

Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies

Benedict Afful¹, Kassim Alabani¹, 

¹. Department of Economic Studies, University of Cape Coast, Cape Coast, GHA

Received: February 11, 2026 | Review began: March 01, 2026 | Review ended: June 10, 2026 | Published: June 27, 2026

© Copyright 2026

This is an open access article distributed under the terms of the Creative Commons Attribution License CC-BY 4.0., which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Abstract

This paper explores the potential trade-offs or synergies between manufacturing upgrading and environmental outcomes and investigates whether export sophistication, quality of institutions, and capacity for innovation influence this relationship. The study uses a quantitative cross-country panel research design, which includes the use of pooled Ordinary Least Squares, fixed effects (FE) estimation, quantile regression, and dynamic panel (system and difference Generalized Method of Moments) estimators, to capture the effects of heterogeneity, non-linearity and persistence in the environmental outcomes. The analysis is based on a balanced panel of 43 countries in Sub-Saharan Africa that has been observed for 19 years between 2005 and 2023 (817 country-year observations) sourced from The Global Economy database, which harmonizes the indicators available from World Bank and International Monetary Fund. The findings indicate that there is no evidence of a universal Environmental Kuznets Curve within the sectors. Controlling for country and year FE, the average impacts of manufacturing upgrading on environmental sustainability are weak and statistically insignificant. Pooled quantile regressions show non-linear patterns consistent with an inverted U-shape that grow stronger towards the upper tail of the distribution of the conditional environmental performance and that are largely attributable to cross-country composition and not to dynamics within the country, but that are weak - virtually monotonic over the observed range - among environmental laggards. The moderating role of high-tech exports is small and not strong, and is not noticeable when country-specific trends and dynamic adjustments are considered. The ability to improve environmental quality through institutional quality and innovation capacity is not systematic, but rather acts as a constraint on further degradation of the environment. The environmental sustainability outcome is itself very persistent, and the lagged outcome dominates over the dynamic estimates. The findings indicate that the negative and positive implications of manufacturing upgrading are not intrinsic but rather contingent on the convergence of manufacturing structural transformation, technological capacity and institutional environment in order to achieve environmental sustainability. Policymakers should therefore not try to see manufacturing upgrading as an independent route towards improving the environment, but focus on investments that are complementary to upgrading, such as improvements in institutional quality, the diffusion of clean technologies and regulatory enforcement, to ensure that structural transformation brings real environmental benefits.

Categories: Innovation Economics, Sustainable manufacturing, Ethical manufacturing

Keywords: structural change, export composition, environmental performance, governance quality, technological capability, distributional heterogeneity

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. Cureus J Bus Econ 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

Introduction

Manufacturing remains central to structural transformation and economic development, particularly in low- and middle-income countries seeking to diversify production, expand exports, and generate employment (Singh, 2025), (Taşdemir, 2022), and (Muluh et al., 2022). Historically, however, industrial expansion has been closely associated with environmental degradation through increased energy use, pollution, and resource depletion (Alfantookh et al., 2023) (Ruzieva and Ruziev, 2024). This tension between industrialization and environmental sustainability has re-emerged as a key policy challenge in the context of climate change, green growth agendas, and the Sustainable Development Goals.

Recent debates increasingly emphasize that the environmental consequences of manufacturing are not uniform but depend on the nature of industrial activity, technological sophistication, and institutional context (Ahmed et al., 2022), (Aladejare and Nyiputen, 2023), (Alfantookh et al., 2023), and (Aquilas et al., 2024). While traditional pollution-intensive manufacturing may exacerbate environmental pressures, upgrading toward more technologically advanced and knowledge-intensive production has been argued to reduce emissions intensity and improve environmental performance (Jena et al., 2024), (Mishra and Vikram, 2024), and (Machado et al., 2024). At the same time, empirical evidence remains mixed, particularly for developing economies, where industrial upgrading often occurs under weak regulatory frameworks and limited technological capabilities (Maduka et al., 2022) (Kinuthia et al., 2025).

High-tech exports represent one potential channel through which manufacturing upgrading may align with environmental sustainability. Export-oriented, technology-intensive sectors tend to embody cleaner production processes, higher energy efficiency, and greater exposure to international environmental standards (Satria, 2020). Yet international technology diffusion is far from automatic: barriers to the absorption of foreign technologies can substantially weaken the environmental benefits that trade in sophisticated products might otherwise transmit (Li, 2011), and recent cross-country evidence suggests that the environmental effects of technological innovation and trade openness depend heavily on the underlying policy and resource context (Sun and Qamruzzaman, 2025).

Industrializing economies therefore face a structural dilemma. Manufacturing upgrading is central to growth, yet its environmental consequences remain uncertain. While some studies suggest that technological upgrading reduces emissions intensity (Wang et al., 2025) (Noeth, 2024), others show that industrial expansion increases environmental pressure, especially under weak regulatory systems (Kalai, 2026), (Bibi et al., 2026), (Zhoumu et al., 2015), and (Oqubay, 2025). The lack of consensus creates a policy problem: should countries pursue manufacturing upgrading as a pathway to sustainability, or does it risk reinforcing environmental degradation? Existing empirical work has largely relied on aggregate income-based Environmental Kuznets Curve (EKC) frameworks, with limited attention to sector-level upgrading and export sophistication. This leaves a gap in understanding whether manufacturing upgrading generates environmental trade-offs or synergies, and under what conditions.

Research questions

This study asks whether manufacturing upgrading improves or worsens environmental sustainability in Sub-Saharan Africa; whether the relationship between upgrading and environmental outcomes is non-linear in a manner consistent with sector-level EKC dynamics; whether high-tech export orientation conditions this relationship; and whether institutional quality and innovation capacity shape the environmental outcomes of upgrading.

Study aims

In line with these questions, the study aims to estimate the average and non-linear effects of manufacturing upgrading on environmental sustainability; to examine the moderating role of high-tech exports; to assess the role of institutional quality and innovation capacity as boundary conditions; and to explore heterogeneity across the environmental performance distribution. Together, these aims allow the analysis to move beyond average effects and to identify the specific structural, technological, and institutional conditions under which manufacturing upgrading is associated with environmental trade-offs or synergies.

How to cite this article:

The remainder of the paper is organized as follows. First, the theoretical and empirical literature is reviewed, and the conceptual framework and hypotheses are presented. Next, the data, variables, and empirical strategy are described. This is followed by the presentation and discussion of the results. Subsequently, the findings are synthesized, and the paper concludes with policy recommendations, the study's contributions, and its limitations.

Literature review

Theoretical Literature

Three theoretical frameworks underpin this study. The first is the EKC hypothesis, which posits an inverted U-shaped relationship between income and environmental degradation, suggesting that environmental quality initially worsens with economic growth before improving as countries cross a critical development threshold (Jaeger et al., 2022), (Setyari and Kusuma, 2021), and (Pasten and Figueroa, 2012). While influential, the EKC has been widely critiqued for its sensitivity to model specification and its limited capacity to account for sectoral composition effects (Pesce, 2017), (Lau et al., 2025), and (Mitić et al., 2019). Indeed, a recent reassessment across 214 countries shows that EKC-type relationships are highly contingent on economic, institutional, technological, and social conditions rather than universal (Wang et al., 2024). These critiques motivate the present study's focus on manufacturing upgrading rather than aggregate income.

The second framework is structural transformation theory, which argues that shifts in production toward more technologically sophisticated and knowledge-intensive activities drive productivity growth, export diversification, and long-run development (Oqubay, 2025), (Singh, 2025), and (Taşdemir, 2022). In the African context, technological innovation has been identified as a key driver of structural transformation, although its diffusion remains uneven across economies (Muluh et al., 2022). This theory predicts that upgrading reshapes energy use and material intensity, with ambiguous environmental consequences depending on the pace of technological diffusion relative to production scale.

The third framework draws on institutional economics and innovation systems theory, which emphasize that regulatory quality, enforcement capacity, and national innovation systems determine whether structural transformation translates into environmentally favorable outcomes (Noeth, 2024), (Aquilas et al., 2024), and (Danish and Ulucak, 2020). Comparative country experiences, such as those of Türkiye and South Korea, illustrate how the maturity of national innovation systems conditions the pace and quality of technological upgrading (Kabadurmus et al., 2021) (Şeker, 2022), while measurement studies caution that innovation for sustainability transitions remains difficult to capture with aggregate indicators (Krljev and Terstriep, 2022) (Secka, 2023). Together, these three frameworks position environmental sustainability as a conditional outcome of manufacturing upgrading rather than an automatic consequence of industrial expansion.

Empirical Literature Review

Recent empirical studies converge on the idea that industrialization and structural transformation generate complex and often ambiguous environmental outcomes. Wang et al. (Wang et al., 2025) provide one of the most integrated empirical assessments by examining the economic, employment, and carbon-emission implications of China's dual circulation strategy using a value-chain decomposition approach. Their findings show that domestic demand-driven industrial expansion simultaneously increases output, employment, and emissions, highlighting the persistence of trade-offs rather than automatic environmental gains. While the study is methodologically strong in linking multiple macro outcomes, its focus on a single country limits generalizability. In contrast, Chen et al. (Chen et al., 2025) adopt a broader perspective, showing through a metacoupling framework that international trade influences sustainability through interconnected domestic and global channels. However, their work remains largely conceptual and does not directly estimate sector-specific environmental effects. Taken together, these studies suggest that trade and industrial expansion cannot be assumed to deliver environmental improvements, but they stop short of identifying the specific conditions under which upgrading leads to either trade-offs or synergies.

A related strand of empirical work emphasizes the role of innovation, industrial structure, and technological change in shaping environmental outcomes. Kalai (Kalai, 2026) finds that corporate social responsibility contributes to environmental sustainability primarily through its effects on innovation and structural transformation, using cross-

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

country data. While this approach highlights indirect channels, CSR serves as a broad proxy and may not fully capture the structural dynamics of industrial upgrading. By comparison, Bibi et al. (Bibi et al., 2026) provide more granular evidence using a three-stage least squares framework applied to China's textile and fashion industry. Their results show that digitalization, environmental innovation, and green energy supply significantly enhance green production. The strength of this study lies in its sectoral specificity and rigorous identification strategy, although its industry focus limits external validity. At the global level, Machado et al. (Machado et al., 2024) find that economic development, innovation, and environmental performance can be integrated, but only under supportive policy frameworks, while Sun and Qamruzzaman (Sun and Qamruzzaman, 2025) show for the BRICS+T economies that the environmental effects of technological innovation and trade openness vary substantially across alternative sustainability indicators. The comparison reveals a key gap: while these studies recognize the importance of technology and innovation, none directly evaluates how manufacturing upgrading at the macro level interacts with export structure to influence environmental sustainability.

A further strand examines institutions directly. Maduka et al. (Maduka et al., 2022) find for Nigeria that institutional quality moderates the growth-emissions nexus, although the underlying relationship departs from the standard inverted U-shape. Kinuthia et al. (Kinuthia et al., 2025) similarly report that institutional quality conditions the link between economic growth, financial development, and carbon emissions, while Sah (Sah, 2021) shows that institutional quality improves environmental protection in CEMAC countries and Adebisi et al. (Adebisi et al., 2022) document asymmetric institution-environment linkages in Nigeria. Danish and Ulucak (Danish and Ulucak, 2020) conclude that institutional quality "makes a difference" in pollution mitigation, but the size of the effect depends on the pollution measure and estimator employed. These studies collectively suggest that institutions matter for environmental outcomes in Africa, but they do not connect institutional quality to the environmental consequences of manufacturing upgrading specifically.

