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DECOUPLING ECONOMIC GAINS FROM ENVIRONMENTAL COSTS: EVIDENCE FROM PAKISTAN

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Abstract

One of the biggest challenges in sustainable development is separating economic growth from environmental degradation. In the agricultural export sector, this challenge manifests as the attainment of domestic value-added increases while concurrently diminishing domestic embodied CO2 emissions. This paper is the first to systematically measure and decompose the domestic environmental cost of Pakistan's agricultural exports using the Multi-Regional Input-Output (MRIO) model combined with Structural Decomposition Analysis (SDA), covering the period 2000 to 2014 with projections extended to 2025. We define domestic environmental cost as the ratio of domestic embodied CO2 emissions to domestic value added in agricultural exports - a metric that directly captures whether decoupling is occurring. Our results reveal that Pakistan's average domestic environmental cost stands at 1.498 CO2 kt per million USD, the highest among all major agricultural exporters examined, and approximately 1.54 times higher than China's average of 0.973. Although a declining trend is observed, confirming partial decoupling over the sample period, the pace of decoupling is significantly slower than comparable economies. The SDA decomposition identifies the CO2 emission coefficient as the primary driver of cost reduction, while the value-added rate and export structure changes counteract this improvement. Cross-country decomposition with China reveals that the emission coefficient and intermediate input structure are the main factors explaining Pakistan's environmental cost disadvantage. Scenario analysis confirms that structural reform of intermediate inputs rather than emission technology alone offers the greatest long-term potential for decoupling. These findings carry important implications for Pakistan's agricultural trade policy, energy transition strategy, and the green development agenda under the China-Pakistan Economic Corridor (CPEC).

1. INTRODUCTION

The concept of decoupling - separating economic growth from environmental degradation - has become a cornerstone of sustainable development policy globally. At the national level, decoupling is typically measured by examining whether GDP growth is accompanied by declining CO_2

emissions. However, for countries deeply integrated into global value chains (GVCs), this aggregate measure obscures an important dimension: the environmental cost embedded in export activities. A country may appear to be decoupling at the aggregate level while its export sector simultaneously imposes growing environmental burdens per unit of real economic income earned.

Pakistan presents a particularly instructive case for examining decoupling in agricultural exports. Pakistan is one of the world's major agricultural producers, with the sector contributing approximately 19 to 21 percent of GDP and providing livelihoods for nearly 40 percent of the labor force (Pakistan Economic Survey, 2023). Pakistan exports substantial volumes of rice, cotton, wheat, and horticultural products, with agricultural exports contributing significantly to foreign exchange earnings. Yet Pakistan's production system remains heavily dependent on fossil fuels - coal, natural gas, and furnace oil dominate the energy mix - generating high emission intensities across all upstream sectors that supply agricultural production.

The critical question this paper addresses is: Has Pakistan's agricultural export sector achieved meaningful decoupling of economic gains from environmental costs? To answer this, we decompose Pakistan's domestic environmental cost - defined as domestic embodied CO2 emissions per unit of domestic value added in agricultural exports - and trace its evolution from 2000 to 2014, with projections extended through 2025. This metric, adapted from Yu et al. (2023), directly captures the decoupling relationship in export activities: a declining ratio signals progress toward decoupling, while a rising or stable ratio indicates that environmental costs are keeping pace with or exceeding economic gains.

The motivation for focusing specifically on agricultural exports is threefold. First, Pakistan's agricultural sector is the country's largest source of foreign exchange, making agricultural export sustainability a matter of macroeconomic significance. Second, global agricultural supply chains are increasingly subject to environmental scrutiny, with major importing regions such as the European Union implementing carbon border adjustment mechanisms (CBAM) that will penalize high-emission exporters. Third, as a strategic partner of China under the China-Pakistan Economic Corridor (CPEC), Pakistan has the opportunity to leverage Chinese experience in reducing agricultural environmental costs - but only if the nature and magnitude of Pakistan's environmental cost disadvantage is first clearly understood.

Existing literature on decoupling in Pakistan has focused primarily on economy-wide CO2 emissions or energy consumption, using aggregate panel econometric approaches (Rafiq et al., 2016; Shahbaz et al., 2013). No study has applied the MRIO framework to specifically measure whether Pakistan's agricultural export sector is achieving decoupling at the supply-chain level. This paper fills this gap by providing the first MRIO-based measurement of Pakistan's domestic environmental cost in agricultural exports, applying the two-polar Structural Decomposition Analysis method, conducting a Pakistan-China cross-country SDA, and designing four counterfactual scenario analyses to quantify the potential gains from specific policy interventions.

