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Assessing the Synergistic Effects of Export Diversification on Energy Efficiency in South Asia

ABSTRACT

This study examines the determinants of CO_2 intensity in South Asian economies (except Afghanistan) from 2004 to 2023 using System GMM and Kinky Least Squares (KLS) estimation techniques. The analysis explores the impact of foreign direct investment (FDI), GDP growth, trade openness, and export diversification on carbon emissions intensity. The System GMM results suggest that FDI and export diversification significantly reduce CO_2 intensity, supporting the pollution halo hypothesis and structural transformation arguments. However, the KLS model, that is used to address the issue of weak instruments, presents contrasting findings, particularly on export diversification, indicating potential non-linear effects. The study highlights the importance of methodological choices in environmental econometrics and provides policy insights for sustainable development in South Asia. While GDP growth and trade openness show weaker statistical significance, the persistence of CO_2 intensity (captured by the lagged dependent variable) underscores the need for long-term decarburization strategies. The findings contribute to the ongoing debate on economic growth versus environmental sustainability in emerging economies.

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1. INTRODUCTION

The relationship between export diversification and energy efficiency represents a critical yet under-explored dimension of sustainable development in South Asia, where rapid economic expansion continues to strain energy systems and exacerbate environmental degradation. As the region grapples with energy intensity levels that persistently exceed global averages (Murshed, 2018), policymakers face mounting pressure to reconcile economic growth with climate commitments, creating an urgent need to understand how strategic economic and financial interventions can jointly enhance energy performance. The theoretical foundations of this inquiry draw from multiple strands of economic and environmental literature, beginning with the diversification-innovation nexus articulated in endogenous growth theory (Romer, 1990), which posits that diversified export structures facilitate knowledge spillovers and technological upgrading. Can et al. (2021) recently extended the framework for energy systems, who explain how export diversification in developing countries incentivizes the use of energy-efficient production systems due to stiff competition and access to modern technologies. At the same time, green finance has emerged as a field establishing clear relationships between sustainable financial products and their environmental impacts. Iqbal et al. (2023) showed how specially designed financial policies can assist in overcoming capital constraints to energy efficiency investments in emerging markets.

Distinctive pattern of South Asia's development makes it an important region to consider at how these factors interplay. South Asia still depends upon fossil fuels for more than 75% of its primary energy sources (IEA, 2023), yet it has already started diversifying its exports. For example, countries like India is making real progress by diversifying their exports beyond traditional goods (Ali & Memon, 2019), and Bangladesh is utilizing new ideas to finance green projects (Kumar et al., 2024), but still the gap exists especially in South Asian region in suggesting that diversifying exports may affect positively to energy efficiency. Although there is increasing evidence from other areas that suggest that diversifying exports may strengthen energy efficiency, for example, Rehman et al. (2023) using BRICS found that export diversification initially reduces renewable energy use but eventually promotes it as countries gain comparative advantage. This study aims to fill this important gap in knowledge by looking closely at how these two policy levers work together in South Asia's unique institutional and economic setting, where old energy infrastructure, limited access to financial markets, and a high concentration of exports make it both hard and easy to make the switch to sustainable energy.

A new methodical framework is used to analyze the function of export diversification in improving energy efficiency. It builds on recent methodological advances in energy economics, such as Hu et al.'s (2020) use of synergistic effect models and Qudrat-Ullah (2023) development of threshold analysis techniques. The study is especially timely because the region's climate vulnerabilities are getting worse and there is an urgent need for policy solutions that are based on evidence and can improve both the economy and the environment at the same time. The study's goal is to give policymakers useful information on how to best use their resources between export promotions to get the most energy efficiency gains by looking at whether and how these two strategies make each other more effective. Additionally, the analysis advances practical knowledge of how developing economies can use financial innovation to accelerate sustainable energy transitions in line with both national development priorities and global climate objectives, while also contributing to theoretical discussions about the circumstances under which economic diversification strategies yield environmental co-benefits.

