. combine on-site PV, wheeling contracts, and grid backup under single energy setup creating optimized electricity generation and consumption.

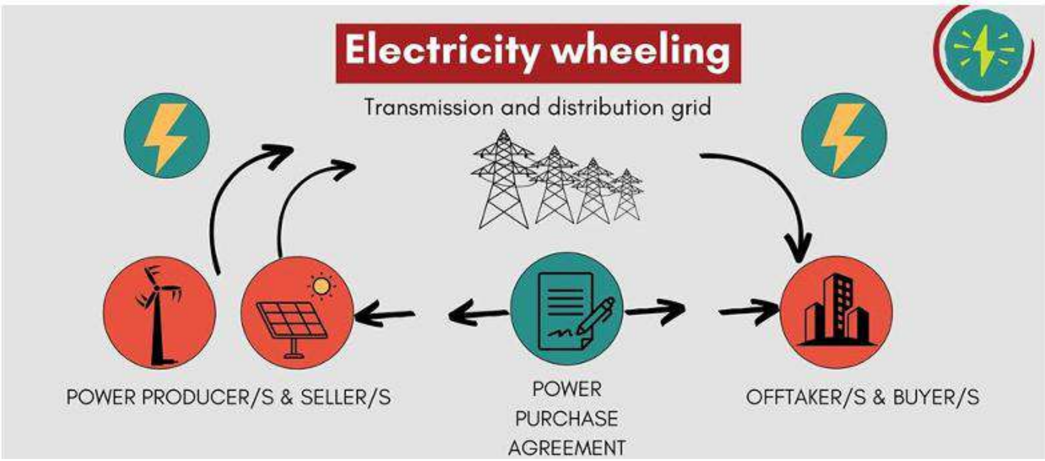

Figure 7: Wheeling mechanism in CTBCM adoption [36]

CTBCM has the potential to be transformative for Pakistan's textile sector, but whether it truly becomes a game changer depends on how several stakeholder groups behave and whether current demands get addressed in realistic and fair policy. Nearly every large mill operates its own power plant (often fueled by subsidized natural gas) just to avoid load shedding. The viewpoint of large textile firms confirms this: industries "do not use the electricity grid because [gas] subsidy makes the grid uneconomic as compared to captive generation, and because the grid is unreliable" [48]. The result is a dual-subsidy waste: the government pays for idle generation capacity on the grid and for cheap gas to industrial CPPs. Textile operators note that, despite surpluses on paper, distribution losses and administrative constraints prevent affordable grid access. Indeed, building or upgrading grid connections for mills can cost billions PKR and take years [49]. Economically, Pakistan's industrial tariffs are among the region's worst, roughly 30–60% higher than neighboring Bangladesh or India [50,51]. This energy premium, combined with outdated machinery and infrastructure gaps, has made Pakistani textiles globally uncompetitive and has even driven industrial decline in some parts of Punjab.

Keeping this reality in view, the textile industry (led by APTMA and related exporters) is openly in favor of CTBCM; mills see it as a route out of crippling grid tariffs, irregular power supply, and uncompetitive energy costs. They are demanding wheeling charges in the range of *1–1.5 cents/kWh*, removal of extraneous costs (cross-subsidies, stranded costs), and predictable tariff design [52–54]. Wheeling charges are the charges imposed by NEPRA to utilize the grid as a medium for bilateral electricity contracts. In grounded terms, textile mill representatives are pragmatic: CTBCM can deliver real benefits; lower daytime energy costs where wheeling and trading prices are favorable, additional revenue from selling surplus solar at competitive rates, and better optimization of hybrid portfolios combining on-site PV, wheeled solar and grid/captive backup; but only if market rules are simple and predictable. Large mills (for example, Interloop, Tayyab and Sapphire) report measurable bill reductions from daytime solar (under current net-metering) and view wheeling as a practical way to monetize rooftop or nearby solar farms and meet export buyers' green requirements. Smaller firms and many SMEs, however, are worried: high or opaque Use-of-System Charges erase savings; contracting and registration processes are slow and legalistic; and the costs of MRV, metering and third-party verification are real barriers [36]. Industry associations therefore press for lower eligibility thresholds so smaller firms can pool, standardized PPA templates, and a one-window contracting helpdesk; otherwise liquidity is too thin and price risk too large to justify moving away from captive fuels. Technically, local grid limits (transformer capacity, feeder strength and voltage control) are recurring constraints: several mills reported export curtailment or reverse-flow worries until distribution upgrades are completed.

Government behavior so far is mixed: there is public commitment, consultation, and inclusion of CTBCM in policy documents, but administrative caution and legacy financial burdens (capacity payments, cross-subsidy obligations) threaten to undermine viability. Proposed high wheeling charges (previously PKR 27 per unit) raised industry alarm, though a recent fixation around PKR 12.5 per unit has been broadly welcomed as a hopeful step toward viable trading [54,55]. IPPs and GENCOs occupy a cautious middle ground: they could benefit from larger, more liquid contracts under CTBCM but many hold existing PPAs that guarantee revenue under old rules and thus fear loss of fixed payments or exposure to competitive risk; their interest in participating is conditioned on clear protections. The Council of Common Interests (CCI) and the wider industrial-export community express conditional optimism: they see CTBCM as a route to export competitiveness and carbon compliance but insist on transparency, correct cost placement and accelerated policy reform if CTBCM is to move beyond theory into practice. If CTBCM is structured with affordable wheeling **(≈1–2 cents/kWh as proposed by**

APTMA), exclusion of irrelevant costs, clear treatment of legacy PPAs, and reliable policy guarantees, it could reduce energy costs for textile mills by several cents per kWh, improve reliability during peak hours, and align exports with emerging carbon compliance norms. If wheeling stays high, costs remain unpredictable, or IPPs' obligations remain opaque, CTBCM risks becoming another reform that looks promising on paper but leaves textile mills with only marginal improvement; or worse, new cost burdens.

Textile industry voices have made their position plain: leading figures publicly demanded swift CTBCM implementation at a July 2024 conference, arguing that competitive energy pricing is essential for survival in global markets [56]. Environmental advocates note CTBCM permits firms to "procure clean energy directly from developers" under bilateral contracts, helping reduce scope-2 emissions. Yet many factories report poor outreach and guidance on CTBCM rules; officials often seem disconnected from ground realities and many factory owners are still unaware of CTBCM [57]. This communication gap, combined with concerns about potential excessive network charges and slow progress on practical market mechanics, has created skepticism: mills that invested millions in solar fear delays and opaque charges will undermine their gains. Thus, while the industry recognizes CTBCM's potential for lower costs and greener power, stakeholders remain impatient and demand clear, enforceable rules and rapid, well-designed pilots that prove benefits without shifting hidden costs onto producers.

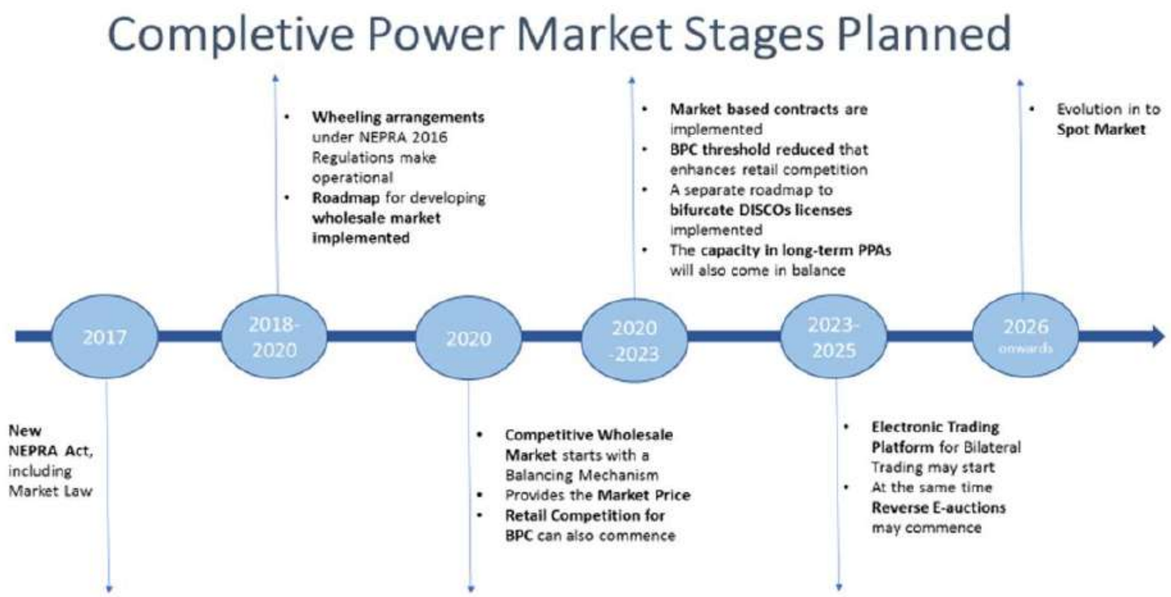

Figure 8: Roadmap for CTBCM adoption [58]

Table 3: Stakeholder Perspectives on CTBCM (2025) [30,59,60]

Stakeholder	Position	Key Concern

NEPRA	CTBCM enables "choice and competition"	Slow DISCO restructuring
Textile Industry	Supports supplier choice but seeks lower caps (e.g., 0.5 MW)	High transmission costs due to UoSC
Independent professionals and analysts	"Delusion of a market", i.e. cautiously optimistic but warn CTBCM needs PPA and market fixes	Risk that powerful incumbents and slow reforms could block real benefits

1.8 Rationale and Scope

This study responds to clear, practical barriers which block scalable solar and market reform in Pakistan's textile hubs. Current rules for net-metering and distributed generation (NEPRA 2015 and later) helped start rooftop PV but remain weak for industrial clusters: export limits, tariff accounting, licensing changes and uncertain allocation of losses all raise investor risk and weak returns [61,62]. CTBCM promises to remove some constraints by enabling bilateral trades, but core implementation details; wheeling under UoSC, standardized PPA clauses, loss allocation, settlement and dispute processes; are unresolved or uneconomical for many mills. High wheeling and inconsistent tariffs can wipe out levelized cost advantage of solar for smaller plants, and mixed NM/GM/CTBCM rules create vague, risky returns that discourage investment [1,52,63].

Technical, financial and market pressures make action urgent. Many mills run captive gas or diesel plants for reliability, but these carry high fuel cost, low efficiency and local environmental degradation, and they expose firms to tariff shocks and supply risk [2,64]. Rapid solarization must be accompanied by better interconnection standards, time-resolved metering, distribution upgrades and curtailment management to avoid reverse flows and voltage issues which negatively impact dense clusters [65]. Financing remains a bottleneck for SMEs: high upfront cost, short loan tenors and uncertain wheeling/PPA rules limit third-party and group-captive models [40,66]. Finally, export and environmental pressures make measurable decarbonization essential; on-site solar plus robust MRV can cut Scope-2 emissions and reduce exposure to carbon compliance costs such as CBAM, while improving market access [63,67]

By focusing on two of Pakistan's largest textile hubs, this study provides a representative analysis of industrial energy dynamics in context of Pakistan as a developing-country. The integration of GIS-based solar mapping, stakeholder surveys, and detailed cost-benefit analysis under multiple regulatory regimes ensures comprehensive presentation of pros and cons of renewable adoption under CTBCM regime. Moreover, synchronizing findings with CBAM compliance offers both short-term and long-term strategic insights. Eventually, the report aims to bridge technical, financial, environmental and policy divides to enable a resilient, low-carbon future for Pakistan's textile industry. The overarching problem is therefore not simply "can textile mills install more PV?" but rather: How can textile mills took advantage of solarization and CTBCM implementation and how can NEPRA effectively align metering and wheeling rules with textile recommendations, and design financing and PPA templates so that textile clusters can cost-effectively and credibly decarbonize while preserving reliability and export competitiveness.

In addition, this proposed mechanism provide solutions to all the problems listed above prevailing in textile sector. With the right enabling environment, these systems can also support *microgrid architectures, blockchain-based energy trading, and VPPs* in the future, aligning with recent trends of digitalization and decentralization in the energy sector [68,69].

1.9 Summary

This chapter sets the stage by linking the strategic importance of Pakistan’s textile industry to the urgent need for a reliable, affordable and low-carbon power supply. It highlights how chronic grid instability and rising energy costs have pushed mills toward captive generation and growing adoption of on-site solar, while also exposing them to fuel volatility and competitive risk. Thus, for Pakistan's crucial textile sector; a major exporter and employer; this shift presents both a challenge and an opportunity. Pakistan's power sector has undergone reforms, moving from a state-monopoly to introducing models like net metering and gross metering to encourage renewable energy. However, these are limited for large-scale industrial use. The emerging CTBCM model is a transformative policy that allows large consumers, like textile mills, to buy power directly from generators through bilateral contracts. This can enable cheaper, greener electricity procurement via solar power and wheeling. Yet, its implementation faces hurdles like regulatory complexity, high operational charges, and institutional resistance. The study aims to explore how CTBCM can enable the textile industry to adopt renewable energy through direct power purchase agreements, thereby improving sustainability in economic and environmental performance. Key stakeholders, including regulators, DISCOs, and industries, are identified, along with the technical, economic, and policy barriers that need to be addressed for successful implementation. Also, the study aims to analyze these frameworks, specifically for the textile hubs of *Faisalabad and Multan*, to provide a roadmap for integrating renewables under CTBCM, thereby improving competitiveness, reducing operational costs, and meeting climate goals. Thus, understanding the techno-economic feasibility and trade-offs of solar/captive power systems under the new CTBCM regime becomes essential: it promises not just cost savings, but resilience, environmental compliance and long-term competitiveness. The lesson is simple: policy design (tariffs, wheeling, metering, measuring, reporting and verification (MRV) for carbon) determines whether industries see competitive markets as an opportunity or a risk.

Chapter 2: Methodology of Study

2.1 Content of the anticipated report:

The study is divided into three major phases:

Phase 1: Inception, stakeholder mapping, data collection & solar potential assessment

1. Literature review and policy alignment

2. Stakeholder Identification

3. Solar mapping and industrial surveys

4. GHG emission calculations

Phase 2: Techno-economic, regulatory analysis, stakeholder engagement & co-design

1. Techno-economic modeling

2. CTBCM Integration and policy gap analysis

3. Workshops & Consultations

4. B2B Partnership Models

Phase 3: Roadmap development, advocacy, dissemination & monitoring

1. Integration roadmap (short, medium and long-term)

2. Policy Briefs & Advocacy

3. Seminars

4. Policy recommendations

2.2 Expected Outcomes and Final deliverables:

1) Expected outcomes

- **Technical**: % reduction in grid/gas dependency via solar (fossil-fuels phase out) and related implications.
- **Economic**: % lower energy costs, CBAM savings of PKR/year, % higher IRR and ROI achieved.
- **Policy**: Revised CTBCM rules to enable private solar procurement.

2) Final deliverables: Techno-economic models, CBAM routes, policy briefs, and a stakeholder-endorsed roadmap.
3) The adopted analysis framework ensures alignment with Pakistan's energy transition goals, CTBCM privatization, and EU market access while fostering B2B solar growth in textiles.

Flowchart of methodology: Scoping Study on Solar PV Integration in Textile Sector

The flowchart in **Figure-9** shows alignment with **green business transformation** (profit efficiency, ESG branding), privatization, while fostering stakeholder collaboration at each stage.

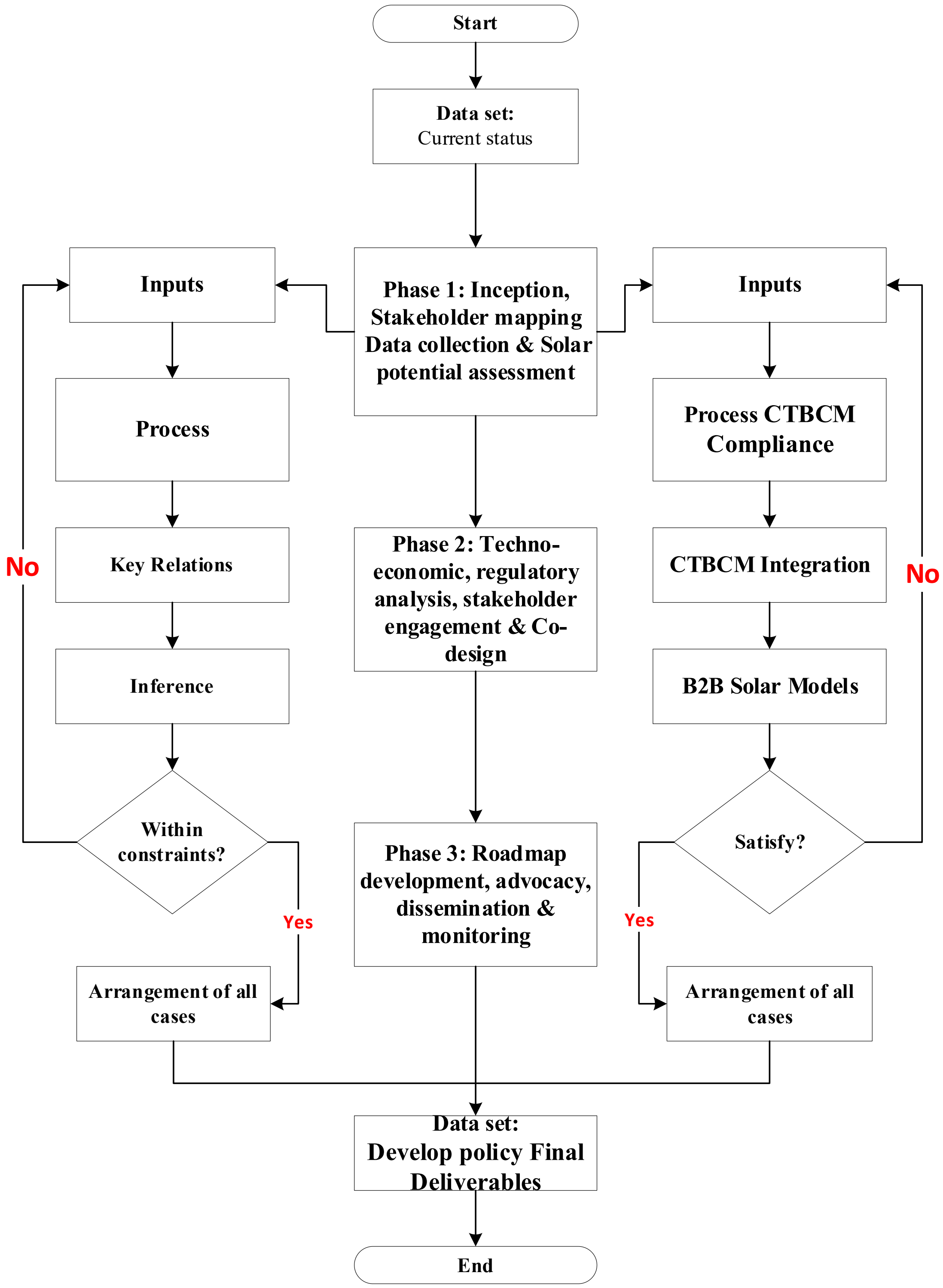

Figure 9: Detailed methodology of proposed study.

Phase 1: Inception, stakeholder mapping, data collection & solar potential assessment

Inputs:

- Framework, regulations, ADS/AREC objectives.
- GIS tools, textile unit surveys, energy audits.

Process:

- Desk review → Policy alignment
- Stakeholder identification → Regulators, industry, financiers, advisors.
- GIS solar mapping → Rooftop/land potential.
- Energy dependency → Grid/gas dependency analysis.
- GHG assessment → Carbon footprint calculation.

Output:

- Stakeholder matrix, inception report.
- Solar potential maps, GHG baseline data.

Stakeholders:

- Textile units, NEPRA, APTMA, etc., solar developers.

Phase 2: Techno-economic, regulatory analysis, stakeholder engagement & co-design

Input:

- Energy consumption data and rules.
- Techno-economic models, policy gaps.

Process:

- LCOE comparison → Solar vs. grid/gas.
- CTBCM privatization analysis → Third-party solar suppliers.
- Policy gap identification → Wheeling, net metering.
- Workshops → B2B solar partnerships (group captive models).
- Financial product design → Green loans for CAPEX.

Output:

- Techno-economic models, policy gap report.
- Partnership frameworks, co-designed solutions.

Stakeholders:

- Solar developers, NEPRA, Financiers, and solar developers.

Phase 3: Roadmap development, advocacy, dissemination & monitoring

Input:

- Co-designed solutions, policy gaps.
- Final roadmap, policy briefs.

Process:

- Roadmap drafting → Short/medium/long-term actions.
- Policy briefs → Compliance guidelines, tax rebates.
- Seminars → Training on solar O&M and reporting.
- Monitoring framework → Track adoption rates, GHG reductions.

Output:

- Decarbonization roadmap, advocacy materials.
- Stakeholder workshops, monitoring dashboard.

Stakeholders:

- Policymakers, EU delegation, APTMA, textile units, regulators.

Key relationships & feedback loops

- **Regulators** ↔ **Industry**: Policy reforms ↔ Industry adoption.
- **Solar Developers** ↔ **Textile Units**: B2B PPAs ↔ Profit efficiency.
- **EU** ↔ **Pakistan**: Compliance ↔ Emission reporting standards.

Unlike generic renewable assessments, this study anchors its analysis in **site-specific realities**:

- **Primary Infrastructure Mapping:** Accounting for 1,043 MW captive capacity in Faisalabad alone (across 40 textile industries), categorizing plants into seven power-source profiles (e.g., gas-only, solar-grid hybrids, tri-hybrids).
- **GIS Solar Assessment:** High-resolution satellite analysis of 20 facilities (15 in Faisalabad, 5 in Multan), validating 162.5 MW of installed PV and identifying 27.3+ hectares of untapped rooftop potential at GHI of 1,947–1,952 kWh/m^2/yr.
- **Policy-Integrated Modeling:** Simulation of eight deployment scenarios; from business-as-usual to partial-to-full CTBCM integration; to isolate optimal thresholds (e.g., CTBCM viability >500 kW systems under net metering) in techno-economic and environmental perspective and evaluating performance metrics at variable configurations.

2.3 Summary

As Pakistan stands at the verge of energy market privatization and green industrial transformation, this study provides the directional vision to turn solar potential into profit, policy into practice, and compliance into competitive advantage. This chapter outlines a three-phase methodology for integrating solar PV into Pakistan's textile sector. Phase 1 involves foundational work: conducting a literature review, mapping stakeholders, and using GIS to assess the solar potential and carbon footprint of industrial hubs. Phase 2 is the analytical core, featuring techno-economic modeling to compare energy costs and a regulatory analysis of the CTBCM framework to identify policy gaps, all informed by stakeholder workshops. The final phase focuses on synthesizing these findings into a practical decarbonization roadmap and actionable policy briefs. The expected deliverables include techno-economic models, CBAM compliance strategies, and a stakeholder-endorsed plan to reduce energy costs and GHG emissions through scalable solar adoption.

