

CBAM POLICY DEVELOPMENT, ADAPTATION AND COMPLIANCE: A CASE STUDY OF TEXTILE SECTOR IN PUNJAB

Mashhood Urfi¹, Yasir Zada Khan², and Nameer Urfi³

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¹ Manager, Research & Development, Carbo-X (Private) Limited, Lahore.

² Economist/ Director, Iqtisadi Strategic Solutions (SMC-Private) Limited, Lahore.

³ Managing Director, Carbo-X (Private) Limited, Lahore.

ABSTRACT

The European Union's Carbon Border Adjustment Mechanism (CBAM) presents a growing regulatory and competitiveness challenge for Pakistan's textile sector, which is highly export-oriented and closely integrated with EU markets. This study assesses the readiness of Pakistan's textile industry to comply with CBAM requirements and evaluates the economic consequences of non-compliance, with a particular focus on Punjab's major textile clusters.

The research adopts a mixed-methods approach across three components. Component 1 undertakes a regulatory review and gap analysis to examine the alignment between EU CBAM obligations and Pakistan's federal, provincial, and industry-level policy frameworks. Component 2 develops a firm-level CBAM Readiness Index (CRI) using primary survey data from 27 leading textile exporters, supported by focus group discussions and key informant interviews. The CRI combines ten pillars covering emissions measurement, energy use, MRV systems, traceability, governance, and preparedness, and is estimated using expert-weighted, equal-weighted, and PCA-based methods. The results show moderate-to-high readiness among sampled firms, with a mean expert-weighted CRI score of 66.8 (out of 100), and strong consistency across alternative weighting approaches. Component 3 quantifies the economic disadvantages of non-compliance by comparing expected non-compliance costs with compliance costs through a Net Advantage of Compliance (NAC) framework.

The findings reveal a central paradox. While leading exporters display substantial technical awareness and reporting capacity for CBAM, domestic policy instability, particularly in energy pricing and renewable energy regulations, has emerged as the main barrier to decarbonisation investment. Quantitative results indicate that 93 percent of firms exhibit a positive net advantage of compliance, implying that expected losses from non-compliance already exceed compliance costs. The study concludes that CBAM readiness in Pakistan's textile sector is no longer primarily a technical issue, but a policy coordination challenge requiring predictable energy policies, strengthened MRV implementation, and targeted green financing to safeguard export competitiveness.

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ABBREVIATIONS

BAU	Business-As-Usual (emissions scenario)
CAPEX	Capital Expenditure
CBAM	Carbon Border Adjustment Mechanism
CC	Compliance Cost
CII	Compliance Investment Index
CRI	CBAM Readiness Index
DFI	Development Finance Institution
DPP	Digital Product Passport
EEA	European Environment Agency
EnMS	Energy Management System
EPR	Extended Producer Responsibility
ESG	Environmental, Social, and Governance
ETS	Emissions Trading System
GHG	Greenhouse Gas
HSD	High-Speed Diesel
ICAP	International Carbon Action Partnership
ISO	International Organization for Standardization
LPI	Logistics Performance Index
MEPS	Minimum Energy Performance Standards
MRV	Monitoring, Reporting, and Verification
NAC	Net Advantage of Compliance
NCC	Non-Compliance Cost
NDC	Nationally Determined Contribution
PCA	Principal Component Analysis
RLNG	Regasified Liquefied Natural Gas
tCO ₂	Tonnes of Carbon Dioxide

INTRODUCTION

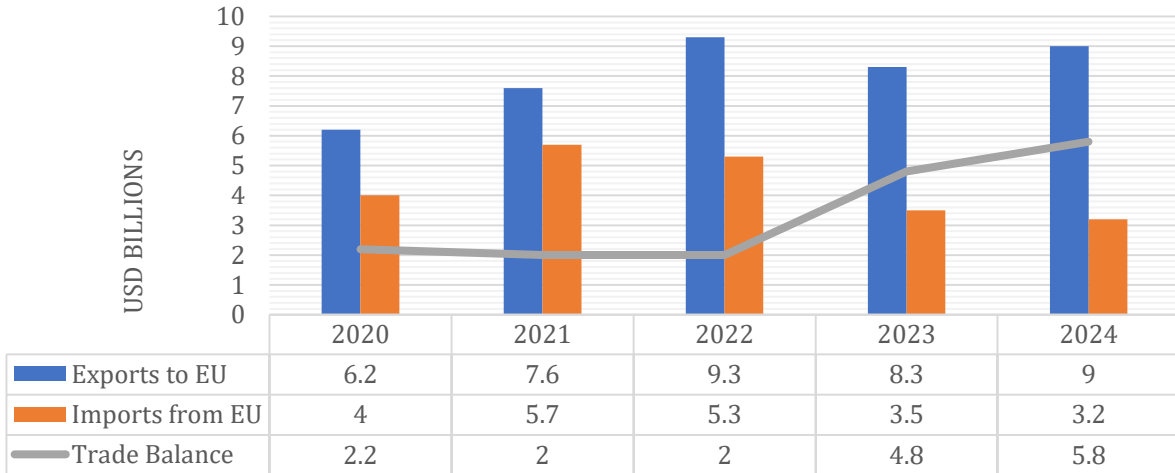
The European Union's Carbon Border Adjustment Mechanism (CBAM) represents a pivotal policy innovation designed to complement the EU Emissions Trading System (ETS) and prevent carbon leakage. The ETS, introduced in 2005, is a cap-and-trade system that places a price on carbon emissions by requiring industries to hold allowances for each ton of CO₂ emitted (European Commission, 2023c). While the ETS effectively incentivizes decarbonization within the EU, it creates a risk that carbon-intensive production might relocate to regions with laxer climate regulations, undermining global emissions reduction efforts. CBAM addresses this by imposing a carbon price on imports of selected goods such as steel, cement, and aluminum (and other carbon-intensive products covered under the Regulation), mirroring the costs EU producers face under the ETS (European Commission, 2023c).

Although designed to be WTO-compatible, CBAM has raised legal and diplomatic concerns and is being implemented in phases, beginning with a transitional reporting period in October 2023 and moving toward certificate surrender obligations from 2026 onward. By extending EU carbon pricing to imports, CBAM aims to level the competitive field while encouraging decarbonization beyond EU borders (Marcu et al., 2020; ERCST, 2021). However, concerns persist regarding its potential effects on developing countries that may lack the financial, technical, or institutional capacity to comply with emerging standards (Abnett, 2025). CBAM therefore sits at the intersection of climate policy, trade governance, and global equity.

Established under Regulation (EU) 2023/956 and operational in its transitional phase since 1 October 2023, CBAM's binding price-alignment mechanisms will take effect beginning in 2026 (European Commission, 2023b). As one of the world's major textile exporters, Pakistan where textiles account for a substantial share of exports and approximately 8.5% of GDP is directly exposed to CBAM's trade and climate implications (Invest Pakistan, 2023; Pakistan Trade Council, 2023). Textiles constitute a dominant share of Pakistan's merchandise exports (often cited near two-thirds depending on classification), making any compliance costs or EU demand shifts nationally significant. Punjab, which hosts a large concentration of textile production, faces particular vulnerability due to continued reliance on fossil fuels and uneven energy efficiency and emissions management systems (Invest Pakistan, 2023; APTMA, 2024).

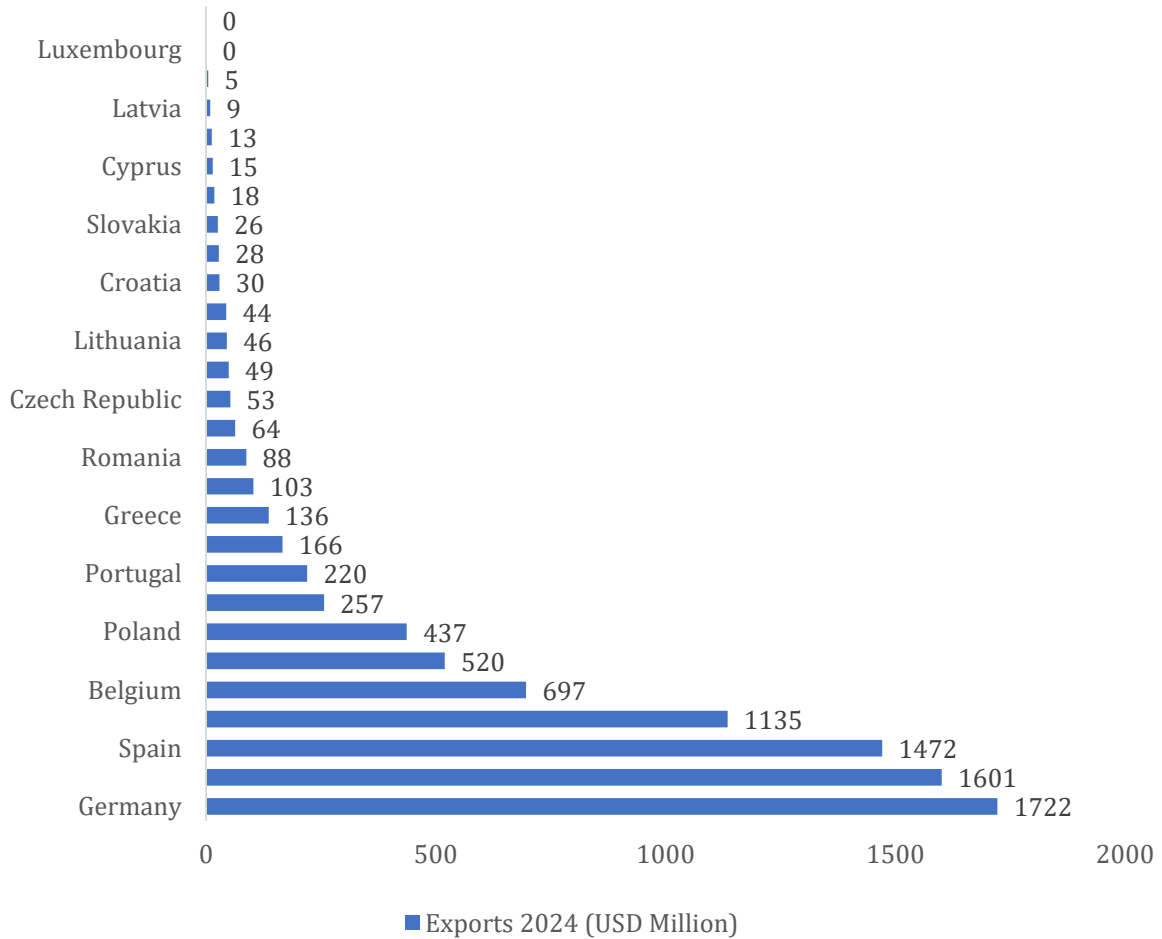
Pakistan's overall trade with EU has been illustrated in Figure 1 and the exports to respective EU members have been illustrated in Figure 2.

Figure 1 Pakistan's Trade with the European Union (USD Billion)



Source: Author's illustration, data obtained from Pakistan Business Council and ITC Trade Map.

Figure 2 Pakistan's Exports to EU Member States (2024)



Source: Author's illustration, data obtained from Pakistan Business Council and ITC Trade Map.

The All-Pakistan Textile Mills Association (APTMA), representing over 200 member mills, plays a central role in industry governance, policy engagement, and the sector's sustainability transition. Industry bodies have begun piloting MRV (monitoring, reporting, and verification) systems, coordinating training, and facilitating access to finance; however, practitioners report a significant gap between current operational standards and anticipated CBAM compliance requirements (APTMA, 2024). Absent timely adaptation, firms risk reduced EU market access, exposure to tariffs or administrative barriers, reputational costs, and capital reallocation. Conversely, alignment with CBAM may open access to climate finance, strengthen competitiveness, and support integration into low-carbon global value chains (European Commission, 2023a; KPMG International Limited, 2024).

1.1. Problem Statement

Pakistan's textile sector, a cornerstone of the national economy contributing approximately 60% of merchandise exports and 8.5% of GDP, faces significant challenges from the European Union's Carbon Border Adjustment Mechanism (CBAM). As one of the world's major textile exporters, Pakistan is highly exposed to CBAM's requirements for carbon reporting and pricing on imports, which could impose tariffs, disrupt market access, and increase compliance costs starting from 2026. In Punjab, where the bulk of textile production is concentrated, many firms rely on fossil fuels, lack robust monitoring, reporting, and verification (MRV) systems, and struggle with limited access to climate finance and institutional support. Without adequate preparation, this could lead to lost revenues, reputational damage, and relocation of production, exacerbating vulnerabilities in developing countries like Pakistan. Existing literature highlights macroeconomic risks but lacks firm-level insights into readiness gaps, compliance costs versus non-compliance disadvantages, and actionable strategies for SMEs, creating an urgent need for targeted analysis to safeguard exports and promote a sustainable transition.

1.2. Research Objectives

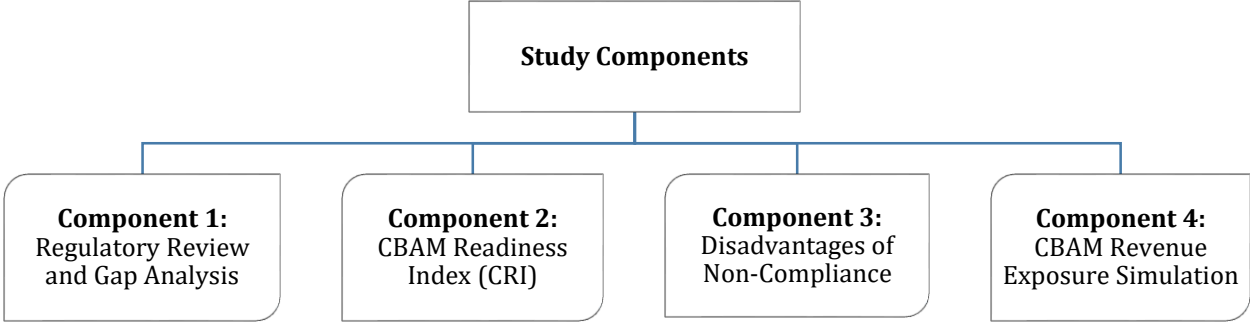
This study aims to address the challenges posed by CBAM to Punjab's textile sector through the following objectives:

- To conduct a regulatory review and gap analysis of Pakistani (federal, provincial, and APTMA) policies against EU CBAM requirements, identifying alignments and misalignments to inform policy harmonization.
- To develop a CBAM Readiness Index (CRI) using a situational analysis of the sector's readiness based on firm-level surveys, key informant interviews (KIIs), and focus group discussions (FGDs), to benchmark preparedness across key pillars such as emissions performance, energy transition, and MRV capacity shall be used.
- To evaluate the disadvantages of non-compliance (e.g., tariffs, contract losses) compared to the costs of compliance (e.g., investments in renewables and certifications), providing a cost-benefit framework to guide decision-making.
- To propose evidence-based policy interventions and firm-level measures that enhance CBAM compliance, protect EU market access, and accelerate the sector's shift toward low-carbon practices.