While previous studies have advanced our understanding of export diversification's role in sustainable development, much less is known about how it interacts with other factors to enhance energy efficiency. There may be interaction effects, as suggested by emerging research from other regional contexts. For example, the analysis on East Asian economies of Ulucak (2020) suggested that financial policy interventions can substantively enhance the positive environmental externalities

originated from trade diversification, suggesting possible complementarity mechanisms running between economic domains. Nevertheless, the inherent structural features of South Asian economies — such as policy fragmentation, financial market underdevelopment and a path-dependent energy sector — may alter these dynamic interactions in a manner that calls for further investigation into their region-specific nature.

This study thus attempts to fill this crucial knowledge void by conducting a thorough empirical investigation of the case in South Asia (all countries except Afghanistan) for the period ranging from 2004 up to 2023; incorporating state-of-the-art panel data econometric tools that also incorporate South Asian issues like endogeneity using system GMM and Kinkly least square method. The analysis will systematically evaluate three key dimensions: first, the individual marginal effects of export diversification on energy efficiency metrics; second, the nature and magnitude of its interactive relationship (whether complementary, substitutive, or neutral); and third, the policy implications of these findings for sustainable energy transitions in developing economy contexts.

By establishing empirical evidence for these relationships within South Asia's distinctive institutional environment, this research makes three substantive contributions to the literature: it advances theoretical understanding of the trade-environment nexus in development economics, extends methodological approaches to analyzing complex policy interactions in energy systems, and provides actionable insights for policymakers seeking to optimize the trade for enhanced energy efficiency outcomes. These insights are especially relevant for South Asian governments grappling simultaneously with economic transitions and climate commitments, providing country-specific evidence on how policy synergies across export diversification policies could drive shared value creation through rapid progress in the attainment of sustainable development goals while ensuring sustained economic competitiveness.

2. LITERATURE REVIEW

The literature on sustainability, trade policy and environmental economics has largely explored the relationship between export diversification (EDIV) and Carbon Intensity (CI). As nations seek to balance economic aspirations with environmental sustainability, understanding how export structures influence carbon emissions is of critical importance. This literature review brings together existing theories and empirical evidence on the relationships between EDIV and CI with a focus on key mechanisms, regional differences, and policy implications.

There is a de facto consensus that export diversification stimulates industrial upgrading and creates economic resilience (Hesse, 2008). In macroeconomic terms, diversified export patterns lead to a structural change in the trading profile towards cleaner manufacturing and services at the expense of carbon heavy industries (as primary commodities and fossil fuels). Hesse (2008), identified that the CI was negatively related to EDIV, higher in economies with higher EDIV because they were more efficient in their production and therefore needed less volatile energy. This is particularly evident in countries that change from being exporters of almost exclusively raw materials to exporting high value added, product-intensive manufactures.

Technological spillovers from international trade serve to strengthen this relationship. According to Adom et al. (2022), there is a considerable influence of international markets, particularly on energy-efficient technologies uptake in developing nations. In their research focusing on sub-Saharan Africa, they show that EDIV has a CI effect by supporting the use of cleaner industrial processes and diminishing dependency on carbon-intensive energy sources. Can et al. (2021) also discover that export diversified economies suffer less diffusion of green technologies leading to less CI in manufacturing.

EDIV also elicits competition at the firm level to support increased energy efficiency. Cadot et al. (2015) for enterprise-level data in developing economies find the export-oriented firms systematically

decrease CI to satisfy international environmental standards. This work also exposes how being part of an international market pushes businesses to use low-carbon production systems, resulting in the reduction of their global CI.

Nonetheless, for some sectors, this relationship is stronger than others. Ali and Memon (2019) and South Asian economies, observe that EDIV decreases CI in the manufacturing category but with weaker results than agriculture and extractive industries. This indicates that the environmental benefits of EDIV are highly dependent on their economic structure.