Chapter 3: Mapping existing energy infrastructure of textile industries in Faisalabad and Multan

3.1 Visualizing current energy context in selected textile hubs:

In this section, *power sector (energy infrastructure) mapping for textile industries of targeted regions, data extraction and preliminary analysis regarding solar PV integration under CTBCM regime* is comprehensively performed. Critical mapping ensures current power allocation across various sample textile industries, to assess renewable potential among those industries. Also, it evaluates the power production mix for various selected textile mills in Faisalabad and Multan. This section reports on a sample of **80** textile mills (50 in Faisalabad, 30 in Multan), examining their on-site power mix. Table shows the list of textile industries being surveyed/data gathered through critical engagement with stakeholders (particularly NEPRA, DISCOs, APTMA etc.):

Table 4: Textile Industries Analyzed in this study in selected industrial hubs, i.e. Faisalabad and Multan

Faisalabad (1)	Faisalabad (2)	Multan (1)	Multan (2)
A.A Spinning Mills	Loyal Textiles	Ahmad Hassan Textile Mills Ltd.	Three Stars Hosiery Mills
Abdullah Fibres (Pvt) Ltd.	Lucky Textile Industries Ltd.	Ahmed Fine Textile Mills Ltd.	Zephyr Textile
Ahmad Din Textile Mills (Pvt) Ltd.	Malik Textiles (Pvt) Ltd.	Al-Rahim Textiles	Zahra Textile Industries / Zahra Tent Industries
Al Ghafoor Industries	Masood Textile Mills	Alhamd Corporation (Pvt) Ltd.	—
Al Jilanee Textile Mills Ltd.	Master Textile Mills Ltd.	Alpha Textiles	—
Al-Habib Dyeing	Modern Apparels	Chaman Sultana Fabrics (Pvt) Ltd. *(Yousafzai Brothers Group)*	—
Al-Karam Textile Mills Ltd.	M/S United Textile Printing Industries (Pvt) Ltd.	Colony Textile Mills Ltd.	—
Aslam Textile Mills Ltd.	M/S Usman Cloth Mills (Pvt) Ltd.	Euro Linen Private Limited	—
Ayesha Spinning Mills (Pvt) Ltd.	Munir Textile Industries	Fazal Cloth Mills (All Units)	—
Bhanero Textile Mills (Pvt) Ltd. *(Umar Group)*	Nafees Textiles Ltd.	Fatima Textile Mills *(Fatima Group)*	—
Chenab Ltd.	Nishat Mills Ltd.	Finetex Trade (Textiles)	—
Crescent Bahuman Ltd.	Nishat Tek Ltd.	Gadoon Textile Mills Ltd. *(Yousafzai Brothers Group)*	—

Crescent Textile Mills Ltd.	Noor Fatima Fabrics	HBR Textiles	—
Fazal Cloth Mills	Sadaqat Ltd.	Hussain Mills Ltd.	—
Gatron Industries Ltd.	Sana Industries	MA Industries	—
Ghazi Fabrics International Ltd.	Sapphire Fibres Ltd.	Mahmood Group (Mahmood Textile Mills)	—
Gohar Textile Mills (Pvt) Ltd.	Sapphire Finishing (Pvt) Ltd.	Masood Roomi	—
Gulistan Textile Mills Ltd.	Sapphire Textile Mills Ltd.	Masood Textile Mills Ltd.	—
Haroon Corporation	Shahzad Textile Mills	MG Apparel	—
Hilal Textile Corporation (Pvt) Ltd.	Sharif Textile Industries	Nafeesa Textiles Ltd.	—
Ibrahim Fibres Ltd. *(Ibrahim Group)*	Sitara Chemical	Rahimbaksh Textile Mills Ltd. (RYK Mills)	—
Ibrahim Textile Industries *(Ibrahim Group)*	Tayyab Group (partnered with Anhui Hasun Energy)	Reliance Weaving Mills Ltd. *(Fatima Group)*	—
Interloop Limited	Zahidjee Textile Mills Ltd.	Riaz Textile Mills	—
Kamal Limited	—	Roomi Fabrics Ltd. *(Fatima Group)*	—
Kohinoor Genertek	—	Shujabad Textile Mills Ltd.	—
Libas Group	—	Tanveer Textiles	—

3.2 Assessment of Power Dependency

Almost 50 facilities in Faisalabad and thirty in Multan (as per gathered data) are reviewed in this study. Each was classified by primary fuel source:

- **Thermal (Gas/Coal/Oil)**: Captive generation using fossil fuels
- **Renewable (Solar/Wind)**: On-site PV or wind turbines
- **Grid**: Reliance on national grid connection (backup or primary)

It reveals that captive thermal generation (gas/coal/oil) dominates, powering approximately 62.8% of facilities as a primary power resource, whereas renewable sources (solar + wind) are adopted by about 9-10% of mills (neglecting the integrated power generation). The data from Faisalabad show:

- **Captive thermal only (Gas/Coal/Oil):** 12 mills (15%) accounting for 273.8 MW (26.3% of total sampled capacity)
- **Renewables only (Solar):** 2 mills (2.5%) / 65.3 MW (6.3%)

- **Grid-only:** 15 mills (18.8%) / –
- **Hybrid (Gas + Solar):** 9 mills (11.3%) / 286.2 MW (27.4%)
- **Hybrid (Gas + Grid):** 13 mills (16.3%) / 94.95 MW (9.1%)
- **Hybrid (Solar + Grid):** 13 mills (16.3%) / 28.61 MW (2.7%)
- **Tri-hybrid (Gas + Solar + Grid):** 16 mills (20%) / 294.36 MW (28.2%)

Faisalabad alone (40 sites, excluding pure-grid and unavailable data) hosts *1043 MW* of on-site capacity broken down as shown above, confirming that hybrid configurations (*Gas + Solar ± Grid*) constitute over 65% of capacity and tri-hybrids represent the single largest share *(28.2%)*. Multan's 30-mill sample echoes this diversification trend, with 20% tri-hybrid adoption. Grid connections remain essential: though pure grid-only mills account for 18.8% of plants, 62% of all sampled mills use the DISCO network (FESCO/MEPCO) as a backup. Solar PV capacity totals 145 MW in Faisalabad *(≈12% of local captive capacity*) and 91.96 MW in Multan (≈18%), illustrating solid but still partial adoption.

3.2.1 Analyzing data from Faisalabad cluster

Table 5 shows capacity-wise mapping of energy mix of selected industrial hubs in Faisalabad:

Table 5: Capacity-wise Power resource mapping in Faisalabad (Sample)

Listed Technologies (Faisalabad) (Sample considered, 40 sites total, excluding Unavailable data and Grid)		
Category	**Capacity (MW)**	**% of Total Capacity**
Gas only	273.8	26.25%
Solar only	65.3	6.26%
Gas + Solar	286.2	27.43%
Gas + Grid	94.95	9.10%
Solar + Grid	28.61	2.74%
Gas + Solar + Grid	294.36	28.22%
Total	**1043.22**	100.00%

The capacity breakdown in Faisalabad reveals a pronounced shift toward hybrid solutions: while purely gas-fired plants still account for roughly a quarter of installed capacity (273.8 MW, 26%), the largest single share belongs to mixed gas + solar + grid tri-hybrid systems (294.4 MW, 28%). This reflects mills hedging against gas supply disruptions and high fuel costs by integrating solar PV and can be targeted for adopting retaining grid backup under CTBCM wheeling schemes. The sizeable gas + solar segment (286.2 MW, 27%) further shows accelerated PV adoption, enabled by net-metering and emerging wheeling tariffs; while solar/wind standalone projects (65.3 MW, 6%) hint at early movers testing purely renewable models. As CTBCM matures, tri-hybrid plants are well positioned to increasingly adopt or leverage bilateral PPAs for cheaper solar off-take during daytime peaks, use grid when competitive, and fall back on captive gas in low-sun periods, maximizing cost savings and reliability.

A total of *40 industries from the Faisalabad textile cluster* have also been selected as a representative sample for detailed *techno-economic and environmental analysis* under broader scenarios. The study includes examination of electricity generation capacities, self-consumption, surplus trading potential, renewable integration opportunities, and comparative performance indicators with the Multan textile cluster for strategic sectoral insights.

3.2.2 Analyzing data from Multan cluster

The data presented below excludes integration, and describes power consumption strategies of selected textile markets in Multan.

- **Total facilities**: 30
- **Thermal dependency**: 17 mills → **56.7%**
- **Renewable adoption**: 15 mills → **50.0%**
- **Grid connection**: 24 mills → **80.0%**

This numerical data illustrates the heavy reliance on captive fossil systems, Grid backup and the nascent but growing uptake of renewables in the textile sector.

Table 6 shows capacity-wise mapping of energy mix of selected industrial hubs in Multan:

Table 6: Plant-wise Power resource mapping in Multan (Sample)

Multan		
Category	**# Plants**	**% of Total**
Gas only	2	6.67%
Solar only	0	0.00%
Grid only	8	26.67%
Gas + Solar	4	13.33%
Gas + Grid	5	16.67%
Solar + Grid	5	16.67%
Gas+Solar+Grid	6	20.00%
Total	**30**	**100%**

3.3 Solar PV Facilities by City

3.3.1 Faisalabad

Current solar PV adoption among selected industries in Faisalabad are shown in **Table 6**.

Table 6: Existing Solar adoption by textile companies in Faisalabad (Sample)

Producer	Solar Capacity (MW)	% of Local Capacity (Sample)[1]
Ahmad Din Textile Mills	5	3.45%
Al-Karam Textile Mills	5.2	3.59%
Crescent Textile Mills	3.5	2.42%
Crescent Bahuman Ltd.	8	5.53%
Gatron Industries Ltd.	7.31	5.05%
Ibrahim Textile Industries	5.2	3.59%
Ibrahim Fibres Ltd.	3.54	2.45%
Interloop Limited	16.6	11.47%
Kamal Limited	2.8	1.93%
Libas Group	0.1	0.07%
Malik Textiles (Pvt) Ltd.	0.3	0.21%
Modern Apparels	0.2	0.14%
Nafees Textiles Ltd.	0.5	0.35%
Nishat Mills Ltd.	14.2	9.81%
Sadaqat Ltd.	1	0.69%
Sapphire Textile Mills Ltd.	16	11.05%
Sana Industries	0.2	0.14%
Sitara Chemical	1	0.69%
Tayyab Group	20	13.82%
Lucky Textile Industries Ltd.	12	8.29%
Gohar Textile Mills Pvt Ltd.	18.8	12.99%
Loyal Textiles	3.3	2.28%
Total	**144.75**	**100%**

[1] Percentages relative to the sum of solar capacities in Faisalabad (only shown for industries considered (sample), actual figures may vary).

3.3.2 Multan

Current solar PV adoption among selected industries in Multan is shown in **Table 7**.

Table 7: Existing Solar adoption by textile companies in Multan (Sample)

Producer	Solar Capacity (MW)	% of Local Capacity (Sample)[2]
Masood Roomi	20	22%
Mahmood Group	15	16%
Ahmad Hassan Textile Mills Ltd.	0.95	1%
Alhamd Corporation (Pvt) Ltd.	1	1%
Allawasaya Spinning Mills Ltd.	0.5	1%
Allawasaya Textile & Finishing	3	3%
Nafeesa Textiles Ltd.	Not mentioned	—
MG Apparel	2	2%
Reliance Weaving Mills Ltd.	7.3	8%
Roomi Fabrics Ltd.	14	15%
Zephyr Textile	0.5	1%
Riaz Textile Mills	3.2	3%
Gadoon Textile Mills Ltd.	2.9	3%
Fazal Cloth Mills	21.61	23%
Total	**91.96**	**100%**

[2]Percentages relative to the sum of solar capacities in Multan (only shown for industries considered (sample), actual figures may vary).

3.4 Collective breakdown of Power Utilization

3.4.1 Plant-wise Power Mapping

Below are the capacity and shares of *all 80 facilities* in Faisalabad and Multan by their on-site power-generation "mix." Each plant is classified by whether it uses Gas, Solar, Grid (as a primary or backup supply), in any combination.

Table 8: Cumulative Energy mapping of sample industries across Faisalabad and Multan

Plant-wise Mapping (Sample considered)		
Faisalabad		
Category	**# Plants**	**% of Total**
Gas only	10	20.00%
Solar/Wind only	2	4.00%
Grid only	7	14.00%
Gas + Solar	5	10.00%

Gas + Grid	8	16.00%
Solar + Grid	8	16.00%
Gas + Solar + Grid	10	20.00%
Total	**50**	100.00%
Multan		
Category	**# Plants**	**% of Total**
Gas only	2	6.67%
Solar only	0	0.00%
Grid only	8	26.67%
Gas + Solar	4	13.33%
Gas + Grid	5	16.67%
Solar + Grid	5	16.67%
Gas + Solar + Grid	6	20.00%
Total	**30**	**100%**
Combined		
Category	**# Plants**	**% of Total**
Gas/Thermal only	12	15.00%
Solar/Wind only	2	2.50%
Grid only	15	18.75%
Gas + Solar	9	11.25%
Gas + Grid	13	16.25%
Solar + Grid	13	16.25%
Gas + Solar + Grid	16	20.00%
Total	**80**	**100%**

Notes on classification

- **Gas only**: captive thermal units (NG, HFO or diesel) with no solar or grid connection.
- **Solar only**: pure PV systems with no captive fossil units or grid backup.
- **Grid only**: rely solely on national-grid supply (including in-house grid stations).
- **Gas + Solar**: hybrid captive plants combining gas (or RLNG) turbines/engines with on-site PV but no grid tie.
- **Gas + Grid**: captive thermal plus grid backup (no solar).
- **Solar + Grid**: PV systems that remain grid-tied (no captive fossil unit).
- **Gas + Solar + Grid**: fully integrated "tri-hybrid" sites with captive gas, on-site PV and grid connection.

The data can be visualized as follows:

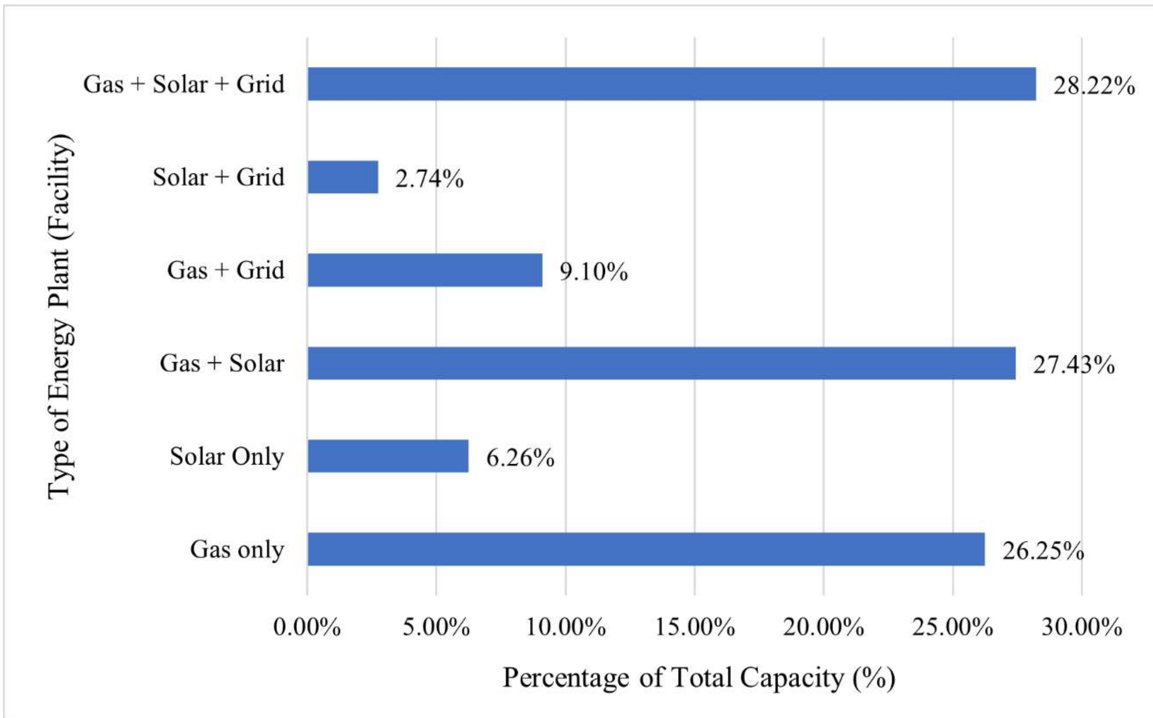

Figure 10: Capacity-wise Plant Data for Faisalabad Textile industries (40 sites total)

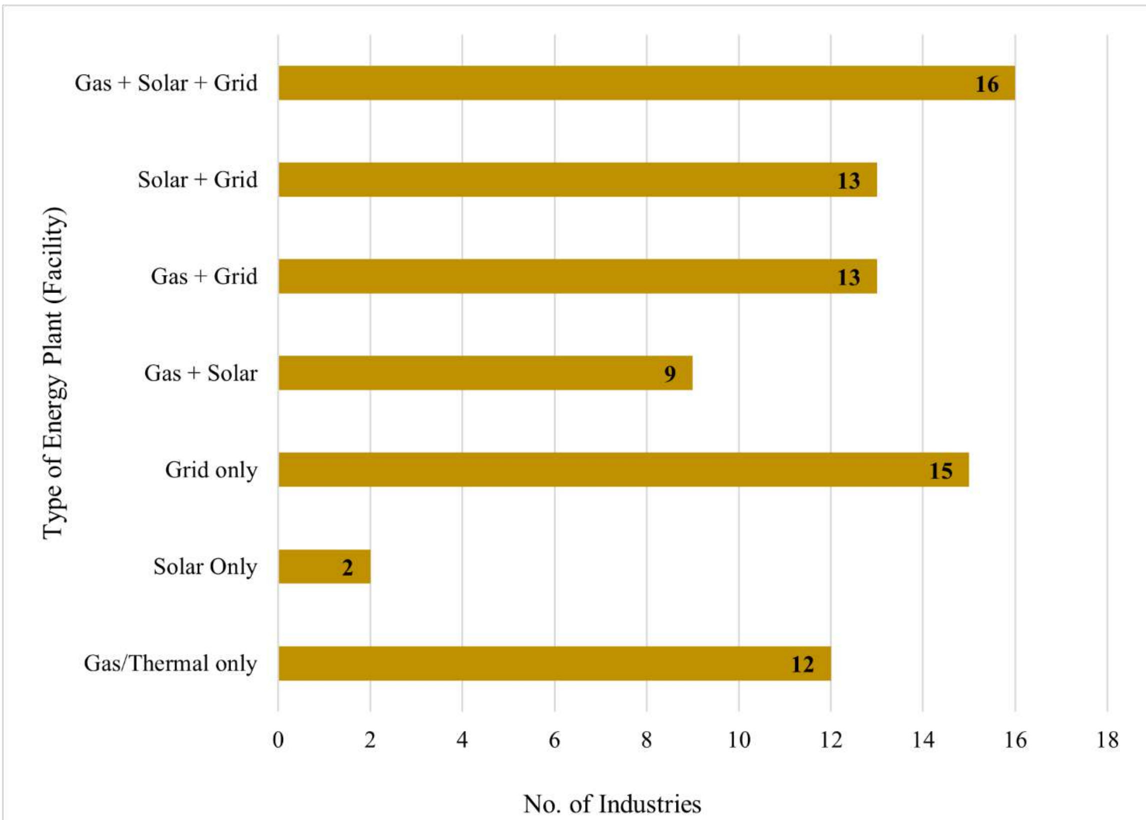

Figure 11: Comparative energy profile of Sample Textile industries (Combined Faisalabad and Multan)

Among 50 Faisalabad mills, one in five has adopted a fully tri-hybrid configuration (20%), while another 10–16% operate gas + solar or gas + grid hybrids. This distribution highlights a rapid industry pivot from single-source captive generation toward diversified sourcing. Tri-hybrids enable textile units to participate in CTBCM auctions; securing competitively priced solar energy via wheeling; yet maintain operational security through captive gas and grid connections. The modest 4% of solar-only sites suggests that most mills still require firm capacity, but the larger 16% solar + grid group demonstrates confidence in net-metering and grid-tie arrangements. And these grid tied systems can be further enhanced in economic effectiveness through advanced and modernized models, particularly based on competitive marketing. These trends indicate a maturing market where hybridization is the dominant strategy for balancing cost, risk, and sustainability.

In Multan, hybrid adoption is already significant: 20% of mills run tri-hybrid systems and 13–17% each operate gas + solar, gas + grid, or solar + grid combinations. Pure grid reliance (26.7%) reflects some mills' willingness to outsource reliability risks to MEPCO despite higher tariffs, whereas the minimal gas-only share (6.7%) speaks to local gas shortages pushing firms toward grid or solar alternatives. The absence of solar-only sites underlines the need for firm backup. Under CTBCM, these hybrid models can contract solar PPAs for a share of their load, use grid wheeling for mid-tier demand, and run captive gas at night or during outages—maximizing financial gains and reducing GHG footprints in this emergent market.

Looking at the combined sample, nearly half or more than half of all the mills (50-60%) employ hybrid or tri-hybrid configurations, signaling a sector-wide transition. Tri-hybrids alone represent 20% of sites, illustrating that the most forward-looking mills are leveraging CTBCM's bilateral trading and wheeling provisions to secure cost-competitive solar while preserving captive and grid resilience. Grid-only (18.8%) and thermal-only (15%) groups are shrinking cohorts as incentives and tariff structures increasingly favor renewables. The 6.2% of solar-only pioneers showcase the long-term vision for fully renewable factories. Thus, these trends signal accelerated PV adoption under CTBCM, as drivers of the industry recognize that hybrid energy portfolios deliver the greatest economic, environmental, and operational benefits.

3.5 Key takeaways, Discussion and Summary

Owing to unreliable grid supply and high automation, textile mills have invested heavily in CPPs, with over 1300 MW of gas-based CPP capacity dedicated to textiles. Off-grid solar PV and modern hybrid plants promise cost savings, improved reliability, and lower emissions (~ 0.6 tCO_2/MWh avoided), especially when combined with the CTBCM to unlock private PPAs. The sector is thus moving from predominantly single-fuel captive plants toward resilient, multi-source configurations, with over *60% of mills* already operating hybrid or tri-hybrid (gas + solar + grid) systems; which tells that mills value flexibility and firm capacity. The data from 80 sampled textile mills (50 in Faisalabad, 30 in Multan) show a clear and practical story: mills are actively experiencing grid unreliability by building mixed power systems rather than merely relying on a single source. Faisalabad leads in installed rooftop and captive PV (≈145 MW in the sample) while Multan shows meaningful uptake too (≈92 MW), but pure solar-only plants are still rare (only ~6% of sites), because textile operations need guaranteed, 24/7 power for sensitive processes. Captive thermal plants remain important (roughly 15% of plants are thermal-only and gas-based captive capacity is large), but they operate at low efficiency compared with grid RLNG units, giving a strong economic and emissions scenario for shifting daytime load to PV while keeping thermal plants as a backup.

From a CTBCM perspective, the hybrid and tri-hybrid footprint is encouraging: these configurations are technically well suited to wheeling daytime solar via bilateral PPAs while keeping captive or grid backup for night and outages. However, the economics are fragile; high UoSC, unclear settlement rules, and licensing around exporting surplus can quickly erode solar's cost advantage for many mills. Operationally, many mills already use the DISCO grid as backup (≈62% of sampled mills), so CTBCM benefits would require transparent wheeling, low losses, and predictable losses/charges to be realized. Thus, the sample highlights practical barriers: administrative burdens for new contracts, limited access to long-tenor finance for mid-sized mills, and weak local capacity for O&M and energy auditing; all of which must be addressed to scale the observed early adoption into a broad industry transition.

Chapter 4: GIS mapping of Solar PV infrastructure

4.1 Design of GIS study

A targeted GIS mapping is carried out to validate and document the existing solar installations on twenty textile plants; fifteen in Faisalabad and five in Multan; using high-resolution Sentinel-2 satellite imagery and ArcGIS Pro's Solar Analyst. After importing each mill's rooftop and boundaries, we ran Global Horizontal Irradiance (GHI) models to estimate the local solar resource, applied a shading mask to remove any areas with more than 30 percent obstruction, and enforced a minimum roof tilt criterion of 15°. We then digitized the actual PV array footprints, yielding georeferenced layers that record both the area and orientation of each installation [70].

Figure 12: GIS Study methodology

The mapping process relied on high-resolution satellite imagery, combined with open-access geospatial datasets and field-verified coordinates of installed solar PV systems. Raster datasets for land use, grid proximity, rooftop availability, and solar irradiance (obtained from the Global Solar Atlas and NASA's POWER platform) were incorporated using ArcGIS Pro 3.1.1 [71]. The spatial resolution for satellite image analysis was kept below 1 m to ensure rooftop-level precision. Layered spatial data was integrated to display not only the exact locations of PV installations but also their capacity clusters, infrastructure typologies (rooftop, ground-mounted, hybrid), and relationship to industrial zoning and transmission corridors [72].

In Faisalabad, these layers confirmed a total of *125.79 MW of installed PV* spread over approximately *28.75 hectares of rooftop and adjacent ground-mounted arrays*. Individual sites ranged from small installations; like Crescent Bahuman's 8 MW system covering 1.75 ha; to large plants such as Tayyab Textile's 20 MW array spanning 4.5 ha. The average GHI across these fifteen sites was about 1947 $kWh/m^2 \cdot yr$, aligning with regional solar resource estimates. Multan sample contributed another *49.85 MW of capacity* mapped across nearly *11.5 hectares*. Mills like Mahmood Textile (15 MW, 3.4 ha) and Fazal Cloth Mills (11.53 MW, 2.6 ha) demonstrated similarly strong solar potential, with an average GHI of 1952 $kWh/m^2 \cdot yr$. These mapping results provide a solid baseline of current PV deployment in the textile sector; an essential first step before exploring how to scale these installations further under the CTBCM framework.