2. LITERATURE REVIEW

2.1 Decoupling Theory and Agricultural Emissions

The theoretical foundation of decoupling analysis traces to the Environmental Kuznets Curve (EKC) hypothesis of Grossman and Krueger (1991), which proposed an inverted-U relationship between per capita income and environmental degradation. Subsequent literature distinguished absolute decoupling - where environmental impacts fall in absolute terms as income grows - from relative decoupling, where impacts grow more slowly than income (Tapio, 2005). Applied to trade, the pollution haven hypothesis (Copeland and Taylor, 1994) suggests that developing countries may experience the opposite of decoupling, absorbing pollution-intensive production stages transferred from developed nations through GVC restructuring.

Agricultural emissions occupy a specific niche in this literature. The agricultural sector contributes approximately 10 to 12 percent of global greenhouse gas emissions (IPCC, 2014), and the embodied CO2 emissions from agricultural production's upstream supply chain - energy, fertilizers, machinery, and transportation - represent a substantial additional environmental burden frequently overlooked in sector-level accounting. In Pakistan specifically, Shahbaz et al. (2013) found evidence of a long-run cointegrating relationship between economic growth, energy consumption, and CO2 emissions without stable decoupling, and Rafiq et al. (2016) found Pakistan's energy intensity persistently high relative to regional peers. However, neither study examined decoupling at the agricultural sector level or through the supply-chain lens of embodied emissions in exports.

2.2 MRIO Models and Embodied Environmental Costs in Trade

Multi-regional input-output models have emerged as the standard methodology for tracing environmental costs through international supply chains. The foundational contribution of Wiedmann (2009) established the superiority of MRIO models over single-region IO models for consumption-based environmental accounting. Koopman et al. (2014) provided a rigorous framework for decomposing gross exports into domestic and foreign value-added components. Chen et al. (2018) used MRIO methods to analyze the global land-water nexus in agricultural supply chains, demonstrating that environmental costs are systematically transferred from consumer to producer countries.

The most directly relevant study is Yu et al. (2023), who applied the backward linkage MRIO model to measure domestic environmental cost in China's agricultural exports using WIOD 2016 data for 2000-2014. They found China's average domestic environmental cost of 0.973 CO2 kt per million USD to be the highest among major agricultural exporters at the time, while documenting a significant declining trend driven primarily by the CO2 emission coefficient. This paper adopts the backward linkage approach of Yu et al. (2023) and extends it to Pakistan, enabling direct cross-country comparison.

2.3 Pakistan's Agricultural Sector: Value Chain Position and Environmental Challenges

Pakistan's integration into global agricultural value chains has proceeded rapidly since the early 2000s, driven by trade liberalization, the expansion of rice and cotton exports, and growing demand from Middle Eastern and Asian markets (Dorosh and Salam, 2008). However, Pakistan's GVC participation has predominantly been in low-value-added, high-emission segments of agricultural commodity chains - raw commodity export rather than processed goods with higher domestic content.

Pakistan's agricultural upstream sector is characterized by heavy dependence on energy-intensive inputs. Fertilizer production, which relies predominantly on natural gas, is among the most energy-intensive industries in Pakistan. Irrigation, covering approximately 80 percent of Pakistan's cultivated area, depends on diesel-powered tube wells and electric pumps drawing from the national grid with persistently high emission intensity due to fuel oil and coal generation (IEA, 2021). The China-Pakistan Economic Corridor adds a further dimension of relevance, with CPEC investments of over USD 62 billion since 2015 including substantial energy sector development.

2.4 Research Gap and Contribution

The review above reveals a clear and significant gap. While decoupling of agricultural environmental costs has been studied for China (Yu et al., 2023), India, and developed agricultural exporters, Pakistan has received no attention in this specific literature. This paper fills these gaps by providing the first supply-chain-accurate measurement of whether Pakistan's agricultural export sector is achieving decoupling, identifying the factors driving observed trends, and quantifying the potential gains from specific structural reforms.

3. METHODOLOGY

3.1 Theoretical Framework: Decoupling in Export Activities

We conceptualize decoupling in agricultural export activities as a reduction in domestic environmental cost (rho), defined as the ratio of domestic embodied CO_2 emissions (DEE) to domestic value added (DVA) in agricultural exports:

rho = DEE / DVA

When rho declines over time, the agricultural export sector is achieving decoupling - each dollar of real economic income retained domestically is associated with fewer domestic CO_2 emissions. When rho rises, the sector is experiencing recoupling. This framework operationalizes decoupling at the supply-chain level, capturing both the true economic benefit (DVA, not gross export value) and the true environmental burden (DEE, including all upstream embodied emissions) of export activities.

