

No Robust Evidence for a GDP–Methane Relationship in Africa, 1970–2024: A Multi-Specification Test Against the Environmental Kuznets Curve and STIRPAT Frameworks

Short title: GDP and methane emissions in Africa, 1970–2024

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Abstract

The green growth hypothesis, that economic growth can be decoupled from environmental harm, is embedded in the Sustainable Development Goals and national climate strategies, yet remains contested, with recent evidence questioning whether decoupling occurs fast enough to meet climate targets. Methane policy for Africa, including the Global Methane Pledge's 22-plus African signatories, implicitly assumes some relationship between economic development and emissions

trajectories, following the Environmental Kuznets Curve (EKC) or STIRPAT/IPAT traditions. Two prior studies, each on six-country African subsamples, reported a positive GDP-methane relationship and EKC-consistent nonlinearity. We test both frameworks on a substantially larger, more representative sample: a 53-country, 1970–2024 panel (2,765 country-years) combining EDGAR CH₄ emissions with World Bank population and GDP data, analyzed via two-way fixed-effects regression with cluster-robust standard errors under four complementary specifications, a non-parametric shape check, and a formal test of parameter stability across an independently identified 1995 structural break. Population was strongly associated with CH₄ (elasticity approximately 1.06, $p < 0.001$); GDP was not significant once population was controlled for ($p = 0.082$). A nominally significant inverted-U pattern ($p = 0.025$) was supported by only 1.2% of observations from 3 of 53 countries, and lost significance ($p = 0.068$) when those countries were excluded. The canonical per-capita EKC specification showed no nonlinearity at all ($p = 0.452$), confirmed non-parametrically, and a formal interaction test found no evidence either coefficient differed before versus after 1995. Across every specification and robustness axis tested, no credible evidence supports a growth-driven methane trajectory in Africa. This provides a region- and gas-specific data point in the broader empirical debate over whether growth-compatible environmental transformation is occurring, and indicates that methane mitigation policy should rest on sector-specific interventions rather than assumptions about economic development pathways.

Author Summary

Economic growth is often expected to bring changes in environmental pressures. One influential idea proposes that environmental damage may initially increase as economies grow but later decline as countries become wealthier. We asked whether this pattern can be detected for methane emissions in Africa, where methane is an important contributor to near-term warming and an increasing focus of climate policy.

We examined methane emissions, population, and economic data for 53 African countries from 1970 to 2024. We compared several ways of testing the relationship between economic activity and methane emissions and then

examined whether any apparent pattern remained under alternative analyses. Population showed a strong and consistent association with methane emissions, whereas the relationship with total economic output was not statistically robust after population was taken into account. An apparent rise-and-fall pattern was also fragile: the observations supporting the estimated turning point came from only three countries and represented about 1% of the country-years analysed. Removing those observations eliminated conventional statistical evidence for the curved relationship. We also found no evidence of a rise-and-fall relationship when both methane emissions and economic output were expressed per person.

Our findings indicate that economic growth alone should not be assumed to produce a predictable methane trajectory across Africa, highlighting the importance of understanding the specific activities responsible for methane emissions.

Introduction

Whether continued economic growth can be reconciled with the environmental limits on which sustainability transformation depends is one of the most consequential open questions in sustainability science. The “green growth” position holds that technological change and structural shifts can decouple growth from environmental harm; this assumption is embedded directly in the Sustainable Development Goals and in most national and international climate strategies [1]. A substantial empirical literature disputes this, finding little evidence that decoupling of resource use or emissions from GDP occurs at a pace consistent with climate targets, and cautioning that policy built on an unverified decoupling assumption risk misallocating scarce transformation effort [2]. Resolving this question region by region and sector by sector rather than treating it as settled at the global, all-gas level is itself part of the sustainability-transformations research agenda, which emphasizes that transformation pathways are contextual and cannot be assumed to generalize from one setting to another [3].