4.2 Textile industries solar mapping for Faisalabad sector

The majority of the mapped solar PV infrastructure is concentrated in the industrial zones along Sheikhupura Road, Satyana Road, M-3 Industrial estate, and Faisalabad Industrial Estate Development & Management Company (FIEDMC). A significant number of rooftop installations were observed on medium-to-large textile mills. Clustering of capacities between 300 kW to 2 MW was evident, primarily under net-metering regimes.

Figure 13: Al Karam Textile Mills GIS Solar Tracking

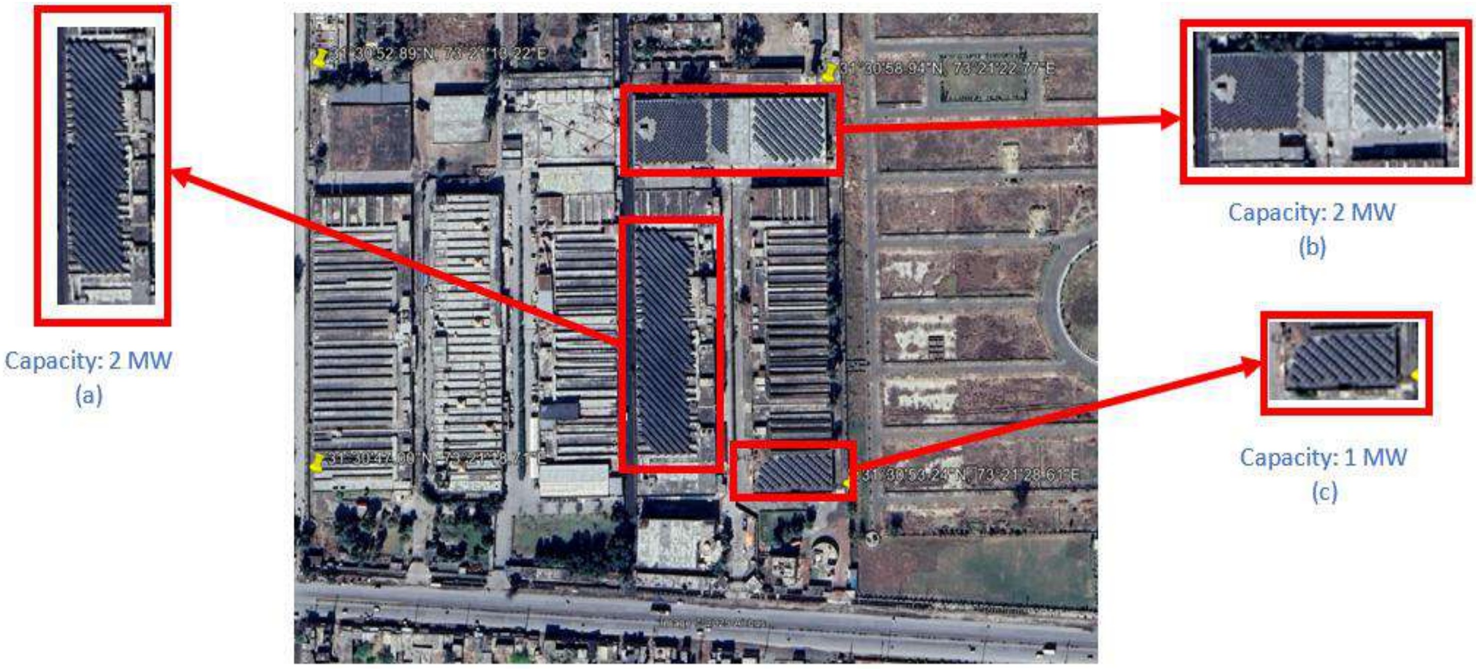

Figure 14: Ahmad Din Textile Mills GIS Solar Tracking

Figure 15: Gohar Textile Mills GIS Solar Tracking

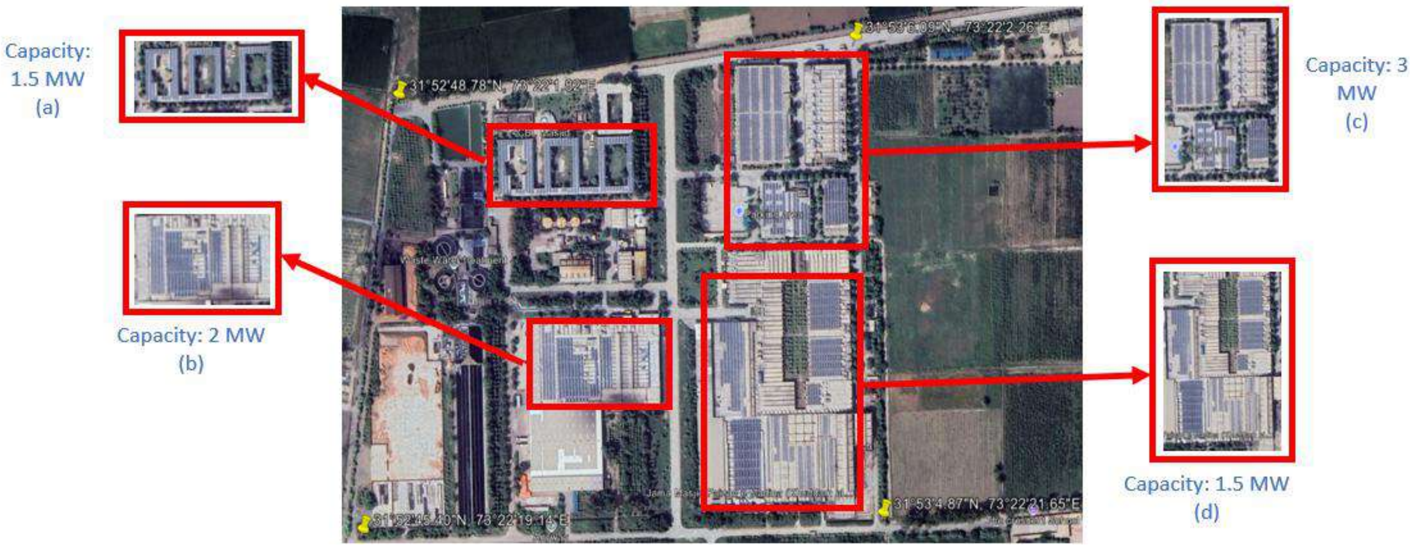

Figure 16: Crescent Bahuman Limited GIS solar Mapping

Figure 17: Crescent Textile Mills GIS solar Mapping

Figure 18: Ibrahim Fibers Limited GIS solar Mapping

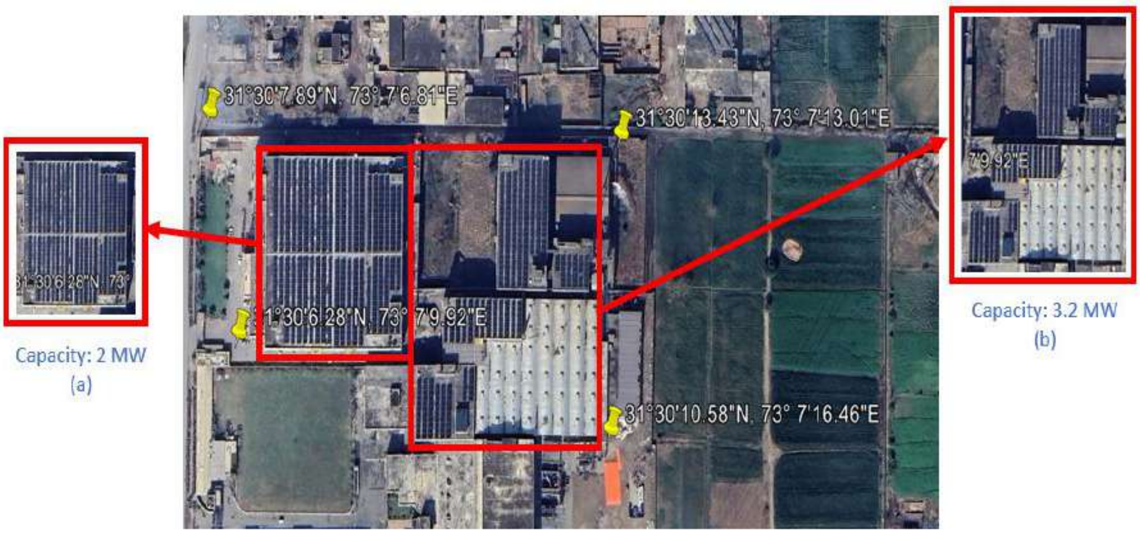

Figure 19: Ibrahim Textile Mills GIS solar Mapping

Figure 20: Interloop Industries Limited GIS solar Mapping

Figure 21: Lucky Textile Mills GIS solar Mapping

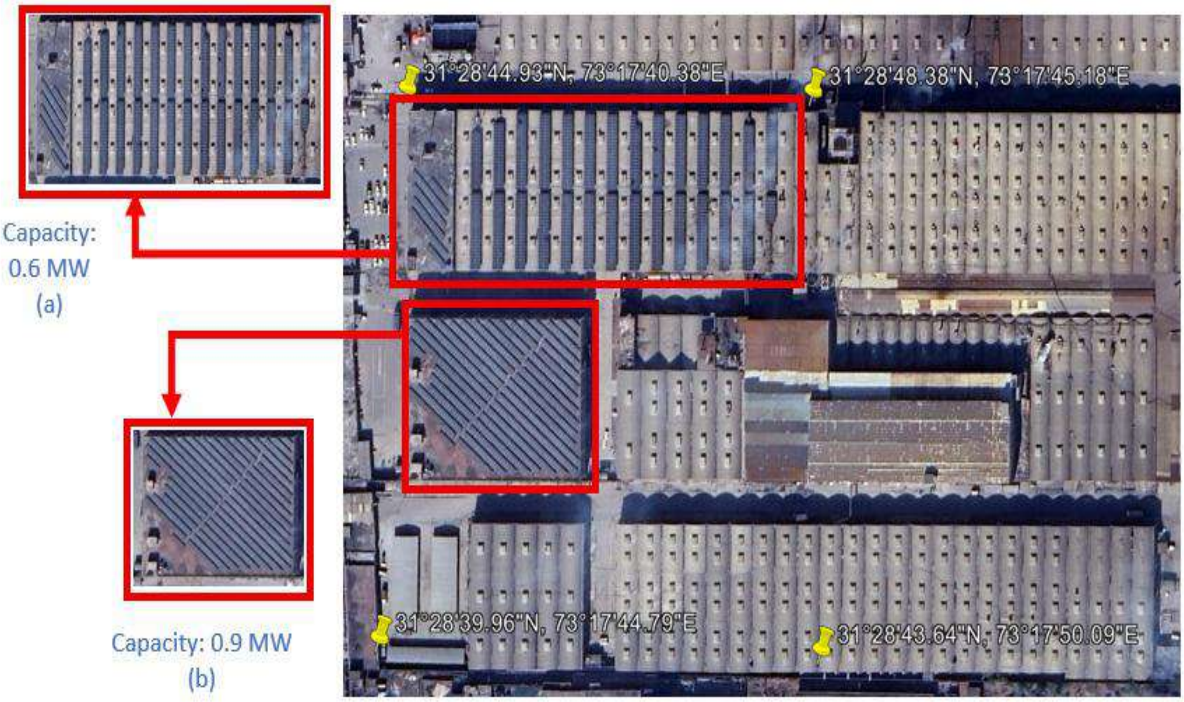

Figure 22: Kamal Industries GIS solar Mapping

Figure 23: Kamal Limited GIS solar Mapping

Figure 24: Nishat Industries GIS solar Mapping

Figure 25: Sapphire Textile Mills Ltd. GIS solar Mapping

Figure 26: Sitara Chemicals GIS solar Mapping

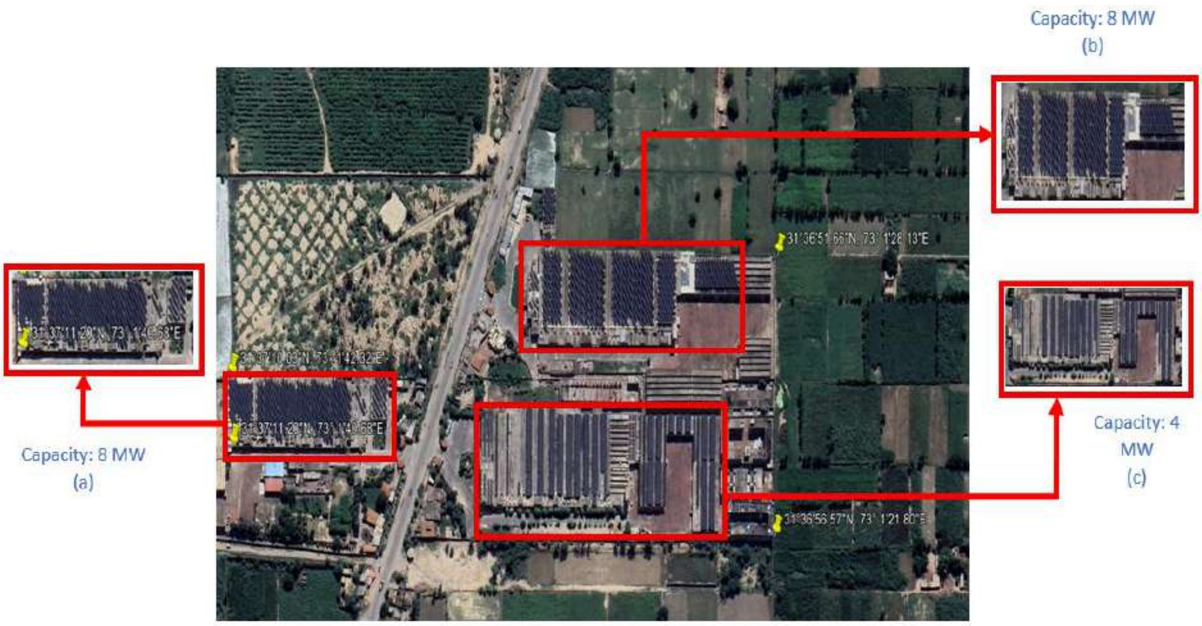

Figure 27: Tayyab Textile Mills Limited. GIS solar Mapping

4.3 Textile industries of Multan

PV installations are dispersed more broadly across the industrial estate areas of Vehari Road and Bosan Road. Ground-mounted systems were more common here compared to Faisalabad, especially for textile facilities with expansive land holdings. A few installations exceeding 1.5 MW in capacity were detected, signaling the beginning of large-scale solar adoption.

Figure 28: Fazal Cloth Mills, Multan; GIS solar Mapping

Figure 29: Mehmood Textile Mills Limited., Multan; GIS solar Mapping

Figure 30: MG Industries, Multan; GIS solar Mapping

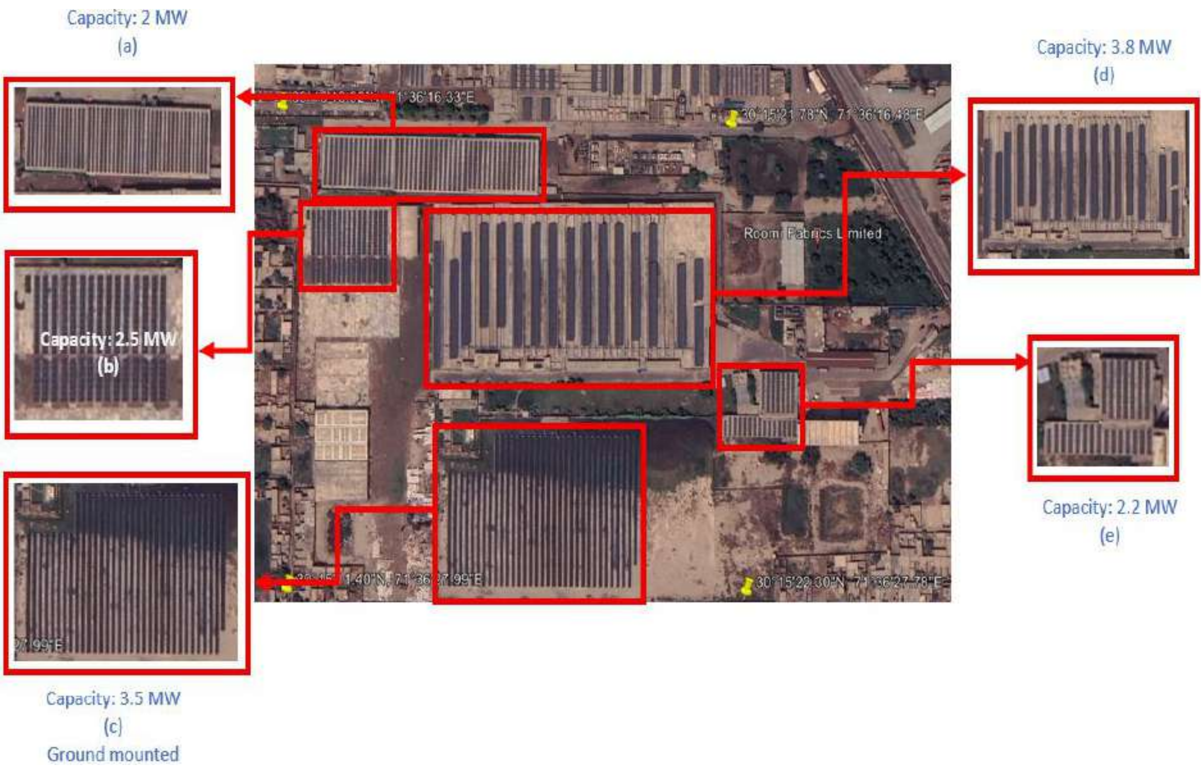

Figure 31: Roomi Fabrics Limited., Multan; GIS solar Mapping

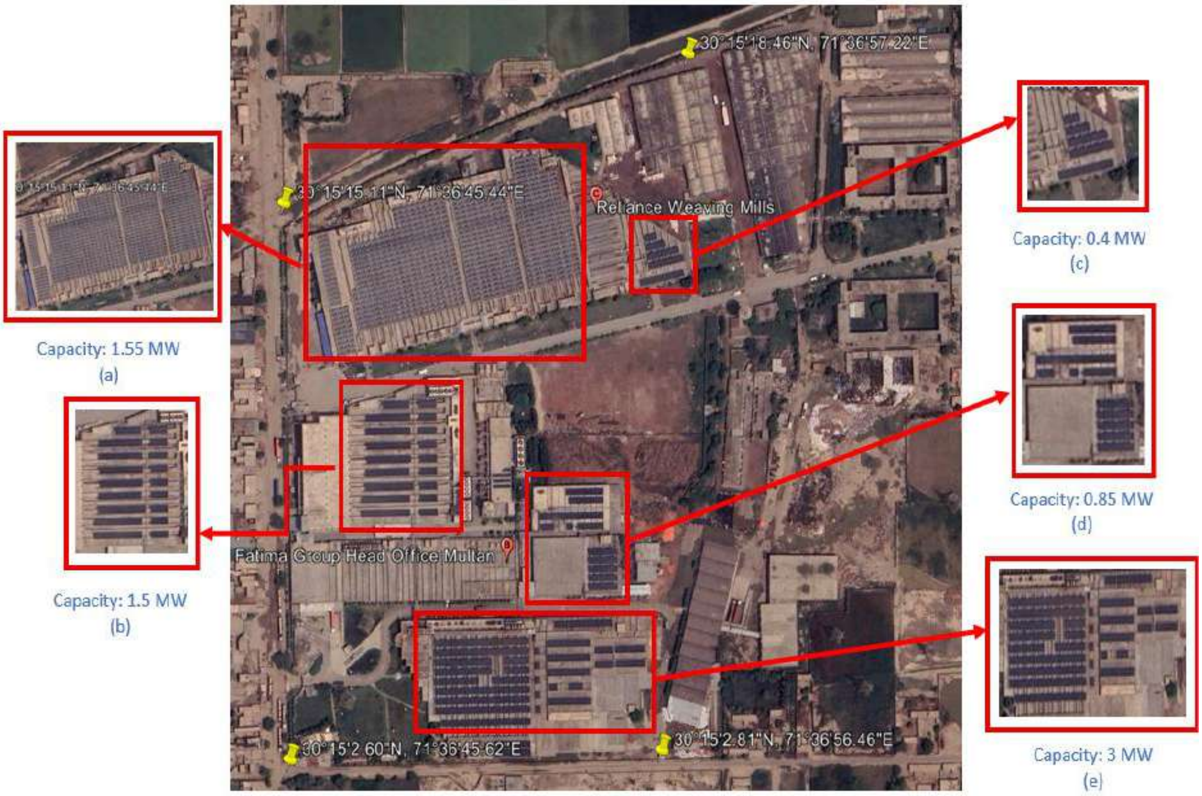

Figure 32: **Reliance Weaving Mills, Multan; GIS solar Mapping**

4.4 Final Evaluation

The specific mapping results for some of selected sites are shown below:

Table 9: Solar GIS Mapping Results

Mill Name	Installed PV (MW)	Mapped PV Area (ha)	Avg. GHI (kWh/m²·yr)
Faisalabad			
Crescent Bahuman Ltd.	8.00	1.75	1930
Crescent Textile Mills	3.50	0.8	1960
…	….	….	…..
Lucky Textile Industries Ltd.	12.00	2.8	1935
Nishat Mills Ltd.	14.20	3.4	1950
Sapphire Textile Mills Ltd.	16.00	3.8	1960
Sitara Chemical	1.00	0.2	1945
Tayyab Textile Mills Ltd.	20.00	4.5	1950
Totals & Averages	**125.79**	**28.75**	**1947**

Multan			
Fazal Cloth Mills Multan	11.53	2.6	1960
Mahmood Textile Mills Ltd.	15.00	3.4	1955
MG Industries Multan	2.00	0.4	1950
Reliance Weaving Mills	7.30	1.7	1945
Roomi Fabrics Ltd.	14	3.35	1950
Totals & Averages	**49.83**	11.45	**1952**

Zones within 2 km of the primary grid facility and having solar capacity >1 MW were classified as **"CTBCM-ready pockets"**, where bilateral trading under CTBCM regime can be initiated with minimal infrastructural upgrades [27,28].

CTBCM-Ready Sites Identified:

1. **Tier 1 (Immediate):** 28 mills with >2 hactares contiguous rooftop.
2. **Tier 2 (Near-term):** 34 mills requiring renewables and grid upgrades.
3. **Tier 3 (Long-term):** 18 mills with land constraints.

4.5 Summary

This chapter presents a detailed GIS-based mapping study of existing solar PV infrastructure across twenty textile mills in Faisalabad and Multan. Using high-resolution satellite imagery and geospatial analysis tools, the study precisely digitized and quantified the capacity and area of installed solar arrays. The results show a significant existing investment in solar, with 125.79 MW mapped across 28.75 hectares in Faisalabad and 49.83 MW across 11.45 hectares in Multan. The analysis also calculated the strong solar resource potential (Global Horizontal Irradiance) for both regions, confirming the technical viability for further expansion. A key outcome was the identification and classification of "CTBCM-ready" sites based on their proximity to grid infrastructure and solar capacity. These sites are categorized into tiers for immediate, near-term, and long-term potential to participate in bilateral energy trading. The mapping validates that the current renewable penetration is close to national policy targets (ARE 2019), as it was estimated that wheeling-enabled offsite PPAs could raise renewable penetration by roughly +8.2% vs. current levels (~12.4% Faisalabad, ~15.1% Multan). and demonstrates that the CTBCM framework could accelerate this adoption by enabling more off-site power purchase agreements, helping the textile sector meet its energy and decarbonization goals.

Chapter 5: Scoping Solar PV into energy infrastructure under CTBCM regime – A technoeconomic analysis

5.1 Proposed scoping scenarios for renewable integration Framework

This section defines eight system configuration scenarios proposed to evaluate solar PV integration pathways under Pakistan's CTBCM regime to evaluate environmental and techno-economic feasibility. The scenarios systematically analyze renewable penetration levels, grid interaction mechanisms, and CTBCM variables to identify optimal configurations for textile manufacturing clusters.

The objective of analysis is to *quantify trade-offs between renewable fraction (solar penetration), grid dependency, and economic outcomes* under realstic ground level implementation strategies in Pakistan's textile hubs. *HOMER Pro 3.14* with custom CTBCM module is used as modeling design framework. Table 10 shows input parameters taken for techno-economic analysis.

