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RISK MANAGEMENT AND MITIGATION STRATEGIES IN PURIFIED TEREPHTHALIC ACID (PTA) PLANTS IN PAKISTAN: A PROCESS SAFETY AND ENTERPRISE RISK PERSPECTIVE

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Abstract

The risk management and mitigation methods in purified terephthalic acid (PTA) plants in Pakistan in an integrated process safety and enterprise-risk. PTA production is a socio-technical system of high hazards where oxidation chemistry, solvent, and barrier reliability, wastewater treatment, reliance on utility, and digital operational controls collaboratively affect plant resilience. Constructs a conceptual model between process safety management, barrier reliability and environmental-control reliability, cyber-physical security, and evidence-based managerial learning and two enterprise-risk outcomes: environmental risk exposure and financial risk exposure. Through literature examines Annual Report 2025 of Lotte Chemical Pakistan Limited. The results demonstrate that the PTA business can stay afloat during macroeconomic pressure, with the revenue growing by 49.3, profit after taxation by 117.9, and EBITDA by 115.0, despite the decreased production and sales volumes by 9.2 and 10.3, respectively. On the environmental aspect, evidence shows compliant and systems-driven performance, such as effluent and gaseous-emission compliance, 67.32 million man-hours with no lost time case, ISO re-certification with no major non-conformity and commissioning an anaerobic effluent treatment plant and a reported power reduction following plant modification. The article finds that environmental and financial risks not independent of each other and must be addressed by layered technical, organizational, environmental, and cyber-operational controls that ensure compliance, continuity, and enterprise resilience. These exposures through a project risk-management lens, arguing that barrier upgrades, wastewater-treatment improvements, and control-system modernization should be governed as formal risk-reduction projects rather than isolated technical tasks.

Introduction

The PTA is a strategically substantial preliminary material used in the polyester value chain, because it is the major starting point of polyethylene terephthalate, polyester fibers, polyester films and packaging materials. In homelands like Pakistan, where textile and polymer-related industries continue to be economically significant, the safe and dependable running of PTA plants extends much beyond the plant perimeter. It is worth noted that the production of PTA is not a regular low-hazard chemical process. Modern literature indicates that the liquid-phase oxidation of p-xylene in acetic acid under cobalt–manganese–bromide catalytic chemistry is the most prevalent industrial route, with purification operations needed to produce a polymer-grade quality (Tomás et al., 2013; Lapa and Martins, 2023). In parallel, wastewater and effluent treatment studies show that PTA production also creates persistent environmental-control challenges that must be managed as part of the overall plant-risk picture (Pophali et al., 2007; Lu et al., 2021). This is a process that integrates risky reaction chemistry, corrosive media, solvent management, off-gassing, reliance on utilities, and effluent streams that are challenging to the environment within one system.

The manufacturing process-safety importance of PTA itself starts with the oxidation part. According to Tomas et al. (2013), the production of industrial terephthalic acid is controlled by the reaction kinetics, catalyst structure, solvent behavior, impurity formation, mass transfer, and heat-removal behavior. As demonstrated by Lapa and Martins (2023), recent innovation in PTA production still continues to accumulate catalytic efficiency, purification pathways, and optimization at the reactor level, which means that risk reduction cannot be decoupled and isolated from process design and operating discipline. In reality, shifts in air feed, solvent structure, catalyst ratio, temperature regulation, corrosion tolerance, or impurity control could promptly escalate from losses in quality to more general process-safety risks with operations and environmental effects.

This is why the PTA plants are to be considered in the perspective of a complex process-safety and enterprise-risk instead of operating in a single prism of specific occupational safety. Process safety deals with the avoidance of fires, explosions, loss of containment, and catastrophic increase. Enterprise risk expands the scope to production interruption, asset wear and tear, non-compliance with the environment, unreliability of utilities, cyber-physical interruption, reputation losses, and financial exposure. In contemporary chemical production, these dimensions are becoming more and more blurred. The start of an engineering deviation can be a cooling-water upset, a leak caused by corrosion, a failure of the wastewater treatment system, or a disturbance of the control system but can quickly turn into a business-continuity event. Recent scholarship holds that accident prevention must be incorporated into resilience, security, and dynamic decision-making and not as an independent compliance role (Bin Ab Rahim et al., 2024; Wang et al., 2024; Yuan et al., 2024).

The ecological aspect is particularly crucial in PTA facilities. PTA wastewater is known to be challenging to treat due to the presence of refractory organics as well as issues of poor biodegradability and toxicity. Research published in Chemosphere and the Journal of Hazardous Materials demonstrates that not only end-of-pipe disposal capacity is necessary but also a carefully configured biological and membrane-based treatment to achieve a stable treatment (Ma et al., 2020; Kudisi et al., 2022). More recent PTA wastewater scholarship also emphasizes the role of anaerobic digestion, metal handling, and recovery-oriented treatment logic in reducing long-term environmental burden and improving operational resilience (Pinheiro et al., 2026). It implies that risk management at PTA plants should not be based on the reactors and storage systems but on the reliability of effluent treatment, the reliability of upset recovery, the environmental compliance, and reputational exposure. A technically stable plant in its core area of production and an unstable one in wastewater treatment are still at risk of a severe enterprise risk.

The other fact that makes the topic timely is the rapid development of the process-safety field itself. A recent Q1 review notes that risk-assessment practices in the chemical process industry are now moving beyond traditional, inactive approaches to dynamic, systemic approaches like FRAM and STAMP, but resilience has not yet been integrated, despite its role in prevention and recovery (Bin Ab Rahim et al., 2024). In the same vein, Yuan et al. (2022) demonstrate that the research on safety barriers has shifted beyond mere lists of safety barriers to performance-based safety barrier classification and performance and lifecycle management of safety barriers. The developments are of high relevance to PTA plants since these types of facilities are tightly coupled sociotechnical systems, where the integrity of the equipment, the control of the processes, the quality of the maintenance, the preparedness for the emergency, and the management decisions all contribute to the absorption or amplification of the small disturbances. This broader orientation is also consistent with recent reviews showing that organizational governance, chemical safety and security integration, and safety-culture maturity are central to modern chemical risk management (Fouzi et al., 2024; Ayob et al., 2022).

The risk boundary is further widened due to the increasing digitalization of chemical plants. Parker et al. (2023) reveal that there are operational-technology and information-technology vulnerabilities in modern chemical operations in process control, operations, and supply chains. According to Yuan et al. (2024), the emergence of cyber-physical threats needs to be managed through safety and security barriers, and Yuan et al. (2025) bring the argument further to multi-source risk information based on dynamic barrier management. Recent review work on real-time process safety and smart chemical manufacturing likewise shows that digital twins, dynamic risk analysis, and online decision-support are becoming more relevant to safe plant operation (Braniff et al., 2025). This important precaution is added by Arunthavanathan et al. (2024), who believe that artificial intelligence in the process industries ought to supplement, but not substitute, human judgment in the safety-critical setting.