1.3. Study Design

The report is structured around four analytical components. Each component presents results separately, while interpretation and synthesis across components are provided in a consolidated Discussion section. These components are illustrated Figure 3:

Figure 3 Study Design



Source: Author's illustration.

LITERATURE REVIEW

2.1. The EU CBAM Framework and Global Debate

The Carbon Border Adjustment Mechanism (CBAM), a core element of the EU Green Deal, has been widely examined by trade economists, environmental policy scholars, and industrial strategists. Literature from 2021–2024 highlights its dual objective: preventing carbon leakage and levelling the competitive field for EU producers subject to the EU Emissions Trading System (EU ETS). Adopted under Regulation (EU) 2023/956, CBAM entered a transitional reporting phase on 1 October 2023, with definitive certificate surrender obligations taking effect from 1 January 2026, alongside the phase-out of free allowances under the EU ETS (European Commission, 2023b, 2026, OECD, 2025b).

CBAM initially applies to carbon-intensive sectors; iron and steel, cement, aluminium, fertilizer, electricity, and hydrogen; while downstream sectors such as textiles remain under review. Textile inclusion is therefore possible but not scheduled for the 2026 definitive phase; proposals for expansion to additional downstream products in steel and aluminium are slated for consideration from 2028 onward (European Commission, 2023a, 2026; OECD, 2025b). European Commission (2022b) estimates that CBAM will eventually cover roughly 50% of EU imports in carbon-intensive sectors, with textiles potentially incorporated in later phases (GOP, 2021).

The literature underscores CBAM’s environmental and trade rationale, aligning imported goods with EU carbon costs to prevent leakage while also emphasizing legal, administrative, and equity concerns in extending EU carbon pricing extraterritorially (WTO, 2022; Marcu et al., 2020). The CBAM Implementation Package, refined in 2023 through the Omnibus Regulation, adopted in October 2025, clarifies reporting and pricing rules: embedded emissions must be verified or assigned default values; certificate purchases begin in February 2027; and annual surrender obligations start in September 2027 for the preceding year’s imports (European Commission, 2023b; European Commission, 2026). International institutions warn that without complementary finance and capacity-building, CBAM could disproportionately affect developing-country exporters lacking robust MRV systems and access to concessional finance (WTO, 2022; OECD, 2025b; Cornago & Berg, 2024).

2.2. Pakistan’s Exposure to CBAM and Policy Context

Pakistan’s exposure to CBAM arises from the dominance of textiles in its export basket. In FY2022–23, textiles accounted for approximately 59–60% of merchandise exports, making the sector highly sensitive to EU market access and regulatory standards (GOP, 2023a). Pakistan’s Updated NDC (2021) commits to reducing projected GHG emissions by up to 50% by 2030, 15% unconditional and 35% conditional on international support (GOP, 2021b). However, sectoral diagnostics, including the Pakistan Climate Adaptation Plan (2023), highlight gaps in firm-level MRV systems, limited emissions baselines, and weak access to climate finance, constraints that reduce the textile sector’s responsiveness to regulatory shifts such as CBAM.

The National Climate Finance Strategy (2022) further notes that textiles receive less than 3% of total climate-linked financing, underscoring substantial transition funding gaps (GOP, 2023b).

2.3. Comparative Experiences from Textile-Exporting Economies

Experiences from other textile-exporting economies illustrate varied policy responses to CBAM-type risks. Bangladesh’s policy debates around LDC graduation highlight the vulnerability of an apparel sector heavily reliant on EU markets; research suggests that the loss of preferential tariffs, combined with potential carbon border measures, could significantly increase effective trade costs, reinforcing the need to integrate trade strategy with decarbonization (Razzaque et al., 2024).

Vietnam has advanced institutional preparations, including a national carbon registry and domestic carbon market pilots, alongside sectoral incentives to enhance exporter readiness (OECD, 2025a). China, operating a national ETS covering over 4.5 billion tonnes of CO₂, has promoted renewable energy procurement and trade-linked carbon labeling in textiles, enabling pre-emptive adjustment to EU regulatory shifts (Dai & Pollitt, 2025).

These cases demonstrate combinations of market instruments, fiscal incentives, and buyer-driven reporting requirements that offer lessons for Pakistan, despite institutional differences (Razzaque, et al., 2024; ICAP, 2025; OECD, 2025b; World Bank, 2023).

2.4. Climate Finance and Industrial Policy Instruments

Climate finance and industrial policy literature identifies blended finance, fiscal incentives, and performance-linked instruments as key enablers of sectoral decarbonization (Li & Ananthakrishnan, 2022; Cordonnier & Saygin, 2023). Pakistan’s National Climate Finance Strategy (GOP, 2024a) seeks to mobilize substantial resources for mitigation and adaptation; however, historical access to concessional climate finance has been limited, and textiles have received a relatively small share of climate-tagged investment (GOP, 2024a; CDPR reviews, 2024–2025).

This financing gap is critical, as capital expenditure for energy efficiency, renewable integration, and MRV upgrades constitutes a primary constraint for firms. At the same time, fiscal frameworks continue to subsidize fossil fuels, PKR 112 billion in 2022, contradicting transition objectives. Industrial energy consumption remains 64% fossil-based, with renewable penetration in textiles below 7% (Pakistan Economic Survey, 2023c). APTMA (2023) calls for expanded green financing pipelines and systematic carbon auditing to safeguard EU market access.

Recent mixed-method research on Bangladesh further shows how LDC graduation combined with CBAM-type charges could materially increase apparel trade costs, underscoring the importance of early mitigation through diversification, cleaner energy, higher value products, and targeted finance (Razzaque & Rahman, 2022; Khan, 2025; Schröder, 2024).

2.5. Composite Indices and Measurement Frameworks

Composite indices are widely used to capture multidimensional policy challenges through transparent indicator selection, normalization, weighting, and aggregation, supported by robustness testing (Nardo et al., 2005; Greco et al., 2019). Prominent examples include the Environmental Performance Index (EPI) (Wendling et al., 2020) and the World Bank’s Logistics Performance Index (LPI) (World Bank, 2018), which translate complex data into actionable benchmarks.

Methodological transparency is critical: alternative weighting and aggregation choices can materially affect rankings, particularly for mid-ranked entities (Greco et al., 2019; Gómez-Limón et al., 2020; Alqararah, 2023; Jain & Mohapatra, 2023). These lessons directly inform the CBAM Readiness Index (CRI), where indicators such as CO₂ intensity, MRV capacity, and renewable energy share require clear coding rules, justified weighting, and sensitivity analysis. By applying established best practices, the CRI aims to provide a credible, internationally aligned benchmarking tool (Saisana et al., 2005; OECD, 2008).

2.6. Pakistan-Specific Empirical Studies and Sector Diagnostics

Empirical research on textile decarbonization in Pakistan remains limited and is largely policy-driven rather than econometric. Across studies, three recurring themes emerge: (i) gaps in firm-level MRV systems and limited energy audit coverage; (ii) financing constraints and high CAPEX barriers; and (iii) concentrated EU exposure among larger exporters, leaving SMEs less prepared (SDPI, 2024; World Bank, 2023).

Firm-level evidence reinforces these patterns. An assessment by Alternate Development Services (ADS) found that only 13 of 29 surveyed units had completed formal energy audits, and even fewer had conducted product-level carbon footprint assessments (ADS, 2024). Cluster-based assessments in Punjab and Karachi report awareness of carbon reporting requirements but weak documentation and baseline tracking, particularly among SMEs (SDPI, 2024; UNCTAD, 2023).

Policy-oriented analyses further emphasize macroeconomic exposure, institutional coordination gaps, and the need for early MRV institutionalization (SDPI, 2024). The World Bank (2023) identifies industrial energy efficiency and renewable procurement as priority reforms, while APTMA (2023) highlights operational barriers including energy tariffs, limited green financing, and the absence of pooled carbon auditing facilities. Overall, existing diagnostics confirm structural vulnerabilities but remain largely descriptive.

2.7. Research Gaps and Contribution of the Present Study

Despite expanding literature on CBAM and national policy responses, three gaps remain:

- No industry-specific CBAM readiness benchmarking exists for Pakistan's textile sector at firm or cluster level.
- Empirical comparison of compliance costs versus non-compliance disadvantages at firm level is limited.
- Perspectives of SMEs, supplier firms, and operational MRV staff are underrepresented in existing analysis.

Previous studies emphasize regulatory challenges and broad policy recommendations but lack firm-level measurement and quantitative exposure simulation. This study addresses these gaps by generating primary survey, KII, and FGD evidence; constructing a CBAM Readiness Index (CRI) at firm and cluster levels; and comparing compliance costs with non-compliance disadvantages.

COMPONENT 1: REGULATORY REVIEW AND GAP ANALYSIS

3.1. Objective and Focus

This component systematically evaluates the alignment between Pakistan’s domestic policy framework (federal, provincial, and industry-level including APTMA) and the EU’s CBAM regulations. It identifies alignments, misalignments, and gaps in carbon pricing, MRV systems, energy efficiency, and green financing, with specific relevance to Punjab’s textile sector. The analysis highlights policy levers to enhance CBAM readiness, reduce trade risks, and support low-carbon transition, while acknowledging related EU sustainability instruments (e.g., Circular Textile Strategy and Digital Product Passport) where they intersect with CBAM obligations.

3.2. Methodology

A qualitative desk-based review and comparative policy mapping were conducted using official documents from federal ministries (Ministry of Climate Change, NEECA), provincial authorities (Punjab EPA, PEECA), APTMA publications, and EU regulations (European Commission, 2023b).

Documents were screened using thematic keywords (“carbon levy,” “energy audits,” “Article 6” and others as related) and coded as full alignment, partial alignment, or gap based on regulatory stringency, implementation mechanisms, and sectoral relevance. The review covered 2015–2025/26, capturing the evolution of Pakistan’s climate and industrial policy architecture post-Paris Agreement. Findings were cross-validated with secondary sources and stakeholder consultations.

3.3. Results – Regulatory Review and Gaps

3.3.1. Federal Policies

Pakistan’s federal climate framework has evolved from strategic commitments toward fiscal and market-based instruments. The National Climate Change Policy (GOP, 2021b) and Updated NDC (GOP, 2021a) remain anchor documents, committing to up to 50% reduction in projected GHG emissions by 2030 (15% unconditional; 35% conditional on international support) (GOP, 2021b). Sectoral targets include expanding renewables (target ~60% generation by 2030), electric vehicle penetration (30% of new sales by 2030), and a moratorium on new imported coal (GOP, 2021b).

Fiscal and Pricing Instruments:

The FY2025–26 federal budget introduced an explicit carbon levy (Rs 2.5 per litre on petrol, HSD, and furnace oil, with discussion of staged increase to Rs 5/L in FY2026–27) to internalize fossil-fuel costs and generate green revenue (Siddiqui, 2025). IMF-supported reform frameworks recommend pairing such levies with targeted social protection (e.g., BISP) to mitigate regressive impacts (Siddiqui, 2025). However, final design and phasing remain politically contested.

Central Regulatory Tension - Energy Subsidies versus Carbon Pricing:

The federal regulatory review reveals a structural policy contradiction at the core of Pakistan’s decarbonization challenge. On the one hand, export-facing sectors are increasingly exposed to carbon pricing mechanisms such as the EU’s Carbon Border Adjustment Mechanism (CBAM). On the other

hand, domestic energy policy continues to rely heavily on subsidies and administered pricing that keep industrial energy costs artificially low.

This creates a central paradox: policies that shield firms from true energy costs domestically weaken the incentive to invest in energy efficiency and renewable energy, while external carbon regulations penalize emissions regardless of domestic pricing structures.

Three regulatory implications emerge. First, subsidized or under-priced energy distorts investment signals, slowing adoption of low-carbon technologies. Second, fossil-fuel subsidies consume fiscal space that could otherwise finance transition support, such as concessional loans or MRV system upgrades. Third, the burden of external carbon compliance falls unevenly across firms, large exporters may adapt, but SMEs face higher relative risk.

In effect, current energy policy reduces short-term production costs but increases long-term exposure to border carbon adjustments. Without coordinated reform; including gradual subsidy rationalization, targeted transition finance, and institutional alignment between finance, commerce, and climate authorities; Pakistan risks facing external carbon costs without having built internal readiness capacity.

A key empirical pattern, anticipated later in Component 2 and Component 3, is that technical awareness of CBAM among leading exporters is high, driven by buyer requirements and industry association activity. However, awareness has not uniformly translated into verified MRV systems or capitalized investments. We therefore distinguish between awareness (knowledge/intent) and operational readiness (documented MRV, dedicated budgets, and third-party verification) throughout the report.

Carbon Markets & Article 6 Preparedness:

Pakistan has initiated institutional steps toward participation in Article 6 carbon markets under the Paris Agreement. The Policy Guidelines for Trading in Carbon Markets outline a federal architecture for voluntary and compliance-based trading, including authorization procedures and registry development (GOP, 2024b; UNEP, 2025). Objectives include mobilizing climate investment, generating tradable credits, and unlocking Article 6 revenue opportunities.

The National Climate Finance Strategy (GOP, 2024a) complements this by mapping mitigation finance needs and proposing blended finance, green bonds, and institutional reforms.

Despite strong policy signaling, operational readiness remains limited. Effective Article 6 participation requires robust MRV systems, credit authorization protocols, transparency safeguards, and inter-ministerial coordination, all still under development.

Sectoral Instruments and Energy Efficiency:

Federal industrial instruments relevant to textiles include minimum energy performance standards (MEPS), mandatory energy audits for large consumers, and NEECA-led certification of energy managers under the NEEC Action Plan 2023–30. These measures aim to reduce industrial energy intensity and align firms with international buyer expectations (NEECA, 2023).

Implementation challenges persist, including limited accredited testing infrastructure and incomplete audit coverage, requiring complementary capacity-building and financing.

Textile-Specific Measures & Green Financing:

Federal and industry documents emphasize green financing windows, energy audits, and renewable incentives for export-oriented sectors. APTMA and other industry bodies pushed for both protection of competitiveness and support for energy/efficiency upgrades; government documents and the NCFS noted that targeted blended finance, concessional loans, and public-private pilots were required to close the large CAPEX gap for textile decarbonization. Recent government communications and budget measures (including the carbon levy revenues and increased allocations to social protection) indicated an intention to pair carbon pricing with compensatory and financing measures, though scale and allocation mechanisms remained to be operationalized.

Equity, governance and implementation risks:

Policy frameworks pair carbon pricing with social protection (e.g., BISP) to enhance political feasibility. However, observers highlight transparency, governance integrity, and institutional capacity as critical risks in implementing carbon markets and pricing reforms (Transparency International Pakistan, 2025). International partners (IMF, World Bank, DFIs) provide technical support and catalytic finance to mitigate these risks.