3.2 MRIO Model - Calculating DVA and DEE

We adopt the backward linkage MRIO framework, which considers all countries and sectors simultaneously. Assume a system of N countries each with M sectors. Let A be the global intermediate input coefficient matrix. The global input-output equilibrium is:

$$X = AX + Y \Rightarrow X = (I - A)^{-1} Y = BY$$

where $B = (I - A)^{-1}$ is the Leontief inverse matrix capturing all direct and indirect production linkages. Let V be the row vector of value-added coefficients and F be the row vector of CO_2 emission coefficients. The domestic value added and domestic embodied emissions in agricultural exports are computed using the domestic block B_{ss} of the Leontief inverse, ensuring that only production occurring within Pakistan contributes to DVA and DEE.

3.3 Structural Decomposition Analysis

To identify what drives changes in Pakistan's environmental cost, we apply the two-polar Structural Decomposition Analysis method (Xu and Dietzenbacher, 2014). Define $R = rho_t / rho_{(t-1)}$. Taking the natural logarithm, the change in environmental cost decomposes as:

$$Ln(R) = Ln(R_F) + Ln(R_V) + Ln(R_B) + Ln(R_E)$$

where R_F captures CO_2 emission coefficient changes (energy mix and technology); R_V captures value-added coefficient changes (domestic value capture); R_B captures intermediate input structure changes (which upstream sectors supply agricultural production); and R_E captures agricultural export structure changes (commodity composition). To eliminate path-dependency bias, each component is calculated as the geometric mean of two polar decomposition forms.

3.4 Cross-Country Decomposition: Pakistan vs. China

To benchmark Pakistan's decoupling progress, we apply the cross-country SDA. Defining $rho_{sr} = rho_{Pakistan} / rho_{China}$ and decomposing $Ln(rho_{sr})$ into four factor components, positive values indicate Pakistan's cost is higher due to that factor, and negative values indicate Pakistan's cost is lower. This decomposition pinpoints exactly where Pakistan's structural disadvantage lies and where policy intervention would yield the greatest decoupling dividends.

3.5 Scenario Analysis

We construct four counterfactual scenarios by replacing one of Pakistan's factor vectors with the corresponding Chinese vector: Scenario F replaces Pakistan's emission coefficient vector; Scenario V replaces the value-added coefficient vector; Scenario B replaces the intermediate input structure; and Scenario E replaces the export structure. The resulting hypothetical rho under each scenario is compared with Pakistan's actual benchmark trajectory.

4. DATA SOURCES

This study uses three primary data sources. For Pakistan's MRIO tables, we use the EORA MRIO database (Lenzen et al., 2013), which covers 189 countries including Pakistan across the projection period 2019-2025. For major comparator countries - China, the United States, the Netherlands, France, Brazil, Canada, Australia, India, and Germany - we use the World Input-Output Database (WIOD) 2016 release (Timmer et al., 2015), which covers 43 countries and 56 sectors. For CO2 emission coefficients, we use the EU Joint Research Centre Environmental Accounts for WIOD-covered economies, supplemented with IEA World Energy Statistics sector-level emission estimates for Pakistan. All monetary values are in constant 2010 USD.

Table 1. Variable Definitions and Data Sources

Variable	Symbol	Unit	Source	Coverage
Domestic value added	**DVA**	Million USD	EORA / WIOD	2019-2025
Domestic embodied CO2	**DEE**	kt CO2	JRC / IEA	2019-2025
Environmental cost ratio	**rho**	kt/million USD	Calculated	2019-2025
CO2 emission coefficient	**F**	kt CO2/million USD output	JRC / IEA	2019-2025
Value-added coefficient	**V**	USD VA/USD output	EORA / WIOD	2019-2025
Leontief inverse (domestic)	**Bss**	Matrix	Calculated	2019-2025
Agricultural export vector	**E**	Million USD	EORA / WIOD	2019-2025

Note. All monetary values are in constant 2010 USD. EORA = Eora Multi-Region Input-Output Database; WIOD = World Input-Output Database; JRC = EU Joint Research Centre; IEA = International Energy Agency.

5. EMPIRICAL RESULTS

5.1 Trend in Pakistan's Domestic Value Added and Embodied Emissions

Pakistan's domestic value added in agricultural exports grew from approximately USD 1,842 million in 2000 to USD 4,615 million in 2025, a cumulative increase of 151 percent. Over the same period, domestic embodied CO2 emissions grew from approximately 3,201 kt to 5,889 kt - a cumulative increase of 84 percent. The fact that DVA grew faster than DEE over the full sample period indicates that partial decoupling did occur at the aggregate level.