The Pakistani industrial environment reinforces the fact of this study. Even though the literature of PTA-specific risk governance in Pakistan is not extensive, the experience of refining industry in the country shows that process-safety awareness and practice are not evenly distributed, implying that larger-hazard plants could use more systematic and evidence-based safety systems (Anwar et al., 2019). In line with this, this subject is important in that it connects the PTA process technology, process safety management, and enterprise risk in a single analytical structure. The PTA plants in Pakistan need to be layered mitigated with the foundation based on solid process design, integrity of barriers, reliability of environmental control, digitalization cyber-security, and evidence-based managerial learning. Project management wise, they are not only operating exposures but they are also project risks that arise during turnarounds, debottlenecking programs, wastewater-treatment upgrades, barrier replacement, and modernization of digital controls. PMBOK-based project governance focuses on the discipline of the scope, alignment of stakeholders, schedule control, lessons learned, and the formal risk registers and ISO 31000 considers risk management as the key organizational-wide process that is integrated into governance, planning, monitoring, and constant improvement. The use of these lenses in PTA plants facilitates the understanding of how technical drift can result in cost and schedule overruns, failure to comply, and disrupting an enterprise in case the risk treatments are not governed effectively (ISO, 2018; PMI, 2021).

Literature Review

The literature related to the PTA plants could be split into two overlapping streams including the study of the PTA production and environmental impact and the study of the process safety and resilience and integrated risk management of the chemical process industries. The former stream explains the source of risk in the manufacturing of PTA, and the latter explains how risk has to be assessed, controlled and mitigated. Tomás et al. (2013) remain on the level of process as they associate the chemistry and kinetics of p-xylene oxidation with the functioning and optimization of industry. Their review discloses that catalytic behavior, reaction intermediates, solvent effects, impurity control, and process-integration choices affect PTA production and that is not only dictated by conversion efficiency. Lapa and Martins (2023) revise this image, analyzing catalytic progress, reactor development, process modeling, and purification developments since 2014. Combined, these reviews illustrate that the PTA process is multi-variable in nature and disturbed easily. In terms of safety, it translates to the fact that the operation of windows, the quality of instrumentation, the management of corrosion, and the disciplined change control are not peripheral issues; they are core safeguards. Such a conclusion is supported by the environmental-risk literature, including studies on PTA effluent treatment redesign and combined anaerobic–aerobic alternatives that connect wastewater management directly with plant reliability and compliance (Pophali et al., 2007; Lu et al., 2021).

Ma et al. (2020) indicate that integrated biological treatment configurations can enhance the performance of PTA wastewater treatment, whereas Kudisi et al. (2022) indicate that PTA wastewater is still a challenge due to low biodegradability, toxicity, and long-term membrane fouling. Earlier techno-economic work and newer review evidence alike suggest that treatment design, anaerobic stability, and metal handling are part of the core risk landscape of PTA production rather than downstream housekeeping issues (Pophali et al., 2007; Pinheiro et al., 2026). This is relevant literature since it extends the general definition of plant risk. Reactors, tanks, and piping are the non-exclusive exposing possibilities of a PTA facility; the stability of its environmental-control systems also exposes it. Therefore, wastewater-treatment resilience, monitoring, and recovery planning should be central risk control measures, instead of being marginal environmental activities. The second stream of major literature is related to process safety management (PSM). According to Nwankwo et al. (2020), no single PSM system fits all departments of the process industries, despite the fact that sound and flexible PSM selection is a la carte in minimizing significant accidents. This is particularly applicable to PTA plants as they integrate oxidation chemistry, solvent service, integration of utilities, and purification as well as environmental treatment under a single envelope of operation. More modern studies by Wang et al. (2024) suggest evidence-based process safety management (EBPSM), whereby incident records, hazard studies, audits, and scientific evidence are thoroughly incorporated into managerial decision-making. In the context of the industrial environment in Pakistan, such an approach is especially helpful as it provides the means of transcending the reactive correction towards structured learning. This is also compatible with broader chemical risk- management literature highlighting organizational approaches and safety-culture maturity as practical enablers of safer performance (Fouzi et al., 2024; Ayob et al., 2022).

The current literature has also come to place central focus on barrier-based safety management. The state-of-the-art review performed by Yuan et al. (2022) demonstrates that the field has developed beyond the simplistic thinking of layers of protection to more stringent consideration of the classification of barriers, performance metrics, flexibility, recoverability, and lifecycle management. This is very applicable in PTA plants, where a combination of barriers is required to be effective: process design margins, material selection, corrosion control, alarms, interlocks, procedures, emergency response, and environmental treatment systems. The main implication is that risk mitigation must not inquire about whether or not a barrier is present but rather whether it is reliable under start-up, steady-state, upset, and recovery conditions. This reading is reinforced by maintenance literature in downstream process industries, where equipment criticality and risk-based maintenance are treated as essential to safety, environment, and production continuity (Wari et al., 2023). Recent publications also indicate that the use of statistical hazard assessment is becoming inappropriate to complex process plants. According to Bin Ab Rahim et al. (2024), a shift to dynamic and systemic approaches like FRAM and STAMP is observed because these are more appropriate to describe the sociotechnical complexity of current chemical operations. Sun et al. (2024) reinforce this trend by integrating STAMP with cascading-failure modeling to develop a time-dependent analysis of risk capitalization in chemical systems.

The authors Tong and Gernay (2023) also assess dynamic resilience in process-industry facilities using dynamic Bayesian networks, where the performance of protection and the growth of the accident may be depicted as time-varying processes. In the case of PTA plants in Pakistan, these studies indicate that periodical HAZOPs and fixed risk matrices are to be supplemented with approaches that can monitor the degradation of barriers, utility disruptions, maintenance history, and atypical operating conditions. Escalation management and resilience are also crucial. Zeng et al. (2022) create a barrier-management framework of Natech domino effects and chemical-cluster resilience, focusing on whole-cycle planning on the design, operation, accident, and recovery levels. Though wider in scope than PTA by itself, the principle is immediately applicable: mitigation must not end at prevention but also prepare the plant to take disruption in, contain propagation, recover without risk, and learn in a systematic way. This is consistent with the broader finding of Bin Ab Rahim et al. (2024) that process safety, process security, and resilience are not independent silos but are instead related disciplines. An additional layer of enterprise risk is provided by the digitalization literature. Parker et al. (2023) demonstrate that currently cybersecurity threats have penetrated into the process control, operations, and supply-chain interfaces of chemical industries. In response, Yuan et al. (2024) suggest the concept of integrated safety and security barrier management of chemical plants with risks of cyber-physical attack, whereas Yuan et al. (2025) augment the concept to a dynamic framework that is constantly achieving the necessary modifications in the barrier strategies. Braniff et al. (2025) extend this direction by linking online process safety, dynamic risk analysis, fault diagnosis, and digital twins to real-time decision-making in chemical manufacturing.