3.3.2. Provincial (Punjab) Policies

Punjab hosts roughly 70% of Pakistan's textile capacity, concentrated in Faisalabad, Lahore, and Multan (PERI, 2021). Yet firm-level evidence reveals limited CBAM readiness. A study by Alternate Development Services found that only 13 of 29 surveyed units completed formal energy audits, and only 8 conducted product-level carbon footprinting (ADS, 2024).

Uneven enforcement of regulations

Provincial regulatory instruments and programs existed but were unevenly enforced. Punjab's environmental and industrial frameworks included the Punjab Environmental Quality Standards (PEQS) and sector-specific waste and hazardous substances rules (Punjab EPA/PEQS), and provincial energy conservation initiatives coordinated with federal NEECA action plans (NEECA, 2023). The Punjab Energy Conservation Agency (PEECA) and provincial agencies ran limited energy-audit campaigns and public-sector retrofit audits, but private-sector coverage, especially among SMEs and smaller cluster firms in Faisalabad and Multan, remained low (PERI, 2021; ADS, 2024).

Institutional capacity

The province recently convened textile-sector committees to feed into an upcoming provincial industrial policy and to advise on competitiveness and green transition measures, indicating political will to close implementation gaps (GOP, 2022). Nevertheless, persistent barriers remained: limited accredited testing and verification labs, patchy adoption of energy management systems (EnMS), weak supplier traceability in garment value chains, and low access to small-ticket concessional finance for CAPEX, factors that together made Punjab more vulnerable to CBAM's reporting and verification demands than many competitor jurisdictions (PERI, 2021, ADS, 2024).

Taken together, the provincial lens mattered because CBAM readiness depended on local enforcement of environmental standards, availability of accredited MRV/verifier services, cluster-level pooled solutions (shared MRV platforms, pooled verification, certification hubs), and targeted provincial support to onboard SMEs into compliance pathways. Strengthening these provincial levers; through scaled energy audits, accreditation of verifiers, public-private pilot projects, and provincial green financing windows linked to federal NCFS priorities; was critical to ensure Punjab's textile clusters could meet EU buyer requirements without losing competitiveness (NEECA, 2023; PERI, 2021).

3.3.3. All Pakistan Textile Mills Association (APTMA) Measures

APTMA took a lead role in driving environmental compliance and emissions reduction across Pakistan's textile sector through a series of structured policies and initiatives. It established the National Compliance Centre to help mills align with international standards on climate change, environmental governance, and circularity, particularly in response to EU Green Deal and CBAM requirements (APTMA). APTMA's Sustainable Production Centre supported energy audits, trained energy managers, and promoted cleaner production practices through partnerships with GIZ, SMEDA, and UET. It also advocated for green energy adoption via solar net metering, captive RLNG usage, and integration of renewables. In agriculture, the APTMA Cotton Foundation worked with the Better Cotton Initiative to encourage sustainable cotton farming. Additionally, APTMA collaborated with WWF and ILO on improving water efficiency, wastewater management, and reducing hazardous discharge (Sattar & Akhtar, 2023). These initiatives formed a comprehensive industry-level response aimed at reducing emissions intensity and meeting the environmental expectations of global markets.

3.3.4. EU's CBAM Measures

The European Union rolled out a robust and multi-layered regulatory package that put pressure on Pakistan's textile sector to implement comprehensive green reforms if it wanted continued access to the EU market. The cornerstone of this framework was the CBAM, which introduced mandatory reporting of embedded carbon for high-emission imports since October 2023, with the definitive regime entering into force on 1 January 2026 and certificate purchases commencing in February 2027 for annual surrenders starting in September 2027 for the preceding year's imports, meaning that EU importers must submit ("surrender") CBAM certificates each year equivalent to the verified embedded emissions in the goods they imported during the previous year (European Commission, 2023d; European Commission, 2026). Importantly, CBAM applied initially to a narrow set of carbon-intensive sectors (cement, iron and steel, aluminium, fertilisers, electricity, hydrogen), with textiles not yet included but with potential future expansions under review (European Commission, 2023d). Alongside CBAM, the EU launched its Circular and Sustainable Textile Strategy, which introduced binding eco-design criteria such as durability, recyclability, and recycled content, together with extended producer responsibility requirements. This implied that Pakistani exporters had to adapt their choice of materials, manufacturing processes, and end-of-life waste strategies to align with EU standards (APTMA, 2023; European Environment Agency, 2022).

Digital Product Passports (DPP):

Digital Product Passports require lifecycle environmental data, strengthening traceability and verification of embedded emissions (European Commission, 2022; McKinsey, 2023). For Pakistani exporters, this creates dual requirements: carbon reporting under CBAM and digital supply-chain transparency under DPP.

Measures on Waste Management:

Related measures on waste management also increased compliance demands. New EU rules prohibited the destruction of unsold garments and tightened standards on used-clothing exports. This meant Pakistan had to establish or upgrade local systems for collection, sorting, recycling, and traceability to avoid non-compliance and trade disruptions (*Associated Press of Pakistan, 2025*). Taken together, these initiatives created a tightly interlinked regulatory environment where CBAM, Circular Textile Strategy, and DPP reinforced each other. For example, circular design standards influenced emission intensity, while DPP traceability provided data needed to monitor compliance.

3.3.5. Awareness of CBAM Standards and MRV Requirements

Across FGDs and KIIs, awareness of CBAM fundamentals is high. Most firms understand:

- Product-level carbon footprinting
- Scope 1 vs Scope 2 emissions
- Third-party verification requirements under the EU Implementing Regulation

Several large exporters have already conducted CBAM-aligned audits or engaged international verifiers ahead of the 2026 definitive phase.

As one Faisalabad-based composite mill stated:

“We have been tracking Scope 1 and Scope 2 emissions for EU brands since 2023. The CBAM calculation methodology is now part of our annual sustainability reporting template.”

While SMEs show lower operational preparedness, awareness remains meaningful, driven by industry workshops and buyer-led questionnaires. Among major export-oriented firms, technical knowledge of MRV is no longer the primary constraint.

However, KIIs emphasized that awareness does not eliminate exposure. Firms without verified product-level emissions risk assignment of conservative default values under CBAM, effectively a disciplinary benchmark. This default-value risk is particularly salient for smaller firms and subcontractors, highlighting the gap between conceptual understanding and verified implementation.

3.3.6. Domestic Energy Policy as the Central Constraint

Despite this technical preparedness, respondents consistently identified domestic energy policy volatility as the dominant barrier to effective CBAM readiness. The most frequently cited concern, raised unprompted in every FGD and in ten out of twelve KIIs, was the Off-the-Grid (Captive Power Plants) Levy Act, 2025 (Act XIV of 2025).

The levy, applied to natural gas and RLNG used in captive power generation and scheduled to rise progressively through 2026, was widely described as placing firms in a state of “policy limbo.” Because the levy is calculated as the difference between grid tariffs and captive generation costs and revised monthly, firms reported being unable to make long-term decisions regarding energy investments.

As one FGD participant observed:

“Gas was always our cheapest fuel. Now we pay a levy that changes every month while the grid tariff keeps rising. We cannot decide whether to invest in more efficient captive boilers, convert to grid, or accelerate solar.”

Several KIIs further noted that the levy was perceived as an IMF-driven fiscal measure, rather than part of a coherent domestic decarbonisation strategy, contributing to uncertainty and eroding confidence in policy continuity. Respondents also pointed to a broader asymmetry between domestic carbon pricing instruments and CBAM’s ETS-linked border pricing mechanism. While Pakistan’s carbon levies internalize some fossil-fuel costs domestically, they are not creditable against CBAM obligations, raising concerns that exporters could face a double burden through both domestic levies and EU border charges if textiles are brought within CBAM’s scope in future review cycles.

3.3.7. Solar Adoption and the Impact of NEPRA Prosumer Regulations 2025

Despite the captive levy, solar penetration among the sampled firms is already substantial. The majority of mills in the Top 100 export cohort have installed 5–10 MW rooftop or ground-mounted solar systems, most under the previous net-metering regime. Net metering has been the primary route for reducing reliance on expensive captive gas generation during daytime loads.

However, the National Electric Power Regulatory Authority (Prosumer) Regulations, 2025 published in December 2025 and replacing the 2015 Net Metering Regulations introduced significant changes that participants viewed with alarm:

- Shift from net metering to net billing with export tariff reduced to approximately 50 % of the import rate (currently ~Rs 13/kWh instead of ~Rs 26/kWh)
- Contract duration shortened from 7 to 5 years
- System capacity capped at 1 MW under the simplified prosumer route (larger systems require additional approvals)

KII participants reported that these changes have halted new solar investments and created uncertainty around the bankability of existing installations. A sustainability manager summarized the impact as follows:

“We finally had a viable transition path, cheap daytime solar offsetting captive gas use, but the Prosumer Regulations 2025 pulled the rug out from under us.”

Several respondents also linked these regulatory shifts to broader concerns about compliance with EU sustainability requirements beyond CBAM, noting that renewable energy adoption underpinned

not only emissions reduction but also credibility under related EU frameworks such as buyer-led decarbonisation targets and emerging digital traceability requirements.

3.3.8. Functional Matrix – Gap Analysis

Table 1 organizes the regulatory landscape affecting CBAM readiness in Pakistan’s textile sector.

Table 1 Policy Alignments and Gaps for CBAM Compliance in Pakistan's Textile Sector

Policy Dimension	Federal (Pakistan)	Provincial (Punjab)	APTMA (Industry)	EU CBAM & Related Policies	Alignment / Gap Assessment
Carbon Pricing / Levies	Carbon levy on petroleum (Rs 2.5/L in FY2025-26; potential Rs 5/L FY2026-27); IMF-supported reforms with BISP transfers	Limited enforcement; relies on federal levy; uneven across industrial clusters	Supports green incentives; no direct pricing	CBAM border carbon price on imports (€83-104/tCO ₂ in 2026; certificates from 2027)	Partial alignment: Federal levy internalizes fossil costs aiding decarbonization; Gap: No domestic ETS, CBAM expansion risk post-2028; political delays possible
Emissions Reporting / MRV	NDC: 50% GHG reduction by 2030 (15% unconditional, 35% conditional); Carbon Market Guidelines (Article 6); NEECA audits for large consumers	PEQS standards; limited audits (13/29 units); weak verifier capacity	National Compliance Centre supports MRV; audits & training via Sustainable Production Centre	Mandatory embedded emissions reporting (from 2023 transitional, full 2026); third-party verification; default values if data unavailable	Partial alignment: Federal MRV supports exporters; Gap: Provincial/SME implementation weak; low carbon footprinting uptake risks CBAM defaults
Energy Efficiency / Renewables	MEPS; mandatory audits under NEEC (2023-30); 60% renewable target; coal import moratorium	PEECA initiatives; patchy EnMS adoption; low textile hub coverage	Promotes solar net metering, RLNG, renewables; GIZ/UET partnerships	EU ETS incentives; Circular Textile Strategy mandates eco-design/recyclability (binding 2026)	Partial alignment: Federal targets support efficiency; Gap: 64% industrial fossil dependency; provincial audit barriers; textile renewable penetration <7%
Green Financing / Incentives	NCFS (2024); blended finance/green bonds; concessional loans for exports; carbon levy revenue for green initiatives	Linked to federal NCFS; SME support limited; low CAPEX access in clusters	Advocates green financing; pilot efficiency upgrades	CBAM encourages low-carbon practices; EU climate finance conditional on compliance	Partial alignment: NCFS provides pathways; Gap: Low textile allocation (<3%); fossil subsidies (PKR 112B in 2022) contradict goals; CAPEX scale-up needed
Governance / Equity / Risks	BISP subsidies; transparency via TI Pakistan; international support (UNEP/IMF/World Bank)	Textile committees for policy input; enforcement gaps but growing political will	Leads compliance/circularity; WWF/ILO collaborations	WTO-compatible; equity for developing countries; DPP traceability from 2026	Partial alignment: Federal equity measures aid feasibility; Gap: Provincial disparities; carbon market integrity risks; oversight weak in clusters

Supply Chain Traceability / Waste	Limited mandates; NCFS supports pilots	Weak supplier traceability; sectoral waste rules poorly enforced	Better Cotton Initiative; WWF wastewater/hazardous discharge	DPP lifecycle data (from 2026); Circular Strategy; EPR; bans on unsold garment destruction	Weak alignment; Gap: No robust systems; high vulnerability under CBAM/DPP; collection/recycling upgrades needed
Sector-Specific (Textiles)	Export-focused audits/incentives; low renewable penetration (<7%); fossil reliance 64%	Hosts 70% national capacity; clusters face operational challenges (8/29 firms footprinted)	Sustainability Centre; EU Green Deal advocacy; Net-Zero alignment	CBAM initially excludes textiles; review for expansion post-2028; overlaps with eco-design/waste rules	Partial alignment: Export focus helps; Gap: Fossil dependency, low MRV; cluster-based shared audits critical for EU access

Notes: While these themes conceptually overlap with the ten pillars of the CBAM Readiness Index (CRI), Table 1 focuses on policy and regulatory environment, whereas Table 2 operationalizes firm-level readiness indicators from survey data.

Source: Author's compilation.

COMPONENT 2: CBAM READINESS INDEX (CRI)

4.1. Data Collection Design

All primary instruments, structured firm questionnaire, Key Informant Interview (KII) guide, and Focus Group Discussion (FGD) protocols, were explicitly aligned with the CBAM Readiness Index (CRI) pillars and indicators.

- The questionnaire generated firm-level quantitative inputs for CRI scoring.
- KIIs captured policy, regulatory, and institutional perspectives.
- FGDs provided cluster-level and SME validation of quantitative findings.

This integrated design ensured full alignment between instruments, sampling, and analytical objectives.

4.1.1 Sampling Strategy

The study employs a purposive, export-weighted sampling framework targeting textile firms with the highest exposure to the European Union market. Using firm-level export data for FY 2023–24, the top 100 textile exporters were identified and ranked by export value. Given the policy-oriented objective and the disproportionate export share and regulatory exposure of large firms, the design approximates a targeted census of high-impact exporters rather than probabilistic sampling. All firms within the defined frame were approached.

Primary outreach resulted in 27 complete and usable responses. Although firm-level emissions and compliance data are commercially sensitive, the responding firms represent a substantive cross-section of leading exporters in terms of size, product specialization, and EU integration. Geographically, most respondents are concentrated in Central Punjab particularly Faisalabad, Lahore, and Multan which constitute the core of export-oriented textile production. A limited number of large Karachi-based firms were included due to their significant export volumes and national strategic importance, strengthening representation of diversified and deeply EU-integrated exporters.