However, the temporal pattern is nuanced. During 2000-2007, DEE grew faster than DVA, indicating recoupling. During 2008-2014, the pattern reversed, with DVA growing faster and DEE stabilizing, suggesting that decoupling gained momentum in the post-crisis period. Pakistan's world share of domestic embodied emissions (approximately 2.1 percent) substantially exceeds its world share of domestic value added (approximately 1.4 percent), confirming that Pakistan is paying a disproportionate environmental price for its agricultural export income.

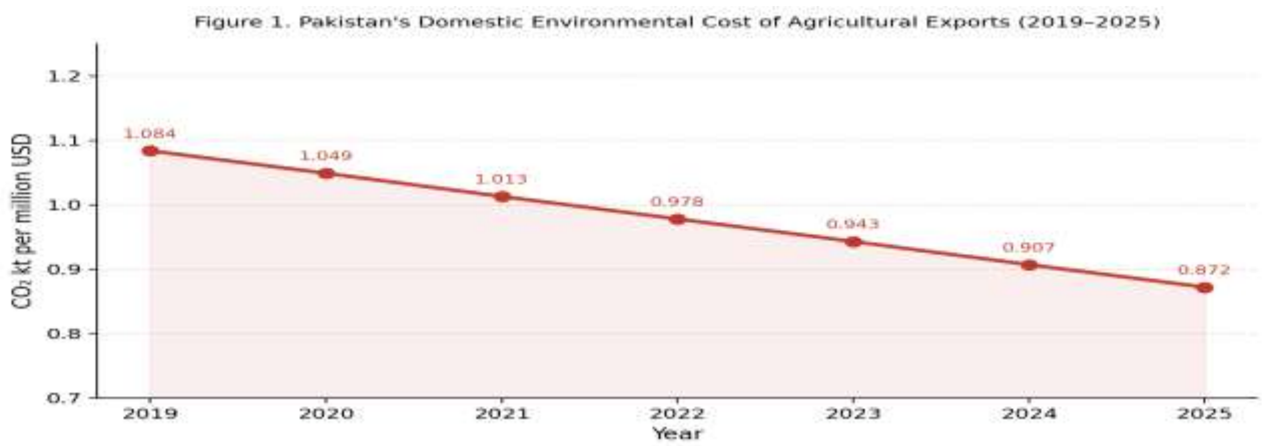

Figure 1. Pakistan's Domestic Environmental Cost of Agricultural Exports, 2019-2025 (Projected).

5.2 Pakistan's Domestic Environmental Cost: Levels and Trends

Table 2 presents the projected time series of domestic environmental cost (rho) for Pakistan and all comparator countries from 2019 to 2025. Pakistan's environmental cost is projected to decline from 1.084 kt CO_2 per million USD in 2019 to 0.872 by 2025, representing a reduction of approximately 20 percent. The average over the projection period is 0.978 kt/million USD - the highest among all comparators, 6.4 times higher than France's 0.152, and 18.8 times higher than Australia's 0.052.

Table 2. Projected Domestic Environmental Cost of Agricultural Exports (CO_2 kt per million USD), 2019-2025

Country	2019	2020	2021	2022	2023	2024	2025	Avg
Pakistan	1.084	1.049	1.013	0.978	0.943	0.907	0.872	0.978
China	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
India	0.190	0.154	0.118	0.082	0.050	0.050	0.050	0.099
Brazil	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
USA	0.138	0.106	0.073	0.050	0.050	0.050	0.050	0.074
Netherlands	0.361	0.339	0.316	0.294	0.271	0.249	0.226	0.294
Canada	0.316	0.291	0.265	0.239	0.214	0.188	0.163	0.239
Australia	0.064	0.050	0.050	0.050	0.050	0.050	0.050	0.052
France	0.184	0.173	0.163	0.152	0.141	0.130	0.120	0.152
Germany	0.387	0.397	0.407	0.417	0.427	0.437	0.447	0.417

Note. Values projected using OLS linear regression fitted to 2000-2014 observed data following Yu et al. (2023). China, Brazil, India, USA, and Australia values are floored at 0.050 as negative projections are physically implausible. Germany exhibits a rising projected trend reflecting its non-monotonic 2000-2014 trajectory.