A different argument to the same effect is made by Arunthavanathan et al. (2024), who argue that AI in process industries must be used as intelligence augmentation and not as a replacement of human supervision. In the case of PTA plants, it implies that optimization and monitoring can be enhanced through modernization as long as digital tools are controlled in a security structure that maintains human expertise and control-room discretion. There is a significant gap in the Pakistani literature. In their evaluation of PSM practices in the refining industry of Pakistan, Anwar et al. (2019) note that the quality of process-safety awareness and implementation is not even. Although the given work is not PTA-specific, it can be considered very relevant since it implies that the high-hazard facilities in Pakistan remain in need of better institutionalization of PSM and more formalized safety governance. What the existing literature lacks is a targeted framework that can be used to translate the global Q1 research into the realities of the PTA production in Pakistan. The literature describes PTA chemistry, wastewater treatment issues, barrier management, resilience, and cyber-physical threats, yet it seldom unites these strands into a single decision-making framework of PTA plants in the context of an emerging economy.

The literature in general indicates that risk management of PTA plants should be multi-layered and evidence-based. Technically, mitigation should deal with stability of oxidation

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processes, integrity of assets, control of solvents and off-gases, dependability of purification, and wastewater treatment efficiency. Organizational-level requirements include organizational PSM structures that are fit-for-purpose, change management, assurance of barrier-performance reliability, as well as systemic learning. This synthesis offers the conceptual foundation to consider the PTA plants in Pakistan as high-hazard sociotechnical systems that cannot separate the process safety and enterprise risk.

Enterprise Risk in the Context of Project Management

As far as project management is concerned, enterprise risk in PTA plants ought to be interpreted as a potential that a technical, environmental, schedule, cost or stakeholder-related occurrence in a plant intervention project will impact the overall organizational goals. This especially applies to the shutdown planning, reliability-enhancement programs, wastewater-treatment retrofit programs, emissions-control investment programs, and technology-upgrade programs, the effectiveness of risk treatment in which project governance is as important as engineering design. The ISO 31000 would come in handy in this case as it connects the risk treatment to the organizational objectives, communication, monitoring, and review, compared to the PMBOK which focuses on structured planning, stakeholder engagement, managing uncertainties, and discipline in delivering the project over the project life cycle (ISO, 2018; PMI, 2021). This environmental-risk narrative is also enhanced by this project-oriented framing. Upgrades of wastewater-treatment, anaerobic-treatment commissioning, effluent-reuse, and emissions-control upgrades are not just environmental housekeeping measures; they are capital-intensive compliance and reliability measures whose delay, under-design, or poor implementation may have regulatory, reputational and financial impacts. The malfunctioning of these plants can increase the exposure of enterprises in PTA plants despite apparently stable operation of the main production train in the facility (Pophali et al., 2007; Ma et al., 2020; Lu et al., 2021).

The composition of effluent and the stability of its treatment is technically sensitive in any PTA facility, which is why even with a seemingly stable operation of the main This worry is intensified by the Pakistani environment, as the internal barrier to enterprise risk is influenced not just by the barriers within the plant, but also by the reliability of the utility, logistics of trade, and access to imported inputs and essential spares. According to evidence of World Bank, it has been evident that the energy sector in Pakistan is still plagued by reliability issues attributed to the old equipment and supply disruptions, and the delays of imports and weak customs, adds to the cost of obtaining key inputs in production. In the case of the PTA plants, it implies that the time lag in the supply of instrumentation, rotating-equipment parts, components of the control system, or treatment chemicals could convert an otherwise routine maintenance or upgrade activity into a broader continuity and compliance risk, particularly in industrial locations that rely on Karachi-linked trade flows (Anwar et al., 2019; World Bank, 2023; World Bank).

In this respect, the literature gap is not just the lack of more technical discourse concerning the PTA chemistry or the wastewater; it is the lack of a coherent framework which links these hazards with project-governance and enterprise-risk logic in an emerging-economy context. This paper fills this gap by creating a conceptual framework where the process safety management, barrier reliability, environmental-control reliability, cyber-physical security, and evidence-based managerial learning are regarded as management capabilities that have an impact on two quantifiable risk outcomes, namely, environmental risk exposure and financial risk exposure.

Sustainability Perspective in PTA Risk Management

From a sustainability perspective, risk mitigation in PTA plants connects environmental stewardship with long-term financial continuity. Wastewater-treatment reliability, emissions control, energy conservation, resource efficiency, safe operations, and cyber-secure process control are not only compliance activities; they support sustainable industrial performance by reducing ecological burden, operational disruption, reputational exposure, and avoidable financial loss. Therefore, this study treats sustainability as an embedded outcome of enterprise-risk management, where environmental risk exposure and financial risk exposure are evaluated together rather than as separate concerns (Ma et al., 2020; Kudisi et al., 2022; ISO, 2018).

Research Gap

Although the existing literature discusses PTA chemistry, wastewater treatment, process safety, barrier management, cyber-physical risk, and project risk governance, these streams are often treated separately. There is still limited empirical work that links these capabilities with both environmental and financial risk exposure in Pakistani PTA plants. In particular, the literature lacks a questionnaire-based and SPSS-supported framework that examines how process safety management, barrier reliability, environmental-control reliability, cyber-physical security, and evidence-based managerial learning jointly explain enterprise-risk outcomes in PTA operations. This study addresses this gap by combining the conceptual risk framework with questionnaire-based statistical analysis and secondary evidence from PTA-industry reporting.

Research Questions

RQ1: Which risk-management capabilities are most critical for reducing environmental and financial risk exposure in PTA plants in Pakistan?

RQ2: How do utility unreliability, supply-chain delays, and barrier-maintenance constraints amplify process risks into enterprise-level risks in PTA operations?

RQ3: To what extent do process safety management, barrier reliability, environmental-control reliability, cyber-physical security, and evidence-based managerial learning explain environmental and financial risk exposure in PTA plants?

Focus of the Study

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This study examines PTA plants in Pakistan as socio-technical systems with high hazards where deviations in the processes, the failures of barriers, the weaknesses of the environmental-control, and the cyber-operational interferon can cause two broad groups of exposure: environmental risk and financial risk. To that end, the analytical focus of the research does not focus on the technical safety, but rather on the assessment of the effectiveness of the integrated risk-management capabilities on the environmental compliance, loss prevention, business continuity, and financial resilience in the framework of the PTA activities.

Objectives of the Study

1. To identify the major risk-management factors affecting PTA plants in Pakistan.
2. To examine the effect of these factors on environmental risk exposure in PTA plants.
3. To assess the effect of these factors on financial risk exposure in PTA plants.
4. To analyze PTA risk from an integrated enterprise-risk perspective combining environmental and financial dimensions.
5. To propose mitigation priorities that can reduce risk exposure and strengthen plant-level resilience.