Table 10: Key Input Parameters for detailed techno-economic analysis

Parameter	Value	Source
Solar CAPEX (inclusive of installation, commissioning, supervision etc. costs)	$707/kW	Database 2025/ Feasibility Studies [20]
Inverter CAPEX	$156/kW	Database 2025 [73]
O&M Cost	2.5% of CAPEX	Industry Surveys (Faisalabad) [74]
Land & Miscellaneous Costs	10% of CAPEX	Assumed
Discount Rate	11%	Standard Discount rate for current year [75]
Inflation Rate	3.20%	Standard inflation rate for current year [76,77]
Project Lifetime	25 years	-
Grid Tariff (exclusive of taxes)	PKR 36.5/kWh ($0.1/kWh) (peak), PKR 28 ($0.13/kWh)	Average FESCO/MEPCO 2025 Tariffs [21,78]
CTBCM Trading Rate	PKR 24/kWh ($0.086)	Assumed
Wheeling Charges	PKR 6–25/kWh ($0.022–0.090)	Analysis according to Market dynamics
Grid Losses (in NM/GM cases)	15%	-
Grid Losses (in CTBCM cases)	5%	-
Tax Rates	10%	-
NM/GM sellback rates by consumers	PKR 19.32/kWh ($0.068/kWh)	Proposed reduced tariffs by NEPRA [22]

5.2 Core Renewable Penetration Scenarios

Considering the existing solar potential analyzed by 40 industries from Faisalabad, a comprehensive technoeconomic analysis is carried out analyzing impacts of CTBCM adoption in textile sector, and a regulatory framework is developed. Two types of technoeconomic models are proposed:

A. **Higher Renewable Fraction** and low grid dependency modelled such that Solar PV is sized to meet approximately 87% of the total electrical load. The system is designed for minimum dependency on the grid. This scenario emphasizes energy self-reliance, higher capital expenditure (CAPEX), and potential surplus energy sales under CTBCM contracts.
B. **Lower Renewable Fraction** and moderate grid dependency modelled such that Solar PV is sized for 75% load fulfillment, maintaining a moderate reliance on grid purchases. This scenario optimizes initial investment while leveraging CTBCM mechanisms for partial grid trading and flexibility in load management.

In **Scenario A**, Solar PV sizing and thus generation is done so that a major proportion of load demand is met by generation on-site but at the expense of higher upfront (initial investment) costs, while in **Scenario 2**, upfront costs are lowered, and grid dependency is increased moderately. In context of CTBCM, scenario A can be interpreted as unit sales-based model, and scenario B can be interpreted as unit purchases-based model. The economic gains of each case is independently analyzed and critically evaluated in terms of revenues generated and paybacks incurred. Co-design is also analyzed with partial and full integration of CTBCM in grid regulatory framework is successively analyzed. Use of system charge (UoSC), an important CTBCM parameter, is considered to be highly dependent on wheeling charges , which are the charges utilized by consumers to use the grid for transmission of 1kWh energy across the grid. Thus, the impact of wheeling charges on economic feasibility of energy projects is also determined. Following are general details of each modelled scenario:

Scenario A: High Renewable Fraction (87% Solar)

- **Configuration:**
    - On-site solar meets 87% of load (3,733 MW capacity)
    - Minimal grid dependency (13%)
- **CTBCM Interpretation:** *Unit Sales-Based Model*
- **Economic Profile:**
    - High CAPEX ($2.43B)
    - Low operational cost
    - Curtailment risk during peak solar hours

Scenario B: Low Renewable Fraction (75% Solar)

- **Configuration:**
  - On-site solar meets 75% of load (2,175 MW capacity)
  - Moderate grid dependency (25%)
- **CTBCM Interpretation:** *Unit Purchases-Based Model*
- **Economic Profile:**
  - Lower CAPEX ($1.43B)
  - Higher grid cost exposure
  - Reduced curtailment

5.3 Regulatory Grid Interaction Scenarios to analyze industrial growth

Following 8 cases are considered to assess economic impact of solar integration in textile sector under competitive trading bilateral contract markets (CTBCM) regime:

1) Business as usual case (around 50% diesel, natural gas, LFO generators, 30% solar, 20% grid dependency).
2) Solar dominant with Net metering.
3) Solar dominant with Gross metering.
4) Solar dominant with Net metering for < 1MW systems, and CTBCM for >1MW systems.
5) Solar dominant with Gross metering for < 1MW systems, and CTBCM for >1MW systems.
6) Solar dominant with Net metering for < 500 kW systems, and CTBCM for > 500 kW systems.
7) Solar dominant with Gross metering for < 500 kW systems, and CTBCM for > 500 kW systems.
8) Solar grid ratio (75%, 25%), solar dominant with CTBCM implementation through complete grid.

Table 11: Cases analyzed Matrix Design

Case	Metering Mechanism	CTBCM Threshold	Scenario Applicability
1	N/A (Business-as-Usual with NM for PV)	N/A	Baseline
2	Net Metering	N/A	A/B
3	Gross Metering	N/A	A/B
4	Net Metering <1MW + CTBCM >1MW	1 MW	B (Mid-size mills)
5	Gross Metering <1MW + CTBCM >1MW	1 MW	B (Mid-size mills)
6	Net Metering <500kW + CTBCM >500Kw	500 kW	A (Large mills)

7	Gross Met. <500kW + CTBCM >500kW	500 kW	A (Large mills)
8	Full CTBCM Implementation	0 kW	A/B

For **case 8**, sensitivity analysis is also carried out, i.e. impact of further 2 parameters, i.e. wheeling charges, and trading rate is assessed on economic feasibility, and results are recorded to adapt policy recommendations. It is also noted that grid losses are considerable in net metering and gross metering setups, while it is significantly reduced in CTBCM setups, as the energy is traded to nearest consumers at a set trading rate, which is lesser than tariffs set by NEPRA.

5.4 Comparative Technoeconomic Results Obtained

Scenario A achieved high renewable penertration and low grid dependency. Baseline is kept same for both the cases for better interpretation. The extracted data reveals significant techno-economic differences between the high-renewable S1 (scenario A, 87% Renewable adoption) and moderate-renewable S2 (scenario B, 75% Renewable adoption) scenarios across various policy cases. Understanding the drivers behind these trends is crucial for strategic decision-making. The results show a consistent pattern: the larger, more renewable-dense system (S1, 3,750 MW) produces the **lowest system LCOE** across every case (e.g., Case 8 LCOE S1 = $0.0309/kWh vs S2 = $0.0567/kWh), and it yields the **largest absolute NPV** (Case 8: S1 NPV $6.22 billion vs S2 $5.21 billion). By contrast, the smaller system (S2, 2,175 MW) delivers materially **higher investor returns**; IRR, ROI and faster payback in every case (Case 8: S1 IRR 28.60% vs S2 IRR 41.65%; payback S1 3.52 yr vs S2 2.424 yr). In simpler terms: S1 is best for minimizing total cost to the system and maximizing aggregate value; S2 is best at converting capital invested into rapid private returns. Both facts are economically consistent and the core divergence is caused by the designed system scales and their inherent cost-revenue structures:

- S1 (87% RE, 3750 MW): Characterized by higher upfront capital investment due to the massive solar deployment. However, this scale enables greater economies of scale (lower per-unit costs) and significantly higher potential energy generation for sale back to the grid or market.
- S2 (75% RE, 2175 MW): Features a substantially lower initial capital outlay due to the smaller solar capacity. While this reduces absolute financial risk initially, it also results in lower total energy generation potential for sale and potentially less leverage on economies of scale compared to S1.

All the cases within scenarios are designed and modeled and results are interpreted as follows:

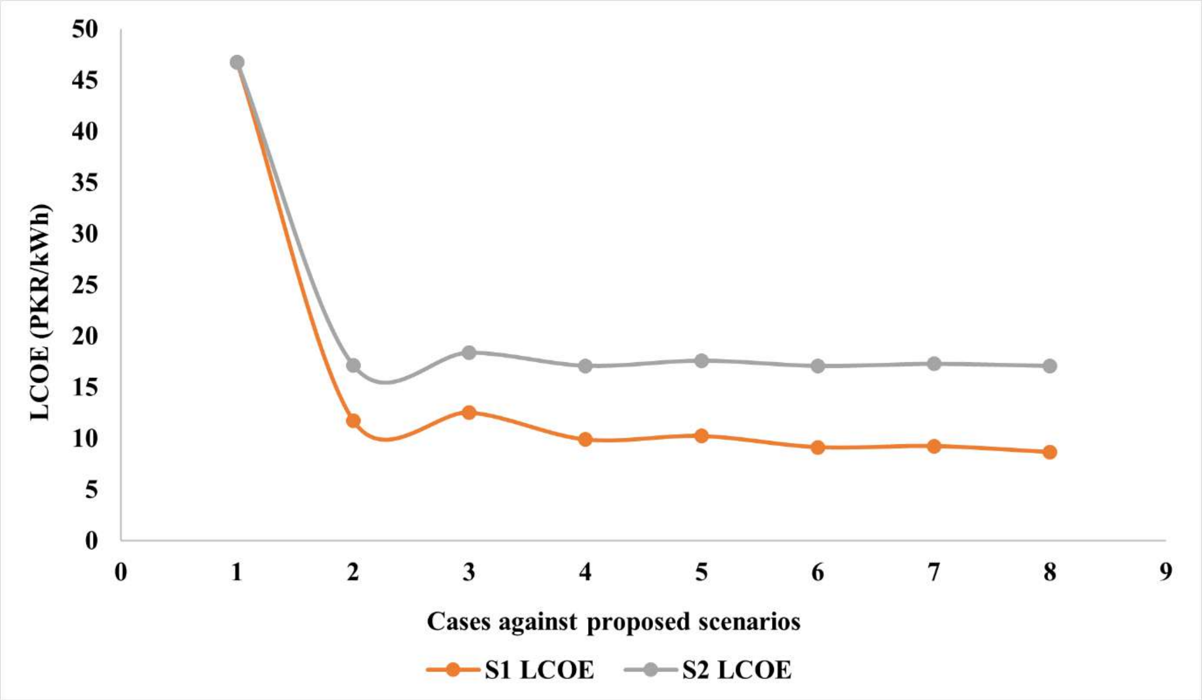

Figure 33: LCOE obtained against various cases across proposed scenarios

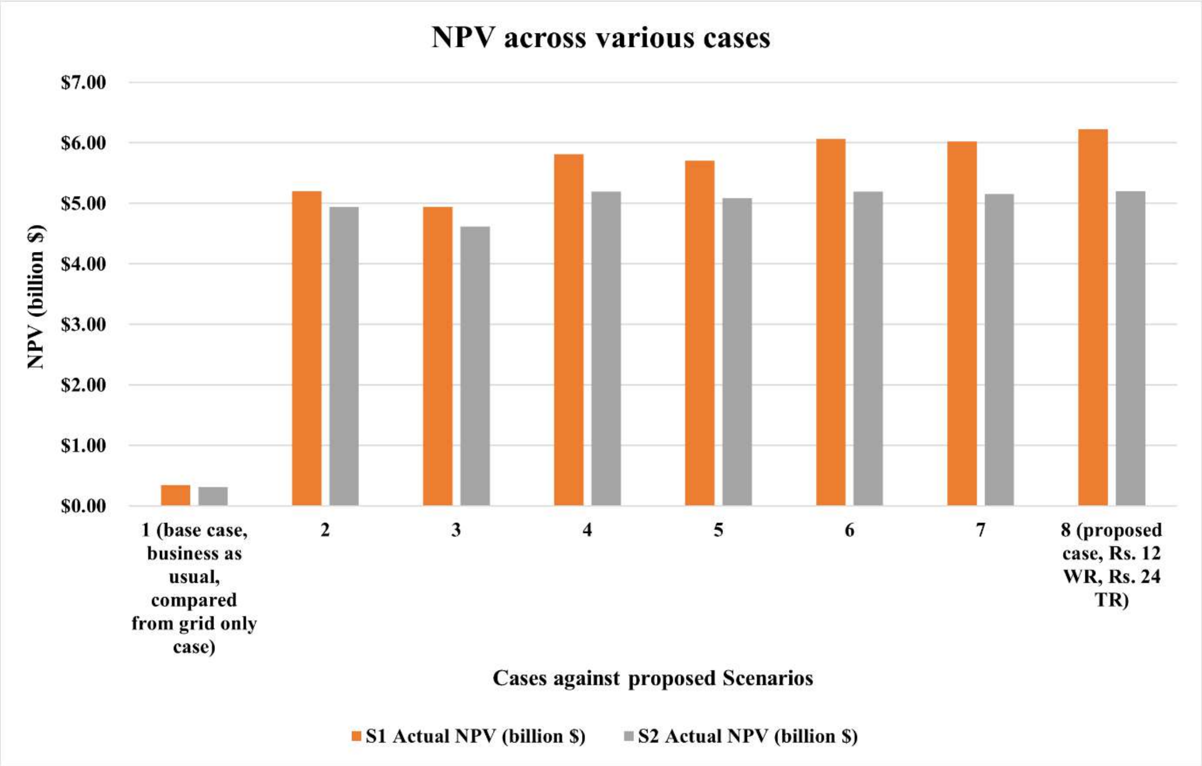

Figure 34: NPV obtained against various cases across proposed scenarios

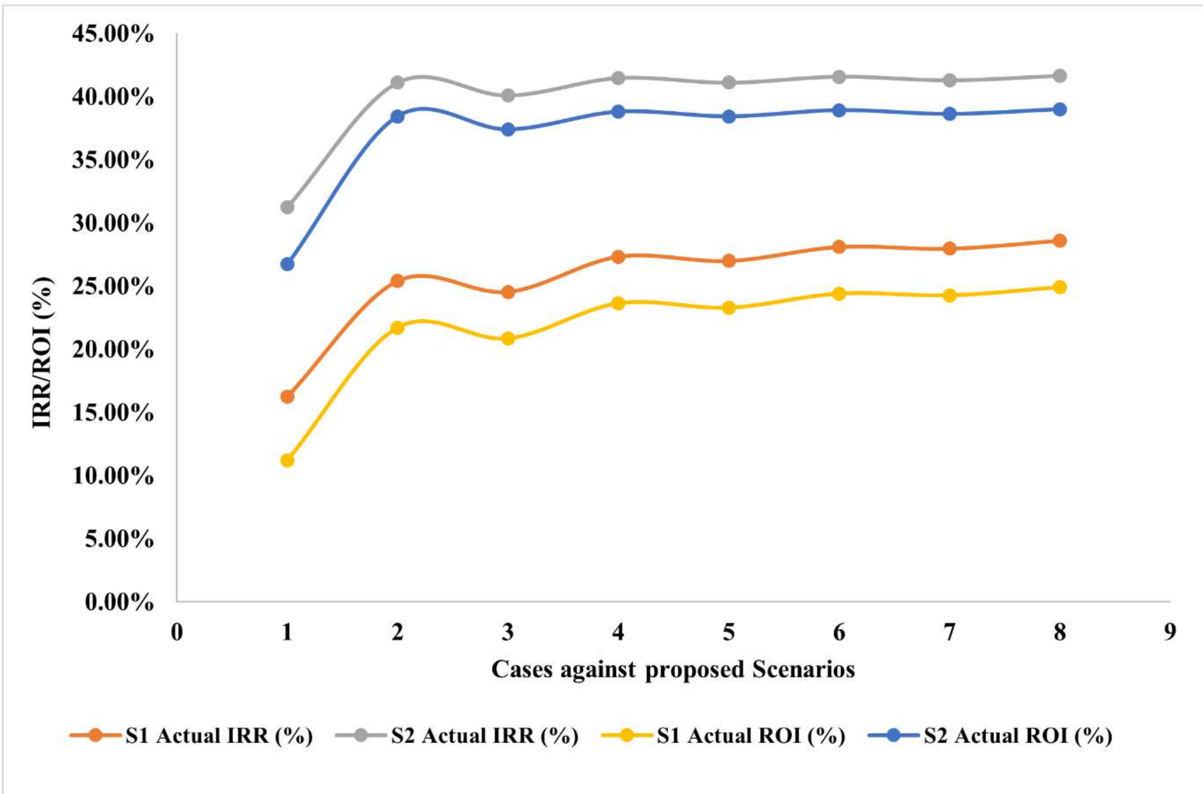

Figure 35: Internal Rate of Return/Return on investment obtained against various cases across proposed scenarios

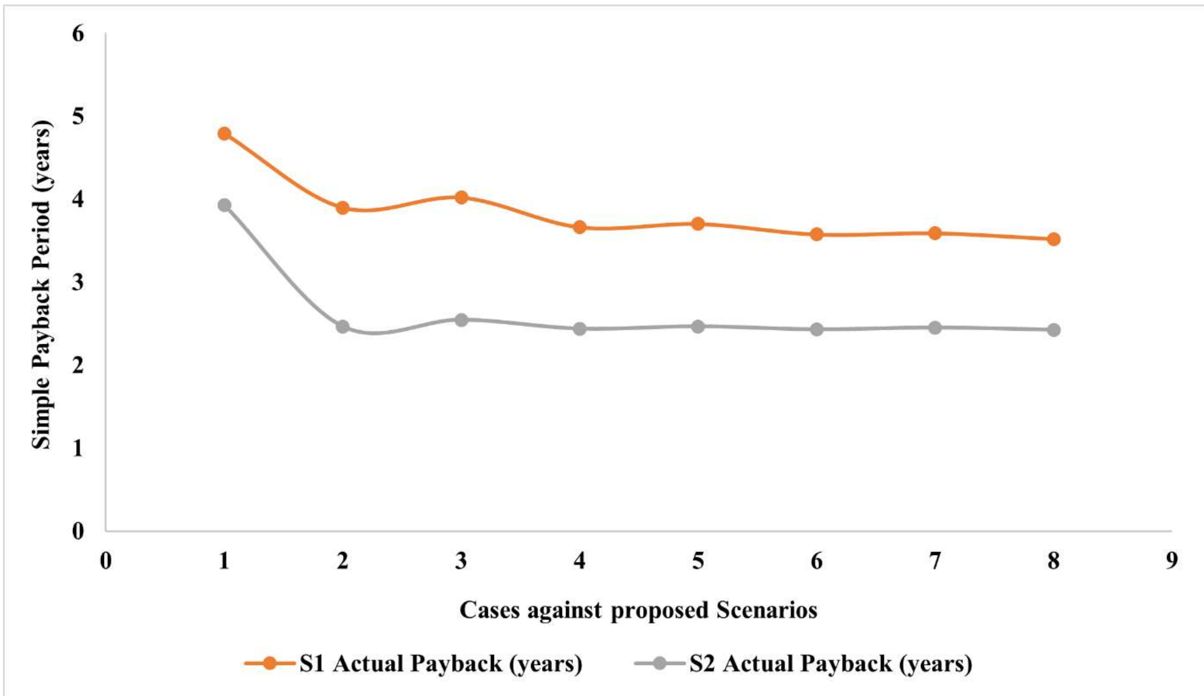

Figure 36: Payback period obtained against various cases across proposed scenarios

5.4.1 Key Performance Indicators Analysis & Comparative Trends

1. **Levelized Cost of Energy (LCOE):**

Both scenarios show dramatic LCOE reductions moving from the fossil fuel-Base Case (Case 1: $0.167/kWh) to the renewable-dominant cases. S1 consistently achieves lower LCOEs than S2 across all comparable cases (e.g., Case 8: S1 $0.0309/kWh vs S2 $0.0567/kWh).

Cause: This is primarily driven by the massive displacement of expensive diesel/LFO/NG generation with near-zero marginal cost solar. The larger scale (S1) achieves superior economies of scale in solar CAPEX and balance-of-system costs, pushing its LCOE significantly lower than S2. Grid dependency costs also decrease more substantially in S1.

2. **Internal Rate of Return (IRR) & Return on Investment (ROI):**

S2 consistently demonstrates **higher IRR and ROI percentages** than S1 across all cases (e.g., Case 8 IRR: S2 41.65% vs S1 28.60%; ROI: S2 39.00% vs S1 24.91%).

Cause: This counter-intuitive result (given S1's lower LCOE) stems directly from the capital intensity difference. S2's significantly lower upfront investment means that the substantial operational savings and revenue streams generated (though smaller in absolute terms than S1) translate into a much higher percentage return relative to the initial capital deployed. S1's massive investment requires larger absolute returns to achieve similar percentage returns.

3. **Net Present Value (NPV):**

S1 achieves *significantly higher absolute NPV* than S2 in all cases (e.g., Case 8: S1 $6.22B vs S2 $5.21B). This is true even when S2 has a higher IRR/ROI (like Case 8).

Cause: NPV represents the *absolute* net dollar value created over the project lifetime. While S2 offers higher *relative* returns, the *sheer scale and lower operating costs of the S1 system generate vastly larger cumulative net cash flows*. S1's lower LCOE and higher energy sales potential dominate NPV calculation, outweighing its higher initial cost when discounted over time.

4. **Payback Period:**

S2 exhibits **consistently shorter payback periods** than S1 across all cases (e.g., Case 8: S2 2.424 yrs vs S1 3.52 yrs).

Cause: This directly correlates with the IRR/ROI trend. The *lower initial investment of S2* allows the project to recoup its costs *much faster* from the operational savings and revenues, even though these are smaller in absolute terms than S1. S1's higher capital hurdle takes longer to overcome despite larger annual savings.

5.4.2 Policy Case Evolution & Impact (Cases 2-8)

Metering and market structure primarily affects how value is *realized* rather than whether value exists. Net-metering increases retail bill savings for prosumers but often translates into lower immediate cash receipts for sellers (fewer direct cash sales), which negatively impacts investor IRR relative to gross-metering or market sales; however, long term gains of NM mechanism are way better than GM, but lower than CTBCM. *Gross-metering* instead converts generation into a cash sale at a feed-in or buyback tariff; this gives more liquid, predictable cashflows for investors, even if selling price per-kWh may be lower than retail. CTBCM lets larger plants sell into the market at wholesale prices and capture peak premiums; by doing so it not only lowers system LCOE through favorable dispatch mechanisms, lower distribution losses and less curtailment, but also it can substantially raise seller revenues during high-price hours. The trade-off is that CTBCM exposes sellers to price volatility and market risk, so successful participation usually requires risk-management practices and stronger market governance. Thus, moving beyond the Base Case (Case 1), the policy refinements significantly enhance economics for both scenarios:

- **Metering Mechanism:** Cases 2 (Net) & 3 (Gross) show Net Metering generally outperforming Gross Metering due to the higher effective value of offsetting retail tariffs vs. receiving potentially lower wholesale/generation rates.
- **Hybrid Models (Cases 4-7):** Introducing Competitive Trading and Bilateral Contracting Market (CTBCM) frameworks for larger systems (>1MW or >500kW) consistently improves results over pure metering models. CTBCM allows larger producers to negotiate better prices or participate in wholesale markets, capturing more value than fixed feed-in tariffs (implied in Gross Metering) or simple netting.
- **Optimal Case (Case 8 - Full CTBCM):** Implementing CTBCM across *all* system sizes yields the best overall results for *both scenarios* (Lowest LCOE, Highest IRR/ROI/NPV, Shortest Payback). This demonstrates CTBCM's superiority in *maximizing revenue potential* for generated solar power, especially for larger systems, by enabling market-based pricing and flexible contracting compared to regulated metering schemes.