To capture ecosystem-wide vulnerabilities, FGDs and KIIs purposively included SME cluster representatives and service providers, covering both upstream and downstream risks. Non-response bias was mitigated through a structured follow-up protocol: initial invitations via APTMA/TDAP, two telephone reminders, and in-person scheduling within Lahore and Faisalabad clusters. Non-response was documented and, where exceeding 20 percent, corrective measures such as weighting or peer matching were applied.

Between October 2025 and January 2026, 12 KIIs were conducted with senior industry, regulatory, and finance experts, alongside 8 FGDs with cluster managers and mill owners. These qualitative inputs validated survey proxies, triangulated cost benchmarks used in Component 3, and provided institutional context.

4.1.2. Data Handling and Triangulation

Survey responses were digitized and coded in Stata for descriptive and econometric analysis. Primary data were complemented with ESG disclosures, sustainability reports, energy audits, and compliance documentation where available. In selected cases, audited energy bills, verification certificates, and trade records were used for triangulation.

4.1.3. Statement of Consent and Anonymity

Participation in this study was voluntary, and informed consent was obtained from all participating firms prior to data collection. Respondents were clearly informed about the purpose of the research, the nature of the information requested, and the intended use of the data for academic and policy analysis. To protect confidentiality, all firm-level information was collected and stored securely, and no identifying details are disclosed in the analysis or reporting. Data are presented only in anonymized and aggregated form, ensuring that individual firms cannot be identified directly or indirectly. Participants were assured that their responses would be used solely for research purposes and would not be shared with third parties.

4.2. Methodology

4.2.1. Normalization and Construction of CRI

The CBAM Readiness Index (CRI) for Punjab's textile firms is constructed in three stages:

- 1) normalization of indicators,
- 2) aggregation into pillar scores, and
- 3) computation of composite CRI scores using three weighting approaches.

All final CRI versions are scaled to 0–100 for interpretability and readiness band classification.

Normalization of Indicators to a 0-1 Scale:

Because questionnaire indicators vary in scale (binary, ordinal, categorical, counts, and percentages), all variables are normalized to a common 0–1 metric, where:

- 0 = lowest readiness
- 1 = highest readiness

This ensures comparability across heterogeneous indicator types.

(a) Higher-is-better indicators

$$n_x = \frac{x - \min(x)}{\max(x) - \min(x)}$$

(b) Lower-is-better indicators

$$n_x = 1 - \frac{x - \min(x)}{\max(x) - \min(x)}$$

(c) Percentage indicators

$$n_x = \frac{x}{100}, x \in [0,100]$$

(d) Categorical / ordinal indicators

Manual recoding is applied to approximate linear scaling (e.g., five ordered categories mapped to 0, 0.25, 0.5, 0.75, 1).

This normalization framework preserves directionality while maintaining bounded comparability across indicators.

4.2.2. Aggregation to Pillar Scores

Each of the ten CRI pillars consists of J normalized indicators. Pillar scores are computed as simple arithmetic means:

$$p_k = \frac{1}{J} \sum_{j=1}^J n_{x_j}$$

where p_k represents pillar k .

Simple averaging avoids implicit re-weighting within pillars and maintains transparency.

4.2.3. Weighting and Composite CRI Construction

The final CRI is computed using three complementary methods:

- 1) Expert-weighted CRI (main specification)
- 2) Equal-weighted CRI (robustness benchmark)
- 3) PCA-derived CRI (data-driven validation)

All versions are rescaled to 0–100. Details of the complete pillar score construction is *Annexed-I*.

Weighting Rationale:

Pillar weights reflect CBAM compliance risk exposure and export competitiveness priorities. Core compliance dimensions, such as emissions intensity, energy structure, and MRV/reporting capacity, receive higher weights because they directly determine carbon cost exposure and reporting obligations. Enabling or forward-looking dimensions receive relatively lower weights, reflecting indirect but supportive roles.

This approach follows composite index methodology where weights reflect stakeholder relevance and policy urgency (e.g., OECD 2008; Greco et al., 2019). In Pakistan’s textile context, emissions-related pillars receive the largest shares (e.g., 22 percent) due to their direct linkage to CBAM tariff liability.

Survey Structure and Analytical Construction of CRI Pillars:

The survey instrument was organized operationally (energy use, finance, compliance, export practices). However, the ten CRI pillars were constructed analytically after survey design to capture multidimensional readiness.

Consequently, indicators contributing to a single pillar may originate from multiple questionnaire sections.

This cross-sectional construction reflects the multidimensional nature of CBAM compliance. Pillars therefore aggregate conceptually related variables rather than following administrative survey order, ensuring holistic measurement of readiness.

Determination of Expert Weights:

Expert weights were derived through structured consultation with specialists in:

- Trade policy
- Industrial energy systems
- Climate finance
- Textile sector operations

Each expert independently assigned importance scores (0–100 scale) to the ten pillars based on perceived influence on CBAM compliance risk and export competitiveness.

Individual scores were normalized so that total weights summed to one.

To enhance consistency:

- Experts received a standardized briefing note defining each pillar and clarifying conceptual distinctions (emissions performance, institutional readiness, financial capacity, export exposure).
- A short reconciliation discussion followed initial scoring to reduce extreme outliers and ensure conceptual clarity.
- No forced consensus was imposed.

Final weights reflect the mean normalized values across experts.

4.2.4. Overview of CRI Pillars

Table 2 presents the ten CRI pillars, the number of contributing survey indicators, and the applied weighting schemes across the three CRI specifications.

Table 2 Summary of CRI Pillars: Weight, Indicator Count, Core Theme, and Scoring Method

Pillar	Weight	Indicators	Core questions (indicators)	Scoring method
P1: Emissions Performance	0.22	2	q6 (embedded carbon reporting for major products), q22 (measures embedded carbon in imported raw materials)	Simple average of 2 normalized indicators (0–1)
P2: Energy Transition	0.14	5	q8 (renewable energy % of total consumption), q9 (energy mix shift toward cleaner sources past 5 years), q10 (energy audits past 3 years), q11 (implementation of audit recommendations), q12 (installed solar capacity in kW)	Row mean of 5 normalized indicators (0–1)
P3: MRV & Reporting Capacity	0.14	6	q1 (third-party certified MRV system), q2 (MRV audit/review frequency), q3 (in-house GHG reporting capacity, 1–5), q4 (trained GHG employees), q5 (emissions data public), q7 (team familiarity with CBAM, 1–5)	Row mean of 6 normalized indicators (0–1)

P4: Traceability & Supply Chain	0.12	5	q17 (DPP adoption), q18 (verified material origin tracking), q19 (share of suppliers audited for env. compliance %), q20 (volume share from audited suppliers %), q21 (procurement budget on sustainable/recycled materials %)	Row mean of 5 normalized indicators (0–1)
P5: Certifications & Governance	0.11	7	q14_* binaries (ISO14001, OEKO-TEX, GOTS, Bluesign, BCI → cert_avg as mean), q15 (cert renewal/review frequency), q16 (EU eco-design compliance), q26 (ESG/sustainability report frequency), q27 (CBAM compliance roadmap/strategy), q43 (board/top mgmt ESG/climate review), q44 (designated sustainability officer/team)	Row mean including certification average (0–1)
P6: Financial Readiness	0.09	4	q36 (decarbonization/energy efficiency investments past 3 years), q37_* (barriers to green tech: count of 7 binaries, inverted), q38 (CAPEX % allocated to sustainability), q39 (applied for public/donor green financing)	Row mean of 4 normalized indicators (0–1); barriers inverted
P7: Export Exposure & Risk	0.06	3	q28 (EU export share % of production), q29 (adjust export pricing based on embedded carbon), q30 (confidence in CBAM compliance by 2026, 1–5)	Row mean of 3 normalized indicators (0–1); EU exposure inverted
P8: Environmental Controls & Waste	0.04	3	q45 (wastewater treatment plant/system), q46 (process water reuse/recycling), q47 (hazardous waste management)	Row mean of 3 normalized indicators (0–1)
P9: Enabling Environment	0.04	4	q23 (received gov support for decarbonization), q24 (participating in carbon market/offset), q25 (senior mgmt. trained on climate policy risks), q48 (confidence in GoP support for CBAM, 1–5)	Row mean of 4 normalized indicators (0–1)
P10: Future Preparedness	0.04	2	q31_* (planned actions by 2028: count of 7 checkboxes), q32_* (anticipated challenges by 2030: count of 7 checkboxes, treated as awareness)	Row mean of two normalized counts (0–1)

Source: Author's estimations.

Notes: The table above presents a concise synopsis of the ten CRI pillars, their expert-assigned weights, indicator counts, core themes, and the scoring approach used within each pillar. Each pillar score is computed on a 0–1 scale by averaging its normalized indicators; the CRI aggregate is produced under three aggregation schemes (expert-weighted, equal-weighted and PCA-driven) and rescaled to 0–100 for readability. Classification thresholds are: <50 = Low readiness, 50–74 = Moderate readiness, ≥75 = High readiness. Full technical details including question-by-question recoding rules, category-to-numeric mappings, midpoint justifications, inversion formulas (where applicable), handling of ‘not applicable’, and missing-value imputation procedures (median imputation for missing pillar scores) are provided in *Annex I: Pillar-wise Normalization & Rescaling and Scoring of Indicators*.

4.2.5. CRI – Readiness Classifications

The CBAM Readiness Index (CRI) aggregates the ten normalized pillar scores p_1, p_2, \dots, p_{10} , each defined on a 0–1 scale. Three aggregation methods are used to ensure robustness: expert-weighted,

equal-weighted, and PCA-driven. All final CRI scores are rescaled to 0–100 for interpretability and readiness banding.

4.2.6. Classification Thresholds for Readiness Levels

Cut-off thresholds were pre-specified prior to data analysis:

- Low readiness: $CRI < 50$
- Moderate readiness: $50 \leq CRI < 75$
- High readiness: $CRI \geq 75$

These thresholds follow standard composite index benchmarking logic, where:

- Scores below 50% indicate substantial structural gaps
- 50–75% reflects partial readiness with significant deficiencies
- $\geq 75\%$ indicates relatively strong compliance capacity

After data collection, the empirical score distribution was examined to ensure categories were neither empty nor mechanically concentrated. Firms naturally distributed across all three bands, confirming that thresholds were ex-ante defined rather than data-fitted. This ensures methodological transparency while preserving empirical validity.

4.3. CRI – Estimation Methods

4.3.1. Expert-weighted CRI (Main Method)

This is our primary index. It assigns weights to each pillar based on theoretical importance for CBAM compliance, policy priorities for Pakistan’s textile sector, and insights from literature and stakeholders.

$$CRI_{\text{expert}} = \sum_{k=1}^{10} w_k \cdot p_k$$

where:

w_k are expert-derived weights (summing to 1),

p_k are normalized pillar scores.

Rescaled:

$$CRI_{\text{expert}, 100} = CRI_{\text{expert}} \times 100$$

Core CBAM pillars; emissions performance, energy transition, and MRV/reporting; receive higher weights because they directly determine tariff exposure and verification requirements under EU Regulation 2023/956. Enabling and forward-looking pillars (e.g., governance, finance, preparedness) receive relatively lower weights, reflecting supportive rather than direct compliance roles.

This structure reflects expert consultation (including APTMA and policymakers), theoretical guidance (Gómez-Limón et al., 2020; Jain & Mohapatra, 2023), and composite index principles emphasizing policy urgency.

4.3.2. Equal-Weighted CRI

The equal-weighted specification treats all ten pillars as equally important:

$$CRI_{\text{equal}} = \frac{1}{10} \sum_{k=1}^{10} p_k$$

Rescaled:

$$CRI_{\text{equal}, 100} = CRI_{\text{equal}} \times 100$$

This approach removes subjective weighting choices and provides a neutral benchmark. If firm rankings and readiness classifications remain similar to the expert-weighted version, results are not sensitive to specific weight allocations (e.g., 0.22, 0.14, etc.).

Equal-weight benchmarking is recommended in composite index construction guidelines (OECD 2008; Greco et al., 2019).

4.3.3. PCA-Driven CRI (Data-Driven Weights)

Principal Component Analysis (PCA) provides endogenous, data-driven weights by identifying the dominant common pattern across the ten pillar scores.

Using principal component factoring (*pcf* in *Stata*), the first principal component is extracted:

$$f1 = \sum_{k=1}^{10} \lambda_k \cdot p_k$$

where λ_k are PCA-derived loadings.

Because PCA scores are unbounded, they are normalized:

$$CRI_{\text{PCA}} = \frac{f1 - \min(f1)}{\max(f1) - \min(f1)}$$

Scale to 0–100 for reporting and banding:

$$CRI_{\text{PCA}, 100} = CRI_{\text{PCA}} \times 100$$

This method allows observed clustering patterns among firms to determine weights rather than expert judgment. If PCA rankings align closely with expert- and equal-weighted CRIs, the findings are robust to weighting assumptions.

PCA validation is widely recommended for multidimensional composite indices (Nardo et al., 2005; Saisana et al., 2005; Alqararah, 2023). In practice, the first principal component typically captures the dominant “readiness” dimension, especially when core pillars (emissions, energy, MRV) are strongly correlated.

4.3.4. Robustness and Interpretation

Using three aggregation strategies ensures that conclusions about firm readiness are not artifacts of subjective weighting. Convergence across expert, equal, and PCA-based CRIs strengthens confidence in classification results and policy implications.

All CRI variants are directly comparable on a 0–100 scale and classified using identical readiness bands.

4.4. Reliability, Sensitivity, and PCA Diagnostics

To ensure the CBAM Readiness Index (CRI) is reliable and not driven by arbitrary assumptions, three technical validation checks are performed:

- 1) Internal consistency (Cronbach's alpha)
- 2) Sensitivity analysis of expert weights
- 3) PCA diagnostics for the data-driven specification

4.4.1. Internal Consistency (Cronbach's Alpha)

Cronbach's alpha evaluates whether indicators within a pillar consistently measure the same latent construct (Wendling, 2020). Values above 0.7 generally indicate good reliability.

For a pillar with J indicators $n_{x_1}, n_{x_2}, \dots, n_{x_j}$:

$$\alpha = \frac{J}{J-1} \left(1 - \frac{\sum_{j=1}^J \text{Var}(n_{x_j})}{\text{Var}\left(\sum_{j=1}^J n_{x_j}\right)} \right)$$

Alpha is computed separately for each multi-indicator pillar:

P1 (Emissions): n_{q6}, n_{q22}

P2 (Energy): $n_{q8}, n_{q9}, n_{q10}, n_{q11}, n_{q12}$

P3 (MRV): $n_{q1}, n_{q2}, n_{q3}, n_{q4}, n_{q5}, n_{q7}$

P4 (Traceability): $n_{q17}, n_{q18}, n_{q19}, n_{q20}, n_{q21}$

P5 (Governance): $cert_avg, n_{q15}, n_{q16}, n_{q26}, n_{q27}, n_{q43}, n_{q44}$

P6 (Financial): $n_{q36}, n_{barriers}, n_{q38}, n_{q39}$

P7 (Exposure): $inv_q28, n_{q29}, n_{q30}$

P8 (Waste): $n_{q45}, n_{q46}, n_{q47}$

P9 (Enabling): $n_{q23}, n_{q24}, n_{q25}, n_{q48}$

P10 (Preparedness): $n_{actions}, n_{expectation}$

Alphas above 0.7 confirm internal coherence of indicators within each readiness dimension.