Conceptual Framework

The conceptual model suggests that robust process safety and risk-governance competencies can decrease enterprise risk results in PTA plants. Process safety management, barrier reliability, environmental-control reliability, cyber-physical security, and evidence-based managerial learning are considered the independent variables in this model, and the environmental risk exposure and financial risk exposure two dependent dimensions characterize enterprise risk outcomes.

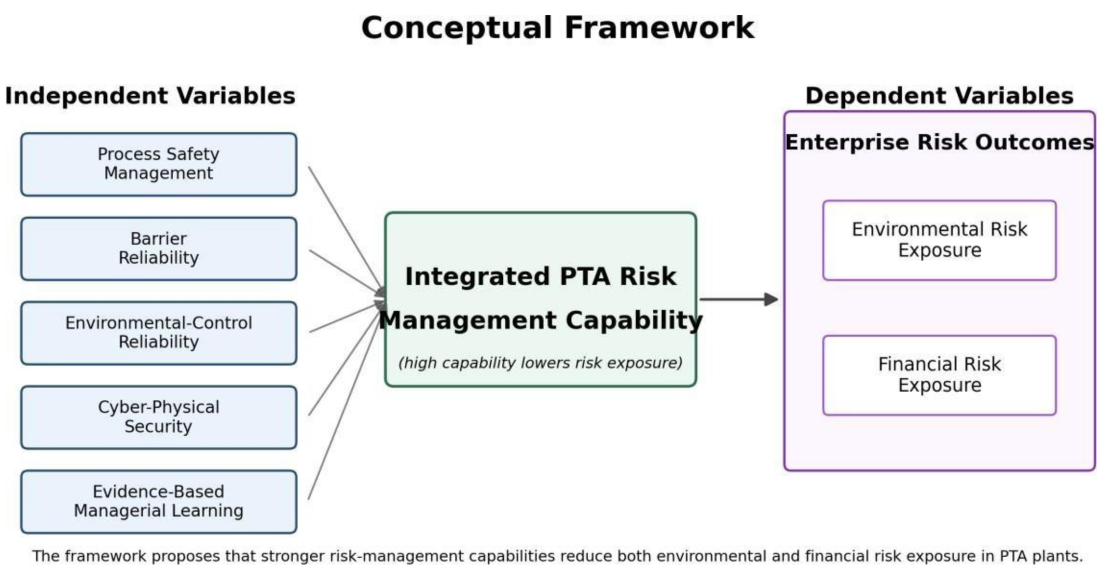

Figure 1. Conceptual Framework of Environmental and Financial Risk Exposure in PTA Plants

Hypotheses

H1: Process safety management has a significant negative effect on environmental and financial risk exposure in PTA plants.

H2: Barrier reliability has a significant negative effect on environmental and financial risk exposure in PTA plants.

H3: Environmental-control reliability has a significant negative effect on environmental and financial risk exposure in PTA plants.

H4: Cyber-physical security has a significant negative effect on environmental and financial risk exposure in PTA plants.

H5: Evidence-based managerial learning has a significant negative effect on environmental and financial risk exposure in PTA plants.

Research Methodology

This study adopts a quantitative, cross-sectional research design. The structured questionnaire will be used to gather primary data based on the process-safety and enterprise-risk literature and adjusted to PTA operations in Pakistan. The identified respondents will be plant managers, process engineers, HSE staff, maintenance staff, operations supervisors, and environmental or compliance staff in PTA-related plant. The questionnaire will be used to measure process safety management, barrier reliability, environmental-control reliability, cyber-physical security, evidence-based managerial learning, environmental risk exposure, and financial risk exposure. Each of the items will be rated using a five-point Likert scale with the 1 = Strongly Disagree and 5 = Strongly Agree. This logic of measurement corresponds to the recent process-safety and safety-culture research which highlights the systematic evaluation of governance, barriers, and organizational learning (Ayob et al., 2022; Wang et al., 2024). The data will be analyzed with SPSS and/or SmartPLS with descriptive statistics, reliability analysis, validity analysis, correlation analysis, and regression/structure model analysis to identify the significance of the proposed relationships.

The methodological option is aimed at converting the literature gap into project-risk and enterprise-risk framework that can be empirically tested. The questionnaire as such not only takes into account the technical controls, but also the management practices that are pertinent to the project execution and risk treatment such as planning discipline, cross-functional coordination, monitoring and organizational learning. By doing so, the research connects the concept of operational reliability to project risk management and offers a systematic framework of focusing mitigation efforts within Pakistani PTA plants (ISO, 2018; PMI, 2021).

Questionnaire Adaptation, Coding, and Statistical Thresholds

For the questionnaire-based component of the study, the measurement items were adapted rather than newly developed. The wording of the instrument was aligned with prior literature on process safety management, safety barriers, environmental-control systems, cyber-physical security, safety-culture maturity, and evidence-based managerial learning. In operational terms, the final instrument retained 28 items across seven constructs: Process Safety Management (PSM), Barrier Reliability (BR), Environmental-Control Reliability (ECR), Cyber-Physical Security (CPS), Evidence-Based Managerial Learning (EML), Environmental Risk Exposure (ERE), and Financial Risk Exposure (FRE). The responses were collected through Google Forms/Google Sheets and exported for SPSS-based coding and analysis, yielding 18 valid cases for the present dataset.

The coding logic followed a five-point Likert scale where 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree. The instrument-assessment criteria used in the study followed widely accepted thresholds: Cronbach's alpha of 0.70 or above was treated as acceptable for internal consistency, values around 0.60 were treated as usable in exploratory settings, factor loadings of 0.50 or above were treated as practically meaningful, KMO values of 0.60 or above were treated as acceptable for factorability, p-values below 0.05 were treated as statistically significant, and VIF values below 10 were treated as acceptable for multicollinearity assessment (Hair et al., 2019; Kline, 2016; Nunnally & Bernstein, 1994).

Accordingly, the questionnaire section of this article should be treated as an adapted measurement instrument anchored in prior studies, while the SPSS-style summary tables generated from the collected responses are reported in Appendix B for documentation and write-up support. The principal adaptation anchors for the questionnaire were drawn from Wang et al. (2024), Nwankwo et al. (2020), Yuan et al. (2022), Yuan et al. (2024), Parker et al. (2023), Ayob et al. (2022), Ma et al. (2020), Lu et al. (2021), and Pophali et al. (2007).

To make the quantitative component more transparent, the questionnaire results are reported through SPSS-style tables and graphical plots in Appendix B. The construct mean plot summarizes the overall tendency of responses for each measurement dimension, while the regression coefficient plots display the direction and relative strength of each predictor for environmental risk exposure and financial risk exposure.