Due to the differences in institutional quality, or policy frameworks and industrial structure, EDIV does not have the same effect across regions. Qudrat-Ullah (2023) claim that in the South Asian region, no stringent policies relevant to environmental protection and infrastructural bottlenecks dock the potential of EDIV to decrease CI. Their study emphasizes that without strong governance, EDIV may merely shift carbon emissions rather than reduce them.

In contrast, East Asian economies exhibit stronger EDIV-CI linkages due to better policy coordination and technological absorption capacity (Ulucak, 2020). Chen et al. (2023) further identify threshold effects, where the combination of EDIV and robust green finance mechanisms leads to disproportionately large reductions in CI. This suggests that EDIV alone is insufficient; complementary policies are needed to maximize its environmental benefits.

Despite growing evidence, critical gaps remain. First, most studies focus on developed or rapidly industrializing economies, leaving South Asia underrepresented (World Bank, 2022). Second, the interaction between EDIV and institutional quality requires deeper empirical investigation (Rashid, 2025). Finally, the role of sectoral heterogeneity in shaping EDIV-CI dynamics remains under-explored. A detail findings for developing countries with respect to different economic indicators are discussed in (Akbar et al., 2024(a); Akbar et al., 2024(b); Ali et al., 2024; Raza et al., 2024; Sana et al., 2024; Khan et al., 2023; Raza et al., 2021(a); Raza et al., 2021(b)).

This study contributes by: (1) analyzing EDIV's impact on CI in South Asia, (2) assessing how institutional quality moderates this relationship, and (3) providing policy recommendations for leveraging EDIV in decarbonization strategies.

3. DATA AND METHODOLOGY

This research employs an econometric model to analyze the interplay between foreign direct investment (FDI), trade openness (TO), gross domestic product (GDP), export diversification (EDIV), and carbon intensity (CI). The baseline specification is given by equation (1) as:

$$CI_{it} = \beta_0 + \beta_1 FDI_{it} + \beta_2 EDIV_{it} + \beta_3 GDP_{it} + \beta_4 TO_{it} + \mu_i + \vartheta_t + \varepsilon_{it} \quad (1)$$

Here, μ_i accounts for country-specific fixed effects, capturing unobserved time-invariant factors that influence the dependent variable. The term ϑ_t represents time-fixed effects, accounting for period-specific shocks that affect all countries uniformly. The residual variation is captured by the error term, $\boldsymbol{\varepsilon_{it}}$, which varies across both countries and time. EDIV is taken from UNCTAD sources while all other variables are taken from world development database (WDI). Descriptive statistics of these variables are given in Table 1.

To address potential endogeneity, we extend the analysis beyond standard Fixed Effects (FE) and Random Effects (RE) models by incorporating the System GMM estimator and Kiviet's (2020) correction method. This leads to a dynamic model specification depicted as equation (2):

$$CI_{it} = \gamma_0 + \gamma_1 CI_{it-1} + \gamma_2 FDI_{it} + \gamma_3 EDIV_{it} + \gamma_4 GDP_{it} + \gamma_5 TO_{it} + \epsilon_{it} \quad (2)$$

Unlike conventional time-series analysis, our study utilizes panel data techniques to explore the dynamic linkages among FDI, GDP, TO, EDIV, and CI. By leveraging both cross-country and temporal variations, we mitigate unobserved heterogeneity and enhance estimation precision. To ensure robustness, we apply three distinct econometric approaches. The choice of econometric methodology are comprehensively discussed in (Akbar et al., 2024(c); Akbar et al., 2023; Waheed et al., 2021; Akbar et al., 2019; Hussan et al., 2019). Methodology selection of system GMM and Kinky least square (KLS) is done based on the following criteria:

Table 1: Comparison between System GMM and Kinky Least Square (KLS) estimations

Features	**System GMM**	**Kinky Least Square (KLS)**
Motive	Estimates dynamic panel models with endogenous regressors	- Estimates piecewise linear models with a structural break - Handles weak or potentially invalid instruments in IV settings
Data Setting	Panel data: large N, small T (many cross-sections, few time periods)	Cross-section or panel data where IV/2SLS struggles
Treatment of Endogeneity	Uses lagged variables as internal instruments	Allows instruments to be correlated with error up to a "kink" bound
Estimator Type	Point estimates (single coefficient values)	Interval estimates (bounds instead of exact values)
Validity	- Deals with endogeneity, autocorrelation, heteroscedasticity - Widely accepted in applied economics - Strong software support	- Robust to weak instruments - Provides sensitivity analysis - Relaxes strict exogeneity assumption
Deficiencies	- Instrument proliferation can bias results - Weak instruments if variables are persistent - Requires strong assumptions about error structure	- Less common in applied work - Harder interpretation (intervals) - Requires subjective kink parameter choice
Usage	- Dynamic models with lagged dependent variables - When valid internal instruments exist - Standard for growth, finance, and development studies	- When instruments are weak or possibly invalid - As a robustness check to System GMM or 2SLS results - When testing sensitivity to exogeneity assumptions
Output Display	Coefficient estimates + diagnostics (Hansen test, AR(2) test)	Bounds/intervals for coefficients depending on kink restriction

Source: Table extracted from Arellano and Bover (1995), Andrews and Armsrong (2017).

4. ANALYSIS AND RESULTS

The regression results, Table 2, from the Fixed Effects (FEM) and Random Effects (REM) models present a consistent picture of the factors influencing CO_2 intensity, with both approaches yielding remarkably similar coefficient estimates and significance patterns. The near-identical results across the two specifications suggest that the unobserved heterogeneity in the data may be largely uncorrelated with the explanatory variables, making both models appropriate for this analysis. The key variables - FDI, GDP, TO, and EDIV - all show statistically significant relationships with CO_2 intensity, with coefficients generally aligning in direction and magnitude between the two models. FDI demonstrates a small but statistically significant negative effect on CO_2 intensity in both specifications, with coefficients of -0.039 in FEM and -0.042 in REM, both significant at the 5% level. This consistent finding across models suggests that FDI inflows are associated with modest

reductions in emissions intensity, possibly through technology transfer or the adoption of cleaner production methods by foreign-affiliated firms. GDP shows a negative and significant relationship with CO_2 intensity in both models, though the coefficient magnitude differs substantially (-0.0101 in FEM versus -0.0421 in REM). This discrepancy might reflect how the fixed effects specification accounts for country-specific time-invariant factors that influence both economic growth and emissions patterns. Both coefficients are statistically significant at the 5% level, confirming that economic development generally correlates with lower emissions intensity, though the exact magnitude of this effect depends on model specification.

Trade openness exhibits a negative and statistically significant (at 10% level) association with CO_2 intensity in both models, with coefficients of -0.002 in FEM and -0.001 in REM. The slightly larger magnitude in the fixed effects specification might suggest that within-country changes in trade patterns have a somewhat stronger association with emissions intensity than between-country differences. Export diversification shows the largest and most statistically significant (1% level) negative coefficients across both models (-1.429 in FEM and -1.411 in REM), indicating that more diversified economies tend to have substantially lower CO_2 intensity. The minimal difference between the FEM and REM coefficients for this variable suggests that export structure affects emissions intensity similarly both within countries over time and across different countries.

The overall consistency between FEM and REM results strengthens confidence in the findings, as it suggests the relationships are robust to different modeling assumptions about unobserved heterogeneity. The results collectively point to export diversification as the most powerful explanatory factor among those considered, followed by more modest but consistent effects from FDI, GDP growth, and trade openness.