From a structural transformation perspective, Oqubay (Oqubay, 2025) highlights the central role of industrial hubs in driving economic catch-up, productivity growth, and technological upgrading in developing economies. However, environmental outcomes are not explicitly modeled, leaving unanswered whether such transformation is environmentally beneficial. Conversely, Noeth (Noeth, 2024) focuses on sectoral decarbonization pathways, emphasizing innovation, regulatory coordination, and institutional support as key drivers of emission reductions, and Peng et al. (Peng et al., 2025) document how international technological cooperation under initiatives such as the Belt and Road can support, but does not guarantee, progress toward the Sustainable Development Goals. While this work clearly addresses environmental sustainability, it does not engage with the structural dynamics of industrial upgrading. The disconnect between these strands of literature is important: development-oriented studies prioritize growth and structural change, while sustainability-focused studies emphasize emissions reduction without fully integrating industrial transformation processes.

In effect, the empirical literature points to three consistent patterns. First, industrial expansion and trade integration often generate environmental trade-offs rather than automatic gains. Second, innovation, digitalization, and institutional quality matter, but their effects are indirect and context dependent. Third, existing studies are fragmented, focusing either on country-specific cases, sectoral analyses, or conceptual trade frameworks. What remains insufficiently addressed is a unified empirical assessment of whether manufacturing upgrading generates environmental trade-offs or synergies across countries, and how this relationship is conditioned by export sophistication, institutional quality, and innovation capacity. This gap motivates the present study, which integrates these dimensions within a single empirical framework to provide a more systematic and context-sensitive understanding of the manufacturing-environment nexus. The study contributes by moving beyond income-based EKC frameworks and focusing on sectoral upgrading, conditional effects, and distributional heterogeneity.

Conceptual Framework

Figure 1 presents the conceptual framework guiding the analysis. The framework positions environmental sustainability as a conditional outcome of manufacturing upgrading rather than an automatic result of industrial expansion. Manufacturing upgrading influences environmental outcomes through changes in production scale, process efficiency,

How to cite this article:

and structural sophistication, but its direct effect is expected to be weak or ambiguous on average. Non-linear effects consistent with EKC dynamics are therefore treated as localized and contingent rather than universal.

High-tech exports enter the framework as a conditioning factor that shapes the technological characteristics of manufacturing upgrading. By influencing production techniques and export composition, high-tech exports may indirectly affect environmental outcomes, although their moderating role is expected to be fragile and context dependent. Institutional and innovation capacity function as boundary conditions that influence regulatory enforcement, compliance, and the adoption of cleaner technologies, thereby constraining whether manufacturing upgrading leads to environmental neutrality or deterioration. Baseline environmental performance introduces distributional heterogeneity, implying that the manufacturing-environment relationship may differ across countries depending on their initial environmental conditions. The framework emphasizes that environmental sustainability emerges only under specific alignments of structural, technological, and institutional factors, rather than as a general consequence of manufacturing upgrading. This is presented in Figure 1.

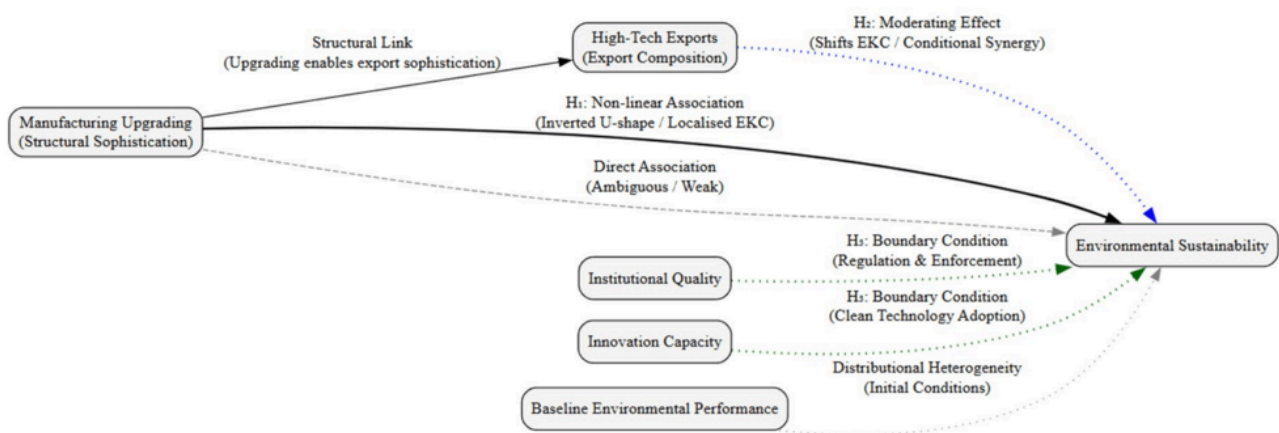


FIGURE 1: Conceptual Framework

Source: Author's visualization. EKC, Environmental Kuznets Curve

Core Hypotheses

H₁: Manufacturing upgrading is associated with a non-linear relationship with environmental degradation consistent with EKC dynamics at the sector level.

H₂: The relationship between manufacturing upgrading and environmental outcomes is conditioned by high-tech export orientation.

H₃: Institutional quality and innovation capacity shape whether manufacturing upgrading leads to environmental trade-offs or synergies.

Research Method

Source of data and empirical strategy

This study employs a balanced panel dataset covering 43 Sub-Saharan African countries over the period 2005-2023, yielding 817 country-year observations after harmonizing data availability across variables. Countries with substantial missing observations were excluded to ensure consistency in estimation. The final sample captures low-, lower-middle-, and upper-middle-income economies, providing sufficient variation in industrial structure, technological capability, and environmental performance. This heterogeneity is essential for identifying conditional and distributional effects. The list of selected countries is presented in Appendix.

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

All variables are obtained from The Global Economy database ([The Global Economy, 2026](#)), a macroeconomic data platform that compiles and standardizes indicators originally produced by the World Bank's World Development Indicators and the International Monetary Fund. The institutional quality measure aggregates the Worldwide Governance Indicators, whose methodology is described in Kaufmann et al. ([Kaufmann et al., 2011](#)); the index is standardized in the estimation sample (mean zero), with higher values indicating stronger governance. The use of a single harmonized secondary source ensures cross-country comparability and consistency over time, and the same source convention applies to all tables and figures reported in this paper.

Environmental sustainability is measured using a composite index capturing multiple dimensions of environmental performance and management; an inverse transformation of the index is used as the environmental degradation measure in robustness checks. Manufacturing upgrading is proxied by an index reflecting the depth and sophistication of manufacturing activity, thereby capturing structural transformation beyond simple expansions in manufacturing output. High-tech exports are measured as the share of high-technology products in total merchandise exports and serve as an indicator of export sophistication and technological intensity. A set of macroeconomic and structural control variables is included in every specification to account for confounding influences on environmental outcomes. These comprise log GDP per capita to capture income effects, GDP growth to reflect cyclical dynamics, trade openness as a measure of integration into global markets, foreign direct investment (FDI) inflows as a share of GDP to capture external capital flows, and domestic credit to the private sector as an indicator of financial development. The full set of controls is reported in every regression table.

The empirical strategy is designed to address three key features of the research problem: (i) unobserved heterogeneity across countries, (ii) potential non-linear and conditional relationships, and (iii) persistence in environmental outcomes. First, fixed effects (FE) models estimate the average relationship between manufacturing upgrading and environmental sustainability while controlling for time-invariant country characteristics and common time shocks; this provides the baseline test of H_1 . Second, interaction terms between manufacturing upgrading and high-tech exports are introduced to examine whether export composition conditions this relationship (H_2). Third, quantile regression explores heterogeneity across the distribution of environmental performance, identifying whether non-linearities and conditional effects are concentrated among specific groups of countries rather than reflected in average estimates. Finally, dynamic panel estimators (system and difference Generalized Method of Moments (GMM)) account for persistence in environmental outcomes and potential endogeneity arising from reverse causality and omitted variables; these models are used as robustness checks rather than primary identification strategies. Taken together, this multi-method approach does not aim to establish strict causal effects, but to provide consistent evidence on whether the relationship between manufacturing upgrading and environmental sustainability is non-linear, conditional, and heterogeneous across contexts.

Baseline specifications

We estimate the relationship between manufacturing upgrading and environmental sustainability using panel data for countries $i = 1, \dots, 43$ observed over years $t = 2005, \dots, 2023$. The baseline specification takes the form:

$$Y_{it} = \alpha + \beta_1 M_{it} + \beta_2 M_{it}^2 + \delta H_{it} + \gamma' X_{it} + \mu_t + \eta_i + \varepsilon_{it} \quad (1a)$$

where Y_{it} denotes the Environmental Sustainability Index for country i in year t . The variable M_{it} represents the manufacturing upgrading index, capturing the depth and structural sophistication of manufacturing activity, and M_{it}^2 is included to test for potential non-linear effects consistent with EKC dynamics. The variable H_{it} denotes high-tech exports, measured as the share of high-technology products in total merchandise exports, and serves as a proxy for export sophistication. The vector X_{it} contains the full set of control variables: log GDP per capita, GDP growth, trade openness, FDI inflows as a percentage of GDP, and domestic credit to the private sector. The term μ_t captures year FE, which control for global shocks and common time-specific factors such as technological change and international economic conditions; η_i represents country FE, accounting for unobserved, time-invariant heterogeneity across countries, including geographical characteristics, historical development paths, and persistent institutional differences; and ε_{it} is an idiosyncratic error term assumed to have mean zero conditional on the regressors and FE.

How to cite this article:

The coefficients β_1 and β_2 jointly test for EKC-type dynamics at the sectoral level. An inverted U-shaped relationship between manufacturing upgrading and environmental sustainability would require $\beta_1 > 0$ and $\beta_2 < 0$, with a turning point at $M^* = \beta_1/(2|\beta_2|)$ lying within the observed range of the upgrading index. Given the potential for long-run development trends to confound these estimates, specifications with country-specific linear time trends are also estimated as a robustness check.

To assess whether any EKC relationship is driven by the inclusion of control variables rather than manufacturing upgrading itself, we re-estimate equation (1a) excluding the full vector of controls. If the inverted U-shaped relationship emerges in this parsimonious specification, it would indicate a genuine EKC dynamic, with the controls serving as channels through which upgrading operates. If the quadratic pattern disappears, the original interpretation holds: manufacturing upgrading has no robust independent effect on environmental sustainability, and any apparent non-linearity is attributable to correlated structural and macroeconomic factors rather than upgrading per se.

To complement the quadratic specification and better approximate the actual functional form of the manufacturing-environment relationship, we supplement equation (1a) by replacing the continuous upgrading term and its square with a set of indicator variables capturing discrete size classes of manufacturing upgrading. Specifically, the upgrading index is divided into three categories: low (bottom tercile), medium (middle tercile), and high (top tercile), with the low category serving as the reference group. This yields the augmented specification equation 1(b):

$$Y_{it} = \alpha + \beta_1 \text{Medium}_{it} + \beta_2 \text{High}_{it} + \delta H_{it} + \gamma' X_{it} + \mu_t + \eta_i + \varepsilon_{it} \quad (1b)$$

where Medium_{it} and High_{it} are binary indicators equal to one when country i falls within the respective upgrading class in year t . The signs and magnitudes of β_1 and β_2 relative to the omitted low category directly reveal the shape of the manufacturing-environment relationship without imposing a parametric functional form. A pattern in which $\beta_1 > 0$ and $\beta_2 < 0$ would be consistent with an inverted U-shaped EKC trajectory, while monotonically increasing or decreasing coefficients would indicate linear dynamics. This approach provides a more flexible and interpretable assessment of non-linearity than the quadratic term alone.

In all static panel models, standard errors are clustered at the country level to account for heteroskedasticity and arbitrary serial correlation within countries over time. Both clustered standard errors and the associated t-statistics are reported in the regression tables.

Moderation by high-tech exports

To examine whether export sophistication alters the environmental implications of manufacturing upgrading, we extend the baseline model by introducing an interaction term between manufacturing upgrading and high-tech exports:

$$Y_{it} = \alpha + \beta_1 M_{it} + \beta_2 M_{it}^2 + \delta H_{it} + \theta (M_{it} \times H_{it}) + \gamma' X_{it} + \mu_t + \eta_i + \varepsilon_{it} \quad (2)$$

The interaction coefficient θ captures whether the marginal effect of manufacturing upgrading on environmental sustainability varies with the share of high-tech exports. A negative and statistically significant interaction term would indicate that the environmental implications of manufacturing upgrading differ systematically with export sophistication. Given that high-tech exports may proxy broader development trajectories, interaction results are interpreted as conditional associations rather than causal effects.