4.4.2. Sensitivity Analysis for Expert-Weighted CRI

To test robustness of the expert-weighted CRI, each pillar weight is varied by $\pm 20\%$, while maintaining total weights equal to 1.

Increased-weight scenario:

$$CRI_{+20\%} = 0.264p_1 + 0.168p_2 + 0.168p_3 + 0.144p_4 + 0.132p_5 + 0.108p_6 + 0.072p_7 + 0.048p_8 + 0.048p_9 + 0.048p_{10}$$

Reduced-weight scenario:

$$CRI_{-20\%} = 0.176p_1 + 0.112p_2 + 0.112p_3 + 0.096p_4 + 0.088p_5 + 0.072p_6 + 0.048p_7 + 0.032p_8 + 0.032p_9 + 0.032p_{10}$$

Both variants are rescaled to 0–100.

Robustness is assessed by computing Spearman rank correlations between the baseline expert-weighted CRI and the perturbed versions. Correlations close to 1.0 indicate stable firm rankings despite weight variation, confirming that results are not highly sensitive to moderate changes in expert judgment

4.4.3. PCA Diagnostics for Data-Driven CRI

For the PCA-based CRI, additional diagnostics verify that the first principal component meaningfully captures a common readiness dimension.

The first component is defined as:

$$f_1 = \sum_{k=1}^{10} \lambda_k p_k$$

where λ_k are factor loadings.

The following diagnostics are evaluated:

(a) Scree Plot: Eigenvalues are inspected for sharp decline after the first component. A clear drop indicates dominance of a single readiness dimension.

(b) Factor Loadings: Loadings $|\lambda_k| > 0.3$ are considered substantively meaningful. Strong loadings for core pillars (emissions, energy, MRV) suggest coherent dimensional structure.

(c) Kaiser–Meyer–Olkin (KMO) Test: Measures sampling adequacy for factor analysis.

- KMO > 0.6: acceptable
- KMO > 0.7: good

(d) Squared Multiple Correlations (SMC): Indicate how much variance in each pillar is explained by others. Higher SMC values support factorability and justify PCA use.

Together, these diagnostics confirm whether the PCA-driven CRI captures a statistically coherent latent readiness factor.

4.4.4. Measurement Considerations

Although survey items differ in original response formats, all indicators were first normalized to a common 0–1 scale. This ensures bounded comparability across dimensions and preserves a shared theoretical continuum of readiness. Differences in granularity do not invalidate reliability or factor analysis, as indicators measure related but distinct subcomponents within each pillar. Cronbach’s alpha and PCA diagnostics therefore remain valid tools for assessing internal consistency and dimensional structure.

4.5. Results – CRI Estimation and Diagnostics

The following presents key results from the CRI estimation and diagnostics, as outlined in the methodology. These include summary statistics for the three CRI methods, correlations among CRIs and pillars, reliability measures (Cronbach's alpha), weight sensitivity analysis ($\pm 20\%$), and PCA diagnostics. All calculations are based on normalized pillar scores after median imputation for missing values.

Detailed statistical outputs are presented in this section while the interpretations are consolidated in final Discussion.

4.5.1. Readiness Classification Across Methods

The main results are consolidated here in Table 3 which shows Across the 27 firms analyzed, the expert-weighted and equal-weighted CRI methods yield comparable central tendencies, with mean scores in the mid-60s and moderate dispersion. In contrast, the PCA-driven CRI exhibits substantially higher variability, spanning nearly the full 0–100 scale.

Table 3 Summary Statistics for CRI Scores Across Methods

CRI Method	Observations	Mean	Std. Dev.	Min	Max
Expert-Weighted	27	66.83	12.09	43.82	84.94
Equal-Weighted	27	64.21	10.93	43.60	83.05
PCA-Driven	27	55.40	29.04	0.00	100.00

Source: Author’s estimations.

Table 4 below summarizes how many firms fall into each readiness category (Low, Moderate, High) for the three CRI methods, along with their percentages (out of 27 firms total). This shows the spread of readiness across the methods in a clear way.

Table 4 Firm Counts and Percentages by Readiness Level

Readiness Level	Expert-Weighted	Equal-Weighted	PCA-Driven
Low (<50)	3 firms (11%)	2 firms (7%)	11 firms (41%)
Moderate (50-75)	15 firms (56%)	19 firms (70%)	7 firms (26%)
High (≥ 75)	9 firms (33%)	6 firms (22%)	9 firms (33%)

Source: Author’s estimations.

For expert-weighted scores, most firms (over half) are moderately ready, with about a third highly ready and few low. Equal-weighted has even more in moderate, fewer high. PCA-driven shows more low-ready firms, balanced moderate and high. This highlights differences in how each method rates readiness.

Overall, while central tendencies differ, the classification patterns suggest that weighting choice primarily affects dispersion rather than directional ranking.

4.5.2. Statistical Diagnostics

Table 5 displays Pearson correlations among the three CRI measures exceed 0.97 in all pairwise comparisons, indicating extremely strong linear association. This implies that, despite differences in means and dispersion, the relative ranking of firms remains highly consistent across weighting schemes.

Table 5 Correlation Analysis Across CRI Methods

	Expert-Weighted	Equal-Weighted	PCA-Driven
Expert-Weighted	1.0000	0.9742	0.9748
Equal-Weighted	0.9742	1.0000	0.9865
PCA-Driven	0.9748	0.9865	1.0000

Source: Author's estimations.

Table 6 presents covariance matrix of the ten pillar scores; generally positive associations among most dimensions, indicating that readiness components tend to move together. Stronger covariances are observed among structural and operational pillars (e.g., emissions, traceability, enabling environment), suggesting interdependence in implementation capacity. Negative covariances are minimal and small in magnitude, implying no substantial trade-offs across readiness dimensions. Overall, the structure supports the interpretation of carbon readiness as a multidimensional but positively correlated construct.

Table 6 Covariance Matrix of Pillar Scores

Pillar	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1	0.0557	0.0143	0.0207	0.0306	0.0067	0.0114	0.0054	0.0221	0.0326	0.0190
P2	0.0143	0.0220	0.0083	0.0147	0.0047	0.0086	0.0025	0.0104	0.0090	0.0012
P3	0.0207	0.0083	0.0226	0.0173	0.0018	0.0069	0.0042	0.0139	0.0106	0.0047
P4	0.0306	0.0147	0.0173	0.0338	0.0053	0.0110	0.0040	0.0218	0.0216	0.0061
P5	0.0067	0.0047	0.0018	0.0053	0.0063	-0.0000	0.0006	0.0092	0.0018	0.0062
P6	0.0114	0.0086	0.0069	0.0110	-0.0000	0.0252	-0.0016	0.0038	0.0104	-0.0033
P7	0.0054	0.0025	0.0042	0.0040	0.0006	-0.0016	0.0142	0.0099	0.0178	-0.0055
P8	0.0221	0.0104	0.0139	0.0218	0.0092	0.0038	0.0099	0.0369	0.0216	0.0091
P9	0.0326	0.0090	0.0106	0.0216	0.0018	0.0104	0.0178	0.0216	0.0536	0.0025
P10	0.0190	0.0012	0.0047	0.0061	0.0062	-0.0033	-0.0055	0.0091	0.0025	0.0562

Source: Author's estimations.

Table 7 lists Cronbach's alpha coefficients for each pillar's indicators as represented earlier in Table 2, along with the number of items and scale reliability. Cronbach's alpha coefficients vary across pillars, ranging from 0.45 to above 0.80. However, given the limited number of items in some pillars and the exploratory nature of the framework, these values remain within acceptable bounds for composite index construction.

Table 7 Cronbach's Alpha for Internal Consistency by Pillar

Pillar	Number of Items	Alpha Coefficient
P1: Emissions	2	0.5622
P2: Energy	5	0.5868
P3: MRV	6	0.7179
P4: Traceability	4	0.6058

P5: Governance	5	0.5214
P6: Financial	4	0.4522
P7: Exposure	3	0.7670
P8: Waste	3	0.8131
P9: Enabling	4	0.7093
P10: Preparedness	2	0.6460

Source: Author's estimations.

Table 8 shows summary statistics for the expert-weighted CRI with weights perturbed by +20% and -20%.

Table 8 Summary Statistics for Sensitivity Analysis ($\pm 20\%$ Weights)

CRI Variant	Observations	Mean	Std. Dev.	Min	Max
+20% Weights	27	80.19	14.51	52.59	101.93
-20% Weights	27	53.46	9.67	35.06	67.95

Source: Author's estimations.

Table 9 displays Spearman rho values between the original expert-weighted CRI and $\pm 20\%$ variants, with observations and significance levels (starred at 0.05). While absolute CRI levels shift mechanically underweight perturbations, Spearman rank correlations between the baseline and adjusted variants equal 1.000 ($p < 0.05$), indicating perfect rank preservation. This confirms that the expert-weighted CRI is highly stable to moderate weight changes. The robustness test strengthens confidence that results are not driven by marginal adjustments in expert judgment.

Table 9 Spearman Rank Correlations for Sensitivity Analysis

	Expert-Weighted	+20% Weights	-20% Weights
Expert-Weighted	1.0000	1.0000*	1.0000*
+20% Weights	1.0000*	1.0000	1.0000*
-20% Weights	1.0000*	1.0000*	1.0000

*Notes: (Observations: 27 for all pairs; * indicates $p < 0.05$).*

Source: Author's estimations.

In Table 10, the first principal component has an eigenvalue of 4.09 and explains approximately 41 percent of total variance.

Table 10 PCA Factor Analysis Results – Eigenvalues and Proportions

Factor	Eigenvalue	Difference	Proportion	Cumulative
1	4.09056	2.58535	0.4091	0.4091
2	1.50521	0.19522	0.1505	0.5596
3	1.30999	0.38247	0.1310	0.6906
4	0.92752	0.24711	0.0928	0.7833
5	0.68041	0.16840	0.0680	0.8514
6	0.51201	0.10316	0.0512	0.9026
7	0.40885	0.12186	0.0409	0.9435
8	0.28699	0.12352	0.0287	0.9722
9	0.16347	0.04847	0.0163	0.9885
10	0.11500	-	0.0115	1.0000

Source: Author's estimations.

Table 11 lists factor loadings for the first three factors and unique variances per pillar score. The second and third components explain 15 percent and 13 percent respectively, bringing cumulative explained variance to roughly 69 percent across three factors.

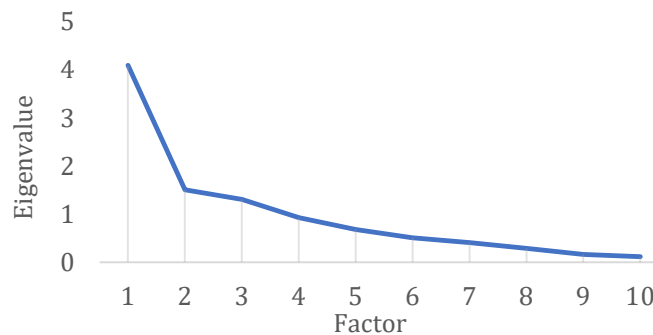
The scree plot in Figure 4 displays eigenvalues, with a sharp drop after Factor 2 (4.09) to Factor 2 (1.51), indicating dominance of the first component.

Table 11 PCA Factor Loadings and Unique Variances

Pillar Score	Factor 1	Factor 2	Factor 3	Uniqueness
p1_score	0.8245	0.1139	-0.0680	0.3026
p2_score	0.6319	0.1135	-0.2832	0.5077
p3_score	0.7039	-0.0132	-0.2007	0.4640
p4_score	0.8590	0.0549	-0.1870	0.2241
p5_score	0.5239	0.5165	0.3645	0.3259
p6_score	0.4028	-0.0842	-0.7524	0.2645
p7_score	0.4234	-0.6948	0.4800	0.1075
p8_score	0.7880	0.0376	0.3541	0.2523
p9_score	0.6933	-0.4966	0.1437	0.2521
p10_score	0.2456	0.6867	0.2730	0.3936

Source: Author's estimations.

Figure 4 Scree Plot - PCA on Pillar Scores



Source: Author's illustration.

In Table 12, Factor 1 loads strongly and positively on most pillar scores, particularly emissions, traceability, waste management, and enabling environment. This suggests that the first component reflects broad structural readiness capacity. Factor 2 exhibits stronger loadings on governance and preparedness-related dimensions, while Factor 3 differentiates financial and exposure components. These patterns indicate multidimensional structure beyond a single aggregate dimension.

Uniqueness values are moderate for most pillars, implying that common components capture a substantial portion of shared variance.

Table 12 PCA Factor Score Coefficients (Regression Scoring Method)

Pillar Score	Factor 1	Factor 2	Factor 3
p1_score	0.20157	0.07566	-0.05190
p2_score	0.15447	0.07540	-0.21615
p3_score	0.17208	-0.00875	-0.15321
p4_score	0.21000	0.03647	-0.14271
p5_score	0.12809	0.34312	0.27825
p6_score	0.09847	-0.05593	-0.57437
p7_score	0.10351	-0.46161	0.36642
p8_score	0.19263	0.02501	0.27033
p9_score	0.16949	-0.32991	0.10969

p10_score	0.06004	0.45622	0.20836
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Source: Author's estimations.

In Table 13, The overall KMO statistic (0.6513) indicates acceptable sampling adequacy for PCA application. Most pillar-level KMO values exceed 0.5, although Exposure shows relatively weaker adequacy.

In Table 14, Squared Multiple Correlations (SMC) suggest that several pillars particularly emissions, enabling environment, and traceability are well explained by common components, while financial preparedness shows comparatively lower communal variance.

Table 13 PCA Kaiser-Meyer-Olkin (KMO) Measure

Pillar Score	KMO Value
p1_score	0.7292
p2_score	0.7851
p3_score	0.6452
p4_score	0.8147
p5_score	0.5444
p6_score	0.5614
p7_score	0.4367
p8_score	0.7280
p9_score	0.5548
p10_score	0.5308
Overall	0.6513

Source: Author's estimations.

Table 14 PCA Squared Multiple Correlations (SMC)

Pillar Score	SMC Value
p1_score	0.7155
p2_score	0.4154
p3_score	0.5798
p4_score	0.7038
p5_score	0.5862
p6_score	0.3721
p7_score	0.6695
p8_score	0.6909
p9_score	0.7612
p10_score	0.3236

Source: Author's estimations.