Data Analysis, Results and Discussion Financial and Environmental Dimensions of Risk in PTA Plants in Pakistan

This section is based on secondary evidence extracted from Lotte Chemical Pakistan Limited's Annual Report 2025. The financial discourse relies on reported operating and financial values whereas the environmental discourse is based on reported HSE, compliance, energy, wastewater and resource-efficiency indicators. Since the report focuses on compliance status and operational initiatives, but not plant-level tonnage of emissions, the environmental analysis is deliberately structured in terms of reported performance indicators and risk implications instead of reported absolute emission data.

4.1 Financial Factor Analysis

The financial aspect of risk was analyzed with the help of reported revenue, profitability, cash-generation, liquidity, leverage, market valuation and operating-volume measures. The data indicate that 2025 was a financially robust year of LCPL though the increase was done at lower sales and production volumes thus implying that the increase earned was more of a margin-based instead of a volume-based increase. The distinction is significant to a PTA risk study as it demonstrates that financial robustness can be enhanced even when a demand pressures, a feedstock volatility and utility constraint are at work in the operating environment.

Table 1. Selected Financial Performance Indicators for LCPL PTA Operations

Indicator	2024	2025	Change (%)	Interpretation
Revenue (Rs million)	67,165	100,266	49.3	Higher realization and improved PTA pricing environment.
Gross profit (Rs million)	7,581	17,824	135.1	Substantial margin expansion relative to prior year.
Profit before taxation (Rs million)	6,499	15,757	142.5	Operating and pricing gains flowed through to earnings.
Profit after taxation (Rs million)	4,643	10,118	117.9	Net profitability more than doubled year on year.
EPS (Rs/share)	3.07	6.68	117.6	Shareholder return capacity improved materially.
EBITDA (Rs million)	8,810	18,941	115.0	Core earnings strength increased despite a difficult macro setting.
Gross margin (%)	11.29	17.78	57.5	Profitability improved faster than sales growth.
Net profit margin (%)	6.91	10.09	46.0	Better earnings retention from each rupee of revenue.

Table 1 shows that revenue increased by 49.3%, while gross profit, profit before taxation and profit after taxation rose by 135.1%, 142.5% and 117.9%, respectively. Analytically speaking, the difference between the sales growth and profit growth suggests that there is a significant increase in the quality of earnings. The gross margin moved from 11.29% in 2024 to 17.78% in 2025, while the net profit margin rose from 6.91% to 10.09%. This is to say that, the Company did not just achieve higher sales in nominal rupee terms; it achieved higher margin performance in the value chain. Risk wise, this result somewhat cancels the exposure to high feedstock prices, inflation, and exchange-rate fluctuations and low downstream demand. However, it is also clear in the report that this high profitability has been achieved in a poor external environment of recessionary pressure, uncertainty of utility and domestic demand shrinkage.

Table 2. Financial Risk Position, Operating Volumes and Market Signals

Indicator	2024	2025	Change (%)	Risk Reading
Production volume (000 tonnes)	519.0	471.2	-9.2	Operational output weakened, reflecting curtailment and overhaul effects.
Sales volume (000 tonnes)	520.0	466.6	-10.3	Demand-side pressure remained visible despite earnings growth.
Current ratio (times)	1.83	1.85	1.1	Short-term solvency stayed stable.
Quick ratio (times)	1.35	1.31	-3.0	Immediate liquidity remained sound but slightly tighter.
Debt-equity ratio (times)	1.09	1.08	-0.9	Leverage profile remained broadly controlled.
Cash and cash equivalents at year end (Rs million)	15,306	13,783	-9.9	Cash cover eased, requiring continued liquidity discipline.
Market capitalization (Rs million)	20,684.1	39,218.0	89.6	Investors revalued the company more positively.
ROE (%)	24.47	43.97	79.7	Higher equity returns signaled strong financial performance.

The second financial table is important because it prevents overstatement of the profit story. Despite a dramatic improvement in earnings, production volume decreased by 9.2 and sales volume decreased by 10.3. Therefore, the financial benefit in 2025 was not followed by an overall growth in the physical throughput. This trend indicates that PTA financial exposure was still pegged to external market and supply-chain factors particularly price of raw materials, currency fluctuations and inadequate downstream demand. Liquidity was also satisfactory with an increased current ratio of 1.85, although, the quick ratio deteriorated to 1.31 and cash equivalents decreased. In this regard, the financial evidence would indicate a profitable and financially superior business by 2025, but still vulnerable to the typical enterprise risks that were listed in the annual report like liquidity risk, foreign-currency risk, customer-demand risk and raw material dependence.

4.2 Environmental Factor Analysis

Environmental aspect was examined based on the HSE, energy conservation, environmental protection and manufacturing, sections of annual report. The environmental disclosures, in contrast to the financial part, are not dominated by the income-statement

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values but rather are measured by the safety records, compliance with regulations, wastewater-treatment, energy-saving initiatives and ecosystem management. Analytically correct in the case of a PTA plant is the fact that the environmental risk is usually reflected in terms of reliability of effluent treatment, control of emissions, abnormal releases, compliance with regulations and is also reflected in the ability of the plant to recover following an upset.

Table 3. Reported Environmental and HSE Performance Indicators

Indicator	2024 / Prior position	2025 / Reported status	Risk Implication
Lost Time Case performance	64.6 million man-hours without LTC	67.32 million man-hours without LTC	Very strong occupational safety record; indicates disciplined HSE control.
Regulatory environmental status	Not numerically detailed	Liquid effluent met national environmental quality standards; gaseous emissions remained within regulatory limits	Suggests compliant environmental operations during the year.
Management systems	Existing ISO-based system	Re-certification of ISO 9001, 14001 and 45001 completed without major non-conformity	Supports governance-based environmental and safety assurance.
Wastewater management	Aerobic treatment system in place	Deep-shaft ETP maintained; anaerobic effluent treatment plant commissioned	Improves effluent resilience and resource recovery.
Energy efficiency	Baseline prior to modification	Main plant modification reduced power consumption by about 3%	Lower energy intensity reduces both cost and environmental burden.
Plant reliability	Not stated in same table	Plant availability reported at 88% despite overhaul and shutdowns	Reliable operations reduce upset-related environmental exposure.
Cogeneration reliability	Not stated in same table	Cogeneration plant availability reached 90.3%	Improves utility stability and continuity of

			controlled operation.
Biodiversity / green stewardship	Prior plantation program ongoing	Around 100,000 trees reported around premises and nearby area	Strengthens ecological stewardship and community-facing environmental profile.

The environmental evidence shows that LCPL had a compliance-focused and systems-based environmental posture in the year 2025. The stated completion of 67.32 million man-hours with no lost time incident, as well as the ISO re-certification with no significant non-conformity, suggests a developed management system and not a haphazard compliance. More importantly in relation to PTA-specific risk analysis, the report directly correlates environmental control to wastewater-treatment reliability, energy optimization and process continuity. The installation of the anaerobic effluent treatment plant, in particular, is crucial since it transforms the logic of waste management into a different one, where waste management is based on recovery and reuse. Within the framework of PTA activity, at which wastewater structure and solvent streams may emerge as a significant source of enterprise risk, analytical importance and consistency with the broader literature on the significance of effective treatment and recovery systems.