5.5 Sensitivity analysis over Case 8 (Full CTBCM implementation)

In this section, two important regulatory parameters governing CTBCM implementation are evaluated against proposed cases. The sensitivities show a clear, economically meaningful pattern: raising wheeling charges materially worsens project economics (higher LCOE, lower IRR/ROI, smaller NPV, longer payback), with **S2** (2,175 MW) exhibiting greater proportional damage to investor metrics than **S1** (3,750 MW). Conversely, increasing the trading price (TR) while holding wheeling fixed strongly benefits the larger S1 system; reducing LCOE, raising IRR and NPV; while S2 shows only marginal changes in LCOE and slightly declining IRR/NPV as TR rises. In short, "*S1 is more responsive to positive price signals in the trading market (it captures upside), while S2 is more exposed to transaction costs (wheeling) and therefore more fragile when wheeling rises*"**.**

5.5.1 Sensitivity to Wheeling Rate (WR) at Fixed Trading Rate (TR = PKR 24/kWh)

The results obtained are depicted as follows:

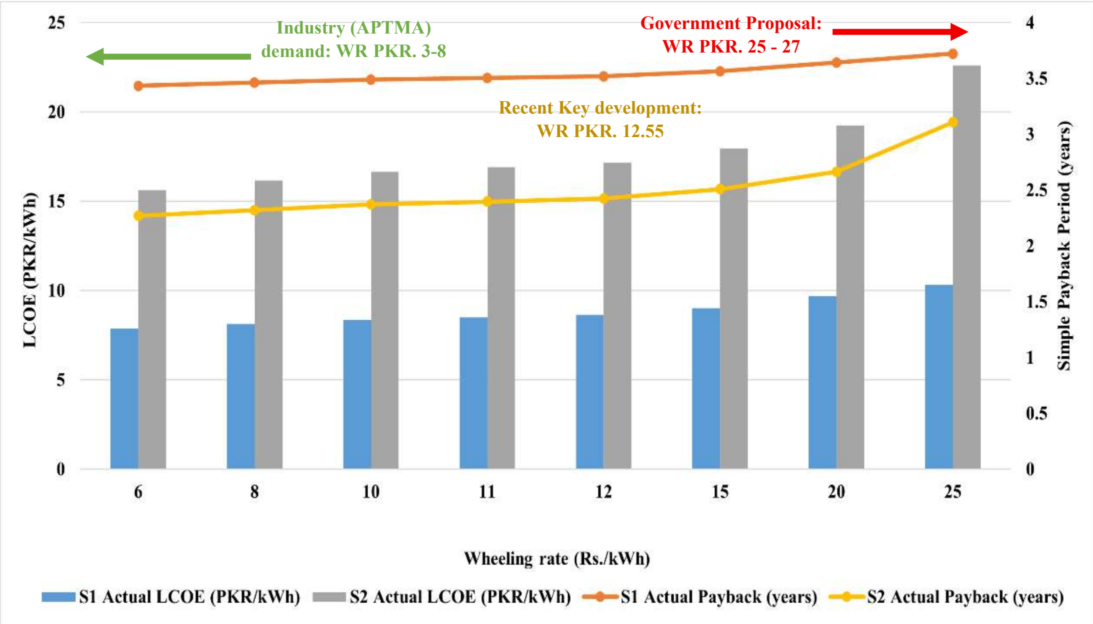

Figure 37: Impact of Wheeling charges on LCOE and Payback period (Case 8)

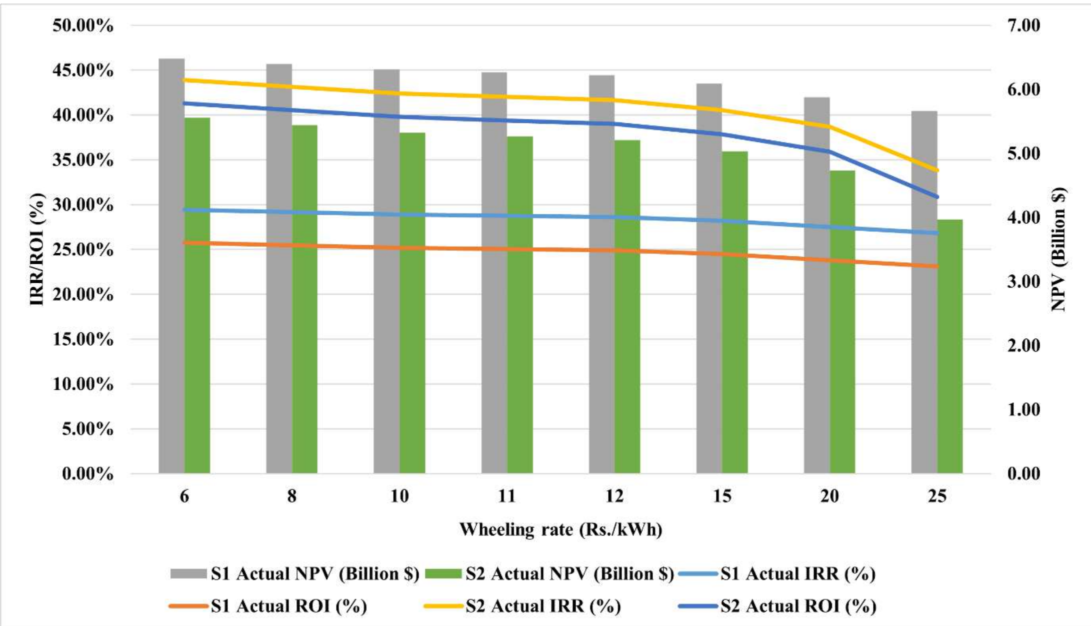

Figure 38: Impact of Wheeling charges on IRR,ROI and NPV (Case 8)

1. **LCOE Impact:**

LCOE increases **significantly and linearly** for **both S1 and S2** as WR rises (S1: $0.0281/kWh at WR6 to $0.0369/kWh at WR25; S2: $0.0558/kWh at WR6 to $0.0807/kWh at WR25).

Cause: Wheeling charges are a direct per-kWh cost for transmitting self-generated solar to off-site consumers through grid. Higher WR directly inflates the delivered cost of solar energy, eroding CTBCM's cost advantage. Since wheeling charges are paid by buyers, *higher wheeling volume (unit purchases)* of S2 make it proportionally *more* sensitive to WR increases than S1.

2. **IRR/ROI Impact:**

IRR and ROI decline *monotonically* for both scenarios as WR increases. S2's degradation is *far more severe* at high WR (S2 IRR drops 10.07% points from WR6 to WR25 vs S1's 2.61% points).

Cause: Higher WR reduces net revenue from energy sales, directly impacting profitability metrics. S2's lower absolute profitability (driven by smaller scale) makes its *relative* returns (IRR/ROI) more vulnerable to cost increases. S1's larger absolute cash flow provides a buffer, slowing the relative decline.

3. **NPV Impact:**

NPV decreases *substantially* for both as WR rises. S1 suffers the largest *absolute* NPV loss (-$0.82B from WR6 to WR25), while S2 suffers the largest *relative* NPV loss (-29% vs S1's -13%).

Cause: Higher WR reduces the *net cash flow over the project life*. S1's massive scale means even small per-kWh cost increases translate to huge absolute dollar losses. S2's lower starting NPV amplifies the relative impact.

4. **Payback Impact:**

Payback periods lengthen for both scenarios with higher WR. S2 experiences the most dramatic worsening (increasing by 0.836 years from WR6 to WR25 vs S1's 0.288 years).

Cause: Reduced annual net cash flows delay capital recovery. S2's shorter initial payback is more susceptible to erosion from rising costs than S1's longer baseline payback.

5.5.2 Sensitivity to Trading Rate (TR) at Fixed Wheeling Rate (WR = PKR 12/kWh)

The results obtained are depicted as follows:

1. **LCOE Impact:**

LCOE decreases *dramatically* for S1 as TR rises ($0.041/kWh at TR15 to $0.0243/kWh at TR30). S2 shows *minimal LCOE sensitivity* ($0.0593/kWh at TR15 to $0.0628/kWh at TR30).

Cause: Higher TR increases the *revenue* earned per kWh sold via CTBCM. For *S1 (Large Merchant Generator),* this revenue directly offsets costs, significantly lowering the *net* levelized cost. For *S2 (Moderate Self-Consumer/Occasional Seller),* its primary benefit is offsetting its own grid purchases; selling surplus is secondary. Higher TR has little impact on its *consumed* energy cost, hence minimal LCOE change, in fact higher TR leads to higher LCOE because of purchase-based model.

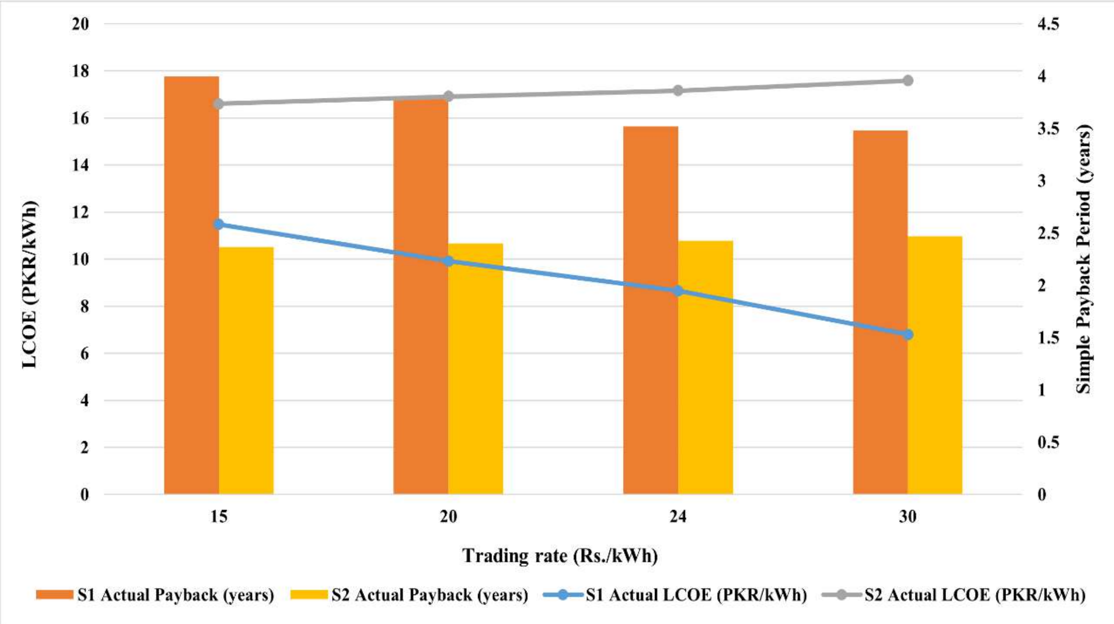

Figure 39: Impact of Trading rate on LCOE and Payback period (Case 8)

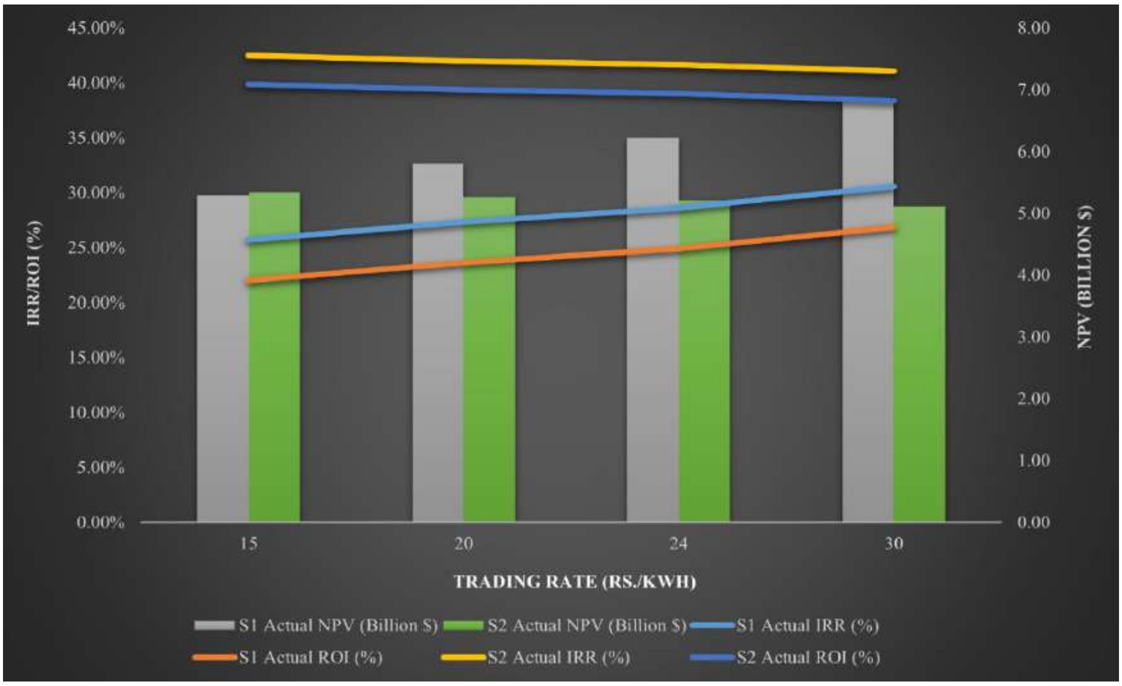

Figure 40: Impact of Trading rate on IRR, ROI and NPV of proposed system (Case 8)

2. **IRR/ROI Impact:**

IRR/ROI increase significantly for S1 with higher TR (IRR +4.83% points TR15-TR30). S2 shows a slight *decrease* (IRR -1.43% points).

Cause: S1's massive generation for sale makes its profitability highly levered to the selling price (TR). Higher TR directly boosts margins. S2's slight IRR/ROI decline is *counter-intuitive but logical*, i.e. Higher TR also likely increases the *cost* of the grid energy it *buys* (if grid tariffs correlate with wholesale prices), slightly offsetting the benefit from its smaller sales.

3. **NPV Impact:**

NPV highly increases for S1 (+$1.55B from TR15 to TR30). S2 shows a slight NPV decrease (-$0.23B).

Cause: S1 captures enormous value from higher energy prices due to its scale. The revenue surge dramatically increases discounted cash flows. S2's minor NPV drop stems from the net effect: small revenue gain from sales minus increased cost for purchased grid power.

4. **Payback Impact:**

Payback shortens modestly for *S1 (-0.514 years TR15-TR30)* due to higher early revenues. S2's payback lengthens slightly (+0.104 years).

Cause: Faster cash generation improves S1's payback. S2's slight payback worsening aligns with its minor NPV decrease and IRR/ROI decline.

5.5.3 Interpretation of Techno-economic Results

Wheeling charges are a per-kWh transaction cost levied when energy is moved across the grid network. Increasing wheeling effectively reduces the net revenue per MWh available to sellers (through increased buyback tariffs) and raises effective cost to buyers. S2 is much more sensitive to WR because its business case depends on modest per-kWh margins and often on selling or buying across the network at small spreads; a rise in WR quickly degrades those margins. The results show this clearly: as WR rises, S2’s LCOE climbs far more (and its IRR drops by considerably high percentage points, specifically when WR exceeds PKR 15/kWh), payback lengthens noticeably, and relative NPV falls steeply. S1 loses more in absolute dollars when WR rises (because it trades larger volumes), but its percentage returns are more resilient because of scale and greater ability to absorb per-kWh fees. Practically, that means high WRs can make many smaller or medium projects uneconomic while only slowing economic returns of very large projects; however, large projects still suffer large total dollar losses.

On the other side, *trading rate (TR) is the market price signal for traded energy*; raising TR increases gross revenue for sellers. S1, with 3,750 MW and higher selling potential and likely better ability to aggregate output and access peak market hours, realizes large incremental revenue as TR rises; this both reduces average system cost (LCOE) via higher utilization/less curtailment and raises NPV/IRR. S2 (2,175 MW) is smaller and likely more dependent on local self-consumption or constrained export capacity; thus S2 does not capture the TR upside to the same degree, and in fact its LCOE shifts upward slightly as TR increases because higher market prices raise the opportunity cost of any purchased energy (or increase settling costs on net purchases during deficit hours). Also, the interconnection of CAPEX structure and revenues matters: S1's larger system probably includes more storage and grid reinforcements which allow it to arbitrage the market (buy low, sell high, or shift generation into high-price hours); hence a higher TR increases the value of that capability. S2's leaner CAPEX makes it more cash-efficient in low wheeling, low trading-price regimes but less capable of arbitrage when TR increases.

5.6 Summary

This chapter conducts a techno-economic analysis of solar PV integration for Pakistan's textile sector under the new CTBCM market. It compares two strategies: a high-investment, high-solar scenario (S1) focused on selling energy, and a lower-investment scenario (S2) focused on self-consumption. The analysis reveals that full CTBCM implementation delivers the best economic outcomes, outperforming traditional net or gross metering. A key finding is the trade-off between the two strategies: S1 achieves the lowest long-term energy cost (LCOE) and highest total value (NPV), while S2 offers a faster return on investment (IRR) and shorter payback period. Crucially, the success of both depends on regulatory design. The S2 model is highly vulnerable to high wheeling charges, which can erase its viability, whereas the S1 model thrives when trading rates are high. The study concludes that for CTBCM to drive solar adoption, policymakers must set low wheeling charges and ensure a market structure that provides competitive trading rates. In short, moving from simple net/gross metering toward a well-designed competitive market (optimized WR and TR rates according to textile industry and relevant market dynamics) can improve overall economics for both centralized and distributed projects, but it must be paired with instruments to manage price risk and preserve predictable cashflows for investors.

Chapter 6: CBAM Compliance and Environmental assessment

6.1 Critical Analysis of CBAM in perspective of textile industry in Pakistan

6.1.1 Current Environmental Standards and Relevance of CBAM to textile sector

For the decarbonization in supply chains, textile companies in export markets already face a significant layer of environmental and sustainability compliance via recognized international standards. For example, according to the Trade Development Authority of Pakistan (TDAP) exporter's guide lists certifications such as OEKO-TEX® STANDARD 100 (for limiting harmful substances), Global Organic Textile Standard (GOTS) (for organic-fibre based textiles) and Bluesign® (for chemical-input stream management) among "non-legal requirements" frequently requested by European buyers [79]. At the same time, leading Pakistani trade-industry bodies such as APTMA emphasize the need for full supply-chain traceability; from cotton origin through to finished garment; as a key environmental/social compliance lever. Collectively, these standards and traceability efforts signal that Pakistani textile firms can build on an evolving baseline of international compliance; but must scale and develop system-wide adoption, particularly among SMEs, to position themselves for export dynamics in CBAM-era [80].

The European Union's CBAM is a revolutionary regulatory measure aimed to address carbon leakage and equalizing carbon costs between domestic producers and foreign importers [39,81]. The main intent is to incentivize cleaner production practices globally while safeguarding the integrity of the EU's internal carbon pricing under the EU Emissions Trading System (EU ETS) [81]. For emerging markets like Pakistan, CBAM introduces a new dimension of environmental compliance and export competitiveness. Even though textiles are not yet among the six sectors initially covered by CBAM, multiple reports indicate that the EU intends to expand CBAM's scope to include textiles by around 2027. This is because textiles account for a large share of Pakistan's exports (around 28% of trade with the EU comes from textiles [82]) and because energy and emission risks in textile supply chains are increasingly being scrutinized [83]. As global brand-buyers demand lower carbon footprints and trade policy shifts penalize high-emission imports, textile exporters from Pakistan will likely face importers demanding emission declarations, potential carbon costs, and stricter compliance [84,85]. Thus, even before formal inclusion, textile firms must prepare or risk losing competitiveness or facing margin erosion [86].

6.1.2 How can textile firms incorporate CBAM into existing textile models?

For Pakistan's textile industry; particularly in industrial zones like Faisalabad and Multan; this highlights the urgent need for decarbonization strategies, energy audits, and renewable energy integration. Textile mills should begin embedding carbon tracking and reporting into their operations now. This means establishing robust Monitoring, Reporting & Verification (MRV) systems (electricity use, fuel use, upstream input emissions). They should shift daytime loads to clean energy (solar PV, hybrid with grid backup), lower dependence on high-emission fuels (diesel, furnace oil), and invest in energy efficiency and cleaner captive plants. Under market reforms and CTBCM, existing or proposed bilateral PPAs, wheeling contracts, and self-generation models should include clauses around emission quantification and third-party verification. Furthermore, firms should prepare cost models that include potential CBAM certificate costs, to understand cost exposure and set competitive pricing for exports. Those who do not internalize CBAM risk via these adjustments may be undercut by firms with cleaner supply chains [87,88].

6.1.3 Is Pakistan's textile sector prepared, and what gains/risks are involved?

The sector shows early signals of readiness: trade bodies (e.g. PRGMEA) are discussing carbon-neutral export models, and some large mills have already invested in solar and cleaner captive generation [89]. But readiness is uneven: many mills, especially SMEs, lack detailed emissions data, MRV systems, or stable renewable-energy contracts. Transparent and predictable policy (stable buy-back rates, fair wheeling charges, removal of hidden or legacy charges) is still lacking. If CBAM is implemented in 2026-27, firms that have made early investments in clean energy and data systems will gain: access to EU markets without surcharges, stronger export demand (for "green" products), and reduced risk of retroactive trade costs. Conversely, firms unprepared will face cost penalties, loss of market share, or higher compliance burdens [90].

6.2 Environmental Feasibility Assessment and Incorporating CBAM in developed Models

In terms of environmental feasibility assessment, following tables show how incorporation of renewables reduce Scope 2 emissions for textile industries in selective industrial hubs.

Table 12: Calculated Scope 2 Emissions in base and proposed cases

Scenario 1 — 87% Renewable Fraction (3,750 MW Solar in-rush)			
Pollutant	**Case 1 (Base) kg/yr**	**Case 2–8 (Renewable) kg/yr**	**Emissions reduced (kg/yr)**
Carbon Dioxide (CO_2)	2,157,012,369	394,502,053	1,762,510,316
Carbon Monoxide (CO)	10,393,569	0	10,393,569
Unburned Hydrocarbons	551,627	0	551,627
Particulate Matter (PM)	88,873	0	88,873
Sulfur Dioxide (SO_2)	5,400,531	3,010,963	2,389,568
Nitrogen Oxides (NO_x)	3,866,775	1,472,515	2,394,260
Scenario 2 — 75% Renewable Fraction (2,175 MW Solar in-rush)			

Pollutant	Case 1 (Base) kg/yr	Case 2–8 (Renewable) kg/yr	Emissions reduced (kg/yr)
Carbon Dioxide (CO_2)	2,157,012,369	538,538,001	1,618,474,368
Carbon Monoxide (CO)	10,393,569	0	10,393,569
Unburned Hydrocarbons	551,627	0	551,627
Particulate Matter (PM)	88,873	0	88,873
Sulfur Dioxide (SO_2)	5,400,531	4,110,290	1,290,241
Nitrogen Oxides (NO_x)	3,866,775	2,010,142	1,856,633

Table 13: Emissions Reduction by Renewable Adoption in selective textile hubs

Scenario 1 — 87% Renewable Fraction (3,750 MW Solar in-rush)				
Case	Total CO_2 emissions (kg/yr)	Total CO_2 emissions - lifetime (kg)	Emissions avoided (kg/yr)	Emissions avoided - lifetime (kg)
Base case (Case 1, business-as-usual)	2,157,012,369	53,925,309,225	—	—
Renewable cases (Cases 2–8 consolidated)	394,502,053	9,862,551,325	1,762,510,316	44,062,757,900
Scenario 2 — 75% Renewable Fraction (2,175 MW Solar in-rush)				
Case	Total CO_2 emissions (kg/yr)	Total CO_2 emissions — lifetime (kg)	Emissions avoided (kg/yr)	Emissions avoided — lifetime (kg)
Base case (Case 1, business-as-usual)	2,157,012,369	53,925,309,225	—	—
Renewable cases (Cases 2–8 consolidated)	538,538,001	13,463,450,025	1,618,474,368	40,461,859,200

In the next phase, as an adoption guideline for CBAM compliance, a fixed carbon credit is taken from available literature (i.e. $15/ton) [91], and incorporated in all the scenarios depicted in **Section 5** and results are analyzed. Introducing a CBAM-based carbon credit produces a consistent positive uplift in project economics for practically every renewable case relative to the no-CBAM baseline. In the analysis of base and proposed cases, the CBAM adjustment lowers adjusted LCOE, raises IRR and ROI, increases absolute NPV, and shortens payback in nearly all renewables cases (cases 2–8), while leaving the pure base case metrics (case 1) unchanged. The modifed results of all cases (as well as sensitivity metrics) are shown below:

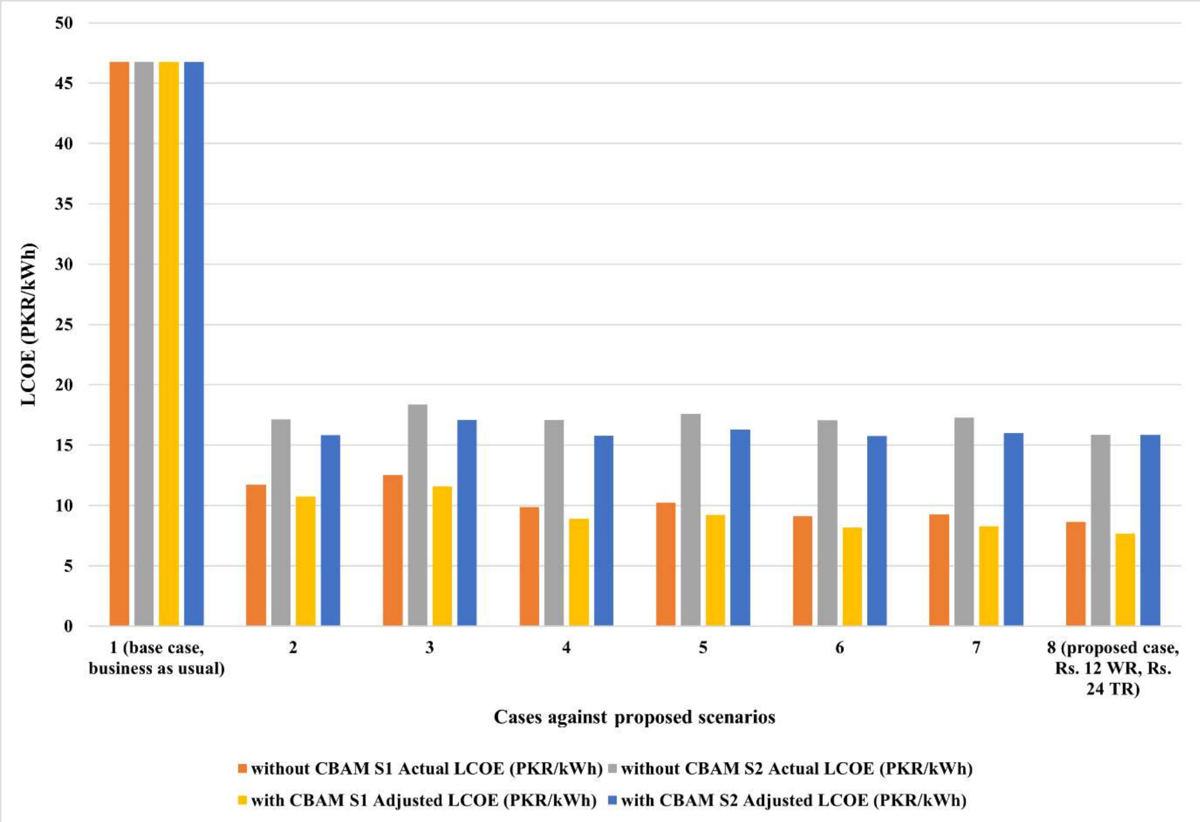

Figure 41: LCOE results obtained across various cases after CBAM incorporation

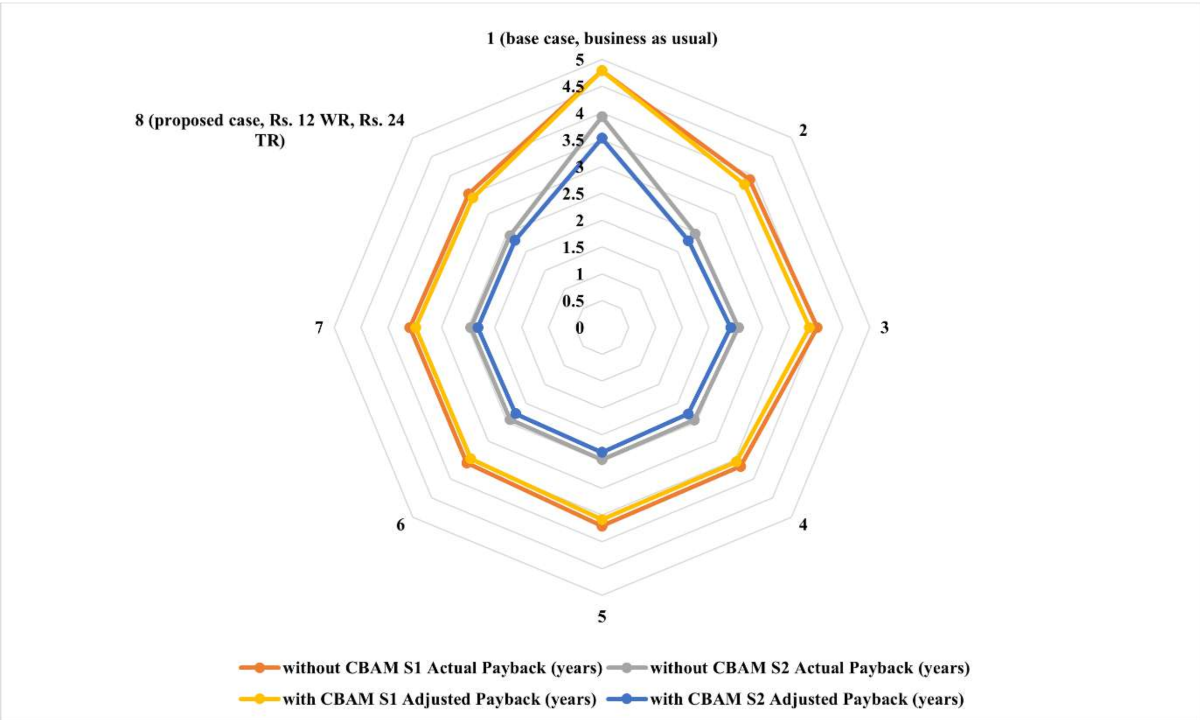

Figure 42: Simple payback periods obtained across various cases after CBAM incorporation

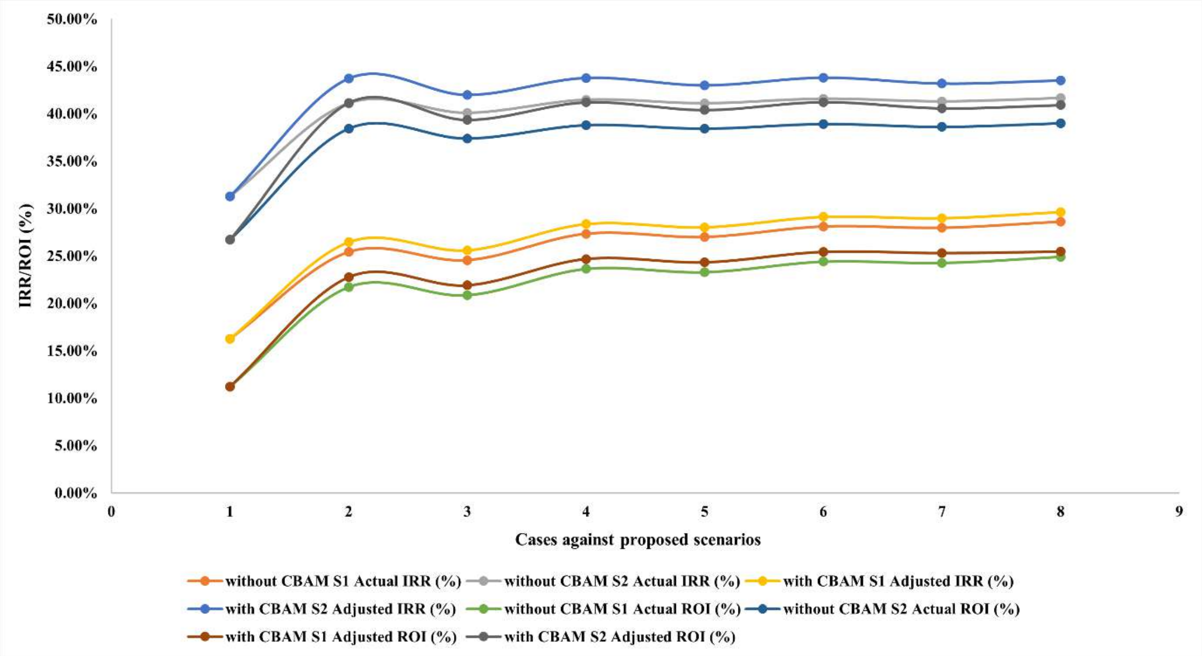

Figure 43: IRR/ROI results obtained across various cases after CBAM incorporation

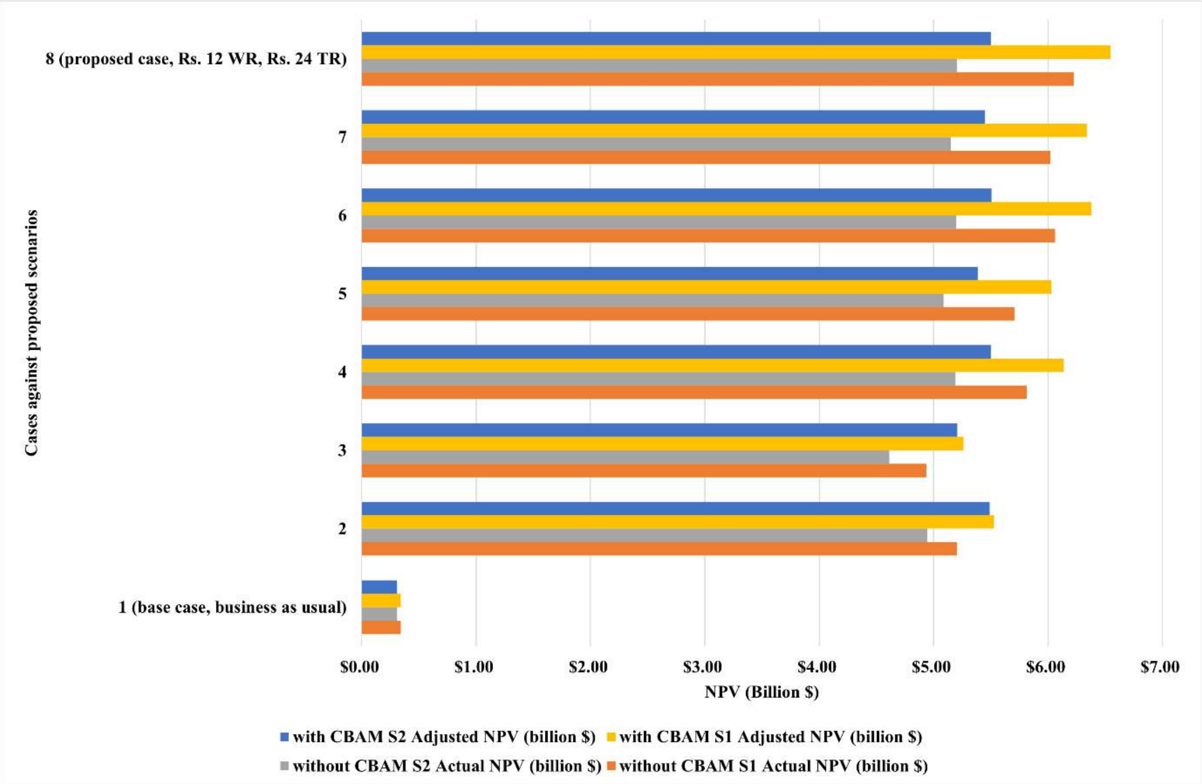

Figure 44: NPV results obtained across various cases after CBAM incorporation

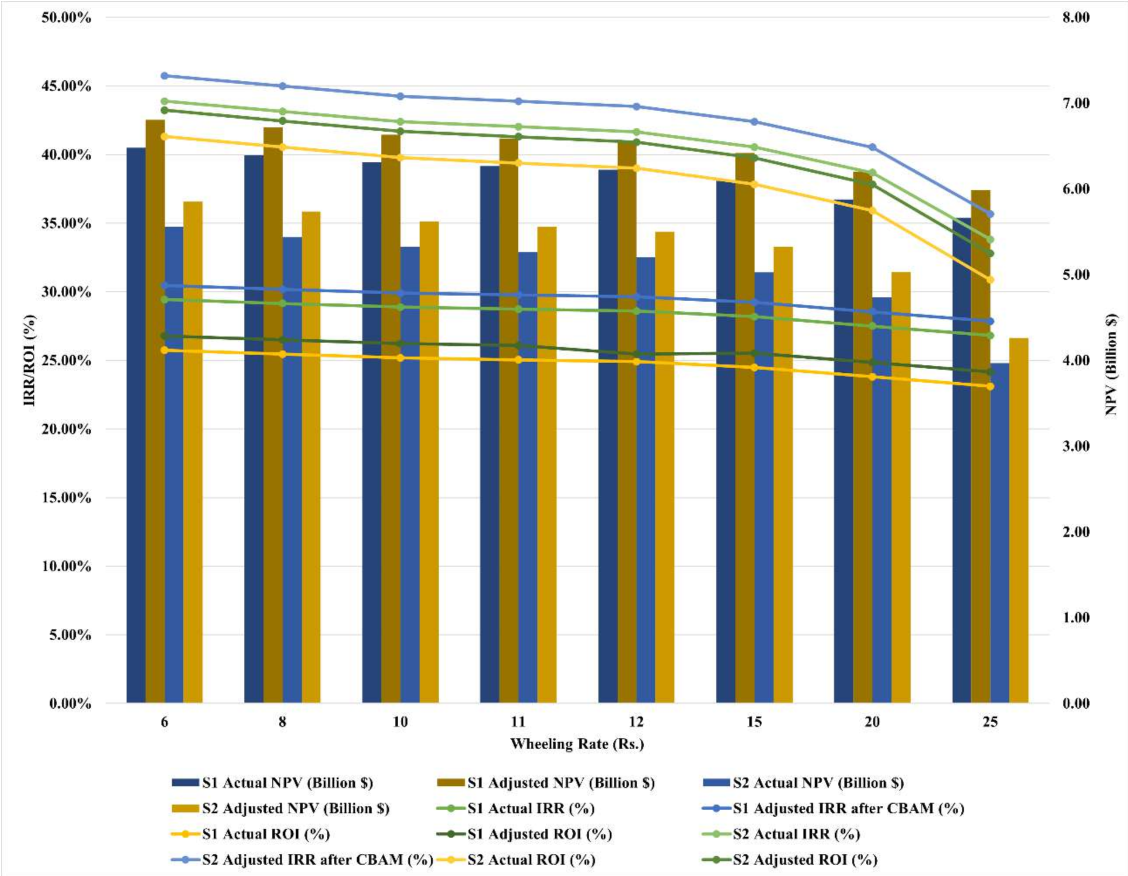

Figure 45: Impact of wheeling rate on IRR/ROI on case 8 obtained after CBAM incorporation

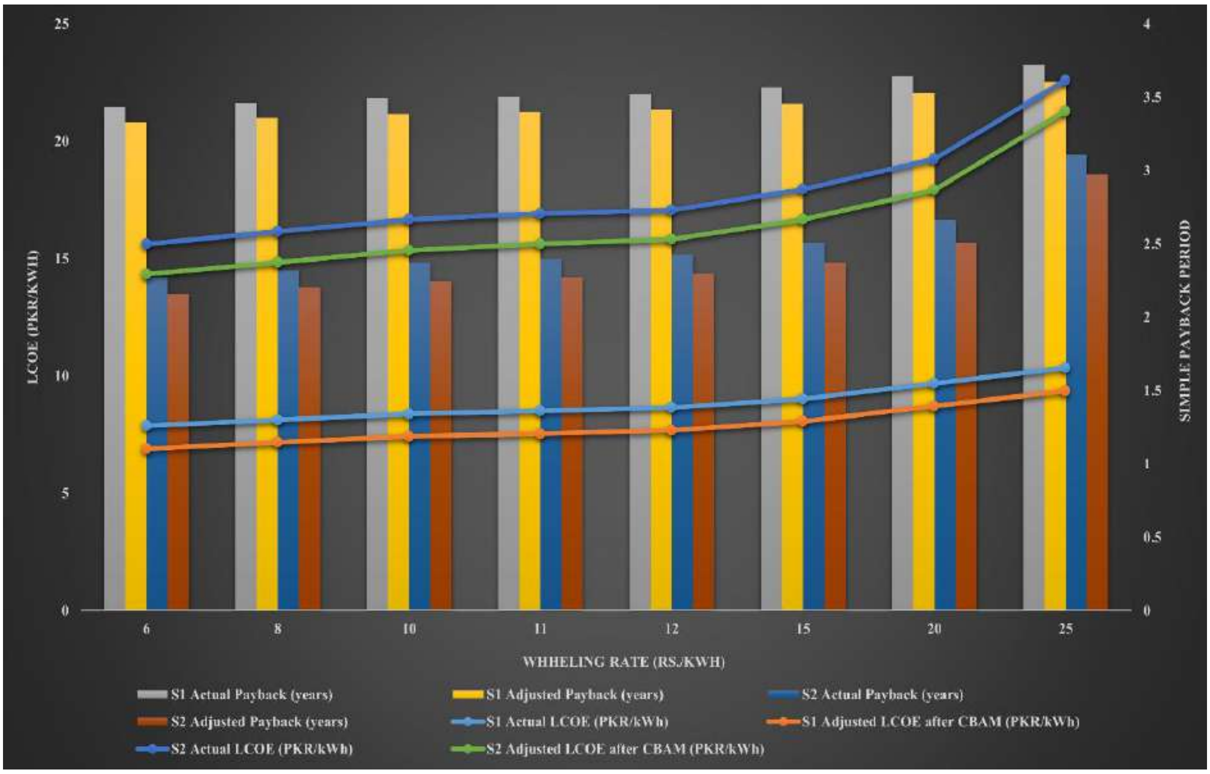

Figure 46: Impact of wheeling rate on LCOE and payback period (case 8) obtained after CBAM incorporation

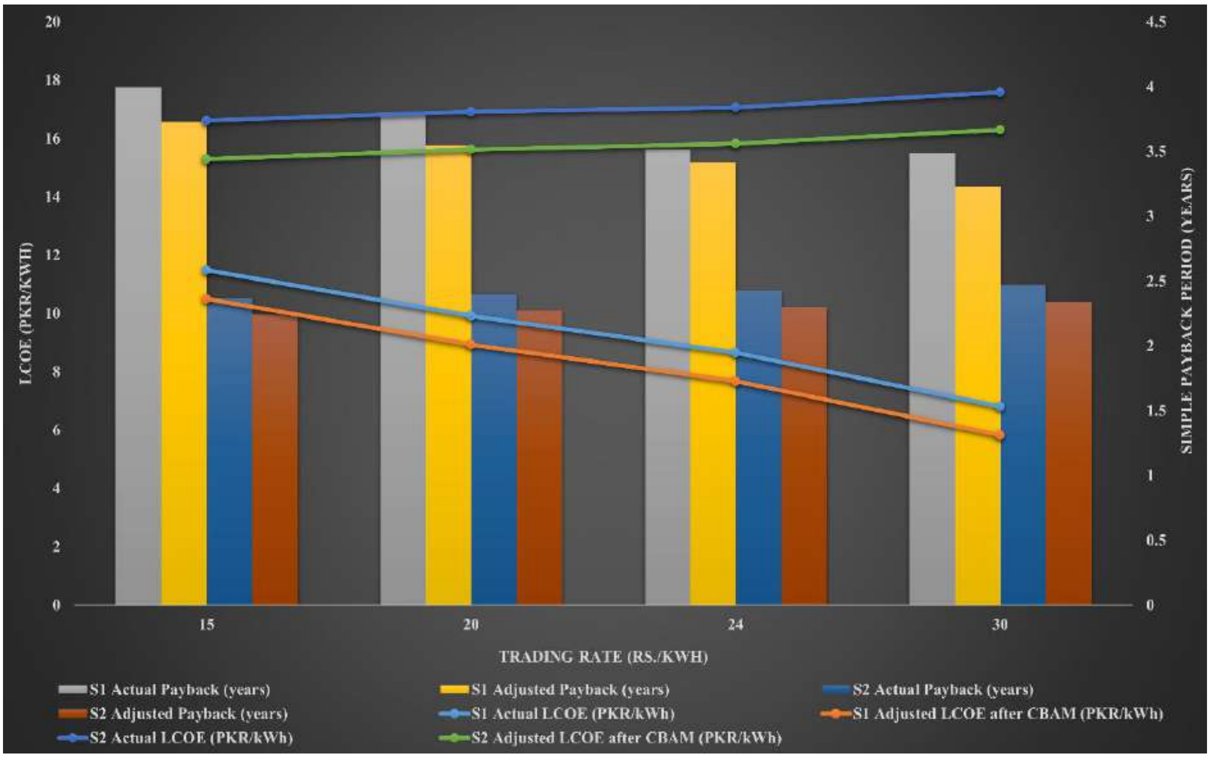

Figure 47: Impact of trading rate on LCOE and payback period (case 8) obtained after CBAM incorporation

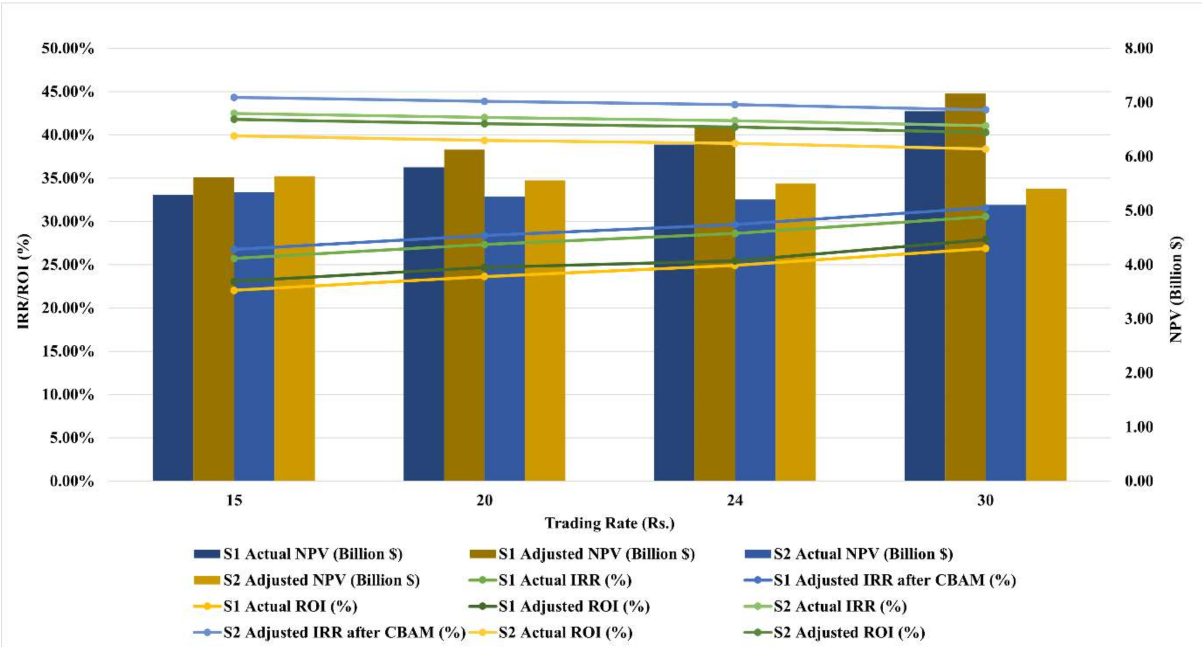

Figure 48: Impact of trading rate on IRR/ROI on case 8 obtained after CBAM incorporation

CBAM acts as an incremental revenue stream (or avoided cost) which effectively reduces the net lifetime cost per kWh for renewable assets. The size of the uplift is critically linked to the quantity of emissions avoided: greater avoided emissions produce larger carbon-credit receipts, so the largest absolute increases in NPV and the largest reductions in adjusted LCOE appear in the scenarios and cases that avoid the most CO_2 (S1 renewables consistently avoid more than S2, and thus capture more CBAM revenue in aggregate). For S1, the annual as well as lifetime avoided emissions grow into significant carbon-credit values; the LCOE is therefore reduced more in absolute and percentage terms for S1 than for S2. That LCOE reduction flows through into financial performance: incremental carbon revenue increases the numerator in IRR/ROI calculations and lifts NPV by the present value of future credit receipts, while payback shortens because additional early-year credit generated revenue accelerates cumulative cash recovery. Because S1 is higher in total capacity, its absolute NPV gains from CBAM are larger (for example, Case 8 S1 NPV increases from $6.22bn to $6.55bn while S2 increases from $5.21bn to $5.50bn). However, on a per-dollar-invested or per-energy unit basis, the relative improvements even favor S2 in percentage terms because S2's smaller CAPEX base makes each dollar of carbon revenue proportionally more impactful on returns. Because each renewable case avoids about the same amount of CO_2, the total carbon value from CBAM is basically the same across those cases. That means the extra money (or avoided cost) that CBAM brings is similar in size for cases 2–7 and for the different WR/TR runs.