Distributional heterogeneity

Average effects may conceal substantial heterogeneity across countries with different baseline levels of environmental performance. To explore this possibility, we estimate quantile regressions at selected points of the conditional distribution of environmental sustainability, focusing on the 25th, 50th, and 75th percentiles, using the same regressor set as equation (2) but estimated on the pooled sample without country or year FE, with conventional (Koenker-Bassett) standard errors. Because the quantile estimates pool within- and between-country variation, they are interpreted as descriptive of the conditional distribution rather than as within-country causal effects. This approach allows the relationship between manufacturing upgrading and environmental sustainability to vary across countries facing different

How to cite this article:

environmental constraints. Quantile regressions are particularly informative for identifying localized EKC dynamics that may not be apparent in mean-based estimations and for assessing whether export sophistication plays a differentiated role among environmental laggards versus higher-performing countries. As a complementary mean-based check, we also re-estimate the FE model on the subsample of observations in the bottom quartile of the environmental sustainability distribution.

Dynamic specification and endogeneity considerations

Environmental sustainability is likely to exhibit strong persistence over time, raising concerns about omitted dynamics and potential endogeneity. To account for these issues, we estimate a dynamic panel model that includes the lagged dependent variable in equation (3):

$$Y_{it} = \alpha + \rho Y_{i,t-1} + \beta_1 M_{it} + \beta_2 M_{it}^2 + \delta H_{it} + \gamma' X_{it} + \mu_t + \eta_i + \varepsilon_{it} \quad (3)$$

This specification is estimated using two-step system GMM, with difference GMM reported as an additional check. The estimators exploit internal instruments derived from lagged levels and differences of the endogenous variables; to guard against instrument proliferation, the instrument matrix is collapsed and lags are restricted to the second and third lags, keeping the number of instruments well below the number of countries. Robust two-step (Windmeijer-corrected) standard errors are reported. Diagnostic tests for first- and second-order serial correlation, AR(1) and AR(2), and the Hansen J-test of instrument validity are reported alongside the estimates to assess model adequacy. Given the high persistence of environmental outcomes and the sensitivity of results to instrument choice, the dynamic estimates are interpreted as robustness checks rather than definitive evidence of causal effects.

Robustness checks

A series of robustness checks assesses the sensitivity of the results to alternative outcome measures and specifications. These include replacing the environmental sustainability index with alternative indicators capturing environmental degradation, innovation performance (the SDG Innovation Index), and structural change (the manufacturing-to-industry ratio). Additional checks involve alternative estimators, the inclusion of country-specific trends, and subsample analyses by level of GDP per capita. Collectively, these robustness exercises ensure that the core findings are not driven by a particular modeling choice or outcome definition. The empirical analysis proceeds in four stages: descriptive statistics characterize the distribution of key variables; FE models estimate average relationships; interaction and quantile models examine conditional and heterogeneous effects; and dynamic panel estimators address persistence and potential endogeneity.

Results And Discussion

Descriptive patterns and stylized facts

Table 1 reports descriptive statistics for all variables used in the analysis across the 817 country-year observations. Environmental sustainability exhibits relatively limited variation, with a mean of 67.97 and a standard deviation of 3.44, suggesting that while most countries maintain moderate environmental performance, a meaningful gap exists between the lowest (58.26) and highest (77.99) performing country-years. Manufacturing upgrading shows wider dispersion, ranging from 0.23 to 23.65, providing sufficient variation to identify structural effects. High-tech exports are highly skewed, with a median of 2.79% compared with a maximum of 95.62%, indicating that export sophistication remains low for most countries in the sample. Institutional quality is standardized with a sample mean of zero; its wide range (−2.50 to 2.64) reflects the substantial governance heterogeneity across the Sub-Saharan African sample, with most country-years recording below-average scores relative to global benchmarks (Kaufmann et al., 2011).

How to cite this article:

Variable	Obs.	Mean	Std. Dev.	Min	25th pct.	Median	75th pct.	Max
Environmental sustainability	817	67.966	3.437	58.264	65.653	67.952	70.250	77.992
Environmental degradation	817	32.034	3.437	22.008	29.750	32.048	34.347	41.736
Manufacturing upgrading	817	9.773	4.531	0.230	6.710	9.480	12.670	23.650
High-tech exports (%)	817	5.414	8.108	0.000	1.060	2.790	5.720	95.620
Institutional quality	817	0.000	0.950	-2.497	-0.637	-0.036	0.444	2.636
Innovation capacity	817	25.131	4.494	10.320	23.100	25.167	27.000	40.900
Log GDP per capita	817	7.048	0.898	4.999	6.431	6.871	7.510	9.363
GDP growth (%)	817	4.120	4.465	-36.390	2.410	4.520	6.340	21.450
Trade openness (%)	817	65.912	9.132	23.000	61.000	65.856	72.000	89.000
FDI inflows (% GDP)	817	4.497	7.951	-17.290	1.320	2.660	5.200	103.340
Domestic credit to private sector (% GDP)	817	21.311	20.442	1.200	11.410	18.530	21.210	142.420

TABLE 1: Descriptive Statistics

GDP, Gross Domestic Product; FDI, foreign direct investment

How to cite this article:Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. Cureus J Bus Econ 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

Table 2 reports model selection and diagnostic tests. The Hausman test rejects the null hypothesis that random effects estimates are consistent ($\chi^2(10) = 39.49$, $p < 0.001$), supporting the use of FE; because Stata reported a non-positive-definite variance matrix for this test, the result is treated as supportive rather than definitive, and it is reinforced by the F-test for joint significance of the country effects ($F(42, 746) = 96.33$, $p < 0.001$). Variance inflation factors are elevated only for manufacturing upgrading and its square (17.22 and 16.99), which is mechanical in quadratic specifications because a variable and its square are necessarily highly correlated (maximum pairwise correlation of 0.966); all other regressors have VIFs well below conventional thresholds and the mean VIF is 2.95, indicating no harmful multicollinearity among the substantive explanatory variables.

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

Diagnostic	Result	Interpretation
Hausman test, FE vs RE	$\chi^2(10) = 39.49; p < 0.001$	Supports fixed effects; Stata reported a non-positive-definite warning, so the result is treated as supportive rather than definitive.
F-test for country effects	$F(42, 746) = 96.33; p < 0.001$	Country effects are jointly significant.
Panel structure	43 countries; 2005–2023; 817 obs.	Strongly balanced panel.
Maximum pairwise correlation	0.966	Between manufacturing upgrading and its square; mechanical in quadratic specifications.
Mean VIF	2.95	Acceptable overall; the upgrading terms have high VIFs only because of the quadratic specification.
VIF: Manufacturing upgrading	17.22	High due to the quadratic term.
VIF: Manufacturing upgrading ²	16.99	Mechanically related to the linear term.
VIF: High-tech exports	1.03	No concern.
VIF: Log GDP per capita	1.80	No concern.
VIF: GDP growth	1.21	No concern.
VIF: Trade openness	1.60	No concern.
VIF: FDI inflows	1.08	No concern.
VIF: Domestic credit	1.74	No concern.
VIF: Institutional quality	2.09	No concern.
VIF: Innovation capacity	1.91	No concern.

TABLE 2: Model Selection and Diagnostic Tests

FE, fixed effects; FDI, foreign direct investment; VIF, variance inflation factor; GDP, Gross Domestic Product

Baseline Fixed Effects Results

Table 3 reports baseline estimates of the relationship between manufacturing upgrading and environmental sustainability. Across specifications (1) through (6), there is no evidence supporting an unconditional inverted U-shaped relationship consistent with EKC dynamics (Hypothesis 1) once country heterogeneity is controlled for. In the pooled OLS

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

model, the linear upgrading term is positive and significant ($\beta = 0.606$, $p < 0.05$), but this association disappears entirely once country FE and year effects are introduced: in columns (3)-(5) the linear term is close to zero and statistically insignificant, and the squared term never exhibits the significant negative sign required for EKC dynamics. The marginally significant negative quadratic in column (2) ($\beta = -0.015$, $p < 0.10$) is not robust to the inclusion of year effects or country-specific trends, suggesting that any apparent non-linearity in simpler models reflects common shocks and long-run trends rather than a structural EKC relationship.

The interaction between manufacturing upgrading and high-tech exports is negative and marginally significant in columns (3)-(5) ($\beta = -0.004$, $p < 0.10$), suggesting that the environmental implications of manufacturing upgrading may vary with the level of export sophistication, consistent with a weakly conditional relationship (Hypothesis 2). However, this moderation is fragile: when country-specific linear trends are introduced in column (6), the interaction collapses to zero ($\beta = 0.000$, $t = 0.07$) and the high-tech export main effect likewise loses all significance ($\beta = -0.003$, $t = -0.18$). This pattern suggests that the high-tech export relationship may absorb unobserved country-specific time trends rather than representing an independent causal mechanism distinct from secular development trajectories. Among the controls, log GDP per capita is positively associated with sustainability in the pooled and simple FE models but turns significantly negative once year effects are included, a sign reversal reflects differences observed across the distribution of environmental performance, as indicated by the quantile regression results.

Variable	(1) Pooled OLS	(2) FE, no year effects	(3) FE + year effects	(4) FE + institutional quality	(5) FE full	(6) FE + country trends
Manufacturing upgrading	0.606** (0.270) [2.24]	0.363 (0.222) [1.64]	0.015 (0.149) [0.10]	0.013 (0.147) [0.09]	0.008 (0.149) [0.05]	−0.073 (0.072) [−1.01]
Manufacturing upgrading ²	−0.015 (0.012) [−1.23]	−0.015* (0.008) [−1.87]	−0.001 (0.005) [−0.17]	−0.001 (0.005) [−0.15]	−0.001 (0.005) [−0.11]	0.002 (0.002) [0.83]
High-tech exports	0.003 (0.030) [0.09]	−0.008 (0.018) [−0.42]	0.049 (0.031) [1.62]	0.050 (0.031) [1.62]	0.049 (0.030) [1.67]	−0.003 (0.015) [−0.18]
Manufacturing × high-tech			−0.004* (0.002) [−1.68]	−0.004* (0.002) [−1.69]	−0.004* (0.002) [−1.74]	0.000 (0.001) [0.07]
Log GDP per capita	1.415*** (0.452) [3.13]	1.810*** (0.447) [4.05]	−1.237*** (0.396) [−3.12]	−1.269*** (0.413) [−3.07]	−1.282*** (0.397) [−3.23]	−0.676*** (0.221) [−3.07]
GDP growth	−0.072** (0.032) [−2.23]	−0.073*** (0.021) [−3.43]	−0.015 (0.010) [−1.46]	−0.015 (0.011) [−1.44]	−0.014 (0.011) [−1.32]	0.007 (0.008) [0.90]
Trade openness	0.000 (0.029) [0.02]	−0.024 (0.020) [−1.20]	−0.013 (0.015) [−0.87]	−0.014 (0.015) [−0.95]	−0.013 (0.015) [−0.88]	0.011* (0.006) [1.88]
FDI inflows (% GDP)	0.043* (0.023) [1.83]	−0.005 (0.011) [−0.50]	−0.001 (0.009) [−0.17]	−0.002 (0.009) [−0.20]	−0.002 (0.009) [−0.18]	0.006 (0.009) [0.60]
Domestic credit	−0.034** (0.014) [−2.51]	0.015 (0.019) [0.79]	0.001 (0.006) [0.16]	0.001 (0.007) [0.12]	0.001 (0.006) [0.21]	0.003 (0.005) [0.50]
Institutional quality				0.121 (0.503) [0.24]	0.113 (0.494) [0.23]	0.206 (0.313) [0.66]
Innovation capacity					−0.047 (0.037) [−1.28]	−0.008 (0.017) [−0.49]
Country fixed effects	No	Yes	Yes	Yes	Yes	Yes
Year fixed effects	No	No	Yes	Yes	Yes	No
Country-specific trends	No	No	No	No	No	Yes
Observations	817	817	817	817	817	817