Table 4. Analytical Interpretation of Environmental Risk Exposure in 2025

Environmental domain	Evidence reported in 2025	Analytical status	Discussion
Occupational and process safety	67.32 million man-hours without LTC; zero injury target achieved during overhaul	Low exposure	The probability of immediate people-related disruption appears controlled, although low frequency risk can never be
Environmental domain	Evidence reported in 2025	Analytical status	Discussion
			treated as zero in high-hazard plants.
Effluent and wastewater	Effluent met standards; deep-shaft ETP in place; anaerobic	Low to moderate	Compliance was maintained, but wastewater remains a

control	reactor commissioned	exposure	technically sensitive area in PTA manufacturing and therefore warrants continuous monitoring.
Air emissions and compliance	Gaseous emissions remained within regulatory limits; no major environmental audit concern reported	Low exposure	The plant remained within regulatory boundaries during the reporting year, indicating stable environmental control under routine conditions.
Energy and carbon intensity	Integrated process design, cogeneration, LED replacement, and 3% lower power use after modification	Moderate exposure improving	Energy remains a structural risk because the report also highlights Pakistan's energy crisis and utility unreliability; however, the mitigation trajectory is positive.
Resource use and biodiversity	Water reuse initiatives, horticultural reuse, RO reject recycling, and around 100,000 trees	Moderate exposure improving	The company appears to be moving from simple compliance toward stewardship-based environmental management.
Residual strategic environmental risk	Aging machinery, old PTA technology and power instability highlighted elsewhere in the report	Moderate exposure	These structural conditions mean that environmental risk has been managed, but not fully eliminated; reliability investment must continue.

Table 4 summarizes the environmental data into an enterprise-risk reading. It is not an image of environmental distress, but of restrained but still technically exposed performance. There is good compliance-based evidence, but even the annual report admits structural pressures like old machinery, old technology, and instability of utilities. Hence, the environmental results are to be viewed as a sign of the good control in the reporting year rather than evidence that the environmental risk does not exist. The distinction is significant to the given study since PTA plants are socio-technical systems where any disruption in utilities, equipment integrity or effluent treatment may quickly turn into an environmental and financial loss.

4.3 Integrated Discussion

When the two dimensions are considered as a unit, the evidence confirms the main point in this paper: financial risk and environmental risk of PTA plants are not independent. LCPL made great profits in 2025 despite the reduction in production and sales volumes. On the environmental front, the company had a good HSE performance, was compliant, enhanced wastewater management and tried to achieve energy-efficiency. Collectively, these findings indicate that enterprise resilience in PTA plants is not only based on market prices and margins, but on the assurance of environmental controls, utility continuity and regimented safety systems. That is, profitability can be safeguarded by a PTA plant only when the controls of environmental and process-safety are maintained under operating pressure. This combined reading is in tandem with the conceptual framework of the article, in which both financial exposure and environmental exposure are viewed as two manifestations of the same enterprise-risk system.

In general, the 2025 case can be used as a valuable empirical base of the current research. The financial performance indicates that the PTA business will be profitable in conditions of macroeconomic and market pressure, whereas the environmental reporting indicates that financial performance is maintained due to the premeditated investments in the reliability of plants, HSE systems, wastewater treatment and resource optimization. To this end, the analysis of the data confirms the hypothesis that mitigation measures in PTA plants should be structured as a set of controls which mutually achieve the protection of earnings, continuity, compliance and environmental legitimacy. This discussion also implies that significant mitigation measures in PTA plants need to be regulated as formal projects and not the technical band-aid. Retrofitting wastewater-treatment, barrier, critical-spares assurance, and cyber-security improvements have to be clearly sponsored, budgeted, scheduled, reviewed at a review gate, and learned after their implementation in order to have a lasting impact on reducing enterprise exposure.

Conclusion

PTA plants in Pakistan ought to be perceived as a high-hazard enterprise system where process safety, environmental control, and financial resilience are in close interaction. Both the literature synthesis and the case of 2025 LCPL demonstrate that risk cannot be viewed solely in the context of accident prevention and solely in the context of business performance. Instead, good profits, consistent compliance and continuity in operations rely on the same underlying capabilities: disciplined process safety management, stable technical and organizational barriers, strong wastewater and emission-control systems, stable utilities, and managerial learning. The financial performance shows that PTA operations can strongly work even in the conditions of macroeconomic pressure, yet the combination of the production and sales volumes decrease proves the fact that enterprise exposure is sensitive to market volatility, dependence on raw materials and utilities disruptions and operational limitations.

The environmental evidence is also educative. The effluent and gaseous-emission limits, good HSE, ISO re-certification, energy-efficiency-benefits, and wastewater-treatment-enhancement all reported that environmental risk was managed in the reporting year. Nevertheless, there are aging machinery, old PTA technology and power instability, which implies that residual risk is structurally relevant. Thus, a layered mitigation approach that integrates safe process design, performance assurance of barriers, environmental-control reliability, cyber-physical protection, maintenance discipline, and evidence-based decision-making is the most effective mitigation strategy of PTA plants. Practically, the Pakistani PTA facilities are anticipated to enhance consolidated risk-governance frameworks that collaborate in securing individuals, assets, the environment, and financial sustainability. This is the best foundation of robust plant resilience, regulatory legitimacy and sustainable industrial performance in the long run. That is why project-management maturity is a topic that must be considered as a subset of plant-resilience in PTA plants. Even with a well-designed technical solution, a risk-reduction initiative, which is not appropriately scoped, resourced, scheduled, and monitored, may fail; hence, subsequent plant-improvement project in Pakistan should consider process safety, enterprise risk, and project governance as part of the same management architecture (ISO, 2018; PMI, 2021).