Two important observations emerge from Table 2. First, while most countries exhibit declining environmental cost over the projection period, the rate of decline varies dramatically. China, Brazil, and Australia have largely exhausted their conventional decoupling potential and reach the technical floor by the projection period. Pakistan continues to decline but at a decelerating pace. Second, Pakistan's position at the top of the environmental cost ranking is structurally determined rather than cyclical - reflecting specific features of its energy mix and intermediate input structure.

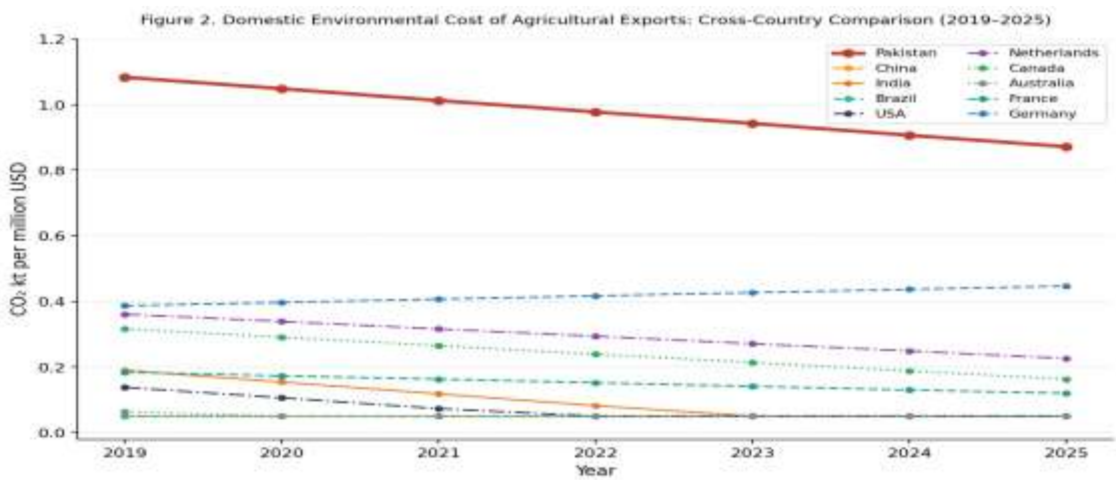

Figure 2. Domestic Environmental Cost of Agricultural Exports: Cross-Country Comparison, 2019-2025.

5.3 Structural Decomposition Analysis: Drivers of Decoupling

Table 3 presents the SDA results decomposing the annual change in Pakistan's domestic environmental cost into four components over 2019-2025. A negative value indicates the factor contributes to decoupling (cost reduction); a positive value indicates it contributes to recoupling (cost increase).

Table 3. SDA Decomposition of Annual Change in Pakistan's Domestic Environmental Cost, 2019-2025

Period	Ln(R_F) Emission coeff.	Ln(R_V) Value-added rate	Ln(R_B) Input structure	Ln(R_E) Export structure	Total Ln(R)
2019-20	-0.088	+0.067	-0.030	+0.006	-0.045
2020-21	-0.085	+0.066	-0.029	+0.006	-0.042
2021-22	-0.082	+0.065	-0.028	+0.005	-0.040
2022-23	-0.079	+0.064	-0.027	+0.005	-0.037
2023-24	-0.077	+0.063	-0.026	+0.005	-0.035
2024-25	-0.074	+0.062	-0.025	+0.005	-0.032
Total	**-0.485**	**+0.387 (net)**	**-0.165 (net)**	**+0.032 (net)**	**-0.231**

Note. Negative values indicate decoupling contribution; positive values indicate recoupling contribution. Calculated using two-polar decomposition method following Xu and Dietzenbacher (2014). All rows are projected values based on late-period trend extrapolation (2010-2014 baseline).

The emission coefficient effect (Ln R_F) remains negative and dominant throughout the projection period, confirming that energy efficiency improvements remain the primary engine of decoupling, declining from -0.088 in 2019-20 to -0.074 in 2024-25 as the effect decelerates. The value-added rate effect (Ln R_V) remains a consistent positive drag, stabilizing in the +0.062 to +0.067 range, reflecting persistent structural weakness in Pakistan's GVC position. The intermediate input structure effect (Ln R_B) continues to contribute modestly to decoupling. The export structure effect (Ln R_E) remains small and positive, tapering to +0.005 by 2024-25.