6.3 Summary

This chapter explains the EU's Carbon Border Adjustment Mechanism (CBAM), why it matters for Pakistan's textile exporters, and how we modeled its impact on solar and hybrid projects in Faisalabad and Multan. To summarize, CBAM benefits depend on credible measurement, reporting and verification (MRV) to ensure avoided emissions are real, additional and not wrongly evaluated or double-counted, otherwise they risk extra costs or lost market access. A conservative carbon credit (USD 15/tCO_2) is tested across our scenarios and found CBAM consistently improves the economics of renewable projects: it lowers the levelized cost of energy (LCOE), raises IRR and ROI, increases absolute NPV, and shortens payback times compared with non-CBAM cases. Large, centralized deployments (S1) gain the biggest absolute dollar uplift because they avoid more CO_2 overall; smaller, distributed projects (S2) often show larger percentage improvements in returns because the same carbon value is a bigger share of their investment. The chapter also flags key cautions: Price volatility in carbon markets or a lower carbon price than the assumed US$15/ton would reduce the uplift; conversely, a higher global carbon price would amplify it. There is also a leakage risk: if CBAM revenue is captured by intermediaries or if emissions are simply shifted geographically (not eliminated), system benefits will be overstated. real value from CBAM. Finally, legal and administrative complexities (border adjustments, international recognition of credits) could delay or reduce the practical value of CBAM receipts. Policy takeaways are straightforward, i.e. build MRV capacity, link green finance to verified emissions reductions, and align national policy (NDCs, export support) so CBAM shifts from a compliance burden into a practical incentive for faster and economically viable decarbonization in Pakistan's textile clusters.

Chapter 7: Policy Recommendations and future directions

7.1 Current Policy Status in Pakistan

Pakistan has committed to rapidly expand renewables: the ARE Policy 2019 sets 20% renewable capacity by 2025 and 30% by 2030, and the IGCEP 2022–31 targets over 3,400 MW of on-grid net-metering by 2031. These national targets support decentralized and off-grid options that align with Pakistan's climate commitments [40,41,92]. NEPRA's DG and Net-Metering Regulations (2015) created the basic legal framework for rooftop and captive solar, and later amendments removed licensing requirements for small distributed generators (≤25 kW) and, from 2023, broadly relaxed licensing for distributed/captive plants; a change that has practical benefits but leaves some regulatory gaps to be clarified. Despite these relaxations, many textile mills operate formally licensed captive plants (generally gas-fired) in the 1–36 MW range [93,94].

7.1.1 Energy Policy and Regulatory Framework:

Delay in CTBCM: The CTBCM policy was approved by NEPRA back in 2020, however implementation delays that would have allowed bulk consumers to purchase power directly from other market players besides NEPRA only. In 2025, still it is not designed, implemented and industries have least consulted. The industrialists, particularly textile manufacturers have to move towards captive plants and PV systems amid unreliable grid. The competition with international market is killed since they are not compatible of 15 US cents, rather than minimum baseline of 9 US cents. Licensing delays (often 6–8 months) also slow CTBCM adoption [37].

Limitation in Net Metering and gross metering policy: The size of DG is limited to 1 MW with rate decrease from 27 PRK/kWh to 11 PRK/kWh. The magnitude is limited for large textile mills with substantial energy demands and reduces the respective economic viability.

High Tariff and Taxes: High tariffs i.e. 30+ PRK/kWh from grid as compared to solar gives a limitation of operation to textile industries. The solar unit around 15-20 PRK/kWh is indeed a competitive edge for textile industry. In CTBCM, non-network costs (debt servicing surcharge of PKR 3.23/kWh and cross-subsidy of PKR 3.47/kWh), can make energy access economically unfeasible i.e. 26 PRK/kWh as compared to 30+ PRK/kWh from the grids. The overall wheeling charges of 12+PRK/kWh can again further reduce the opportunity [28,58,95]. High-profile proposals to cut buyback rates have provoked strong industry pushback, underlining the need for stable policy and clear valuation of exported solar [96].

Financing and Incentives: Financing and incentives exist to support industrial renewables: the State Bank's refinancing scheme offers concessional loans (about 6% markup) for large projects and smaller captive systems, and over 1,000 MW has been financed through such windows. Import duty reductions on panels (2024) and targeted grants or green-finance tools complement credit measures. These programs reduce upfront cost barriers for industry uptake [97,98].

7.1.2 Renewable energy targets and initiatives

Pakistan national goal aims to generate 60% of its electricity from renewable sources by 2030, including solar, wind, and hydropower. Provincial governments in Punjab and Sindh have introduced policies to promote solar adoption. However, these initiatives are primarily focused on residential and agricultural sectors, with limited attention to industrial consumers.

7.2 Policy Recommendations based on Study Results

The solar rush in Pakistan is from bottom to top with on ground installed value above 20 GW. The increased energy rates from utilities make it difficult to compete in the international market. The high penetration of solar is accredited to reduced levelized costs and better compatibility. The NM with 9 GW of installed capacity with above 350,000 license holders has already tipped the scale against the utilities in-terms of recoveries and business model. The high number of distribution transformers have subjected to operational issues are additional constraint on the utilities. The CTBCM with wheeling is although a new opportunity, however it will add to the already increased solar rush and is subjected to restrained from enabling stakeholders. The need of hour is to reinforce grid on strategic locations with high power carrying capability for restricted 800 MW capacity. The CBAM is icing on top with all the instruments well in place for the execution of the integrated framework. The stakeholders interested may contribute to further reinforcing transmission grids to improve the business model on large scale wheeling. The CDM mechanisms must be in place for the better frameworks for local level to upgrade at multiple levels of CBAM. The NM and CTBCM can run side by side with the NM being converted to GM (after license period) and CTBCM + Wheeling to best unit rates in favor of consumers.

7.2.1 Core Findings of the Analysis

Policy-relevant takeaways flow directly from the outcomes. The study reveals a critical policy dilemma:

1. **The Wheeling Paradox:** A high, undifferentiated wheeling tariff destroys the economic viability of traded solar power, stifling private investment (especially for smaller, decentralized projects). Conversely, a tariff that is too low fails to fund grid maintenance and expansion, risking long-term reliability.
2. **The Utility Death Spiral is Active:** The rapid, uncoordinated adoption of industrial solar is reducing grid demand, causing utility revenue loss, and triggering tariff hikes, which in turn pushes more consumers off-grid.

3. **Policy Paralysis is Costing Competitiveness:** Delays in CTBCM implementation and restrictive net metering policies are forcing industries (like textiles) to adopt sub-optimal captive solutions, eroding their international competitiveness due to high grid-based energy costs.
4. **Stakeholder Misalignment:** There is a significant lack of consultation between regulators (NEPRA, Power Division) and industrial consumers, leading to irrational tariff structures and market rules.

7.2.2 Actionable Policy Recommendations

Pakistan's current solar boom is largely a reaction to grid failure and high tariffs rather than the result of cohesive national policy. This reactive adoption risks creating a significant inequality in energy access [95]. To fully harness the potential of off-grid solar PV and captive generation in Pakistan's textile sector under the CTBCM framework, a coordinated framework of regulatory, financial and technical measures is required to be proposed. The measure focuses on removing the remaining barriers to industrial renewable investment, while ensuring grid stability and safeguarding consumer interests. The following recommendations are extracted from real time textile industrial dynamics, stakeholder engagement, international best practices and recent analyses and literature and have been specifically adapted are to suit Pakistan's textile condition [37,95]:

7.2.2.1 Integrated Fast-Track Package for Textile Cluster Market Access

Action: Simultaneously lower CTBCM entry to 500 kW, publish a fixed CTBCM realistic roadmap with Open-Access/UoSC schedules, grant time-limited UoSC relief for MRV-verified pilot projects, and mandate a single-window commercial onboarding (standard PPA/wheeling templates, loss allocation and SLA timelines).

Mechanism: Power Division and NEPRA issue a joint directive; ISMO/CPPA deploy an online one-stop portal and standard contract library; DISCOs required to publish charge schedules and connection SLAs; a small inter-agency steering group (including industry reps) administers temporary UoSC rebates and monitors milestones.

Why: Implementing these reforms removes interdependent barriers at once; improving economic viability, accelerating initialized implementation, protecting smaller mills from abrupt cost shocks, and creating clear, auditable pathways for rapid textile cluster participation in CTBCM.

7.2.2.2 Government & Regulator (NEPRA): Implement a Phased and Differentiated Wheeling Regime

- **Action:** Announce a 5-year schedule for wheeling charges, starting low and increasing predictably. Differentiate rates by:

Distance: Lower for intra-cluster/west-of-grid transactions; higher for long-distance.
Time: Introduce Time-of-Use (ToU) wheeling charges to reflect peak system costs and encourage grid-friendly behavior.
Rationale: This provides investor certainty for the transition, protects smaller projects, and ensures charges eventually become cost-reflective to fund the grid.

7.2.2.3 Government & Regulator: Fast-Track CTBCM with Risk Mitigation Instruments

Action: Prioritize the implementation of CTBCM, coupled with the creation of a "First-Mover Guarantee" fund.
Mechanism: Offer early participants **revenue-stabilizing instruments** such as short-term PPAs or a minimum floor price for traded power to de-risk their investment from initial market volatility.
Rationale: This jump-starts the competitive market by addressing the primary investor fear of downside risk.

7.2.2.4 Regulator & Government: Incentivize Grid-Stabilizing Renewables

Action: Create a "Preferred Access" category in the power market.
Mechanism: Offer larger (S1-style) projects priority access to sell into peak markets or higher time-of-use tariffs, *conditional* on their commitment to incorporate grid-stabilizing assets like storage or demand response capabilities.
Rationale: This internalizes the system benefits of stable power, improves grid LCOE, and prevents market gaming by rewarding projects that reduce system balancing costs.

7.2.2.5 Government & Regulator: Integrate CBAM Revenues with CTBCM to De-risk Renewable Market Entry

Action: Channel part of CBAM (or equivalent carbon credit) revenues into a **"**Green Market Stabilization Fund**"** that directly supports early participants in CTBCM through temporary tariff rebates or floor-price guarantees for renewable PPAs.
Mechanism: Use verified carbon revenue streams to underwrite a First-Mover Guarantee within CTBCM; covering price volatility or settlement delays for initial renewable-to-industry transactions. Eligibility requires certified MRV of emission reductions, aligning CBAM compliance with CTBCM participation.
Rationale: This approach links *carbon finance (CBAM)* with *market reform (CTBCM)* to create a stable, low-risk entry path for renewable energy in Pakistan's textile sector. It ensures carbon revenues

recycle into cost relief for industries, accelerates clean investment, and embeds accountability and transparency in both carbon and power markets.

7.2.3 Contextualizing the Recommendations for Key Stakeholders

7.2.3.1 The Textile Sector & Industry: Challenges and Demands

Their Reality: Facing an uncompetitive grid tariff of 30+ PRK/kWh, the sector is forced into captive solar (15-20 PRK/kWh) as a survival tactic, not a strategic choice. The 1MW cap on net metering is a major constraint.

Their Policy Challenges:

- **High Embedded Costs:** The proposed CTBCM structure, with non-network costs (debt servicing, cross-subsidy ~6.7 PRK/kWh), makes wheeling power economically marginal (effective cost ~26 PRK/kWh vs. captive solar at ~18 PRK/kWh).
- **Policy Uncertainty:** Delays in CTBCM and ad-hoc changes to net metering policies destroy long-term investment planning.

Their Implicit Demand (What They Need):

- **Immediate Liquidity:** A predictable, low wheeling charge during the transition to make cross-network sales viable.
- **Scale:** Raise or remove the 1MW cap on net metering/gross metering for industrial consumers.
- **Cost Relief:** A phased reduction of the cross-subsidy and debt servicing surcharges embedded in wheeling charges.

7.2.3.2 The Government's Stance and Behavior

- **Current Position:** The government is caught between multiple objectives:
  - **Meeting RE Targets:** The 60% by 2030 goal requires massive private investment.
  - **Protecting Utility Finances:** The "utility death spiral" threatens the entire sector's solvency, leading to reactive, protective measures (e.g., potential net metering rate cuts).
  - **Managing Circular Debt:** Adding new, cheaper generation without a clear market mechanism exacerbates the existing financial burden.
  - **Observed Behavior:** Characterized by delay in CTBCM and reactive changes in overall policy (changing net metering rates), often without adequate industry consultation. This behavior stems from a short-term focus on firefighting the utility death spiral rather than executing a long-term structural vision.

7.2.3.3 The Role of Council of Common Interests (CCI)

Current Involvement: To date, the CCI plays mostly a policy-approval and dispute-resolution role, stepping in reactively when policy issues cross federal and provincial lines; for example to approve the Renewable Energy Policy and to settle disagreements over transmission and tariff matters.

Required Shift in Role:

- Evidence-Based Policy Guidance: Rather than reacting to industry backlash, CCI should commission and use studies (such as this one) that quantify how wheeling, grid access, or tariff shocks affect mill operating costs and the export competitiveness of textile clusters.
- Support for Aggregation and Collective Models: CCI can facilitate group PPA negotiations for clusters or virtual wheeling schemes so that smaller mills and SMEs share risks, lower transaction costs, and gain leverage when acquiring solar, storage, or buying power in bulk.

The table below summarizes key recommendations designed to create a more balanced, equitable, and investable energy market.

Table 14: Policy Recommendations Roadmap

Policy Recommendation	Primary Objective	Key Mechanism	Potential Outcome
Design Tiered & Targeted Solar Subsidies	Promote equitable access to solar energy	Provide subsidies for low-income, single-phase consumers and smaller systems; different support tiers for various consumer levels	Prevents a two-tiered energy system; protects low-income consumers
Integrate and Formalize Decentralized Energy	Manage the off-grid solar boom strategically	Recognize decentralized solar as a core part of national strategy; empower provincial-level regulation and planning	Creates a unified national energy vision; improves grid resilience
Promote Solar-Plus-Storage and Hybrid Systems	Enhance grid stability and reduce generator use	Incentivize battery storage paired with solar; phase out diesel generators through regulation and replacement programs	Provides reliable backup power; reduces emissions and fuel costs
Develop Local Solar Manufacturing and Skills	Build a robust domestic solar industry	Support local manufacturing; expand vocational training and technician certification	Creates jobs; reduces import dependency; supports long-term sector growth

7.2.4 Financial Incentives

Green Financing Facilities: SBP must announce trail based concessional green finance lines through local banks and DFIs to provide low-interest loans for solar PV and captive power projects. These loans should prioritize SMEs in the textile sector, which often face financing constraints.

Tax Incentives: FBR should offer tax breaks, tax holidays and accelerated depreciation for investments in energy-efficient machinery, solar PV systems, and energy storage solutions. This will reduce the upfront costs of solar adoption and improve the return on investment for textile manufacturers. (The 2024-budget duty exemption for solar panels [96] is a positive step; maintaining this and expanding it where feasible will keep system costs low.)

Subsidies for Solar-Storage Integration: The subsidies or grants for integrating battery storage systems with solar PV installations will enhance the reliability of solar power and ensure uninterrupted operations during grid outages.

7.2.5 Capacity Building and Stakeholder Engagement

Industry Consultation Forums: The Power Division should establish regular consultation workshops with industry stakeholders, including APTMA and Korangi Association of Trade & Industry (KATI), to ensure policies are aligned with ground realities.

Technical Assistance and Awareness Programs: The national and provincial energy departments need to launch awareness campaigns and provide technical assistance to textile manufacturers on solar PV technologies, regulatory compliance, and financial incentives. Entities like SMEDA, PPIB and provincial energy offices should run training workshops for textile mills on solar project design, energy efficiency and O&M. Demonstration projects such as net-zero energy textile parks or pilot virtual power plants aggregating several mill rooftops could be funded collaboratively by APTMA and Ministry of Energy as public–private partnerships to showcase viability. This will address the lack of awareness hindering solar adoption among SMEs. **Table 15** can be used for key recommendations and responsible stakeholders.

Table 15: Key Recommendations and Responsible Stakeholders

S#	**Recommendation**	**Responsible Stakeholder**	**Timeline**
1	Expand net metering limits to 5 MW	NEPRA and Power Division	Short-term (6-12 months)
2	Exclude non-network costs from wheeling charges	Power Division	Short-term (6-12 months)
3	Introduce concessional green finance lines	State Bank of Pakistan	Medium-term (12-18 months)
4	Provide tax breaks for solar investments	Federal Board of Revenue	Medium-term (12-18 months)
5	Establish industry consultation forums	Power Division and APTMA	Immediate (3-6 months)

7.3 International Tariff Structures and Comparisons

- **United States — tariffs vs. subsidies:** Heavy anti-dumping/countervailing duties on some solar imports (rates up to 3,403.96%) have raised U.S. panel prices ~10–20% and slowed deployment; the Inflation Reduction Act's tax credits/subsidies have proven more effective at creating jobs and boosting domestic manufacturing than protectionist tariffs.

- **European Union — carbon & transparency rules:** The EU's CBAM charges for embedded carbon and rules like Digital Product Passports/strict sustainability reporting push exporters to decarbonize and improve product traceability (critical for textiles) [99,100].
- **Implication for Pakistan's exporters:** To protect market access and competitiveness in the EU, Pakistani industry—especially textiles—should adopt solar PV/captive power, improve emissions accounting, and implement traceability systems.
- **High-level policy takeaway:** Avoid protectionist import barriers that raise costs; instead prioritize targeted investment incentives/subsidies for local clean manufacturing, and regulatory reforms (e.g., wheeling/open-access and traceability) that lower the cost of industrial renewable adoption.

7.4 Policy Analysis and Impact on Textile Sector – Finalized Aspect

7.4.1 Impact of international policies on Pakistan's textile sector

Market access and competitiveness: EU's CBAM and sustainability mandates require Pakistani textile exporters to reduce their carbon footprint and adopt renewable energy. Failure to comply could result in loss of market share to competitors like Bangladesh and Vietnam, which have adapted more swiftly to these demands. Solar PV and captive power systems can help Pakistani manufacturers meet these requirements and maintain competitiveness.

Supply Chain Dynamics: The U.S. tariffs on solar imports have led to a surplus of Chinese solar panels and batteries, which are being exported to Pakistan at lower prices. While this makes solar adoption more affordable in the short term, it also creates dependency on Chinese imports and poses risks if China changes its export policies. Pakistan must develop its domestic manufacturing capacity to ensure long-term energy security.

7.4.2 Strategic Recommendations for Policy Alignment

Align with international sustainability standards: Ministry of Commerce and Trade Development Authority of Pakistan (TDAP) should work with textile exporters to align with international sustainability standards such as Global Organic Textile Standard (GOTS) and OEKO-TEX®. This will enhance market access and ensure compliance with EU and U.S. requirements.

Develop domestic solar manufacturing: Ministry of Industries and Production should launch a PLI-like scheme for domestic solar module and battery manufacturing. This will reduce reliance on imports, create jobs, and lower the costs of solar PV systems over time.

Enhance environmental governance: The Pakistan-EPA should strengthen enforcement of environmental regulations and introduce real-time emissions monitoring for textile units. To that end, EPA should require large textile mills to report energy and carbon metrics, effectively integrating solar energy generation into future "green certification" schemes. Export Finance agencies and trade bodies (like APTMA) could offer preferential financing or bidding advantages to mills that achieve certain renewable energy share. In parallel, efforts to decarbonize other parts of the textile value chain cotton farming, water use and chemical recycling should be coordinated with energy transition, as in the CDPR's "green textile" roadmap [90].This will ensure that solar adoption translates into tangible environmental benefits and compliance with international norms.

7.5 Summary and Final Remarks

This chapter provides targeted, evidence-based policy recommendations to accelerate renewable integration in Pakistan's textile sector. The conflict is not industry vs. government; it is a shared struggle against an outdated market structure. Our recommendations provide a concrete path to align interests:

- **The Government** gets a managed transition that protects the grid and unlocks private investment to meet its RE goals.
- **The Textile Industry** gets the predictable, low-cost energy it needs to regain global competitiveness.

The analysis identifies that the current policy landscape, characterized by delayed CTBCM implementation, high wheeling charges including non-network costs, and restrictive net-metering caps, is a major barrier. Specific, actionable reforms are proposed for relevant stakeholders: *NEPRA and the Power Division* must urgently finalize and implement CTBCM, simplifying the process and expanding the net-metering threshold to 5 MW. Crucially, the *Power Division* should be aiming for a target of PKR 5–8/kWh wheeling charges to ensure viability. Financial incentives are key; the *SBP* should introduce concessional green financing, while the *FBR* must reinstate tax holidays and duty exemptions on solar equipment to facilitate solar influx within textiles. Internationally, lessons from US and India show that rational wheeling charges boost adoption, while the EU's CBAM directly impacts textile exports, making decarbonization through solar a commercial necessity to maintain market access.

To conclude, the transition to off-grid solar PV and captive power systems in Pakistan's textile sector is not only techno-economically feasible but also environmentally imperative under the CTBCM regime. The recommendations provided in this study are specific, actionable, and targeted toward relevant entities, ensuring that they are grounded in evidence and practical realities. By implementing these recommendations, Pakistan can unlock the potential of solar energy to enhance the competitiveness of its textile sector, reduce carbon emissions, and achieve its renewable energy goals. The time for action is now, and stakeholders must move beyond promises to delivery to secure a sustainable energy future for Pakistan's textile industry.

Chapter 8: Outcomes of the Study and Concluding Remarks

This study set out to evaluate pathways for large-scale solar integration into Pakistan's industrial power systems; focusing on textile clusters in Faisalabad and Multan; and to compare three grid-integration mechanisms (net-metering, gross-metering and CTBCM). Also, the work combined detailed mapping and GIS of existing energy and PV assets, a techno-economic assessment of alternative deployment scenarios, and environmental accounting including a Carbon Border Adjustment-style mechanism to monetize avoided CO_2. In terms of scoping, the study mapped energy use and solar adoption across 80 textile mills in Faisalabad and Multan hubs and combines it with stakeholder feedback to test how off-grid/on-site PV and hybrid captive systems would perform under Pakistan's emerging CTBCM contracts. The field data show a fast move to hybrid configurations: roughly 60%+ of sampled mills now run hybrid or tri-hybrid systems (tri-hybrids ≈20%), with ∼145 MW (Faisalabad sample ~145 MW; Multan ~92 MW) of installed PV across the sample. Two system designs were modelled in depth: **S1**, a large, centralized deployment (3,750 MW, ~87% renewable fraction), and **S2**, a smaller, distributed deployment (2,175 MW, ~75% renewable fraction). The analysis produced coherent and policy-relevant outcomes about costs, investor returns, carbon value and regulatory sensitivities. Stakeholders in Faisalabad and Multan (industry leaders, associations, NTU, DISCO/NEPRA representatives) demonstrated CTBCM as a real opportunity, but is flagged with major practical barriers: high and opaque Use-of-System charges, legacy PPAs and DISCO resistance, weak MRV capacity for carbon claims, financing gaps for SMEs, and administrative burdens that could block broad uptake.

From a planning perspective, the results of this study illustrate a classic trade-off: large, centrally coordinated renewable deployment (S1) minimizes long-run system costs and delivers the highest aggregate NPV, but it requires high upfront investment, grid reinforcements and institutional capacity to integrate variable supply. Smaller, distributed programs (S2) accelerate private deployment because they are less capital-intensive per project and deliver superior investor returns, but they do not minimize the total system cost to the same degree. A pragmatic policy should therefore aim to *capture the benefits of S1 (low system LCOE and emissions) while preserving enough investor incentives as in S2* so private capital continues to flow.

A *wheeling increase* above ≈ *PKR 15* materially reduces S2 IRR and pushes S2 payback to higher level; this is a clear investor sentiment threshold. ISMO and tariff regulators should avoid abrupt hikes across this band without transition measures. A *trading rate* uplift from PKR 20 → 30 strongly benefits large-scale sellers (S1) and can justify incremental grid reinforcement and storage investment if accompanied by credible market rules. If the authority wants to favor centralized scale (S1), raising TR is a blunt but effective lever; if the objective is to preserve distributed growth (S2), avoid TR regimes that materially disadvantage small prosumers.

Incorporating CBAM credits at a conservative price materially strengthens the economics of every renewable case. CBAM reduces adjusted LCOE, raises IRR/ROI and increases NPVs; the absolute NPV uplift is larger for S1 (because S1 avoids more CO_2 in total), while percentage improvements in returns are meaningful for both scenarios. The results confirm that credible carbon finance is a useful lever for accelerating large-scale decarbonization while also improving private returns. *In an environmental perspective*, the study confirms substantial emissions reductions are feasible within the textile clusters by converting industrial self-generation and on-site demand to solar. In numerical terms the modelled renewables deployments avoid on the order of 1.6–1.76 billion kg CO_2 per year depending on scenario, which, monetized at proposed rates, translates into hundreds of millions of dollars of carbon credit value over project lifetimes.