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Appendix A. Adapted Questionnaire Basis and Statistical Thresholds Table A1. Adapted Questionnaire Constructs and Source Anchors

Construct	Item codes	Primary adaptation anchors
Process Safety Management	PSM1–PSM4	Wang et al. (2024); Nwankwo et al. (2020)
Barrier Reliability	BR1–BR4	Yuan et al. (2022); Zeng et al. (2022)
Environmental-Control Reliability	ECR1–ECR4	Ma et al. (2020); Lu et al. (2021); Pophali et al. (2007)
Cyber-Physical Security	CPS1–CPS4	Parker et al. (2023); Yuan et al. (2024)
Evidence-Based Managerial Learning	EML1–EML4	Wang et al. (2024); Ayob et al. (2022)
Environmental Risk Exposure	ERE1–ERE4	Ma et al. (2020); Lu et al. (2021); Pophali et al. (2007)
Financial Risk Exposure	FRE1–FRE4	ISO (2018); PMI (2021); Parker et al. (2023)

Table A2. Statistical Thresholds Used in Instrument Assessment and SPSS Interpretation

Criterion	Recommended threshold	Reference basis
Cronbach's alpha	≥ 0.70 acceptable; 0.60–0.69 acceptable in exploratory work	Nunnally & Bernstein (1994); Hair et al. (2019)
Factor loading	≥ 0.50	Hair et al. (2019)
KMO	≥ 0.60	Hair et al. (2019)
Bartlett's test	$p < 0.05$	Hair et al. (2019)
Statistical significance	$p < 0.05$	Kline (2016)
Multicollinearity (VIF)	< 10.00	Kline (2016); Hair et al. (2019)

Appendix B. SPSS Output Summary from the Collected Questionnaire Responses

The following appendix summarizes the SPSS-style output tables generated from the collected questionnaire responses (N = 18). The brief note that appeared on the last page of the stand-alone output file has intentionally been omitted in the present final article version.

Table B1. Case Processing Summary

Item	Value
Valid cases	18
Variables used	28
Constructs scored	7

Table B2. Reliability Statistics

Construct	Items	Cronbach's Alpha	Mean	Std. Deviation
Process Safety Management	4	0.790	3.986	0.661
Barrier Reliability	4	0.857	3.917	0.681
Environmental-Control Reliability	4	0.824	3.847	0.665

Cyber-Physical Security	4	0.840	3.847	0.728
Evidence-Based Managerial Learning	4	0.864	4.014	0.621
Environmental Risk Exposure	4	0.650	3.764	0.481
Financial Risk Exposure	4	0.896	4.153	0.582

Interpretation: Six constructs exceeded the conventional 0.70 threshold. Environmental Risk Exposure yielded an alpha of 0.650, which remains usable for exploratory interpretation in this article because the construct is theoretically central to the proposed framework.

Table B3. Descriptive Statistics for Construct Scores

Construct	**N**	**Mean**	**Std. Deviation**	**Minimum**	**Maximum**
Process Safety Management	18	3.986	0.661	3.000	5.000
Barrier Reliability	18	3.917	0.681	3.000	5.000
Environmental-Control Reliability	18	3.847	0.665	3.000	5.000
Cyber-Physical Security	18	3.847	0.728	2.750	5.000
Evidence-Based Managerial Learning	18	4.014	0.621	3.000	5.000
Environmental Risk Exposure	18	3.764	0.481	3.000	5.000
Financial Risk Exposure	18	4.153	0.582	3.000	5.000

Table B4. Pearson Correlation Matrix

Variable	PSM	BR	ECR	CPS	EML	ERE	FRE
Process Safety Management	1.000	0.863**	0.772**	0.682**	0.797**	0.671**	0.741**
Barrier Reliability	0.863**	1.000	0.742**	0.433	0.873**	0.666**	0.794**
Environmental-Control Reliability	0.772**	0.742**	1.000	0.761**	0.718**	0.490*	0.776**
Cyber-Physical Security	0.682**	0.433	0.761**	1.000	0.419	0.342	0.474*
Evidence-Based Managerial Learning	0.797**	0.873**	0.718**	0.419	1.000	0.688**	0.868**
Environmental Risk Exposure	0.671**	0.666**	0.490*	0.342	0.688**	1.000	0.701**
Financial Risk Exposure	0.741**	0.794**	0.776**	0.474*	0.868**	0.701**	1.000

Note: ** p < 0.01, * p < 0.05. Correlations are shown for construct mean scores.

Table B5. Model Summary for Environmental Risk Exposure

ependent variable	R	R Square	djusted R Square	Std. Error of the Estimate	F	Sig.	N
Environmental Risk Exposure	0.728	0.530	0.334	0.393	2.703	0.073	18

Table B6. ANOVA for Environmental Risk Exposure

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	2.084	5	0.417	2.703	0.073
Residual	1.850	12	0.154	nan	nan

Total	3.934	17	nan	nan	nan

Table B7. Coefficients for Environmental Risk Exposure

Variable	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
Constant	1.563	0.683	nan	2.288	0.041	nan	nan
Process Safety Management	0.300	0.406	0.412	0.739	0.474	0.126	7.939
Barrier Reliability	0.056	0.405	0.080	0.139	0.892	0.119	8.374
Environmental-Control Reliability	-0.136	0.329	-0.188	-0.412	0.687	0.189	5.287
Cyber-Physical Security	-0.007	0.277	-0.011	-0.026	0.980	0.223	4.484
Evidence-Based Managerial Learning	0.333	0.330	0.429	1.008	0.333	0.216	4.629

Table B8. Model Summary for Financial Risk Exposure

ependent variable	R	R Square	djusted R Square	Std. Error of the Estimate	F	Sig.	N
Financial Risk Exposure	0.897	0.804	0.723	0.307	9.875	0.001	18

Table B9. ANOVA for Financial Risk Exposure

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	4.640	5	0.928	9.875	0.001
Residual	1.128	12	0.094	nan	nan
Total	5.767	17	nan	nan	nan

Table B10. Coefficients for Financial Risk Exposure

Variable	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
Constant	0.756	0.533	nan	1.417	0.182	nan	nan

Process Safety Management	0.015	0.317	0.017	0.048	0.962	0.126	7.939
Barrier Reliability	-0.023	0.316	-0.027	-0.072	0.944	0.119	8.374
Environmental-Control Reliability	0.359	0.257	0.410	1.397	0.188	0.189	5.287
Cyber-Physical Security	-0.080	0.216	-0.100	-0.371	0.717	0.223	4.484
Evidence-Based Managerial Learning	0.586	0.258	0.625	2.276	0.042	0.216	4.629