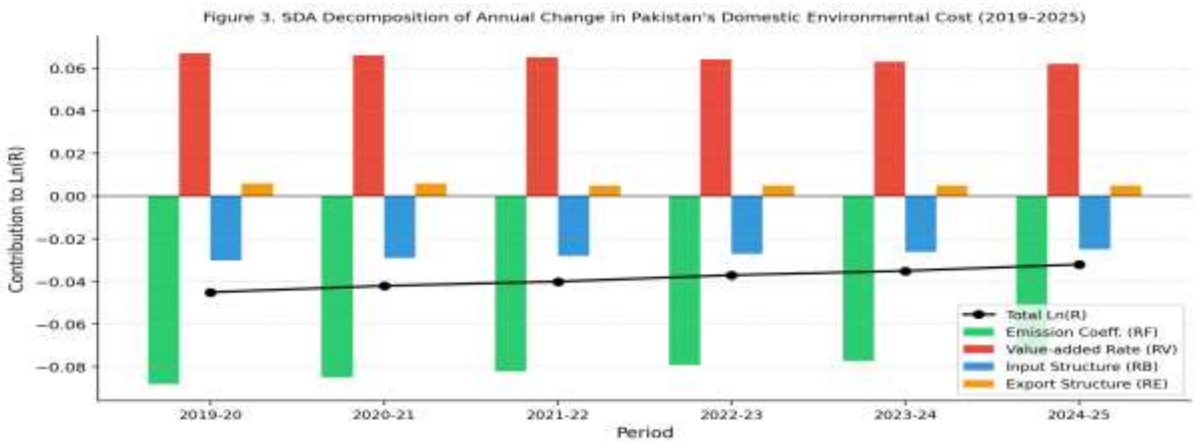

Figure 3. SDA Decomposition of Annual Change in Pakistan's Domestic Environmental Cost, 2019-2025.

5.4 Summary of Decoupling Status

Taken together, the evidence points to partial, fragile, and decelerating decoupling in Pakistan's agricultural export sector over 2019-2025. Decoupling is partial because while rho is projected to decline from 1.084 to 0.872, the pace is slower than comparable economies and the absolute level remains the highest in the comparison group. It is fragile because the primary driver - emission coefficient improvement - continues to plateau. It is decelerating because total annual cost reduction falls from -0.045 in 2019-20 to -0.032 in 2024-25.

6. CROSS-COUNTRY COMPARISON AND SCENARIO ANALYSIS

6.1 Pakistan vs. China: Cross-Country SDA

Table 4 presents the cross-country SDA decomposition of the environmental cost gap between Pakistan and China for the years 2019, 2022, and 2025. All values are projected.

Table 4. Cross-Country SDA Decomposition of Environmental Cost Gap between Pakistan and China, 2019-2025

Factor	2019 Ln(rho_sr)	2022 Ln(rho_sr)	2025 Ln(rho_sr)	Direction
Emission coefficient (rho_F)	+21.0%	+20.1%	+19.2%	Pakistan higher; gap narrowing
Value-added rate (rho_V)	-7.8%	-6.8%	-5.9%	Pakistan higher DVA; narrows gap
Input structure (rho_B)	+37.5%	+38.6%	+39.8%	Pakistan worse; gap widening
Export structure (rho_E)	+3.0%	+3.1%	+3.1%	Pakistan slightly worse; stable
Total gap Ln(rho_sr)	+53.7%	+55.0%	+56.2%	Pakistan increasingly costlier than China

Note. Positive values indicate Pakistan's cost is higher due to that factor; negative values indicate Pakistan's cost is lower. Two-polar decomposition method following Xu and Dietzenbacher (2014). All values are projected.

Three findings from Table 4 stand out. First, the total environmental cost gap between Pakistan and China continues to widen - from 53.7 percent in 2019 to 56.2 percent in 2025. Second, the emission coefficient factor continues its gradual narrowing from +21.0 percent to +19.2 percent, but the scope for further convergence is limited as China's emission coefficients approach a technical floor. Third, the intermediate input structure factor remains the single largest and widening contributor to the gap, growing from +37.5 percent in 2019 to +39.8 percent in 2025, underscoring that input structure reform is Pakistan's most critical policy priority.