How to cite this article:

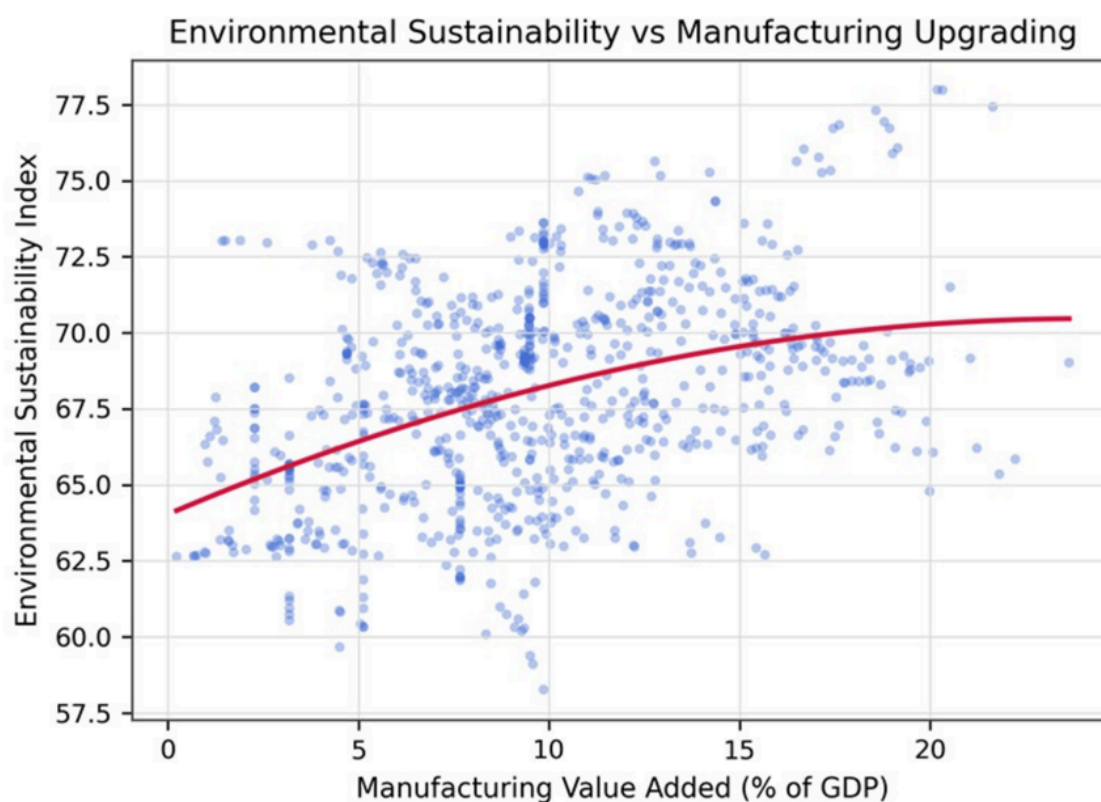
Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

R ² / within R ²	0.284	0.159	0.545	0.546	0.549	0.804
--	-------	-------	-------	-------	-------	-------

TABLE 3: Baseline Estimates of Manufacturing Upgrading and Environmental Sustainability

OLS, Ordinary Least Squares; FE, fixed effects; FDI, foreign direct investment; GDP, Gross Domestic Product

Figure 2 provides a visual counterpart to these estimates by plotting environmental sustainability against the manufacturing upgrading index for the pooled sample, together with a quadratic fit. The fitted curve rises with manufacturing value added at low and intermediate levels and flattens toward the top of the upgrading distribution, mirroring the positive and significant linear term in the pooled OLS specification. The dispersion of outcomes around the curve is, however, very wide at every level of manufacturing activity, and the gradient visible in the pooled data disappears once country FE are introduced in Table 3. The figure therefore illustrates that the apparent pooled relationship is driven primarily by stable between-country differences rather than by within-country environmental responses to upgrading.

**FIGURE 2: Environmental sustainability and manufacturing upgrading (pooled scatter with quadratic fit)**

Source: Authors' calculations based on the study dataset ([The Global Economy, 2026](#)).

Non-linearity, EKC Tests, and Institutional Boundary Conditions (H1 and H3)

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

Table 4 examines non-linear effects and institutional boundary conditions. Columns (1) through (3) confirm the absence of an EKC in the full sample: outside the simple FE model in column (1), the squared upgrading term is statistically indistinguishable from zero across FE and trend specifications. The interaction between manufacturing upgrading and institutional quality is statistically insignificant both in the year-effects specification (column 2: $\beta = 0.039$, $t = 0.59$) and when country-specific trends are included (column 3: $\beta = -0.010$, $t = -0.38$). Hypothesis 3 therefore receives, at best, limited support: institutional quality does not significantly transform the marginal environmental effect of upgrading in any specification, and its main effect is likewise insignificant. This is consistent with the interpretation, developed below, that institutions operate as slow-moving boundary conditions rather than contemporaneous moderators.

Column (4) restricts the sample to observations in the bottom quartile of the environmental sustainability distribution (the “environmental laggards” subsample). In this mean-based subsample regression, the linear and squared upgrading terms have the signs opposite to an inverted U-shape and neither is statistically significant at conventional levels ($\beta = -0.245$, $t = -1.24$; $\beta = 0.016$, $t = 1.49$). Evidence of EKC-type dynamics among environmental laggards therefore does not emerge from mean-based subsample splits; this is consistent with the conditional-quantile evidence in quantile regression results, where inverted U-shaped dynamics are weakest at the 25th percentile of the conditional distribution and strengthen only toward its upper end.

Variable	(1) Main FE	(2) Institutional interaction	(3) With country trends	(4) Bottom-quartile subsample
Manufacturing upgrading	0.363 (0.222) [1.64]	−0.005 (0.156) [−0.03]	−0.072 (0.067) [−1.07]	−0.245 (0.198) [−1.24]
Manufacturing upgrading ²	−0.015* (0.008) [−1.87]	−0.001 (0.005) [−0.13]	0.002 (0.002) [0.86]	0.016 (0.011) [1.49]
High-tech exports	−0.008 (0.018) [−0.42]	0.005 (0.012) [0.40]	−0.002 (0.006) [−0.31]	−0.014 (0.011) [−1.29]
Institutional quality		−0.266 (0.814) [−0.33]	0.300 (0.321) [0.94]	
Manufacturing × institutional quality		0.039 (0.066) [0.59]	−0.010 (0.027) [−0.38]	
Log GDP per capita	1.810*** (0.447) [4.05]	−1.315*** (0.433) [−3.04]	−0.684*** (0.215) [−3.18]	1.576*** (0.316) [4.98]
GDP growth	−0.073*** (0.021) [−3.43]	−0.019 (0.012) [−1.60]	0.007 (0.008) [0.92]	0.012 (0.018) [0.66]
Trade openness	−0.024 (0.020) [−1.20]	−0.012 (0.014) [−0.84]	0.010* (0.006) [1.73]	0.006 (0.022) [0.28]
FDI inflows (% GDP)	−0.005 (0.011) [−0.50]	−0.001 (0.009) [−0.14]	0.005 (0.009) [0.56]	−0.004 (0.006) [−0.72]
Domestic credit	0.015 (0.019) [0.79]	0.000 (0.007) [−0.02]	0.002 (0.005) [0.42]	0.142** (0.054) [2.62]
Country fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	No	Yes	No	No
Country-specific trends	No	No	Yes	No
Observations	817	817	817	205
Within R ²	0.159	0.542	0.804	0.404

TABLE 4: Non-linear Effects and Institutional Quality Interactions (H3)

GDP, Gross Domestic Product; FE, fixed effects

Figure 3 plots the marginal effect of manufacturing upgrading on environmental sustainability across the observed range of high-tech export intensity (from zero to the 95th percentile of the high-tech export share), based on the year-effects interaction specification in Table 3, with cluster-robust 95% confidence bands. The point estimate is essentially zero where high-tech exports are negligible and declines steadily as export sophistication rises, reflecting the negative interaction coefficient. Crucially, however, the confidence band includes zero across the entire observed range of high-

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

tech export intensity: at no point is the marginal effect statistically distinguishable from zero at the 5% level. Read together with the fragility of the interaction term in Table 3, the figure should be interpreted as descriptive of a weak conditional association in the static model rather than as evidence of a robust causal moderation.

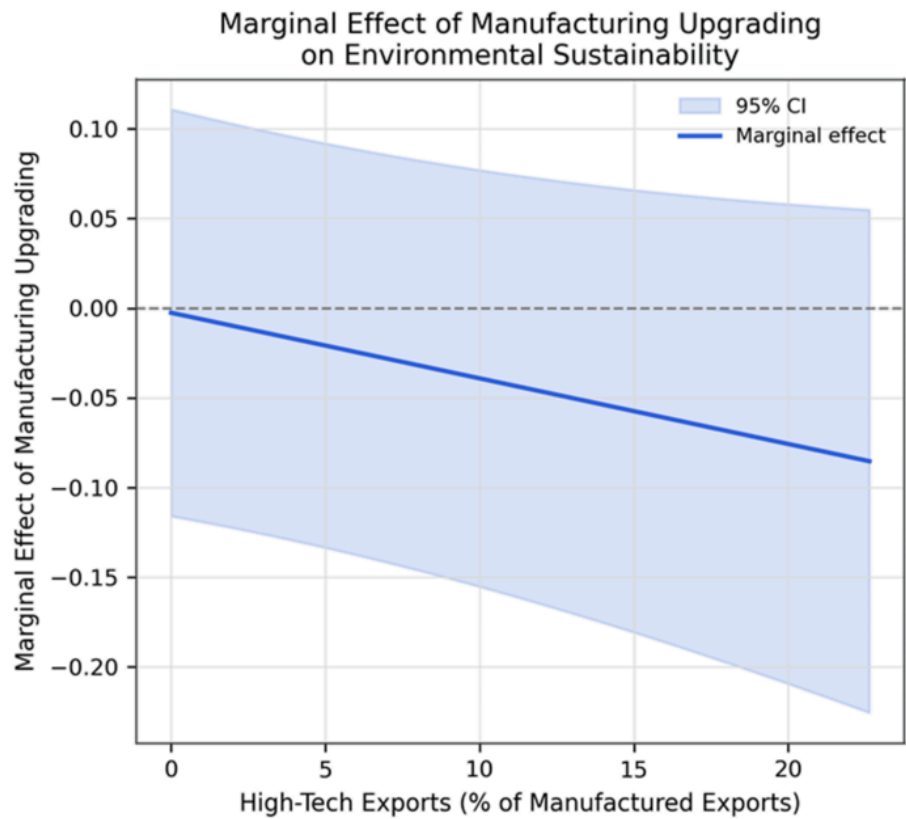


FIGURE 3: Marginal Effects of Manufacturing Upgrading Conditional on High-Tech Export Intensity

Source: Authors’ calculations based on the study dataset (The Global Economy, 2026).

Distributional Heterogeneity

Table 5 investigates heterogeneity by estimating pooled quantile regressions across the conditional distribution of environmental sustainability. In contrast to the within-country estimates of Tables 3 and 4, these regressions characterize the conditional distribution without country FE and therefore reflect both within- and between-country variation. Inverted U-shaped dynamics are clearly visible in the conditional distribution and strengthen toward its upper end. At the median, the linear upgrading term is positive and highly significant ($\beta = 0.863$, $p < 0.01$) and the squared term is negative and highly significant ($\beta = -0.027$, $p < 0.01$), implying a turning point at an upgrading index value of approximately 16.2. At the 75th percentile the pattern is even more pronounced ($\beta = 1.039$ and $\beta = -0.036$, both $p < 0.01$), with a turning point of approximately 14.4, comfortably inside the observed range of manufacturing value added. At the 25th percentile, the linear term remains positive and significant ($\beta = 0.524$, $p < 0.01$) but the quadratic term is only marginally significant ($\beta = -0.011$, $p \approx 0.05$) and the implied turning point of roughly 23.6 lies at the very boundary of the sample distribution, so that the relationship is effectively monotonically increasing over the observed range for environmental laggards.