4.5.3. Overall Interpretation of Results

The empirical findings demonstrate three key conclusions:

- 1) **Strong ranking stability:** All CRI methods produce nearly identical firm rankings despite differences in dispersion.
- 2) **Robustness to weighting:** Expert-weighted results are insensitive to moderate perturbations in pillar weights.
- 3) **Structured multidimensionality:** PCA reveals a dominant readiness factor supplemented by secondary governance and financial dimensions.

Thus, the CRI framework is both statistically coherent and methodologically robust. Differences across weighting schemes primarily influence distributional spread rather than substantive ordering.

COMPONENT 3: DISADVANTAGES OF NON-COMPLIANCE

5.1. Objective

Component 3 evaluates whether non-compliance with emerging European Union sustainability requirements imposes economically meaningful disadvantages on Pakistan's textile exporters relative to the cost of compliance.

Whereas Components 1 and 2 assess regulatory alignment and institutional readiness, this component adopts a comparative cost framework:

Non – Compliance Cost (NCC) vs. Compliance Cost (CC)

In the absence of verified firm-level emissions inventories and audited financial disclosures, all cost measures are constructed as internally consistent, normalized indices. The objective is not to estimate precise monetary liabilities, but to compare relative economic exposure across firms and readiness tiers without implying false precision.

5.2. Methodology

Non-compliance with the European Union's Carbon Border Adjustment Mechanism (CBAM) and related sustainability regulations exposes textile exporters to two broad categories of risk:

- Direct carbon exposure risk (linked to potential ETS pricing)
- Strategic economic risks (buyer behavior, reputational loss, financing constraints)

These risks are modeled separately and then aggregated into a composite Non-Compliance Cost (NCC) index.

Firms are first classified into low-, moderate-, and high-readiness tiers based on their CRI scores. This allows the expected disadvantages of non-compliance to vary systematically with preparedness.

5.2.1. Estimation of Non-Compliance Costs (NCC)

The total non-compliance cost for firm i is defined as the sum of expected carbon-related liabilities and strategic economic losses:

$$NCC_i = (\hat{E}_i \times P_{ETS} \times S_{EU,i}) + L_{contracts,i} + R_{finance,i}$$

where:

- \hat{E}_i denotes estimated firm-level emissions (tCO₂), derived from sectoral emission intensity benchmarks and firm characteristics;
- P_{ETS} represents the prevailing EU ETS carbon price (baseline €90–100 per tonne, with sensitivity analysis), also coined as the Shadow ETS exposure index.
- $S_{EU,i}$ is the share of firm i 's exports destined for the EU, also coined as the Strategic loss index. Firms not reporting EU exposure are conservatively treated as having zero EU export dependence.

- $L_{contracts,i}$ captures expected losses from reduced buyer demand, delayed shipments, or contract termination;
- $R_{finance,i}$ reflects restricted access to international green finance and sustainability-linked credit.

To clarify regulatory timing, we distinguish two scenarios.

- 1) Short-Run Scenario (Current Phase): Textiles are not yet fully covered under CBAM tariff obligations. Only strategic risks apply in the current phase.

$$NCC_i^{SR} = SL_i$$

- 2) Long-Run Scenario (If CBAM Applied to Textiles): If textiles become subject to carbon border charges. This includes both direct carbon exposure and strategic losses.

$$NCC_i^{LR} = ETS_i + SL_i$$

5.2.2. Construction of ETS Shadow Exposure

Emissions Proxy:

In the absence of verified emissions (tCO₂), firm-level emissions intensity is proxied using:

- Pillar 1 score (Emissions Performance)
- Pillar 2 score (Energy Structure and Transition)

$$E_i^{raw} = \text{mean}(P1_i, P2_i)$$

This is normalized:

$$E_i = \frac{E_i^{raw} - \min(E^{raw})}{\max(E^{raw}) - \min(E^{raw})}$$

Thus:

$$E_i \in [0,1]$$

This preserves ordinal ranking of emissions exposure across firms.

EU Export Exposure:

Firm-level EU exposure is constructed from survey responses (Q28):

$$S_{EU,i} = \text{EU export share}$$

If reported as percentage, values are scaled to the [0,1] interval.

ETS Shadow Exposure Formula:

$$ETS_i = E_i \times S_{EU,i} \times P_{ETS}$$

where:

- P_{ETS} = assumed EU ETS price

- Baseline: €95
- Low: €80
- High: €120

Important clarification:

- This is a shadow exposure index, not an actual tariff payment.
- It captures relative carbon price vulnerability conditional on EU market dependence.

5.2.3. Strategic Loss Index (SL)

Strategic risk captures non-tariff disadvantages that already operate under current market conditions. It is constructed from survey indicators:

- q41: Profit impact expectations
- q42: Buyer shift risk
- q39: Access to sustainable finance
- q23: Regulatory confidence

$$SR_i^{raw} = \text{mean}(q41, q42, q39, q23)$$

Normalized:

$$SR_i = \frac{SR_i^{raw} - \min(SR^{raw})}{\max(SR^{raw}) - \min(SR^{raw})}$$

Thus:

$$SR_i \in [0,1]$$

Readiness Conditioning:

To reflect differential vulnerability, strategic risk is weighted by CRI tier:

$$SL_i = SR_i \times \lambda_i$$

where:

- Low readiness: $\lambda = 1.5$
- Moderate readiness: $\lambda = 1.0$
- High readiness: $\lambda = 0.5$

This ensures that CRI affects not only classification but also economic exposure magnitude. λ weights (1.5/1.0/0.5) were selected to reflect the intuition that lower-readiness firms suffer proportionally larger strategic losses per unit of measured strategic risk.

5.2.4. Estimation of Compliance Costs (CC)

Compliance costs represent the investments required for firms to align with CBAM-related requirements and broader EU sustainability standards.

A Compliance Investment (CI) Index is constructed from:

- Pillar 2 (Energy transition)
- Pillar 3 (MRV systems)
- Pillar 5 (Certification)
- Pillar 6 (Financial readiness)

$$CI_i = C_{MRV,i} + C_{energy,i} + C_{cert,i} + C_{gov,i}$$

where the components correspond to expenditures on emissions monitoring and reporting systems (MRV), renewable energy and energy efficiency measures, environmental certifications and reporting, and governance or ESG-related upgrades. These costs are derived from firm-level survey responses and cross-validated using cost benchmarks obtained from KIIs and FGDs with industry representatives and experts.

Important distinction:

- CRI score = overall readiness across ten pillars
- Compliance Investment Index (CI) = subset focusing on investment-intensive dimensions
- A normalized compliance investment index is constructed as the average of Pillars 2, 3, 5, and 6. This index is scaled proportionally to firm revenue and multiplied by an assumed compliance cost share (θ)

To maintain conservative estimation, compliance costs are expressed as a modest proportion of firm revenue or capital expenditure, reflecting phased and incremental adoption rather than full upfront compliance.

Consequently,

$$CC_i = CI_i \times R_i \times \theta$$

where:

- R_i = annual revenue (Q33)
- θ = assumed compliance cost share
 - 1% (low)
 - 2% (baseline)
 - 3% (high)

This represents phased, incremental compliance investment.

5.2.5. Net Advantage of Compliance (NAC)

The economic case for compliance is evaluated through:

$$NAC_i = NCC_i - CC_i$$

- If **NAC > 0**, expected penalties from non-compliance exceed compliance costs. Early action is economically justified.

- If **NAC < 0**, compliance may appear costlier in the short term, although dynamic benefits (market access, reputation, financing access) may still dominate over time.

All values are expressed in normalized units to preserve cross-firm comparability.

5.2.6. Analytical Contribution

This component transforms non-compliance from a qualitative policy concern into a structured economic comparison. Three contributions emerge:

- It conditions economic exposure on measurable readiness (CRI).
- It separates immediate strategic risks from contingent carbon price risks.
- It identifies which categories of firms face the largest economic penalties from inaction.

5.3. Results – Disadvantages of Non-Compliance

5.3.1. Overview

The results from Component 3 demonstrate that non-compliance with emerging European sustainability requirements is economically disadvantageous for nearly all firms in the sample, even under the current regulatory phase in which textiles are not yet fully subject to the CBAM.

In the short-run scenario, where only strategic losses apply, the Strategic Loss Index (SL_i) exceeds the modeled Compliance Cost (CC_i) for the vast majority of firms. This implies that even without an explicit carbon tariff, market and financing penalties already make non-compliance economically costly.

In the long-run scenario, if textiles are brought under full CBAM pricing via the European Union Emissions Trading System (EU ETS), the addition of ETS shadow exposure further increases Non-Compliance Costs (NCC_i), substantially strengthening the economic case for compliance.

The analysis is based on 27 textile exporters categorized into three CRI tiers:

- Low readiness (n = 3)
- Moderate readiness (n = 15)
- High readiness (n = 9)

Results are evaluated under three ETS price assumptions (€80, €95, €120), with all values expressed in normalized comparative units.

5.3.2. Aggregate Results Across ETS Scenarios

Table 15 summarizes the results obtained across all three scenarios.

Table 15 Summary Statistics - Economic Disadvantages on Non-compliance

Variable	Mean	SD	Min	Max
NCC_LOW	1.703	1.222	0.000	3.999
NCC_BASE	1.971	1.461	0.000	4.682

NCC_HIGH	2.418	1.862	0.000	5.820
CC_LOW	0.032	0.004	0.020	0.040
CC_BASE	0.064	0.008	0.040	0.079
CC_HIGH	0.095	0.013	0.060	0.119
NAC_LOW	1.671	1.219	-0.036	3.965
NAC_BASE	1.908	1.456	-0.072	4.614
NAC_HIGH	2.323	1.855	-0.107	5.718

Source: Author's estimations.

Across all ETS price scenarios, three consistent patterns emerge:

- Non-compliance costs increase materially with higher carbon prices.
- Compliance costs remain small relative to expected penalties.
- The Net Advantage of Compliance (NAC) is positive on average in all scenarios.

This indicates that non-compliance is economically more costly than compliance.

5.3.3. Tier-Wise Results by Readiness Level

Table 16 compiles results from baseline scenario across tiers, as followed.

Table 16 Economic Disadvantages at Baseline (€95), Tier-wise means

Readiness Tier	NCC_BASE	CC_BASE	NAC_BASE
Low	0.699	0.051	0.648
Moderate	1.305	0.062	1.242
High	3.506	0.070	3.436

Source: Author's estimations.

Baseline results (€95 ETS) reveal systematic variation across CRI tiers.

High-readiness firms exhibit the largest expected non-compliance costs, followed by moderate- and low-readiness firms. While compliance costs increase slightly with readiness reflecting larger scale operations, the difference is economically small relative to exposure.

Consequently, the Net Advantage of Compliance is strongest for high-readiness firms.

This finding may appear counterintuitive. One might expect low-readiness firms to face the greatest vulnerability. However, the results show that vulnerability is driven primarily by exposure, not weakness. High-readiness firms are more deeply integrated into EU markets and therefore face larger absolute penalties if compliance fails.

In short:

- Low-readiness firms face capacity gaps.
- High-readiness firms face higher economic stakes.

5.3.4. Short-Run vs Long-Run Composition of Risk

Table 17 compiles results from the Baseline components, as followed.

Table 17 Baseline Component Means by Tier

Tier	ETS Exposure	Strategic Loss	Compliance Cost
Low	0.199	0.500	0.051
Moderate	1.010	0.295	0.062
High	3.347	0.159	0.070

Source: Author's estimations.

Decomposition of baseline results reveals distinct risk structures across tiers.

- Low-readiness firms: Strategic losses dominate total NCC. These firms face greater buyer uncertainty, financing constraints, and reputational risk.
- High-readiness firms: ETS shadow exposure dominates total NCC. Their higher EU export shares and stronger market integration translate into larger modeled carbon price vulnerability.

Thus, strategic risks are currently binding for weaker firms, while carbon price exposure becomes dominant for EU-integrated firms in the long-run scenario.

5.3.5. Does Compliance Pay?

Table 18 compiles results obtained from the percentage of firms assumed to be having benefits at compliance, given the current assumptions and scenarios.

Table 18 Percentage of Firms Where Compliance Pays (NAC > 0)

Tier	LOW ETS	BASE ETS	HIGH ETS
Low	100%	100%	100%
Moderate	93.3%	93.3%	93.3%
High	100%	100%	100%

Source: Author's estimations.

This means that;

Across all ETS price assumptions:

- 100% of low-readiness firms benefit from compliance.
- 93% of moderate-readiness firms benefit.
- 100% of high-readiness firms benefit.

Only one moderate-tier firm shows slightly negative NAC under all scenarios. This is strong evidence that early compliance is economically justified for nearly all firms.

5.4. Statistical Validation and Diagnostics

To test whether these patterns are systematic rather than descriptive, three complementary approaches are employed.

5.4.1. Differences across Readiness Tiers

A Kruskal–Wallis test confirms statistically significant differences in NAC distributions across CRI tiers:

- $\chi^2(2) = 11.51, p = 0.0032$

This supports the economic relevance of readiness-based grouping.

5.4.2. Correlation with CRI Score

Spearman rank correlation reveals a strong positive association between CRI score and NAC:

- $\rho = 0.51$, $p = 0.006$

Firms with higher readiness tend to experience larger economic gains from compliance.

5.4.3. Robust Regression (Baseline Scenario)

Regression analysis, as reported in Table 22, represents controlling for EU export share and Compliance Investment index.

Table 19 Determinants of the Net Advantage of Compliance

Variable	Coefficient	Robust Std. Error	p-value
CRI Score	0.067	0.012	0.000
EU Export Share	59.64	8.53	0.000
Compliance Index	0.93	2.34	0.694
Constant	-4.88	1.05	0.000
R ²	0.87		
F-stat	97.55 (p < 0.001)		
Observations	27		

Source: Author's estimations.

This explains that,

- EU export share is the strongest predictor of compliance advantage.
- Higher CRI readiness significantly increases economic returns to compliance.
- Compliance index itself is not statistically significant, indicating:
 - Exposure and market dependence drive economic vulnerability more than internal readiness alone.
- The high R² (86.6%) indicates strong explanatory power.

5.5. Major Findings

Two central insights emerge.

- 1) Non-compliance is already costly:** Even before full CBAM tariff enforcement, anticipated carbon-related liabilities combined with strategic risks; buyer contraction, margin erosion, and restricted access to green finance; exceed modeled compliance costs in nearly all firms.
 - a. Delaying compliance does not reduce costs; it increases medium-term exposure.
- 2) Higher readiness implies higher stakes:** Firms with stronger CBAM readiness face greater absolute non-compliance costs, not because they are weaker, but because they are more exposed. High-readiness firms typically export larger shares to the EU and operate in higher-value segments.
 - a. Thus, readiness does not eliminate vulnerability. It raises the economic consequences of inaction.