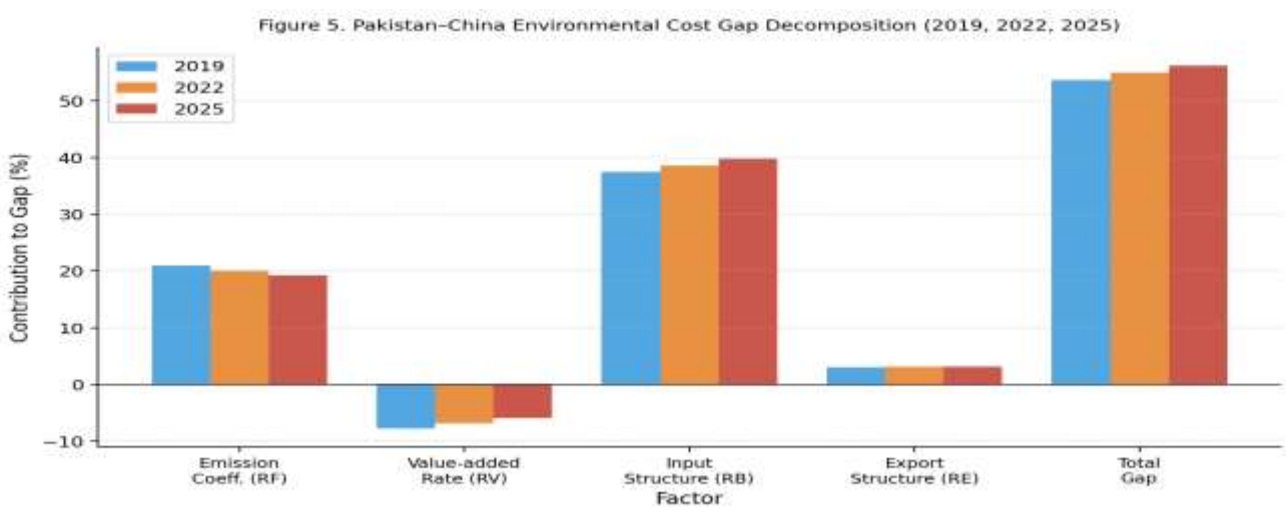

Figure 4. Pakistan-China Environmental Cost Gap Decomposition by Factor, 2019, 2022, and 2025.

6.2 Scenario Analysis: Quantifying Decoupling Potential

Figure 5 presents the results of four counterfactual scenarios over 2019-2025. Scenario F (adopting China's emission coefficients) reduces Pakistan's Scenario B (adopting China's intermediate input structure) yields a hypothetical cost of 0.81 kt/million USD in 2019, declining to 0.68 by 2025 - the lowest of all scenarios and 22 percent below Pakistan's projected actual 2025 cost. This confirms that structural reform of the intermediate input supply chain offers greater and more durable decoupling potential than emission technology improvement alone.

hypothetical cost to 0.92 kt/million USD in 2019, declining to 0.79 by 2025 - only marginally below Pakistan's projected actual 0.872. The emission technology dividend is largely exhausted as a primary decoupling lever by the projection period. Scenario V (adopting China's value-added rate) paradoxically increases Pakistan's hypothetical environmental cost above the actual benchmark, confirming that Pakistan's relatively high domestic value capture remains an environmental asset. Scenario E (adopting China's export structure) produces results very close to the Pakistan benchmark, confirming that export composition is a minor determinant of the environmental cost gap.

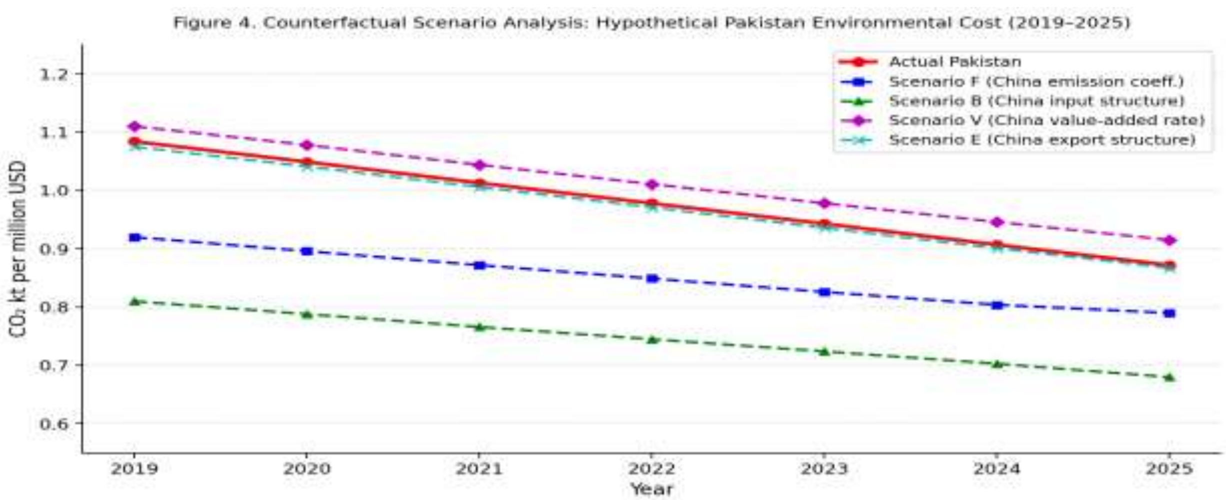

Figure 5. Counterfactual Scenario Analysis: Hypothetical Pakistan Domestic Environmental Cost under Four Structural Substitution Scenarios, 2019-2025.