Methane (CH₄) is a useful and policy-relevant test case for this broader question. It is responsible for roughly a quarter of observed global warming to date, with a warming potency approximately

80 times that of CO₂ over a 20-year horizon [4], making it the primary near-term lever for limiting peak warming independent of long-run decarbonization. This urgency motivated the Global Methane Pledge, launched at COP26 (2021), through which over 150 countries including at least 22 African states committed to cutting methane emissions 30% below 2020 levels by 2030 [4]; subsequent assessments in 2024–2025 report the world off-track for this target [4]. Whether methane mitigation in Africa's Pledge signatories can be expected to accompany continued economic development, as a green-growth-consistent story would suggest, or instead requires deliberate, growth-independent intervention, is not a settled question empirically it is precisely the kind of context-specific test the transformations literature argues must be done directly rather than assumed [3].

Two theoretical frameworks dominate the relevant economics literature on growth-emissions relationships. The Environmental Kuznets Curve (EKC) hypothesis, following Grossman and Krueger's foundational analysis of income and pollution [5], proposes that environmental degradation initially rises with economic growth before declining past some income threshold an early, influential version of the green growth argument. The STIRPAT/IPAT framework [6], developed independently in environmental sociology, instead decomposes environmental impact into population, affluence, and technology terms without assuming a specific nonlinear shape, typically finding population elasticities near unity and, in York et al.'s original cross-national CO₂ analysis, no EKC turning point for total emissions [6].

Two prior studies have applied EKC-style tests to African methane specifically. Djoumessi Djoukouo [7] found cointegration and bidirectional causality between CH₄ and GDP per capita in six CEMAC countries (1980–2018), with the EKC turning point “not yet reached.” Yusuf, Abubakar, and Mamman [8] found a significant positive long-run GDP effect and EKC-consistent

nonlinearity for methane specifically, in six African oil-producing economies (1970–2016). Both studies are informative for their samples but leave two questions open: whether their findings generalize across Africa's much broader range of economic structures (53 countries, not 6), and whether their nonlinear estimates are robust to the removal of individual high-leverage countries a vulnerability Stern's influential EKC critique [9] identifies as endemic to the wider literature, since turning points estimated from a limited income range are frequently artifacts of a handful of extreme observations.

This study tests both the STIRPAT and canonical EKC frameworks, in both linear and quadratic form, on the full continental sample, with an explicit fragility test for any detected nonlinearity and a formal test of parameter stability across time addressing both open questions directly, and providing a concrete, sector-specific data point in the wider green-growth debate that motivates it.

Results

Sample and descriptive trends

The regression sample comprised 2,765 country-years across 53 countries. Continental CH₄ rose from 20,717 Gg (1970) to 47,711 Gg (2024), +130.3% (compound annual growth rate 1.56% yr⁻¹). Over the same period, continental CH₄ per capita fell 44.5% (57.3 to 31.8 kg person⁻¹ yr⁻¹) and CH₄ intensity (per unit GDP, 44 GDP-complete countries) fell 60.2% both consistent with population and GDP growing faster than absolute CH₄, though not, by themselves, establishing a robust statistical GDP–CH₄ relationship (see below).

Linear specification

Table 1 reports the linear models. With GDP alone (Model A), the coefficient was positive but only marginally significant ($\beta=0.454$, $SE=0.242$, $p=0.061$). Once population was included (Model B), the GDP coefficient attenuated further and lost significance at conventional thresholds ($\beta=0.371$, $SE=0.214$, $p=0.082$; 95% CI -0.047 to 0.790), while population showed a strong, highly significant, approximately proportional association with CH₄ ($\beta=1.058$, $SE=0.181$, $p<0.001$).

ln(GDP) and ln(Population) were correlated in levels ($r=0.825$) but the within-transformed variance inflation factor was 1.06, ruling out collinearity as the explanation for the GDP coefficient's attenuation.

Table 1. Linear and quadratic STIRPAT-style fixed-effects models (total CH₄ as a function of total GDP, with and without population).