How to cite this article:

The upgrading $\times$ high-tech interaction is statistically insignificant at every quantile, and the high-tech export main effect is at most marginally negative at the 25th percentile ($\beta = -0.091$, $p < 0.10$), reinforcing the conclusion from the mean regressions that export sophistication does not robustly condition the manufacturing-environment relationship. Log GDP per capita is positive and highly significant across all quantiles, consistent with the pooled OLS estimates in Table 3, while domestic credit is negatively associated with sustainability throughout the distribution. Two caveats are essential when interpreting these results. First, because the quantile estimates are pooled, the inverted-U pattern largely reflects cross-country composition: Table 3 shows that the within-country (FE) counterpart of this relationship is statistically indistinguishable from zero, so the quantile evidence should be read as descriptive of how the conditional distribution of environmental performance varies with manufacturing depth across countries, not as a within-country causal trajectory. Second, the apparent EKC is strongest among environmental leaders and weakest - effectively absent within the observed range - among environmental laggards, indicating that EKC dynamics are contingent on baseline environmental conditions, consistent with recent evidence that EKC relationships are highly heterogeneous across countries and conditioning factors (Wang et al., 2024) (Taşdemir, 2022).

Variable	(1) 25th percentile	(2) 50th percentile	(3) 75th percentile
Manufacturing upgrading	0.524*** (0.118) [4.46]	0.863*** (0.116) [7.45]	1.039*** (0.114) [9.12]
Manufacturing upgrading ²	-0.011* (0.006) [-1.96]	-0.027*** (0.005) [-5.01]	-0.036*** (0.005) [-6.89]
High-tech exports	-0.091* (0.048) [-1.88]	-0.059 (0.044) [-1.36]	-0.043 (0.040) [-1.07]
Manufacturing $\times$ high-tech	0.005 (0.004) [1.27]	0.003 (0.004) [0.86]	0.004 (0.003) [1.27]
Log GDP per capita	1.136*** (0.150) [7.56]	1.356*** (0.171) [7.94]	1.706*** (0.181) [9.41]
GDP growth	-0.040 (0.028) [-1.41]	-0.073** (0.030) [-2.47]	-0.115*** (0.027) [-4.33]
Trade openness	-0.011 (0.016) [-0.69]	-0.005 (0.016) [-0.35]	0.012 (0.014) [0.85]
FDI inflows (% GDP)	0.030 (0.019) [1.60]	0.044*** (0.017) [2.62]	0.036*** (0.013) [2.75]
Domestic credit	-0.030*** (0.008) [-3.65]	-0.037*** (0.008) [-4.75]	-0.063*** (0.006) [-10.28]
Constant	55.917*** (1.425) [39.24]	54.503*** (1.494) [36.49]	53.054*** (1.436) [36.95]
Year effects	No	No	No
Observations	817	817	817
Pseudo R ²	0.148	0.164	0.192

TABLE 5: Distributional Evidence on the Manufacturing–Environment Relationship (Quantile Regression)

GDP, Gross Domestic Product; FDI, foreign direct investment

Robustness to Alternative Outcomes

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

Table 6 assesses whether the core findings are sensitive to alternative dependent variables capturing innovation, environmental pressure, and structural change. When the SDG Innovation Index is used as the dependent variable (column 1), manufacturing upgrading remains statistically insignificant, and neither institutional quality nor innovation capacity exhibits a significant association, indicating that the null environmental results are not an artefact of the particular sustainability index. Using environmental degradation as the outcome (column 2) yields a mirror image of the baseline: upgrading and its square remain insignificant, while the upgrading $\times$ high-tech interaction is positive and marginally significant ($\beta = 0.004$, $p < 0.10$), the exact counterpart of the negative interaction in Table 3, as expected given that degradation is the inverse of the sustainability index. In contrast, when the manufacturing-to-industry ratio is used (column 3), the coefficient on manufacturing upgrading is large, positive, and highly significant ($\beta = 2.849$, $p < 0.01$), confirming that the upgrading measure captures meaningful structural change within industry, even if its environmental implications are limited. These robustness checks indicate that the main findings are not driven by the specific choice of environmental indicator, while reinforcing the conclusion that manufacturing upgrading alone does not guarantee environmentally favorable outcomes.

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

Variable	(1) SDG Innovation Index	(2) Environmental degradation	(3) Manufacturing-to-industry ratio
Manufacturing upgrading	−0.020 (0.035) [−0.57]	−0.008 (0.149) [−0.05]	2.849*** (0.356) [8.00]
Manufacturing upgrading ²	0.000 (0.001) [−0.17]	0.001 (0.005) [0.11]	
High-tech exports	−0.005 (0.004) [−1.10]	−0.049 (0.030) [−1.67]	0.088 (0.175) [0.50]
Manufacturing × high-tech	0.000 (0.000) [0.82]	0.004* (0.002) [1.74]	0.002 (0.010) [0.20]
Institutional quality	0.073 (0.131) [0.56]	−0.113 (0.494) [−0.23]	0.533 (3.670) [0.15]
Innovation capacity	−0.008 (0.008) [−0.99]	0.047 (0.037) [1.28]	0.591 (0.870) [0.68]
Log GDP per capita	0.151 (0.104) [1.45]	1.282*** (0.397) [3.23]	4.761 (10.554) [0.45]
GDP growth	0.005** (0.002) [2.23]	0.014 (0.011) [1.32]	−0.357 (0.289) [−1.24]
Trade openness	0.003 (0.002) [1.27]	0.013 (0.015) [0.88]	−0.175 (0.155) [−1.13]
FDI inflows (% GDP)	0.000 (0.001) [−0.49]	0.002 (0.009) [0.18]	−0.166 (0.176) [−0.94]
Domestic credit	0.003 (0.002) [1.53]	−0.001 (0.006) [−0.21]	−0.108 (0.126) [−0.86]
Country fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	817	817	817
Within R ²	0.746	0.549	0.205

TABLE 6: Robustness to Alternative Environmental and Structural Outcomes

GDP, Gross Domestic Product; FDI, foreign direct investment

Figure 4 provides a complementary cross-sectional perspective by plotting environmental sustainability against manufacturing value added separately for low-, medium-, and high-technology economies, classified into terciles by their period-average high-tech export shares. The dominant visual feature is overlap: all three groups span nearly the entire observed range of both manufacturing depth and environmental performance, and within-group dispersion is large relative to any between-group differences. The high-technology group does contain the cluster of observations combining the deepest manufacturing sectors with the highest sustainability scores in the sample, but it also includes some of the lowest sustainability values, so no clean separation by technology intensity emerges. These patterns demonstrate that the absence of strong average effects is not due to lack of variation, but reflects the coexistence of divergent country-level trajectories: manufacturing-environment linkages are heterogeneous, context dependent, and not well captured by aggregate linear relationships.

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

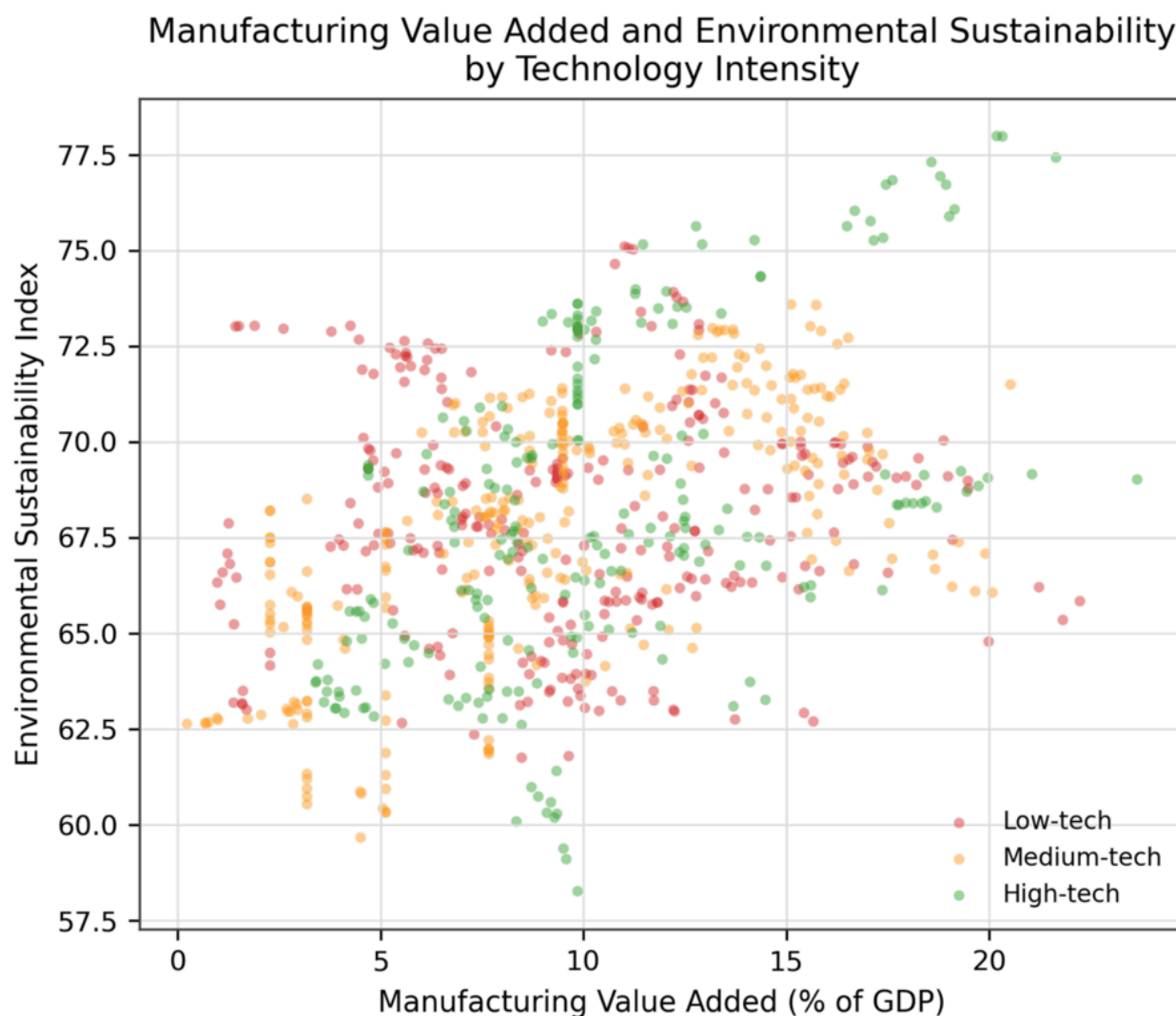


FIGURE 4: Manufacturing Value Added and Environmental Sustainability by Technology Intensity

Notes: Technology-intensity groups are terciles of each country's period-average share of high-technology exports in manufactured exports. Source: Authors' calculations based on the study dataset ([The Global Economy, 2026](#)).

Dynamic Persistence and Endogeneity

Table 7 introduces dynamic panel estimations to account for persistence and potential endogeneity. Environmental sustainability exhibits strong persistence across all specifications, as indicated by the large and highly significant coefficient on the lagged dependent variable (0.989 and 1.014 in the system GMM models; 0.874 in difference GMM), highlighting the path-dependent nature of environmental outcomes. Once dynamics are accounted for, the coefficients on manufacturing upgrading, its squared term, the high-tech export share, and the upgrading $\times$ high-tech interaction all lose statistical significance. This suggests that the weak conditional associations observed in static models do not represent short-run causal effects; to the extent that any synergies exist, they operate through slow-moving, cumulative channels rather than contemporaneous adjustments.