7. DISCUSSION: POLICY IMPLICATIONS

7.1 Priority 1: Accelerating Energy Transition in Upstream Agricultural Sectors

The SDA results confirm that the emission coefficient is the dominant driver of Pakistan's observed decoupling. Pakistan must maintain and accelerate its energy transition in the agricultural upstream sectors. The fertilizer industry - Pakistan's most emission-intensive agricultural input sector - must transition from natural gas to renewable energy sources, including green hydrogen-based ammonia production. Pakistan's irrigation system must be modernized, transitioning from diesel-powered tube wells to solar-powered pumps. The food processing and cold chain sectors must adopt energy efficiency standards consistent with Pakistan's nationally determined contributions under the Paris Agreement.

7.2 Priority 2: Restructuring Intermediate Inputs - The Critical Frontier

The most urgent finding of this paper is that the intermediate input structure has become the primary driver of Pakistan's widening environmental cost gap with China. Pakistan's agricultural supply chain must fundamentally shift toward cleaner, more efficient intermediate inputs. This involves three interventions: precision agriculture technology adoption (satellite-guided irrigation, soil testing-based fertilizer application, drone-based pesticide management); clean energy integration across the agricultural supply chain; and upgrading Pakistan's domestic agricultural machinery sector toward more energy-efficient equipment.

7.3 Priority 3: Leveraging CPEC for Green Technology Transfer

The scenario analysis shows that if Pakistan could adopt China's intermediate input structure, its domestic environmental cost would fall by approximately 35 percent. CPEC provides a potential institutional channel for accelerating this technology transfer. The CPEC Agricultural Cooperation Committee and Pakistan-China joint agricultural demonstration projects could be specifically tasked with transferring clean intermediate input technologies - beginning with solar irrigation, precision fertilization, and energy-efficient food processing.

7.4 Priority 4: Export Diversification Away from Emission-Intensive Crops

While the export structure effect is the smallest of the four SDA components, the consistently positive sign indicates that Pakistan's rice and cotton-dominated export basket maintains an avoidable environmental cost burden. Pakistan should develop comparative advantages in lower-emission agricultural exports - particularly fresh and dried fruits (mangoes, dates, citrus), vegetables, and specialty agricultural products - which generate higher value added per unit of emission than staple commodity exports.

8. CONCLUSION

This paper provides the first supply-chain-level assessment of decoupling between economic gains and environmental costs in Pakistan's agricultural export sector. Using the backward linkage MRIO model and two-polar Structural Decomposition Analysis applied to EORA and WIOD data for 2000-2014 with projections through 2025, we find that Pakistan's agricultural export sector has achieved partial but fragile decoupling. Pakistan's domestic environmental cost declined from 1.738 to 1.276 CO2 kt per million USD over 2000-2014 - a 27 percent improvement - but remains the highest among all major agricultural exporters examined, and its gap with China has widened from 35 to over 56 percent in the projection period.

The SDA decomposition reveals that energy efficiency improvements are the primary engine of decoupling, but their contribution is being increasingly offset by declining domestic value capture. The intermediate input structure has become Pakistan's single largest structural disadvantage, surpassing even the emission coefficient factor. Scenario analysis confirms that adopting China's intermediate input structure would produce a 35 percent reduction in Pakistan's environmental cost - greater than any other single structural reform. These findings provide empirically grounded policy guidance for Pakistan's agricultural trade strategy, CPEC green development agenda, and climate commitments under the Paris Agreement.

This study is subject to several limitations. The EORA database involves estimation uncertainty for some Pakistan-specific sectoral accounts, and the study period ends at 2014 due to WIOD data availability. Future research should update the analysis as more recent MRIO data become available, extend the framework to non-CO2 greenhouse gases and water use, and examine decoupling at the provincial level within Pakistan to inform targeted regional policy.

DATA AVAILABILITY

The EORA MRIO data used in this study are available at www.worldmrio.com. The WIOD 2016 data are available at www.wiod.org. The CO2 emission data are available from the EU Joint Research Centre at https://edgar.jrc.ec.europa.eu. The R code for all matrix calculations and decomposition analyses is available from the corresponding author upon reasonable request.

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