Table 2: Descriptive Statistics of the Variables

Variable	Obs	Mean	Std. dev.	Min	Max
FDI	133	2.24	3.27	-0.64	16.78
GDP	133	24.67	2.29	20.73	28.72
TO	133	57.38	32.73	24.70	165.98
EDIV	133	0.73	0.11	0.44	0.90
CO2Intensity	133	0.53	0.27	0.16	1.19

Table 3: Estimates of FEM and REM

Variables	FEM	REM
	CO_2 - Intensity	CO_2 - Intensity
FDI	-0.039**	-0.042**
	(0.007)	(0.007)
GDP	-0.0101**	-0.0421**
	(0.001)	(0.011)
TO	-0.002*	-0.001*
	(0.001)	(0.001)
IDIV	-1.429***	-1.411***
	(0.31)	(0.326)
Constant	1.399***	1.355***
	(0.159)	(0.182)
Observations	118	118

The regression results of Table 3 from the System GMM and KLS models present strikingly different patterns in their estimation of CO_2 intensity determinants, highlighting how methodological choices can substantially influence findings. The System GMM approach, which accounts for dynamic endogeneity through instrumented lags, produces results that differ markedly from KLS method, particularly regarding FDI and export diversification effects.

FDI shows a significant negative coefficient (-0.097) at the 10% level in System GMM, suggesting potential emissions-reducing technology transfer effects, while KLS estimates an insignificant positive coefficient (0.001). This stark contrast implies that FDI's environmental impact may be sensitive to model specification - either due to GMM's treatment of endogeneity is some way different as compared to KLS's method. The GDP coefficients are negative in both models (-0.010 in GMM, -0.032 in KLS) but insignificant, indicating no robust relationship between economic growth and emissions intensity once accounting for dynamic effects.

Trade openness coefficients are negative but insignificant in both specifications (-0.0009 in GMM, -0.0002 in KLS), with relatively small magnitudes suggesting minimal independent impact. The most dramatic divergence appears in export diversification effects: System GMM shows a large negative coefficient (-3.161) significant at 5%, potentially indicating strong emissions-reducing structural effects, while KLS paradoxically estimates a significant positive coefficient (0.804). This contradiction likely stems from KLS down weighting influential observations that drive GMM's results, revealing fundamentally different interpretations of how export structure affects emissions. The lagged dependent variable shows puzzling results - insignificant in GMM (0.033) where it should theoretically matter most, while KLS shows near-unit persistence (0.971) despite not being designed for dynamic estimation. The constants are significant but oppositely signed (positive in GMM, negative in KLS), further underscoring the models' divergent baseline assumptions. With 119-126 observations covering 7 cross-sectional units, the sample remains constant enough that these differences primarily reflect methodological variation rather than data coverage issues.

Table 4: Estimates of Two Step System GMM Method and Kinky Least Square Method

Variables	**Sys-GMM**	**Kinky Least Square (KLS)**
	CO_2 - Intensity	**CO_2 - Intensity**
FDI	-0.0971*	0.0012
	0.0449	0.0015
GDP	-0.0101	-0.0321
	0.002	0.0140
TO	-0.0009	-0.0003
	0.0002	0.0001
IDIV	-3.1610**	0.8041***
	1.1356	0.1849
L. CO_2-Intensity	0.0332	0.9707***
	0.3925	0.0293
Constant	2.2803**	-0.3735***
	0.8317	0.0911
Observations	119	126

These results collectively demonstrate that conclusions about emissions drivers depend heavily on modeling choices - particularly regarding how to handle endogeneity. The GMM results would support policies promoting FDI and export diversification for emissions reduction, while the KLS findings would reject such conclusions. This tension suggests the need for deeper diagnostic analysis to determine which specification better captures the true underlying relationships.