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

The diagnostics support the validity of the dynamic specifications. The AR(1) tests reject the null of no first-order serial correlation in the differenced residuals ($p \leq 0.005$), as expected by construction, while the AR(2) tests fail to reject the null of no second-order correlation (p-values between 0.33 and 0.56), satisfying the key identifying assumption. The Hansen J-tests do not reject instrument validity (p-values of 0.66-0.81), and because the instrument matrix is collapsed with lag depth restricted to lags two and three, the number of instruments (30-36) remains below the number of countries, mitigating instrument-proliferation concerns. Nevertheless, given the near-unit-root persistence of the outcome, the GMM results are interpreted as supportive rather than decisive, reinforcing the importance of structural and institutional conditions rather than contemporaneous policy shifts.

Variable	(1) System GMM baseline	(2) System GMM with interaction	(3) Difference GMM
Lagged environmental sustainability	0.989*** (0.058) [16.97]	1.014*** (0.067) [15.15]	0.874*** (0.127) [6.89]
Manufacturing upgrading	-0.074 (0.116) [-0.64]	-0.035 (0.095) [-0.37]	0.082 (0.149) [0.55]
Manufacturing upgrading ²	0.003 (0.004) [0.67]	0.001 (0.004) [0.21]	-0.005 (0.006) [-0.78]
High-tech exports	0.002 (0.005) [0.47]	-0.012 (0.049) [-0.24]	-0.079 (0.094) [-0.85]
Manufacturing × high-tech		0.000 (0.004) [0.09]	0.006 (0.008) [0.76]
Log GDP per capita	0.044 (0.101) [0.44]	0.038 (0.096) [0.40]	
GDP growth	-0.003 (0.007) [-0.38]	-0.003 (0.007) [-0.42]	0.001 (0.008) [0.17]
Trade openness	0.005 (0.004) [1.04]	0.004 (0.005) [0.88]	0.011 (0.009) [1.20]
FDI inflows (% GDP)	0.000 (0.011) [0.02]	0.001 (0.009) [0.13]	-0.003 (0.003) [-1.18]
Domestic credit	-0.001 (0.002) [-0.33]	-0.001 (0.003) [-0.35]	0.002 (0.005) [0.32]
Observations	774	774	731
Countries	43	43	43
Number of instruments	33	36	30
AR(1) p-value	0.005	0.005	0.004
AR(2) p-value	0.556	0.504	0.329
Hansen J-test p-value	0.662	0.809	0.810

TABLE 7: Dynamic Persistence and Endogeneity: GMM Estimates

GMM, Generalized Method of Moments; GDP, Gross Domestic Product; FDI, foreign direct investment

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

Structural Heterogeneity by Level of Development

Table 8 splits the sample at the median of log GDP per capita to examine whether the manufacturing-environment relationship differs by level of development. In both subsamples, neither manufacturing upgrading nor its squared term is statistically significant, indicating that the absence of robust EKC dynamics is not confined to a particular development stage. The most notable contrast concerns high-tech exports: in the below-median group, the high-tech export share is negatively and significantly associated with environmental sustainability ($\beta = -0.022$, $p < 0.05$), whereas in the above-median group the coefficient is positive but insignificant ($\beta = 0.035$, $t = 1.45$). This pattern suggests that at low levels of development, technologically sophisticated export activity may coincide with environmental pressures rather than relieving them, plausibly because the absorptive and regulatory capacity needed to translate technological content into cleaner production is still lacking (Li, 2011) (Secka, 2023). It aligns with the broader conclusion of the paper: trade-offs dominate at low development levels, while any synergies emerge gradually and conditionally as structural, institutional, and export capacities improve.

Variable	(1) Below-median GDP per capita	(2) Above-median GDP per capita
Manufacturing upgrading	0.061 (0.149) [0.41]	0.106 (0.316) [0.34]
Manufacturing upgrading ²	−0.005 (0.005) [−0.97]	−0.001 (0.012) [−0.10]
High-tech exports	−0.022** (0.010) [−2.17]	0.035 (0.024) [1.45]
Log GDP per capita	−0.411 (0.598) [−0.69]	−1.265*** (0.453) [−2.79]
GDP growth	−0.003 (0.014) [−0.20]	−0.018 (0.013) [−1.34]
Trade openness	0.022 (0.019) [1.18]	−0.036* (0.020) [−1.82]
FDI inflows (% GDP)	0.013 (0.016) [0.83]	−0.003 (0.011) [−0.27]
Domestic credit	−0.005 (0.020) [−0.26]	0.006 (0.006) [1.01]
Country fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Observations	409	408
Number of countries	29	30
Within R ²	0.446	0.690

TABLE 8: GDP-per-Capita Heterogeneity in Manufacturing–Environment Linkages

GDP, Gross Domestic Product; FDI, foreign direct investment

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

Figure 5 complements the regression results by illustrating the temporal evolution of average environmental sustainability across technology-intensity groups. The dominant pattern is a steady, broad-based improvement: all three groups rise from roughly 65.5-66.3 in 2005 to roughly 69.3-69.9 in 2023, with trajectories that move largely in parallel and repeatedly cross during the first half of the period. High-technology economies record the steepest cumulative improvement, starting lowest in 2005 and finishing highest from around 2019 onward, while medium-technology economies tend to track slightly below the other groups from the mid-2010s; low- and medium-technology economies also exhibit a small dip around 2019 before recovering. The compressed spread between groups - never much more than half an index point in any year - indicates that common, secular improvements dominate technology-specific dynamics, consistent with the importance of year effects in the panel regressions and with the weak conditional role of export sophistication. The modest late-period edge of the high-technology group is suggestive of gradually accumulating synergies but is far too small, relative to within-group dispersion, to constitute evidence of a distinct technology-driven environmental trajectory.

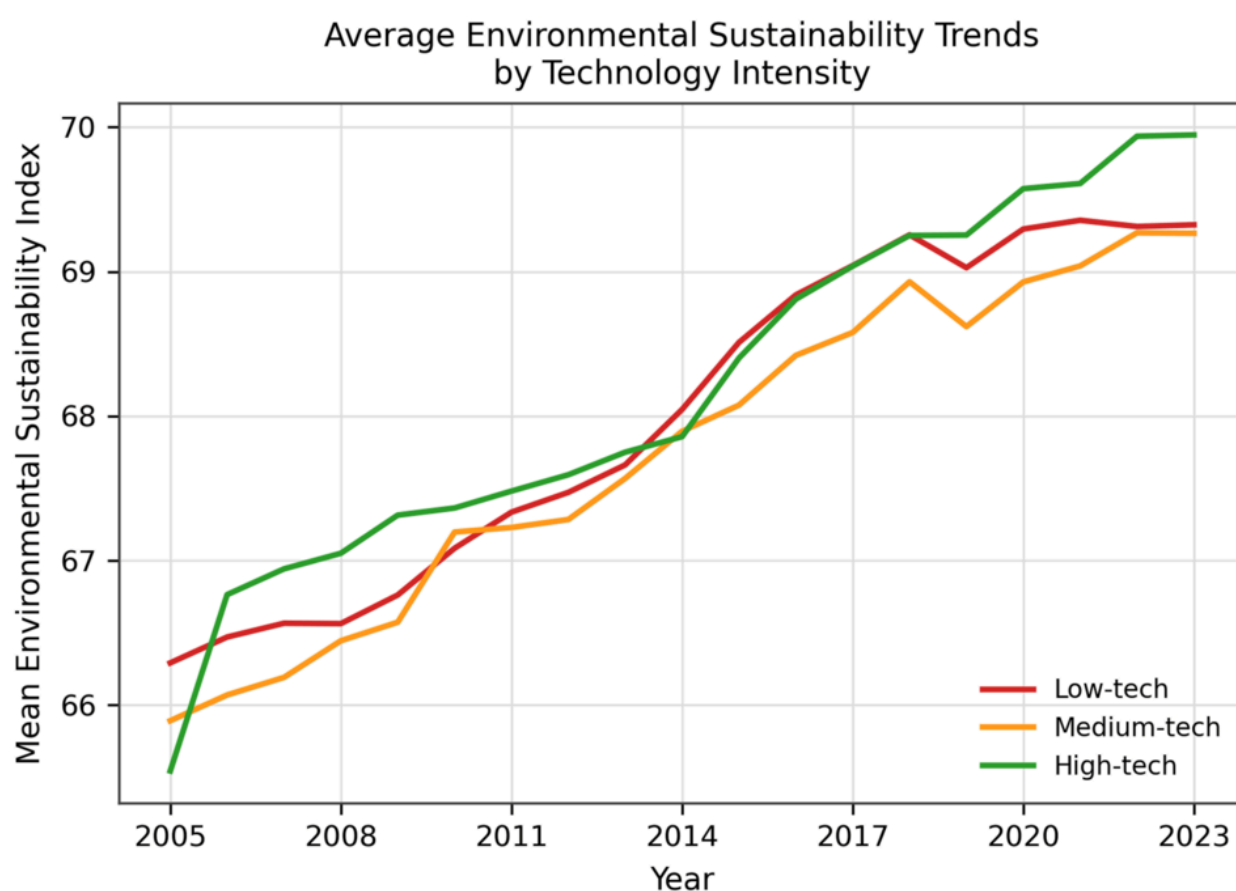


FIGURE 5: Average Environmental Sustainability Trends by Technology Intensity

Notes: Technology-intensity groups are terciles of each country's period-average share of high-technology exports in manufactured exports. Source: Authors' calculations based on the study dataset ([The Global Economy, 2026](#)).

Discussion and synthesis

This study examined whether manufacturing upgrading generates environmental trade-offs or synergies, and whether export sophistication, institutional quality, and innovation capacity condition this relationship. The empirical results do not provide consistent evidence of a universal EKC relationship between manufacturing upgrading and environmental

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

sustainability. Across baseline panel specifications, including pooled OLS, FE, trend-adjusted, and dynamic system GMM estimators, the estimated coefficients on manufacturing upgrading and its squared term are generally statistically insignificant and unstable across models. Rather than indicating the absence of any relationship, these results suggest that the manufacturing-environment nexus is not well captured by a uniform linear or non-linear specification at the aggregate level. The lack of robust significance across estimators reflects sensitivity to model specification, estimator choice, and control structure, reinforcing the need to interpret average effects with caution.

Further analysis using quantile regression reveals that inverted U-shaped dynamics are a feature of the conditional distribution of environmental performance and strengthen toward its upper end: the quadratic pattern is highly significant at the median and 75th percentile, with implied turning points (approximately 16.2 and 14.4 on the upgrading index) that lie comfortably within the observed range, whereas at the 25th percentile the quadratic term is only marginal and the implied turning point sits at the boundary of the sample, so that the relationship is effectively monotonic for environmental laggards. Because these regressions pool within- and between-country variation - and because the within-country counterpart of the relationship in the FE models is statistically indistinguishable from zero - this pattern is best read as reflecting cross-country composition rather than a within-country causal trajectory. Moreover, the relationship is not consistently moderated by high-tech exports in quantile specifications, and the interaction effect observed in mean-based models does not persist under dynamic estimation or alternative outcome measures. Taken together, the findings point to a context-dependent and weakly structured relationship rather than a stable or generalizable EKC mechanism.

Contrary to the expectations of the EKC hypothesis, the analysis finds no evidence of a universal non-linear relationship between manufacturing upgrading and environmental sustainability. Across baseline FE, trend-adjusted, and dynamic specifications, both the linear and squared upgrading terms are statistically insignificant and often carry signs inconsistent with EKC predictions. This challenges the implicit EKC assumption that structural transformation will eventually and automatically yield environmental improvements. While earlier cross-country studies frequently report EKC-type dynamics using income-based measures (Pesce, 2017), (Mitić et al., 2019), and (Zhoumu et al., 2015), the present results suggest that when attention shifts from aggregate income to sector-specific upgrading, such dynamics are far less pervasive. This finding aligns with critiques of the EKC framework that emphasize its sensitivity to model specification and its limited capacity to account for sectoral composition effects (Setyari and Kusuma, 2021) (Pasten and Figueroa, 2012), as well as with recent large-sample evidence that EKC relationships are conditional on a wide set of economic, institutional, and technological factors (Wang et al., 2024).