COMPONENT 4: CBAM REVENUE EXPOSURE SIMULATION

6.1. Objective

This simulation estimates the potential export revenue at risk if large Pakistani textile exporters fail to comply with the EU Carbon Border Adjustment Mechanism (CBAM) and consequently lose access to the European Union (EU) market.

6.2. Methodology

The exercise provides an upper-bound and alternative diversion-adjusted estimates of revenue exposure. The simulation uses assumptions derived from the total 100 samples identified and the total exports and national EU export share from Pakistan Business Council Report (PBC, 2024). Hence;

1. Top 100 Pakistani textile exporters (2024); firm-level export values in USD
2. Pakistan's total exports to the EU (2024):

$$EU_{Total} = 8.951 \text{ billion USD}$$

3. National EU export share (2024):

$$\alpha_{EU} = 27.6\%$$

The firms are then ranked in descending order by total exports:

$$Rank_i = 1, 2, \dots, 100$$

A firm is classified as "large" if:

$$Large_i = \begin{cases} 1 & \text{if } Rank_i \leq N \\ 0 & \text{otherwise} \end{cases}$$

Baseline assumption:

$$N = 20$$

Sensitivity checks are conducted for:

$$N = 15, 25, 30$$

6.2.1. Estimating EU Export Exposure

Because firm-level EU export shares are not directly observed, EU exposure is proxied using the national EU export share.

For each firm:

$$EUExports_i = ExportValue_i \times \alpha_{EU}$$

Where:

- $ExportValue_i$ = total export value of firm i
- $\alpha_{EU} = 0.276$

Total EU exposure among large firms:

$$TotalEUExposure = \sum_{i \in Large} EUExport s_i$$

Average exposure per large firm:

$$EUExposure = \frac{1}{N} \sum_{i \in Large} EUExport s_i$$

6.2.2. Non-Compliance Shock Scenarios

The simulation assumes that non-compliant firms lose EU market access for which three diversion scenarios are considered.

- 1) Scenario 1: No Trade Diversion (Upper Bound) assumes all EU exports are lost, as:

$$Loss_{100} = TotalEUExposure$$

- 2) Scenario 2: 50% Diversion assumes half of EU exports are redirected to alternative markets, as:

$$Loss_{50} = TotalEUExposure \times 0.5$$

- 3) Scenario 3: 75% Diversion assumes 75% of EU exports are redirected (only 25% lost), as:

$$Loss_{25} = TotalEUExposure \times 0.25$$

6.2.3. EU Share Sensitivity Analysis

To account for variation in firm-level EU exposure, the EU export share parameter is varied:

$$\alpha_{EU} \in \{0.25, 0.276, 0.35\}$$

Thus:

$$EUExports_i^{(s)} = ExportValue_i \times \alpha_{EU}^{(s)}$$

This provides lower- and upper-bound exposure estimates.

Concentration Analysis

To evaluate the concentration of EU exposure among large firms:

$$Share_{Concentration} = \frac{TotalEUExposure_{TopN}}{TotalEUExposure_{All}}$$

Additionally, national exposure weight is computed as:

$$NationalShare = \frac{TotalEUExposure_{TopN}}{EU_{Total}}$$

This indicates the proportion of Pakistan's total EU textile exports potentially concentrated in the largest firms.

6.2.4. Key Assumptions

The simulation relies on the following assumptions:

- 1) EU Export Share Proxy: Firm-level EU export share is approximated by the national EU share (27.6%). This assumes large textile exporters have EU exposure comparable to the sectoral average.
- 2) Market Access Shock: Non-compliance leads to full or partial loss of EU sales.
- 3) Diversion Parameters: Trade diversion rates (0%, 50%, 75%) are illustrative and represent alternative adjustment scenarios.
- 4) Static Framework: The simulation does not model Dynamic price adjustments, Exchange rate changes, Gradual CBAM phase-in, and Firm-level mitigation strategies
- 5) No Behavioral Adjustment: Firms are assumed not to invest in compliance within the simulation horizon.

The results represent:

- A revenue exposure estimate, not realized losses.
- A static shock scenario, not a general equilibrium outcome.
- A policy-relevant upper and lower bound of export risk.

The simulation quantifies the potential economic magnitude of CBAM-related non-compliance among large textile exporters. This is an exposure-based risk simulation, not a full equilibrium trade model. The objective is magnitude benchmarking rather than price adjustment modeling.

6.3. Results - CBAM Revenue Exposure Simulation

6.3.1. Baseline EU Exposure of Large Firms

Using the national EU export share of 27.6%, the estimated EU export exposure of the Top 20 textile exporters is:

$$\text{Total EU Exposure (top 20)} = \$1.381 \text{ billion}$$

The average EU exposure per large firm is:

$$\text{Average Exposure per Firm} = \$69.0 \text{ million}$$

Export concentration analysis shows that:

- The Top 20 firms account for 50.5% of EU exposure within the Top 100 exporters.
- Their EU exposure represents 15.4% of Pakistan's total EU textile exports (USD 8.95 billion).

This confirms that EU trade exposure is highly concentrated among a relatively small group of large exporters.

6.3.2. Revenue Loss Under Non-Compliance Scenarios

Three trade diversion scenarios were simulated and are consolidated in Table 23 as followed.

Table 20 Estimated Revenue at Risk (Top 20 Firms)

Scenario	Diversion Assumption	Estimated Revenue Loss (USD)
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No Diversion	100% EU sales lost	1.381 billion
50% Diversion	Half redirected	690 million
75% Diversion	Only 25% lost	345 million

Source: Author's estimations.

Notes: The upper-bound estimate (no diversion) suggests that over USD 1.38 billion in export revenue could be at risk if large firms fail to comply and lose EU market access. Even under conservative diversion assumptions, the potential exposure remains economically significant.

6.3.3. EU Share Sensitivity Analysis

To account for uncertainty in firm-level EU export shares, alternative values were tested and the results are consolidated in Table 24, as followed.

Table 21 EU Share Sensitivity (Top 20 Firms)

Assumed EU Share	Total Exposure (USD)
25%	1.25 billion
27.6% (baseline)	1.38 billion
35%	1.75 billion

Source: Author's estimations.

Notes: If large firms are more EU-dependent than the national average (35%), exposure rises to USD 1.75 billion.

6.3.4. Large-Firm Definition Sensitivity

The exposure estimate was also tested under alternative definitions of “large firms” and results are consolidated in Table 25, as followed.

Table 22 Exposure by Firm Cut-Off

Firm Group	EU Exposure (USD)
Top 15	1.19 billion
Top 20	1.38 billion
Top 25	1.54 billion
Top 30	1.69 billion

Source: Author's estimations.

Notes: The exposure increases steadily as additional large firms are included, indicating that EU risk remains concentrated but extends beyond the top 20 firms.

6.4. Major Findings

The simulation reveals three important findings.

- 1) EU export exposure among Pakistan’s largest textile exporters is substantial. The Top 20 firms alone account for approximately USD 1.38 billion in EU trade exposure, representing over 15% of Pakistan’s total EU textile exports. This confirms that compliance risk is not marginal; it is macroeconomically relevant.
- 2) Even under moderate trade diversion assumptions, potential revenue losses remain large. If half of EU exports can be redirected, revenue at risk still exceeds USD 690 million. Under a

conservative 75% diversion assumption, losses remain above USD 345 million, which is still economically meaningful.

- 3) The results are robust to alternative assumptions regarding EU export shares and firm-size definitions. Exposure ranges between USD 1.25–1.75 billion under plausible EU share variations, and increases to nearly USD 1.7 billion when the Top 30 firms are considered.
- 4) Overall, the simulation suggests that non-compliance with CBAM could place between USD 0.35 billion and USD 1.75 billion of export revenue at risk, depending on diversion capacity and firm-level EU dependence.

These findings provide a quantitative “price tag” to complement the firm-level readiness analysis presented in Component 3, and demonstrate that CBAM compliance is not only a regulatory issue but a significant export risk management concern for Pakistan’s textile sector.

DISCUSSION AND FINDINGS

This section consolidates findings across study components.

7.1. Component 1: Regulatory Review & Gap Analysis

Overall, the regulatory review shows that Pakistan has developed a broad policy framework that partially aligns with EU CBAM requirements, but important implementation gaps remain. At the federal level, climate commitments, carbon levy measures, energy efficiency standards, and Article 6 carbon market guidelines signal clear policy intent. Industry bodies such as APTMA have also taken proactive steps to support compliance, energy audits, and sustainability upgrades. However, alignment is stronger on paper than in practice. There is no domestic ETS comparable to the EU system, MRV systems are unevenly implemented, especially among SMEs, and green financing remains limited relative to the scale of required investment. A key structural tension exists between carbon pricing ambitions and continued fossil-fuel subsidies, which weaken incentives for low-carbon transition while increasing long-term exposure to border carbon adjustments.

At the provincial level, particularly in Punjab, which hosts the majority of textile capacity, implementation capacity is the main constraint. Energy audits, product-level carbon footprinting, accredited verification services, and supply-chain traceability systems remain patchy. While awareness of CBAM among leading exporters is high, operational readiness is uneven, and smaller firms face greater risk of default emission values and compliance costs. Regulatory instability in domestic energy policy, including captive power levies and revised solar net-billing rules, further discourages long-term green investment. Taken together, the findings suggest that Pakistan's challenge is not lack of policy direction but weak coordination, inconsistent enforcement, financing gaps, and energy policy volatility; factors that directly affect CBAM readiness and export competitiveness.

7.2. Component 2: CBAM Readiness Index (CRI)

The CBAM Readiness Index shows that preparedness among leading textile exporters is measurable and consistent. Results are very similar across expert-weighted, equal-weighted, and PCA approaches, meaning firm rankings are stable and not dependent on one method. The average readiness level is moderate, indicating that many firms have started compliance efforts but gaps remain, especially in financial readiness and governance systems. Strong firms tend to perform well across multiple areas, MRV, energy management, traceability, and waste systems while weaker firms face overlapping deficiencies. Overall, the CRI provides a reliable tool for identifying which firms are ready, which need support, and where policy intervention should focus.

7.3. Component 3: Disadvantages of Non-compliance

The analysis shows that non-compliance is already more costly than compliance for most firms. Around 90% of firms have a positive Net Advantage of Compliance (NAC), meaning it is economically rational to comply even before full carbon tariffs apply. In the short run, the main risk is not carbon pricing but Strategic Loss such as losing EU buyers, facing contract disruption, reputational damage, and restricted access to green finance. Firms with higher readiness and deeper EU exposure face larger absolute risks if they fail to comply, because they have more to lose. Regression results confirm

that preparedness and EU exposure matter more than the sheer size of investment. Early and gradual compliance produces stronger economic returns than delayed, reactive spending. CBAM therefore acts as a market-access rule as much as a carbon price.

7.4. Component 4: Simulation Analysis

The simulation analysis shows that as EU climate policy becomes stricter and carbon prices rise, the cost of not complying with CBAM increases, especially for firms that export more to the EU. Even small increases in carbon prices can sharply raise non-compliance costs for highly exposed firms because carbon liabilities and buyer-related risks reinforce each other. The results also show that firms that invest early in compliance, such as improving MRV systems and energy efficiency, face lower overall risks, as buyers view them as more reliable partners. In contrast, firms that delay compliance experience higher losses due to contract uncertainty and limited access to green finance. Importantly, firm rankings remain stable across different carbon price and parameter assumptions, confirming that the economic case for early compliance becomes stronger under tighter climate policy scenarios.

SYNTHESIS OF KEY FINDINGS

Taken together, the four components show a clear pattern: CBAM compliance is no longer just an environmental obligation but a competitiveness strategy. Pakistan has policy intent and growing firm-level awareness, but implementation gaps, energy policy instability, and financing constraints slow progress. The CRI confirms that readiness is measurable and uneven across firms, while the economic analysis shows that non-compliance already carries real and rising costs mainly through buyer loss and market access risk rather than tariffs alone. Simulations further demonstrate that delays will become increasingly expensive as EU climate policy tightens. In short, early, predictable, and well-supported transition policies can convert carbon risk into competitive advantage, whereas uncertainty and delayed adjustment increase both firm-level and national export vulnerability.

POLICY RECOMMENDATIONS

The captive levy, while intended to internalise cross-subsidies and encourage grid take-up, has instead frozen strategic decision-making in an industry that consumes large volumes of gas for captive power. Simultaneously, the 2025 Prosumer Regulations have undermined the economics of the solar transition that many mills had begun as their primary CBAM mitigation strategy.

If Pakistan's textile sector is to meet EU CBAM requirements without losing competitiveness, three urgent policy alignments are required:

1. Stabilization or ring-fencing of the captive levy for export-oriented industries during a defined transition window (2026–2028), linked explicitly to verifiable renewable capacity addition.
2. Restoration of predictable, long-term net-metering economics for industrial-scale solar installations, particularly for systems above 1 MW, where renewable investments begin to materially offset captive fossil-fuel generation in textile production. Alternatively, a dedicated export tariff for industrial prosumers could be introduced to ensure financial viability of multi-megawatt renewable installations required for CBAM-aligned decarbonisation.
3. Accelerated development of pooled MRV platforms and concessional green financing windows under the National Climate Finance Strategy to translate awareness into firm-level action.

In addition to these immediate priorities, the regulatory review highlights several complementary policy measures that are necessary to address structural gaps identified in Component 1 and to reduce future CBAM-related risks:

4. Development of a coherent domestic carbon pricing roadmap for export-oriented sectors, including consideration of an emissions trading or crediting mechanism aligned with EU ETS principles, to reduce the risk of exporters facing simultaneous domestic carbon levies and CBAM border charges.
5. Implementation of a CBAM default-value risk mitigation strategy, including mandatory or incentivised product-level carbon footprinting for large exporters, subsidised third-party verification for SMEs, and clear guidance on the penalties associated with non-verified emissions data.
6. Strengthening MRV governance, accreditation, and data integrity frameworks, through the expansion of accredited verification bodies, establishment of transparent registry systems, and alignment with Article 6 readiness efforts to ensure credibility and international acceptance of emissions data.
7. Targeted support for supply-chain traceability and circularity compliance, including pilot initiatives for Digital Product Passports, investment in textile waste collection and recycling infrastructure, and integration of traceability requirements into export-oriented industrial policy.