8.1 Concluding Remarks

In consideration of the standpoint of mill owners and energy managers in Faisalabad and Multan, a clear picture emerges: "**power is by far their biggest pain point**". Nearly everyone reported heavy investment in multi-fuel generation (gas turbines, diesel gensets, and rising solar PV) just to keep looms running. Solarization offers a clear, practical pathway to gear up competitiveness and resilience in Pakistan's textile hubs: rapid deployment of rooftop, ground-mount and captive PV; paired where appropriate with battery backup and smart dispatch; can cut fuel imports, lower unit energy costs, reduce outage exposure, and deliver measurable Scope-2 emissions reductions that improve market access. Field mapping shows substantial unused rooftop and land potential across Faisalabad and Multan and an existing momentum of hybrid and tri-hybrid plants that can be scaled quickly; converting this latent capacity into bankable projects requires streamlined interconnection, time-resolved metering, concessional financing, and simple standardized contracts that reduce transaction costs for SMEs. Focused pilots, cluster aggregation models, and MRV-ready emissions accounting will accelerate learning, attract capital and demonstrate the replicable business case: faster paybacks for distributed projects, larger system savings from coordinated deployments, and a durable reduction in production risk; making solar the immediate, high-impact lever for a cleaner, cheaper and more competitive textile industry.

In focus groups, mill managers express hope that CTBCM will legitimize the informal PPAs they have been doing and enable new investments in efficiency. The promise of CTBCM; specifically, the ability to wheel new solar energy in, or to sell excess solar to neighbors is met with cautious optimism. As one mill engineer put it, "if I can sign a PPA with a solar farm at PKR 15 per unit TR with <PKR 10 WR (PKR 25 cumulatively per kWh), my bottom line improves dramatically." But there were equally voiced concerns: many simply don't understand how to plug into CTBCM. Also, they stress that for tangible gains, CTBCM must deliver true cost savings. Questions about up-front fees, contract duration, and the actual net savings abound. These ground views align with the theoretical

viewpoint: industry hopes for cheaper, cleaner supply under CTBCM, but worries about design flaws which could nullify the benefits.

In conclusion, the evidence supports a **dual-track approach**: continue to build large centrally managed renewable capacity and grid services (to minimize LCOE and system emissions) while preserving pathways and modest protections which keep distributed, lower-capex projects financially viable (to accelerate deployment and leverage private balance sheets). CBAM is a clear net positive for both tracks, but policymakers must combine it with prudent wheeling design, CTBCM governance, and targeted storage finance to realize both fast deployment and lowest long-term system cost. The technical work; from GIS mapping through TEA and CBAM compliance; demonstrates the feasibility and returns of the proposed approaches and provides clear guardrails and breakpoints (i.e. feasibility hinders above *Wheeling rates > PKR 12*), which regulators and industry can use to devise a pragmatic, investment-friendly transition. Thus, CTBCM implementation is constrained by *bureaucratic (institutional) inertia, inadequate stakeholder engagement, and unresolved policy conflicts*; many of the very issues the reform was meant to solve. Meanwhile, markets evolve: in the absence of CTBCM, industry continues to lock in its own solutions (especially solar PV), potentially shrinking the pool of willing participants when/if CTBCM finally launches.

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Appendix

A.1. Input hourly Textile Load Profile for Analysis

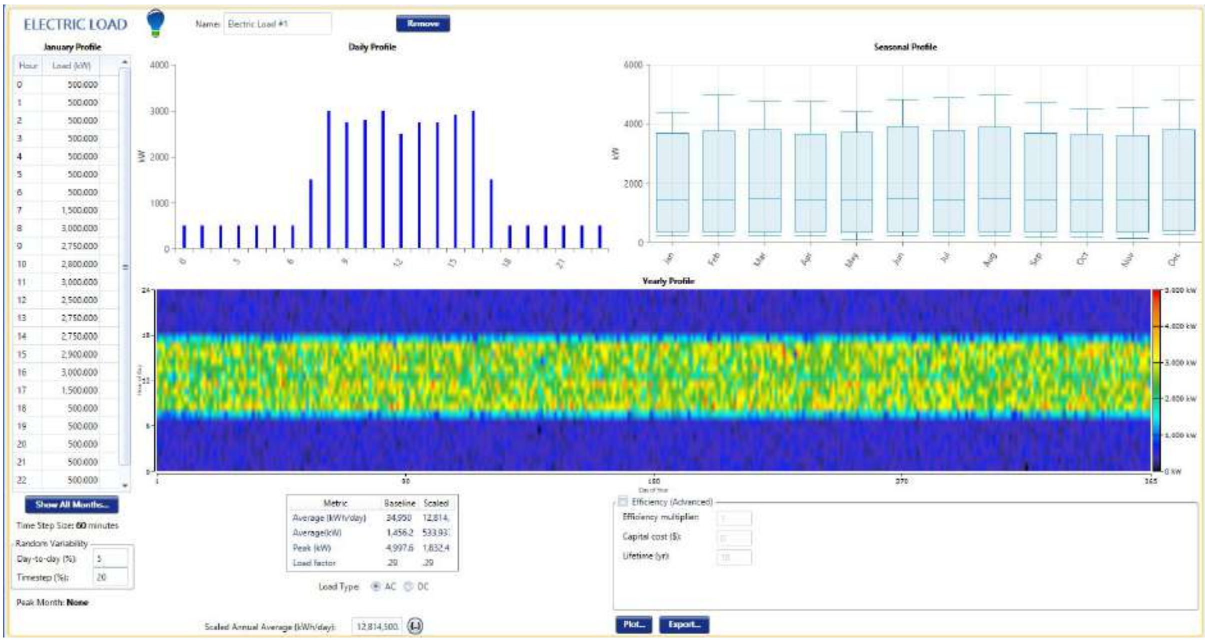
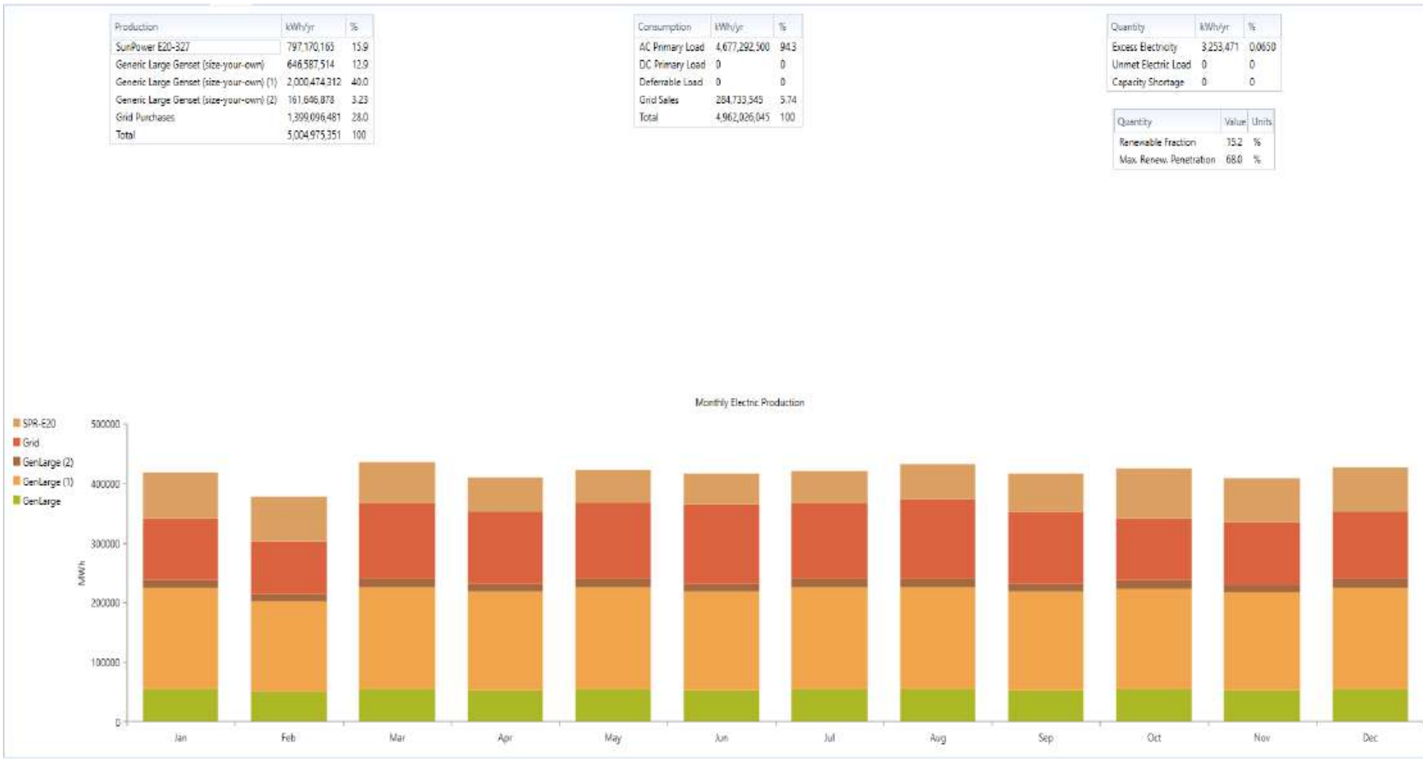


Figure A.1: Load Profile of textile industries considered

A.2. Electrical Load Results and Grid dependency upon various cases

a) Business as usual Case



Production	kWh/yr	%
SunPower E20-327	797,170,165	15.9
Generic Large Genset (size-your-own)	646,587,514	12.9
Generic Large Genset (size-your-own) (1)	2,000,474,312	40.0
Generic Large Genset (size-your-own) (2)	161,646,878	3.23
Grid Purchases	1,399,096,481	28.0
Total	5,004,975,351	100

Consumption	kWh/yr	%
AC Primary Load	4,677,292,500	94.3
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	284,733,545	5.74
Total	4,962,026,045	100

Quantity	kWh/yr	%
Excess Electricity	3,253,471	0.0650
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	15.2	%
Max. Renew. Penetration	68.0	%

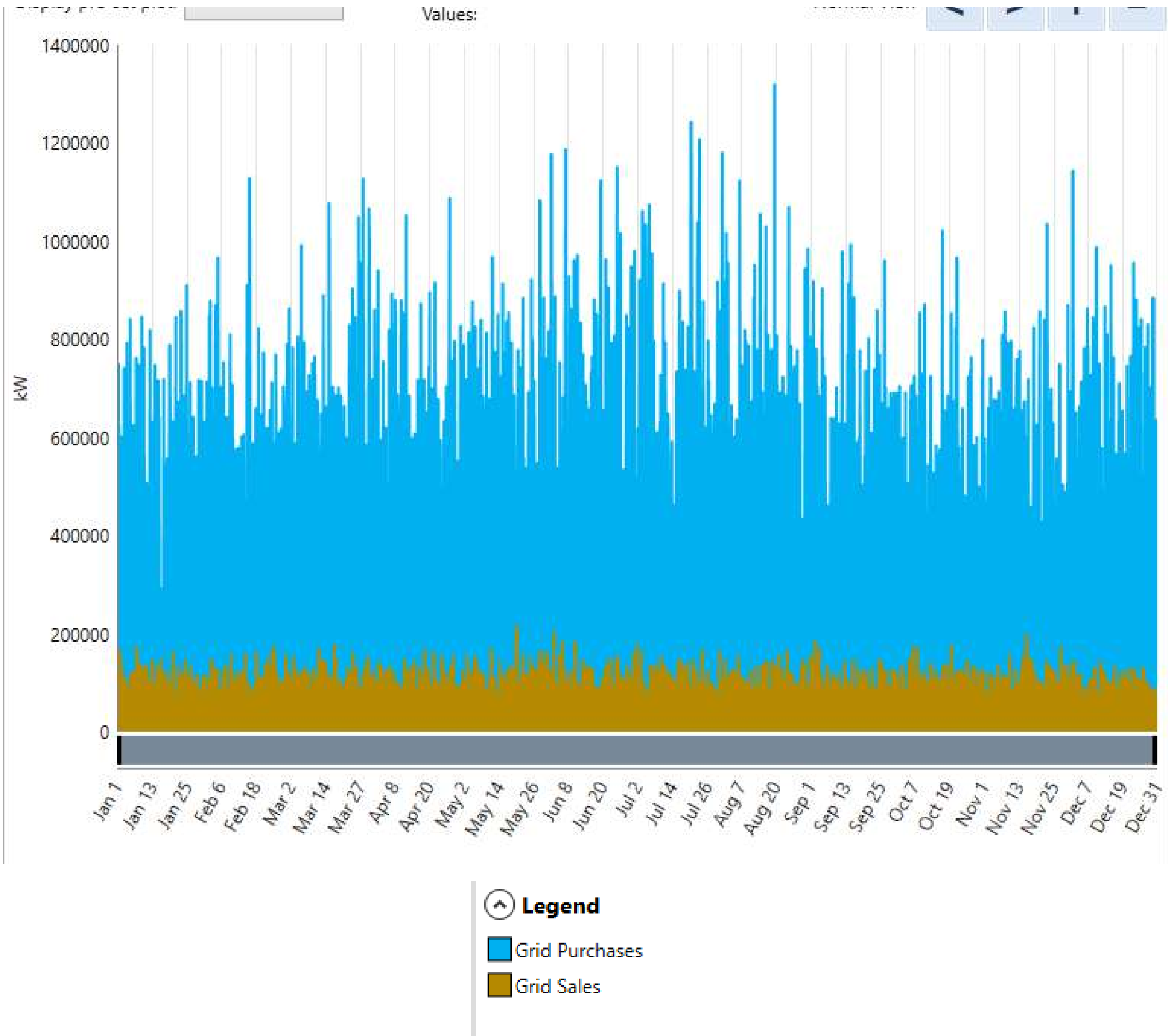


Figure A.2: Electrical Load Served by various sources and grid dependency depicted in case 1

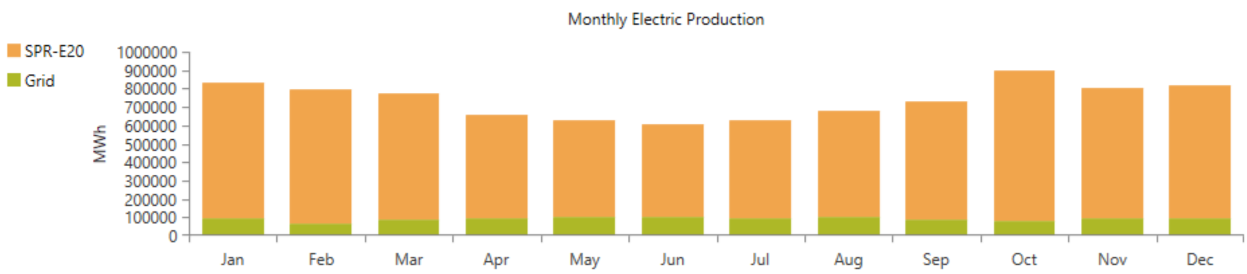
b) Scenario 1 Case 8 (CTBCM adoption with 87% renewable capacity)

Production	kWh/yr	%
SunPower E20-327	7,739,516,169	87.6
Grid Purchases	1,098,891,513	12.4
Total	8,838,407,682	100

Consumption	kWh/yr	%
AC Primary Load	4,677,292,500	55.5
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	3,746,038,818	44.5
Total	8,423,331,318	100

Quantity	kWh/yr	%
Excess Electricity	29,579,532	0.335
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	87.0	%
Max. Renew. Penetration	120	%



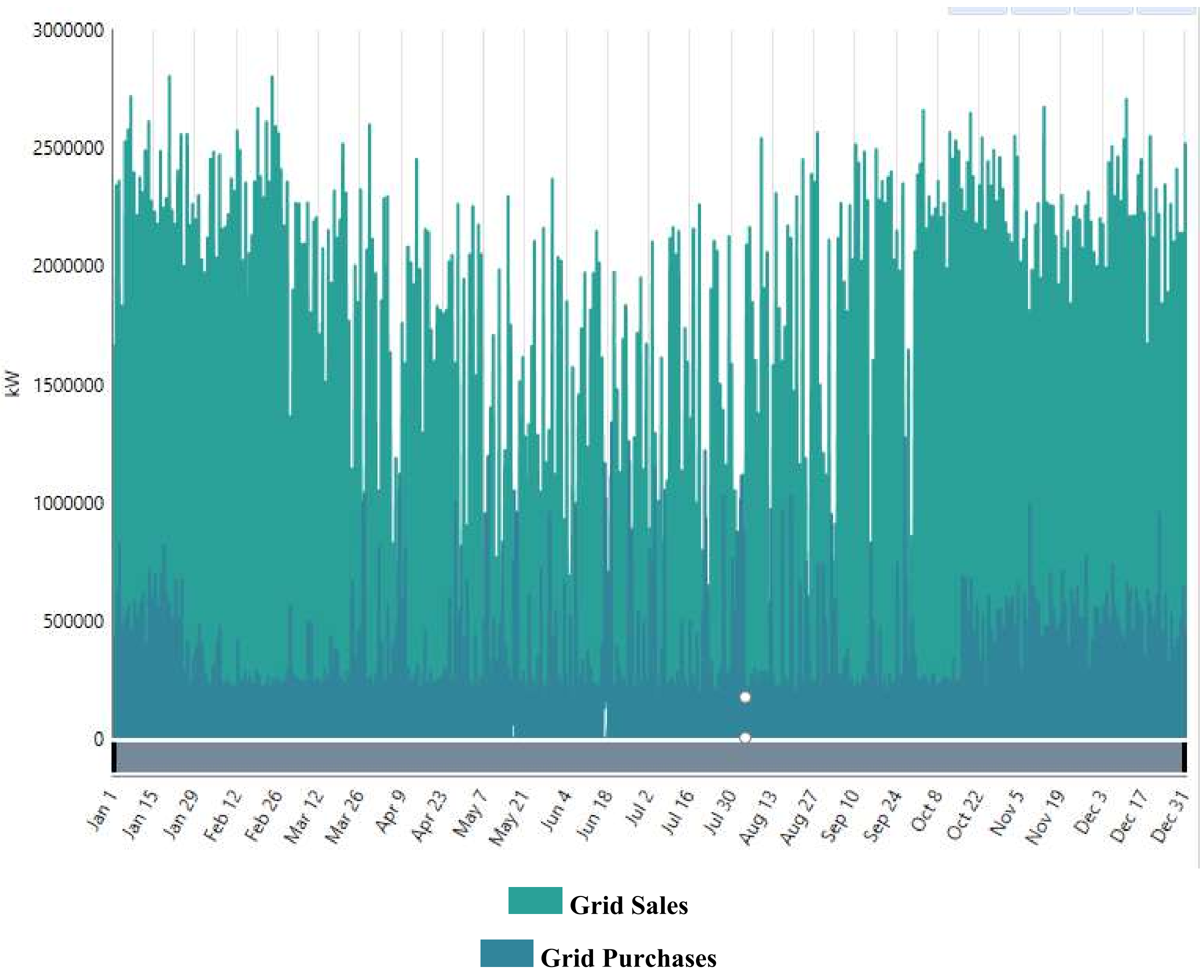


Figure A.3: Electrical Load Served by various sources and grid dependency depicted in case 8 S1

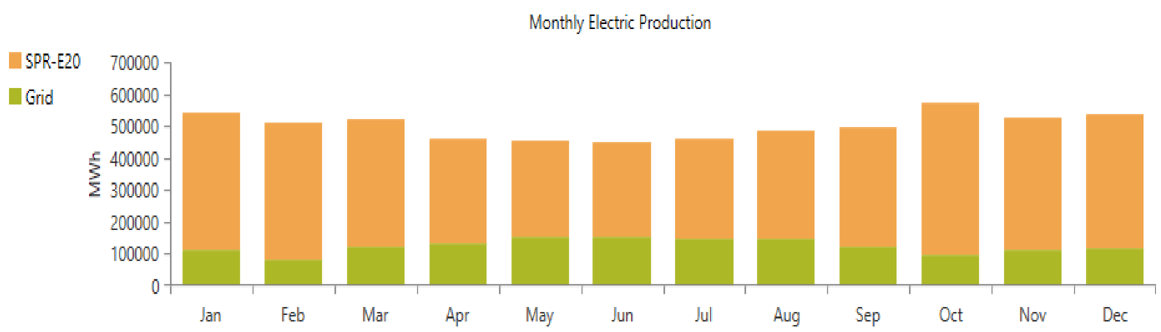
c) Scenario 2 Case 8 (CTBCM adoption with 75% renewable capacity)

Production	kWh/yr	%
SunPower E20-327	4,512,988,651	75.1
Grid Purchases	1,500,105,851	24.9
Total	6,013,094,502	100

Consumption	kWh/yr	%
AC Primary Load	4,677,292,500	81.3
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	1,072,411,352	18.7
Total	5,749,703,852	100

Quantity	kWh/yr	%
Excess Electricity	39,727,597	0.661
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	73.9	%
Max. Renew. Penetration	126	%



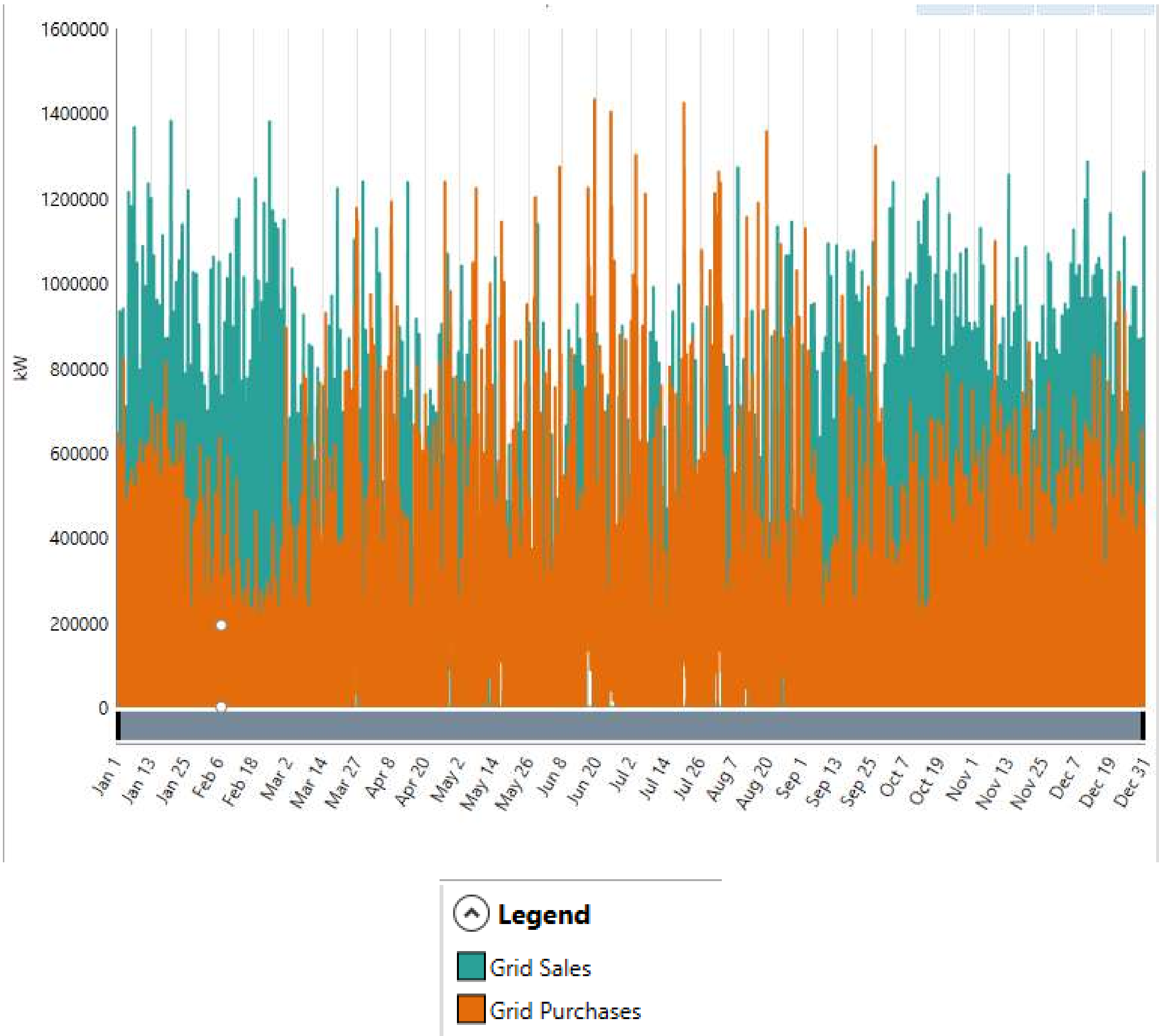


Figure A.4: Electrical Load Served by various sources and grid dependency depicted in case 8 S2.