At the same time, the results do not fully reject EKC logic. Instead, they reveal that EKC-type dynamics are localized rather than universal. In the conditional-quantile framework, inverted U-shaped patterns are clearest among countries toward the upper end of the conditional environmental performance distribution, while among environmental laggards the relationship remains effectively monotonically increasing over the observed range of manufacturing depth - the turning point implied for the 25th percentile lies at the very edge of the sample. This asymmetry suggests that the capacity to convert structural transformation into eventual environmental gains is itself unevenly distributed, concentrated among countries that already perform comparatively well. This finding extends prior empirical work that reports heterogeneous EKC effects across countries and development stages (Ahmed et al., 2022) (Taşdemir, 2022) (Wang et al., 2025) (Kalai, 2026), and reinforces the argument that EKC relationships should not be interpreted as average tendencies, but as contingent outcomes that apply only to specific segments of the distribution.

From the perspective of structural transformation theory, these results are intuitive. Manufacturing upgrading does not merely alter output levels; it reshapes production processes, energy use, and material intensity. In many developing and emerging economies, upgrading may initially intensify environmental pressures as production scales up faster than cleaner technologies and regulatory capacity can diffuse (Muluh et al., 2022) (Li, 2011). The absence of strong average effects in the full sample suggests that structural change alone is insufficient to deliver environmental dividends, echoing findings by Aquilas et al. (Aquilas et al., 2024) and Aladejare and Nyiputen (Aladejare and Nyiputen, 2023), who show that

How to cite this article:

industrialization is environmentally consequential but not automatically beneficial. By focusing explicitly on manufacturing upgrading rather than broad industrial expansion, this study sharpens that conclusion: upgrading can be environmentally neutral or even detrimental unless complementary conditions are met.

The role of high-tech exports further underscores the conditional nature of manufacturing-environment linkages. In static mean regressions, the interaction between manufacturing upgrading and high-tech exports is negative but only marginally significant, suggesting at most a weak tendency for export sophistication to alter the environmental footprint of upgrading. This effect proves fragile: once country-specific trends, distributional heterogeneity, or dynamic persistence are accounted for, the interaction loses significance entirely. This pattern is consistent with concerns raised in the literature that high-tech exports may proxy long-run development trajectories rather than operate as an independent causal mechanism (Jaeger et al., 2022), (Bibi et al., 2026), and (Chen et al., 2025). The quantile results reinforce this interpretation, showing that high-tech exports do not systematically alter the non-linear upgrading-environment relationship even among environmental laggards, and the development-split results in Table 8 suggest that at low income levels a higher high-tech export share can even coincide with worse environmental outcomes. Rather than functioning as a robust moderator, export sophistication appears to support environmentally neutral outcomes at best, aligning with studies that emphasize the indirect and context-dependent role of trade composition and institutional moderation (Maduka et al., 2022) (Sun and Qamruzzaman, 2025).

Institutional quality and innovation capacity were expected, based on institutional economics and innovation systems theory, to play decisive moderating roles. The empirical evidence offers only limited support for this expectation. Interaction effects involving institutional quality are statistically insignificant in all specifications, and innovation capacity shows weak and insignificant associations with the main and alternative outcome measures. These findings resonate with prior work highlighting that governance and innovation matter, but often in ways that are difficult to detect using aggregate indices (Secka, 2023) (Krlev and Terstriep, 2022). They are also consistent with African and CEMAC-region evidence that institutional quality shapes environmental outcomes primarily through enforcement and protection channels rather than through direct contemporaneous effects (Sah, 2021), (Adebiyi et al., 2022), (Kinuthia et al., 2025), and (Danish and Ulucak, 2020). Rather than overturning environmental trade-offs, institutions and innovation capacity appear to operate as boundary conditions that constrain environmental deterioration; weak enforcement and regulatory capture can undermine even technologically advanced manufacturing, while strong institutions may prevent further degradation without necessarily generating immediate environmental gains.

A central contribution of this study lies in its emphasis on distributional heterogeneity and persistence. Quantile regressions reveal that the conditional association between manufacturing depth and environmental performance varies systematically across the distribution, with curvature concentrated among comparatively strong environmental performers and an effectively linear gradient among laggards. This helps explain why average estimates mask meaningful variation and why mean-based subsample splits fail to detect EKC dynamics. Moreover, the dynamic panel results demonstrate strong path dependence in environmental outcomes, with lagged sustainability dominating contemporaneous structural variables. This finding supports arguments in the literature that environmental improvements are slow-moving processes tied to cumulative capability building rather than short-run policy shifts (Chen et al., 2025) (Peng et al., 2025). It also explains why apparent synergies observed in static models dissipate once persistence is taken seriously.

Together, the findings challenge optimistic narratives of “green upgrading” that assume structural transformation will naturally decouple industrial growth from environmental degradation. While theory suggests that upgrading, innovation, and institutions can align to produce synergies, the empirical evidence indicates that such alignment is rare and difficult to sustain. Manufacturing upgrading does not inherently worsen environmental outcomes, but neither does it reliably improve them. Environmental sustainability emerges only when high levels of structural sophistication coincide with favorable baseline conditions and sufficient institutional and technological capacity. Even then, the gains are modest and slow to materialize. In this sense, the study reframes the manufacturing-environment debate: rather than asking whether upgrading is good or bad for the environment on average, the more relevant question is under what conditions

How to cite this article:

upgrading avoids environmental deterioration. By integrating non-linearity, export composition, institutional context, and distributional heterogeneity within a unified empirical framework, this study contributes to a more cautious and context-sensitive understanding of industrialization and sustainability.

Policy recommendations

The policy implications of these findings are necessarily cautious. First, strategies that promote manufacturing upgrading as a primary route to environmental sustainability should be reconsidered. While upgrading does not systematically worsen environmental outcomes, it does not reliably improve them either. Policymakers in industrializing economies, particularly in Sub-Saharan Africa and other regions pursuing export-led industrialization, should therefore avoid assuming that structural transformation will automatically deliver environmental dividends, particularly in low-technology and institutionally constrained contexts.

Second, the results suggest that export composition matters, but only indirectly and conditionally. Policies aimed at expanding high-tech exports should not be justified primarily on environmental grounds; indeed, among lower-income countries in the sample, higher high-tech export shares coincide with weaker environmental performance. Instead, such policies should be embedded within broader industrial strategies that explicitly target cleaner production techniques, energy efficiency, technology absorption, and compliance with international environmental standards. Without these complementary measures, export sophistication is unlikely to generate meaningful environmental gains.

Third, strengthening institutional and innovation capacity remains essential, but expectations should be realistic. Improvements in regulatory quality, enforcement, and innovation systems appear to limit environmental deterioration rather than guarantee positive outcomes. This implies that institutional reforms should focus not only on promoting innovation and industrial growth, but also on ensuring that environmental regulations are enforceable, predictable, and aligned with industrial incentives. Incremental improvements in governance may yield long-run benefits by preventing further degradation, even if short-run environmental gains are modest.

Fourth, the strong evidence of distributional heterogeneity implies that one-size-fits-all policy prescriptions are inappropriate. For environmental laggards, the conditional gradient of environmental performance with respect to manufacturing depth remains positive throughout the observed range, suggesting that fears of automatic environmental deterioration from industrialization are not borne out at the bottom of the distribution; among comparatively strong performers, by contrast, the conditional relationship flattens and eventually turns at moderate levels of manufacturing depth, implying diminishing environmental returns to further structural deepening. Tailored policy approaches that account for baseline environmental conditions, technology intensity, and development stage are therefore more likely to be effective than uniform upgrading strategies.

Finally, the persistence of environmental outcomes highlights the importance of long-term policy horizons. Environmental sustainability is not a short-run outcome of structural change, but a cumulative process shaped by sustained institutional capacity, technological learning, and regulatory credibility. Policies should therefore prioritize long-run capability building over short-term performance targets, recognizing that meaningful environmental improvements are gradual and path dependent.

Contribution of the study

This study makes three main contributions to the literature on industrial transformation and environmental sustainability. First, it challenges the conventional assumption of a universal EKC in the context of manufacturing upgrading. By showing that neither linear nor non-linear effects are robust across standard panel estimators, the study provides evidence that the manufacturing-environment relationship is not adequately captured by aggregate EKC frameworks. Second, the study introduces a conditional perspective by explicitly examining the moderating role of export sophistication. While the interaction between manufacturing upgrading and high-tech exports is marginally significant in mean-based estimations, the lack of consistency across alternative specifications highlights the fragility of synergy-based interpretations and cautions against overstating the environmental benefits of technological upgrading. Third, the study contributes methodologically by integrating FE, interaction models, quantile regression, and dynamic panel estimators

How to cite this article:

within a unified empirical framework. This approach allows for the identification of heterogeneity and distributional patterns that are not visible in average effects, particularly the localized evidence of EKC-type dynamics among environmental laggards. Together, the study shifts the focus from universal relationships to context-dependent mechanisms, emphasizing that environmental outcomes of industrial upgrading depend on structural, technological, and institutional conditions rather than following a predictable development trajectory.

Limitations of the study

Despite its contributions, the study is subject to several limitations. First, the use of a composite environmental sustainability index, while providing broad coverage of environmental outcomes, may mask variation across specific environmental dimensions. The relatively compressed distribution of this index also limits the statistical power to detect subtle structural relationships. Second, the measurement of manufacturing upgrading and innovation capacity relies on aggregate indicators that may not fully capture within-country heterogeneity or sector-specific dynamics; as a result, the analysis may overlook micro-level mechanisms through which upgrading affects environmental outcomes. Third, although dynamic panel estimators are employed to address persistence and potential endogeneity, the identification strategy relies on internal instruments, which may be sensitive to instrument proliferation and specification choices despite the collapsed instrument matrix used here. Consequently, the results should be interpreted as indicative of conditional associations rather than definitive causal effects. Finally, the analysis is conducted at the country level and does not account for firm-level or sectoral variation, which may be critical in understanding the environmental implications of manufacturing upgrading. Future research could extend this work by incorporating more disaggregated data and alternative environmental indicators.

Conclusions

This study examined whether manufacturing upgrading generates environmental trade-offs or synergies, and whether export sophistication, institutional quality, and innovation capacity condition this relationship. Using a harmonised panel dataset of 43 Sub-Saharan African countries over 2005-2023 and a range of complementary estimators, the analysis provides no evidence of a universal or automatic environmental dividend from manufacturing upgrading. Instead, the results point to a conditional and heterogeneous relationship in which trade-offs dominate on average, while synergies emerge only under restrictive and context-specific conditions.

Across baseline, trend-adjusted, and dynamic specifications, manufacturing upgrading exhibits weak and statistically insignificant effects on environmental sustainability in the full sample. Non-linear dynamics consistent with EKC logic are not pervasive and appear only among countries with low baseline environmental performance, and only within the conditional-quantile framework at very high levels of manufacturing sophistication. Even in these cases, the implied turning point lies at the extreme upper tail of the upgrading distribution, suggesting that environmental improvements materialize late, if at all, in the upgrading process.

The moderating role of high-tech exports is similarly limited. While static mean regressions suggest a marginally significant mitigation of environmental pressures, these effects are fragile and disappear once long-run trends, distributional heterogeneity, and dynamic persistence are accounted for. Institutional quality and innovation capacity do not systematically reverse environmental trade-offs, but instead function as boundary conditions that constrain environmental deterioration without guaranteeing improvement. Strong persistence in environmental outcomes further underscores the path-dependent nature of sustainability transitions and cautions against interpreting short-run structural changes as policy-ready solutions.