Based on Component 2, the study proposes the following policy recommendations:

8. Adopt the expert-weighted CRI as a formal diagnostic tool for identifying priority firms and clusters for CBAM-related support, given its strong convergence with alternative methods and its regulatory relevance.
9. Use CRI tiers (low, moderate, high) as the basis for differentiated policy instruments, rather than one-size-fits-all compliance mandates, to reflect meaningful heterogeneity in firm preparedness.
10. Prioritise interventions in low-reliability pillars, particularly financial access and governance, through tailored credit lines, blended finance instruments, and ESG capacity-building programmes.
11. Institutionalise periodic CRI-based benchmarking (e.g., biennial updates) to track readiness progression, support evidence-based policymaking, and provide early warning signals of emerging compliance risks.
12. Integrate CRI metrics into public–private dialogue platforms, enabling industry associations and regulators to align support mechanisms with empirically observed readiness gaps.

Based on Component 3, the study proposed the following policy recommendations:

13. Reframe CBAM compliance as an export competitiveness issue, embedding it within trade, industrial, and export promotion policy rather than treating it solely as an environmental regulation.
14. Prioritise compliance support for EU-exposed firms, particularly those with high export shares but moderate readiness, where targeted assistance can prevent disproportionate economic losses.
15. Develop early-warning systems for non-compliance risk, using CRI scores and export exposure indicators to identify firms at risk of buyer exit or contract loss.
16. Subsidise initial MRV and verification costs for SMEs, recognising that small upfront investments generate large reductions in expected non-compliance losses.
17. Align trade finance and export credit facilities with CBAM readiness, conditioning preferential terms on verified MRV adoption and emissions reporting.
18. Engage EU buyers and financial institutions in co-financing compliance, leveraging the fact that buyer behaviour is a dominant driver of non-compliance costs.

In light of revenue exposure simulation, the following policy recommendations are proposed:

19. Establish a Transitional CBAM Adjustment Facility for Large Exporters. Create a time-bound (2026–2028) compliance transition facility providing concessional financing or tax credits for verified emissions reporting, third-party audits, and renewable energy integration. Given that the largest 20 firms alone represent over USD 1.3 billion in EU exposure, safeguarding their compliance capacity has clear macroeconomic justification.
20. Develop an Export Diversification Risk Mitigation Strategy. Given that full diversion of EU exports is unlikely but partial trade redirection may occur, the Ministry of Commerce should proactively identify alternative high-value markets and negotiate sustainability-aligned trade

facilitation agreements. This reduces overdependence on EU demand while maintaining incentives for emissions compliance.

Without these targeted interventions, the current policy limbo risks converting technical preparedness into commercial disadvantage precisely at the moment CBAM becomes fully operational.

LIMITATIONS OF THE STUDY

This study has several limitations. First, the firm-level sample is relatively small and concentrated mainly in Punjab, so the findings may not fully represent all textile firms in Pakistan or other industrial sectors. Second, estimates of emissions, compliance costs, and non-compliance risks rely partly on self-reported survey data and benchmark proxies rather than fully verified plant-level emissions data. Although interviews and secondary sources were used to cross-check responses, some measurement error may remain. Third, the policy environment is evolving. Future changes in CBAM scope, EU carbon prices, or Pakistan's domestic energy and fiscal policies could alter incentives and cost estimates over time. Finally, while the study considers overlaps with related EU sustainability measures, it does not provide a complete assessment of all downstream regulatory requirements that may affect textile value chains. To protect confidentiality, only aggregate and tier-wise results are reported. An anonymized firm-level appendix with coded identifiers can be shared with peer reviewers under a non-disclosure agreement to allow replication while safeguarding commercial information.

CONCLUDING REMARKS

This study provides clear evidence that the European Union’s Carbon Border Adjustment Mechanism (CBAM) is no longer a distant regulatory development but an immediate policy challenge for Pakistan’s textile exports. While many large exporting firms have begun strengthening emissions reporting, monitoring, and traceability systems, their progress is occurring in a context of domestic policy uncertainty. Inconsistent energy pricing, limited predictability of renewable incentives, and the absence of a clearly sequenced transition roadmap are constraining private investment decisions. Without policy stability and coordinated institutional support, firm-level readiness will remain uneven and potentially unsustainable.

From a national perspective, the economic implications are substantial. Simulation results indicate that USD 1–1.7 billion in export exposure could be vulnerable under adverse non-compliance scenarios. The analysis shows that, for many firms, the long-term costs of non-compliance, including buyer substitution, reputational risks, and restricted access to finance, are likely to exceed the costs of phased compliance investments. This shifts the policy framing of CBAM from being an environmental obligation to an export competitiveness imperative.

The policy message is therefore clear: proactive, coordinated action is required. Priority areas include stabilizing and rationalizing industrial energy pricing, accelerating renewable energy integration for export-oriented sectors, strengthening national MRV (Monitoring, Reporting, and Verification) infrastructure, and expanding access to concessional climate finance, particularly for small and medium-sized exporters. Establishing a clear transition pathway with defined milestones would reduce uncertainty and crowd in private investment. With timely reforms and targeted support, Pakistan’s textile sector can convert the CBAM transition from a risk into an opportunity to upgrade competitiveness, attract climate-aligned investment, and secure continued access to EU markets.

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ANNEXURE: PILLAR-WISE NORMALIZATION & RESCALING AND SCORING OF INDICATORS

Pillar 1: Emissions Performance

Indicators:

- q6 (embedded carbon reporting; higher-better ordinal)
- q22 (embedded carbon in imported materials; higher-better ordinal).

Normalization:

- For q6: Recode (1=1, full reporting → highest), (2=0.75, partial), (3=0, none), (4=0.25, unsure), (5=0.5, planning). Equation: Manual linear mapping to [0,1], approximating
 - $n_{q6} = \frac{\text{rank}-1}{4}$ for ordered categories.
- For q22: Recode (1=1, yes → highest), (2=0, no), (3=0.5, not applicable/domestic), (4=0.25, unsure). Similar linear mapping.

Pillar score:

$$p1 = \frac{n_{q6} + n_{q22}}{2}$$

Weight rationale:

Logically, emissions are the core of CBAM (direct tariff basis, e.g., €85-88/tCO₂ in 2026). Theoretically, high weight reflects carbon leakage prevention priority (European Commission, 2023b); in Pakistan's textile context (fossil-dependent), it emphasizes vulnerability (APTMA, 2024).

Pillar 2: Energy Transition

Indicators:

- q8 (renewable %; higher-better categorical bands)
- q9 (energy shift; higher-better ordinal)
- q10 (audits count; higher-better count)
- q11 (audit implementation; higher-better ordinal)
- q12 (solar capacity; higher-better categorical).

Normalization:

- q8: Recode bands (1=0, 0%), (2=0.125 midpoint of 1-25%), (3=0.375 of 26-50%), (4=0.625 of 51-75%), (5=0.875 of 76-100%), (6=0, not applicable).
 - $n_{q8} = \frac{\text{midpoint}-0}{100}$ approximated linearly.
- q9: Recode (1=0, shifted away), (2=0.25, no change), (3=0.5, slight), (4=0.75, moderate), (5=1, significant), (6=0.5, not applicable).
 - Linear: $n_{q9} = \frac{\text{rank}-1}{4}$.
- q10: Recode (1=0, none), (2=0.33, 1), (3=0.66, 2-3), (4=1, >3).

- $n_{q10} = \frac{\text{category}-1}{3}$.
- q11: Recode (1=1, fully), (2=0.5, partially), (3=0, not), (4=0, no audits).
 - Binary-like with partial.
- q12: Recode (1=0, none), (2=0.2, <10kW), (3=0.4, 10-50), (4=0.6, 51-100), (5=1, >100), (6=0, unknown).
 - $n_{q12} = \frac{\text{category}-1}{5}$.

Pillar score:

$$p2 = \frac{1}{5} \sum n_{qi} \text{ for } i = 8,9,10,11,12$$

Weight rationale:

Energy drives emissions (64% fossil-based in Pakistan, per Economic Survey 2023). Theoretically, equal to MRV as both enable decarbonization (NEECA, 2023); lower than emissions as transitional (opportunities like renewables via NCFS 2024).

Pillar 3: MRV & Reporting

Indicators:

- q1 (MRV system; higher-better)
- q2 (audit frequency; higher-better)
- q3 (GHG capacity; higher-better 1-5)
- q4 (trained employees; higher-better)
- q5 (public emissions; higher-better)
- q7 (CBAM familiarity; higher-better 1-5)

Normalization:

- q1: Recode (1=1, yes), (2=0, no), (3=0.25, unsure), (4=0.75, in process), (5=0.5, internal).
 - Partial steps.
- q2: Recode (1=1, quarterly), (2=0.75, annually), (3=0.5, every 2years), (4=0, never), (5=0.25, on demand), (6=0, unknown).
 - $n_{q2} = 1 - \frac{\text{infrequency rank}}{5}$
- q3: Recode (1=0.2, very low) to (5=1, very high), (6=0.5, outsourced).
 - $n_{q3} = 0.2 \times (\text{rank})$.
- q4: Recode (1=0, none), (2=0.25, 1-2), (3=0.5, 3-5), (4=1, >5), (5=0.75, outsourced), (6=0.875, in-house+).
 - Linear steps.
- q5: Recode (1=1, yes), (2=0, no), (3=0.25, unsure), (4=0.5, selective).
- q7: Recode (1=0.2, not familiar) to (5=1).

- $n_{q7} = 0.2 \times (\text{rank})$.

Pillar score:

$$p3 = \frac{1}{6} \sum n_{q_i} \text{ for } i = 1,2,3,4,5,6,7$$

Weight rationale:

MRV is foundational for CBAM verification (transitional phase since 2023). Theoretically matches energy weight as co-enablers; literature (Marcu et al., 2020) stresses MRV gaps in developing countries like Pakistan.

Pillar 4: Traceability & Supply Chain

Indicators:

- q17 (DPP adoption; higher-better)
- q18 (material tracking; higher-better)
- q19 (suppliers audited %; higher-better bands)
- q20 (supplies volume from audited; continuous %)
- q21 (sustainable procurement %; higher-better bands)

Normalization:

- q17: Recode (1=1, yes), (2=0, no), (3=0.75, planning), (4=0.5, aware), (5=0.25, unaware).
- q18: Recode (1=1, fully), (2=0.5, partially), (3=0, none), (4=0.75, developing).
- q19: Similar to q8, midpoints: (1=0) to (5=1), (6=0).
- q20: $n_{q20} = \frac{q20}{100}$, bounded [0,1].
- q21: Like q19.

Pillar score:

$$p4 = \frac{1}{5} \sum n_{q_i} \text{ for } i = 17,18,19,20,21$$

Weight rationale:

Traceability supports CBAM/DPP (EU 2022). Logically lower than core pillars as indirect (supply chain risks); theoretically, reflects equity concerns for SMEs (OECD, 2025b).

Pillar 5: Certifications & Governance

Indicators:

- cert_avg (average of binary certificate: ISO14001 etc.; higher-better)
- q15 (renewal frequency; higher-better)
- q16 (eco-design; higher-better)
- q26 (ESG reports; higher-better)
- q27 (CBAM roadmap; higher-better)

- q43 (ESG review; higher-better)
- q44 (sustainability officer; higher-better)

Normalization:

- cert_avg: $\text{cert_avg} = \frac{1}{5} \sum q_{14*}$ (binaries, already 0-1).
- q15-q44: Recodes like prior ordinals, e.g., q15 (1=1, yearly) to (5=0.25, not obtained).

Pillar score:

$$p5 = \frac{1}{7} \sum (cert_{avg} + n_{q_i}) \text{ for } i = 15, 16, 26, 27, 43, 44, \text{ and average certification adoption score}$$

Weight rationale:

Governance ensures sustained compliance (ESG per CSRD). Theoretically slightly below traceability as internal; logically, certifications build trust (q50 in survey).

Pillar 6: Financial Readiness

Indicators:

- q36 (decarb investments; higher-better),
- n_barriers (inverted barrier count; lower-better),
- q38 (CAPEX % sustainability; higher-better bands),
- q39 (green financing; higher-better).

Normalization:

- q36: Recode (1=1, major) to (5=0.25, not applicable).
- barrier_count: Sum binaries (0-7)
 - $n_{\text{barriers}} = 1 - \frac{\text{count} - \text{min}}{\text{max} - \text{min}}$.
- q38: Midpoints like q8.
- q39: Recode (1=1, successful) to (5=0, ineligible).

Pillar score:

$$p6 = \frac{1}{4} \sum (n_{\text{barriers}} + n_{q_i}) \text{ for } i = 36, 38, 39$$

Weight rationale:

Finance bridges gaps (GOP, 2024a). Lower weight as conditional (UNFCCC 2021); theoretically, reflects access barriers in developing economies.

Pillar 7: Export Exposure & Risk

Indicators:

- inv_q28 (inverted EU %; lower exposure better if non-adapted),
- q29 (pricing adjust; higher-better),

- q30 (compliance confidence; higher-better 1-5).

Normalization:

- q28: Recode inverted midpoints (1=1, 0%) to (5=0.125, >75%), (6=1, intermediaries low risk).

$$\circ \text{ inv_q28} = 1 - \frac{\text{midpoint}}{100}.$$

- q29, q30: Standard recodes.

Pillar score:

$$p7 = \frac{1}{3} \sum (\text{inv}_{q28} + n_{q_i}) \text{ for } i = 29, 30$$

Weight rationale:

Exposure amplifies risks (59% exports textiles, PBS 2023). Low weight as modifier; theoretically, risk-based (WTO, 2022).

Pillar 8: Environmental Controls & Waste

Indicators:

- q45 (Wastewater Treatment Plant; higher-better)
- q46 (water reuse; higher-better)
- q47 (Better hazardous-waste management; higher-better).

Normalization:

- Recodes like q18, e.g., q45 (1=1, fully) to (4=0.75, planning).

Pillar score:

$$p8 = \frac{1}{3} \sum n_{q_i} \text{ for } i = 45, 46, 47$$

Weight rationale:

Supports sustainability (EEA 2022). Lowest as ancillary to CBAM; theoretically, aligns with broader EU Green Deal.

Pillar 9: Enabling Environment

Indicators:

- q23 (government support; higher-better)
- q24 (carbon market; higher-better), q25 (management trained; higher-better)
- q48 (government confidence; higher-better 1-5)

Normalization:

- Standard recodes.

Pillar score:

$$p9 = \frac{1}{4} \sum n_{qi} \text{ for } i = 23, 24, 25, 48$$

Weight rationale:

Institutional support critical (MoCC 2021). Low as external; theoretically, enables NDCs.

Pillar 10: Future Preparedness

Indicators:

- n_{actions} (2028 actions count; higher-better)
- $n_{\text{expectation}}$ (2030 challenges count; higher-better, code uses non-inverted, assuming more awareness better).

Normalization:

- Counts (0-7);
 - $n = \frac{\text{count} - \text{min}}{\text{max} - \text{min}}$.

Pillar score:

$$p10 = \frac{n_{\text{actions}} + n_{\text{expectation}}}{2}$$

Weight rationale:

Forward-looking (horizons to 2030). Low as prospective; theoretically, per literature on adaptive capacity (Razzaque, et al., 2024).