SPSS Output Plots

Figure B1. Construct Mean Scores from Questionnaire Responses

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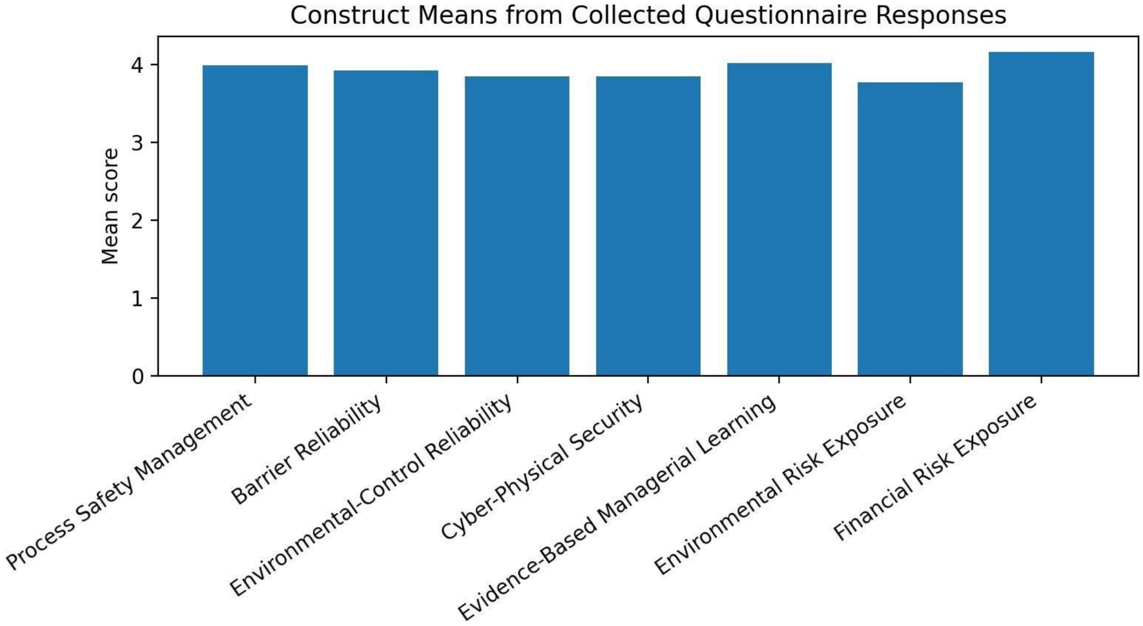


Figure B2. Regression Coefficients for Environmental Risk Exposure

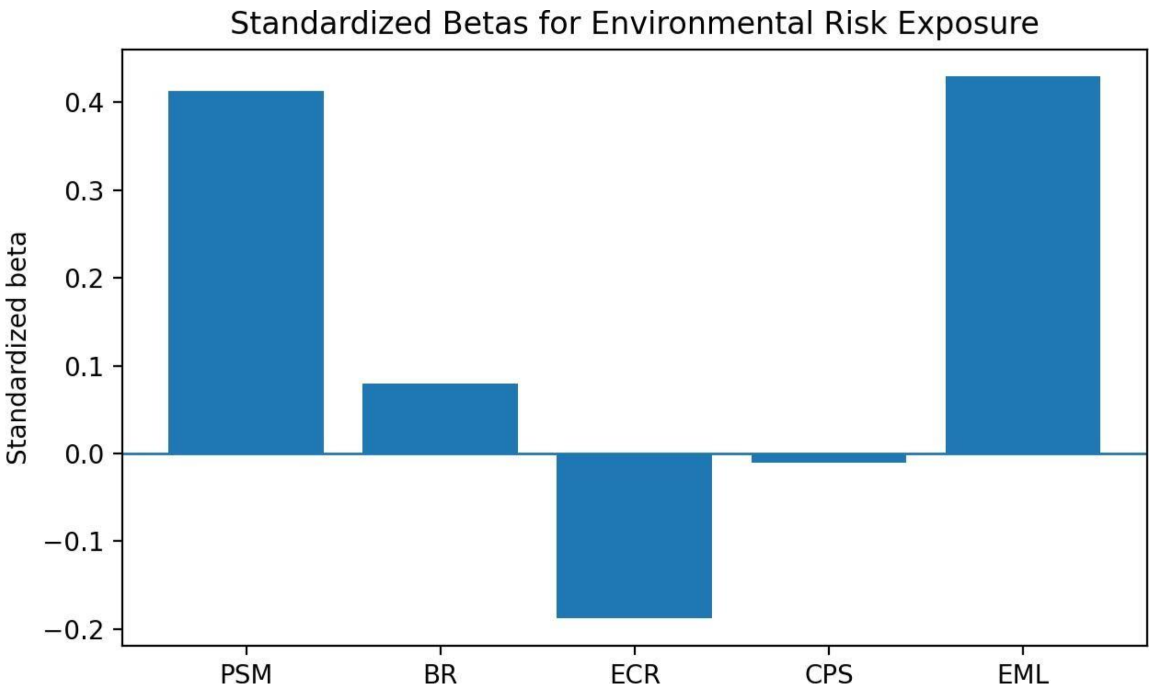
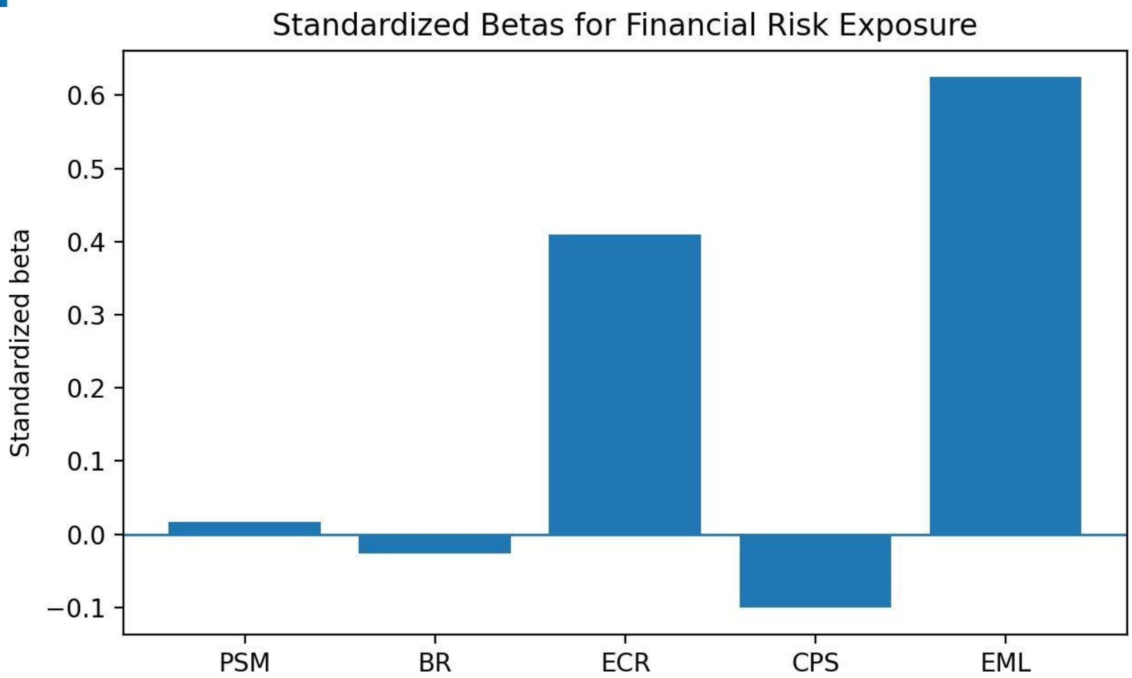


Figure B3. Regression Coefficients for Financial Risk Exposure


Standardized Betas for Financial Risk Exposure
Standardized beta
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
PSM
BR
ECR
CPS
EML