Empirical findings based on the System GMM, KLS estimations are in agreement and in contrast with the corpus of knowledge regarding the factors affecting the CO_2 intensity. The pollution halo hypothesis, which hypothesizes that a transfer of cleaner technology in host countries is promoted by multinational corporations, is congruent with System GMM outcome involving significant negative effect of FDI (-0.097*) (Perkins & Neumayer, 2008). The conclusion is even more relevant to the developing countries, where the foreign direct investment has been associated with more energy efficiency and less emissions (Hubler & Keller, 2010). However, the small positive coefficient (0.001) exhibited by the KLS model provides important depths to the research, potentially demonstrating the way FDI changes the role in different sectors and countries (Cole et al., 2017). The hypothesis of the

Environmental Kuznets Curve that economic development will lead to eventual improvement in the environment can be corroborated by only weakly by the negative but insignificant coefficients of GDP in both of the models (Grossman & Krueger, 1995). The insignificance, nevertheless, aligns with the current criticisms that have challenged the universality of the EKC in the backdrop of increasing new disparities in developing countries whereby environmental pressures can cool initially during growth (Kaika & Zervas, 2013).

Being little negative yet insignificant in both models, the results of trade openness provide an interesting twist to part of the ongoing literature so far published. Such relationship might be less universal and perhaps it varies with the comparative advantage and trade structure of a country (Managi et al., 2009), though there are details that trade can affect the intensity of emissions by efficiency growth, as well as diffusion of technology (Frankel & Rose, 2005). The most significant difference is observed in the results of export diversification, where System GMM indicates the strong negative correlation (-3.161), whereas KLS suggests the great positive impact (0.804). Such a difference could represent different underlying mechanisms that each methodology was capable to represent. The KLS result could indicate the possibility that diversification into specially clean industries (such as renewable energy technologies) does more work in reducing emissions than unspecified distribution (Acemoglu et al., 2012), whereas the GMM result aligns with the notion that diversified export structure leads to a more balanced energy consumption and decreased emissions rate (Cadot et al., 2013). The discrepancies in these models underline the importance of considering the general patterns and unique situations in the process of industrial policy-making to lessen emissions.

The findings have important implications to policymakers that need to reduce CO_2 intensity as an economical objective. The results suggest that the export diversification and FDI promotion policy, in general, can contribute to possible declines in the intensity of emissions, albeit significantly dependent on the implementation peculiarities and national conditions. The differences between the findings of the results of the KLS and the GMM remind us that results need to be checked on heavily on sensitivity and a wide range of analytical instruments need to be applied to the policy choices. In order to learn more about the non-linear connections between these economic factors and intensities of emissions and particularly in different types of development, future studies may want to utilize different techniques such as quantile regression (Binder & Coad, 2011). The presented study has shown unequivocally that the intensity of the CO_2 is influenced by economic factors, however, the nature and direction of these associations can substantively differ based on the methodological choices and the particulars and subject to context, making the informed, evidence-based policy formulation a necessity.

5. CONCLUSION AND POLICY IMPLICATIONS

Using System GMM and KLS to account for endogeneity, this study examined the factors influencing CO2 intensity in South Asian economies (except Afghanistan) between 2004 and 2023. The results reveal that FDI has a significant negative effect on emissions intensity in the System GMM model, aligning with the pollution halo hypothesis, which posits that foreign investment facilitates cleaner technology adoption. However, the KLS model's insignificant coefficient suggests that this effect may not be uniform across all economies, possibly due to varying sectoral compositions of FDI inflows.

Export diversification presents the most striking divergence between models: System GMM indicates a strong negative relationship with CO_2 intensity, while KLS shows a positive effect. This contradiction suggests that while diversification generally reduces emissions through balanced energy use, certain highly specialized (but clean) industries may achieve even greater efficiency. GDP growth

and trade openness exhibit weaker and less consistent impacts, implying that economic expansion alone does not guarantee lower emissions intensity without complementary green policies.

The persistence of CO_2 intensity (evident in the lagged dependent variable) highlights the path-dependent nature of emissions, emphasizing the need for sustained policy interventions. For South Asian economies, these findings suggest that attracting environmentally conscious FDI and promoting strategic export diversification could be effective decarburization strategies. However, policymakers should consider contextual factors, as the relationship between economic variables and emissions varies across countries. Future research could explore sector-specific analyses and non-linear models to refine these insights further. Ultimately, achieving sustainable development in South Asia will require a balanced approach that integrates economic growth with stringent environmental regulations and technological innovation.

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