Together, the findings challenge optimistic narratives that portray manufacturing upgrading as an inherently “green” pathway to development. Structural transformation alone is neither sufficient nor reliably necessary for environmental improvement. Environmental sustainability emerges only when upgrading coincides with favorable baseline conditions, advanced structural sophistication, and supportive institutional and technological contexts. By integrating non-linearity,

How to cite this article:

moderation, and distributional heterogeneity within a unified empirical framework, this study contributes to a more nuanced understanding of the manufacturing-environment nexus and highlights the limits of relying on upgrading as a standalone strategy for sustainable development.

Appendices

The list of 43 Sub-Saharan African countries included in the analysis is provided in Appendix Table [9](#).

No.	Country
1	Angola
2	Benin
3	Botswana
4	Burkina Faso
5	Burundi
6	Cabo Verde
7	Cameroon
8	Central African Republic
9	Chad
10	Comoros
11	Democratic Republic of the Congo
12	Republic of the Congo
13	Côte d'Ivoire
14	Equatorial Guinea
15	Eritrea
16	Eswatini
17	Ethiopia
18	Gabon
19	The Gambia
20	Ghana
21	Guinea
22	Guinea-Bissau
23	Kenya
24	Lesotho

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. Cureus J Bus Econ 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

25	Liberia
26	Madagascar
27	Malawi
28	Mali
29	Mauritania
30	Mauritius
31	Mozambique
32	Namibia
33	Niger
34	Nigeria
35	Rwanda
36	Senegal
37	Sierra Leone
38	South Africa
39	Tanzania
40	Togo
41	Uganda
42	Zambia
43	Zimbabwe

TABLE 9: List of Sub-Saharan African Countries (43)

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Kassim Alabani, Benedict Afful

Acquisition, analysis, or interpretation of data: Kassim Alabani, Benedict Afful

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. Cureus J Bus Econ 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

Drafting of the manuscript: Kassim Alabani, Benedict Afful

Critical review of the manuscript for important intellectual content: Kassim Alabani, Benedict Afful

Supervision: Benedict Afful

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Data Availability Statements

The data (and/or code) supporting this study are openly available at theglobeconomy.com.

References

1. Adebisi M, Ojo T, Adelowokan O, Omojuwa O, Egbukichi E: [Institutional quality and environmental degradation linkage: Asymmetric approach for Nigeria](#). Journal of Economics and Policy Analysis. 2022, 7:15-34. [10.52968/25741022](#)
2. Ahmed F, Ali I, Kousar S, Ahmed S: [The environmental impact of industrialization and foreign direct investment: Empirical evidence from Asia-Pacific region](#). Environmental Science and Pollution Research. 2022, 29:29778-29792. [10.1007/s11356-021-17560-w](#)
3. Aladejare SA, Nyiputen IR: [Ecological response to industrialisation drivers in Africa](#). Environmental Development. 2023, 47:100896. [10.1016/j.envdev.2023.100896](#)
4. Alfantoikh N, Osman Y, Ellaythey I: [Implications of transition towards manufacturing on the environment: Saudi Arabia's Vision 2030 context](#). Journal of Risk and Financial Management. 2023, 16:44. [10.3390/jrfm16010044](#)
5. Aquilas NA, Ngangnchi FH, Mbella ME: [Industrialization and environmental sustainability in Africa: The moderating effects of renewable and non-renewable energy consumption](#). Heliyon. 2024, 10:25681. [10.1016/j.heliyon.2024.e25681](#)
6. Bibi S, Khan A, Fubing X, Jianfeng H, Hussain S: [Integrating digitalization, environmental innovations, and green energy supply to ensure green production in China's textile and fashion industry: Environmental policy and laws optimization perspective](#). Environment, Development and Sustainability. 2026, 28:11767-11807. [10.1007/s10668-024-05417-4](#)
7. Chen N, Sun Z, Xu Z, Xu J: [A review of international trade impacts on sustainable development](#). Marine Development. 2025, 3:9. [10.1007/s44312-025-00053-6](#)
8. Danish, Ulucak R: [The pathway toward pollution mitigation: Does institutional quality make a difference?](#). Business Strategy and the Environment. 2020, 29:3571-3583. [10.1002/bse.2597](#)
9. Jaeger WK, Kolpin V, Siegel R: [The Environmental Kuznets Curve reconsidered](#). SSRN Electronic Journal. 2022, [10.2139/ssrn.4162314](#)
10. Jena MC, Mishra S, Moharana H: [Environmental impact of conventional manufacturing, green manufacturing initiatives to mitigate the impact and enhancing sustainability](#). Research Square, 2024. [10.21203/rs.3.rs-4359942/v1](#)
11. Kabadurmus FNK, Senses C, Turkyilmaz B: [National innovation systems: Comparison of Turkey and South Korea](#). Innovation Management and Growth in Emerging Economies. Webb H, Wu W, Al Numairy H (ed): IGI Global Scientific Publishing, Hershey, PA; 2021. 106-132. [10.4018/978-1-7998-4195-1.ch006](#)
12. Kalai L: [CSR and environmental sustainability: Mediating effects of innovation and industrial structure for developed and developing countries](#). Environment, Development and Sustainability. 2026, [10.1007/s10668-026-07522-y](#)

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. Cureus J Bus Econ 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

13. Kaufmann D, Kraay A, Mastruzzi M: [The Worldwide Governance Indicators: Methodology and analytical issues](#). Hague Journal on the Rule of Law. 2011, 3:220-246. [10.1017/S1876404511200046](#)
14. Kinuthia P, Kemboi I, Onyango J, Adaramola MS: [Economic growth, financial development and carbon emissions: Does institutional quality matter?](#). The Journal of Financial, Accounting, and Economics. 2025, 2:63-79. [10.58857/JFAE.2025.v02.i02.p01](#)
15. Krlev G, Terstriep J: [Pinning it down? Measuring innovation for sustainability transitions](#). Environmental Innovation and Societal Transitions. 2022, 45:270-288. [10.1016/j.eist.2022.11.005](#)
16. Lau LS, Yii KJ, Ng CF, Tan YL, Yiew TH: [Environmental Kuznets curve \(EKC\) hypothesis: A bibliometric review of the last three decades](#). Energy & Environment. 2025, 36:93-131. [10.1177/0958305X231177734](#)
17. Li YA: [International trade, technology diffusion, and the role of diffusion barriers](#). SSRN Electronic Journal. 2011, [10.2139/ssrn.1978304](#)
18. Machado RH, Cavaleiro EA, Corrêa ÉK, Kontz LB: [Integrating economic development, innovation, and environmental performance for sustainable futures: Insights from a global study](#). International Journal of Economics and Finance. 2024, 16:16. [10.5539/ijef.v16n8p16](#)
19. Maduka AC, Ogwu SO, Ekesiobi CS: [Assessing the moderating effect of institutional quality on economic growth-carbon emission nexus in Nigeria](#). Environmental Science and Pollution Research. 2022, 29:64924-64938. [10.1007/s11356-022-20346-3](#)
20. Mishra A, Vikram K: [Environmental impact, sustainability, and future direction](#). Sustainable Manufacturing Processes. Kalita K (ed): De Gruyter, 2024. 163-172. [10.1515/9783111335537-008](#)
21. Mitić P, Kresoja M, Minović J: [A literature survey of the Environmental Kuznets Curve](#). Economic Analysis. 2019, 52:109-127. [10.28934/EA.19.52.12.PP109-127](#)
22. Muluh GA, Miafo Dieubenit T, Gildas NT: [Technological innovations and structural transformation in African economies](#). International Journal of Innovative Technologies in Economy. 2022, 2:[10.31435/rsglobal_ijite/30062022/7833](#)
23. Noeth K: [The pathways to decarbonizing key sectors](#). The ESG and Sustainability Deskbook for Business. Apress, Berkeley, CA; 2024. [10.1007/979-8-8688-0261-4_16](#)
24. Oqubay A: [Introduction to industrial hubs and economic catch-up](#). Palgrave Macmillan, 2025. [10.1007/978-3-031-84624-3_1](#)
25. Pasten R, Figueroa BE: [The Environmental Kuznets Curve: A survey of the theoretical literature](#). International Review of Environmental and Resource Economics. 2012, 6:195-224. [10.1561/101.000000051](#)
26. Peng S, Qian J, Xing X, Wang J, Adeli A, Wei S: [Technological cooperation for sustainable development under the Belt and Road Initiative and the Sustainable Development Goals: Opportunities and challenges](#). Sustainability. 2025, 17:657. [10.3390/su17020657](#)
27. Pesce A: [The decoupling of emerging economies: Theoretical and empirical puzzle](#). Journal of Economic Surveys. 2017, 31:602-631. [10.1111/joes.12165](#)
28. Ruzieva M, Ruziev U: [Assessing environmental problems: Primary indicators and their role in ecosystem management](#). E3S Web of Conferences. 2024, 587:02012. [10.1051/e3sconf/202458702012](#)
29. Sah MR: [Effects of institutional quality on environmental protection in CEMAC countries](#). Modern Economy. 2021, 12:903-918. [10.4236/me.2021.125045](#)
30. Satria AP: [Environmental quality protection in the period of industrialization to realize environmental-based industry](#). UNIFIKASI: Jurnal Ilmu Hukum. 2020, 6:156. [10.25134/unifikasi.v6i2.1962](#)
31. Secka EG: [Measurement of national innovation systems performance trends in Sub-Saharan Africa: A multidimensional study](#). University of North Texas, 2023. [10.12794/metadc2137544](#)
32. Şeker M: [What the National Technology Initiative brings to Türkiye](#). Şeker M (ed): 2022. 1:81-96. [10.53478/tuba.978-625-8352-17-7.ch05](#)
33. Setyari NPW, Kusuma WGA: [Economics and environmental development: Testing the Environmental Kuznets Curve hypothesis](#). International Journal of Energy Economics and Policy. 2021, 11:51-58. [10.32479/ijee.11156](#)
34. Singh CD: [Developments in sustainable manufacturing management: Key concepts and tools](#). Emerald Publishing Limited, 2025. [10.1108/9781835496800](#)

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. Cureus J Bus Econ 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>

35. Sun J, Qamruzzaman M: [Technological innovation, trade openness, natural resources, clean energy on environmental sustainability: A competitive assessment between CO2 emission, ecological footprint, load capacity factor and inverted load capacity factor in BRICS+T](#). *Frontiers in Environmental Science*. 2025, 12:1520562. [10.3389/fenvs.2024.1520562](#)
36. Taşdemir F: [Industrialization, servicification, and environmental Kuznets curve: Non-linear panel regression analysis](#). *Environmental Science and Pollution Research*. 2022, 29:6389-6398. [10.1007/s11356-021-16012-9](#)
37. The Global Economy: [Economic indicators for over 200 countries](#). 2026.
38. Wang Q, Li Y, Li R: [Rethinking the environmental Kuznets curve hypothesis across 214 countries: The impacts of 12 economic, institutional, technological, resource, and social factors](#). *Humanities and Social Sciences Communications*. 2024, 11:1-19. [10.1057/s41599-024-02736-9](#)
39. Wang Y, Ning Y, Bai S: [Economic, employment, and carbon emissions trade-offs under China's dual circulation strategy](#). *Environment, Development and Sustainability*. 2025, [10.1007/s10668-025-06896-9](#)
40. Zhoumu Y, Wen-ping W, Yibo Y, Fen F: [An empirical study of Environmental Kuznets Curve in China](#). *Proceedings of the 21st International Conference on Industrial Engineering and Engineering Management*. Qi E, Shen J, Dou R (ed): Atlantis Press, Paris; 2015. [10.2991/978-94-6239-102-4_112](#)

How to cite this article:

Afful B, Alabani K (June 27, 2026) Manufacturing Upgrading, High-Tech Exports, and Environmental Sustainability: Trade-offs and Synergies. *Cureus J Bus Econ* 3 : es44404-026-00136-7. DOI <https://doi.org/10.7759/s44404-026-00136-7>