Model	Variable	Coefficient	Cluster-robust SE	p	Within R ²
A: ln(GDP) only	ln(GDP)	0.454	0.242	0.061	0.188
B: ln(GDP) + ln(Pop)	ln(GDP)	0.371	0.214	0.082	0.288
B: ln(GDP) + ln(Pop)	ln(Population)	1.058	0.181	<0.001	0.288
C: quadratic, no pop	ln(GDP)	1.874	1.079	0.083	0.219
C: quadratic, no pop	ln(GDP) ²	−0.032	0.021	0.121	0.219
D: quadratic + pop	ln(GDP)	2.075	0.889	0.020	0.331
D: quadratic + pop	ln(GDP) ²	−0.039	0.017	0.025	0.331
D: quadratic + pop	ln(Population)	1.131	0.183	<0.001	0.331

The apparent EKC pattern is not robust
Model D's quadratic term implies a turning point at ln(GDP)=26.57 (≈\$345 billion total GDP, constant 2015 US\$). Only 33 of 2,765 country-years (1.2%) exceed this threshold, from exactly 3 of 53 countries (Table 2). Excluding these three entirely, the quadratic term loses significance (Table 3): $\beta=-0.039$, $SE=0.021$, $p=0.068$.

Table 2. Country-years exceeding the implied Model D turning point.

Country	Years	N
Nigeria	2009–2024 (contiguous)	16
Egypt	2017–2024 (contiguous)	8
South Africa	2015–2019, 2021–2024 (2020 excluded GDP data gap)	9

Table 3. Model D re-estimated excluding Nigeria, Egypt, and South Africa (N=2,600, 50 countries).

Variable	Coefficient	Cluster-robust SE	p
ln(GDP)	2.072	1.060	0.051
ln(GDP) ²	−0.039	0.021	0.068
ln(Population)	1.172	0.194	<0.001

Canonical per-capita EKC specification

Table 4 reports the canonical per-capita models. This specification shows no significant linear or nonlinear association at all a cleaner null than the STIRPAT-style models, and one entirely independent of the turning-point fragility issue above, since Model F's quadratic term is not even signed consistently with an inverted-U (positive, not negative).

Table 4. Linear and quadratic canonical EKC fixed-effects models (CH₄ per capita as a function of GDP per capita).

Model	Variable	Coefficient	Cluster-robust SE	p	Within R ²
E: linear	ln(GDP per capita)	0.360	0.224	0.109	0.134
F: quadratic	ln(GDP per capita)	−0.215	0.721	0.765	0.139
F: quadratic	ln(GDP per capita) ²	0.039	0.052	0.452	0.139

Binning within-transformed CH₄-per-capita residuals by GDP-per-capita decile produced a sign pattern across consecutive deciles of [−,+,+,+,−,+,+,−,+] not the single-peak, monotonic-rise-then-fall pattern a genuine inverted-U would produce. This confirms the absence of nonlinearity is not an artifact of the parametric functional form chosen (S1 Table).

Structural stability across the 1995 break

A naive pre-1995 (N=1,258) versus post-1995 (N=1,507) split of Model B produced visibly unstable point estimates population's coefficient was negative and non-significant pre-1995 (β =−0.108, p =0.791) but positive and non-significant post-1995 (β =0.493, p =0.196), while GDP became significant only post-1995 (p =0.0007 versus p =0.195). Taken at face value this would undermine confidence in the pooled Model B result. However, this comparison is underpowered (roughly half the sample and half the within-country year variation in each half). A formal, adequately-powered interaction test adding GDP×post-1995 and Population×post-1995 terms to the full pooled model found no significant evidence that either coefficient differs across the break (GDP×post-1995: p =0.111; Population×post-1995: p =0.798; Table 5). The naive split's apparent

instability reflects estimation noise from reduced power, not a genuine change in the underlying relationship.

Table 5. Formal test of parameter stability across the 1995 structural break.

Variable	Coefficient	Cluster-robust SE	p
ln(GDP) [pre-1995 baseline]	0.398	0.199	0.045
ln(Population) [pre-1995 baseline]	1.110	0.258	<0.001
ln(GDP) × post-1995	−0.100	0.063	0.111
ln(Population) × post-1995	0.019	0.072	0.798

Discussion

Across four model specifications, a non-parametric shape check, and a formal structural-stability test, this analysis finds no robust evidence for either a linear or EKC-consistent nonlinear relationship between GDP and methane emissions in Africa a materially different conclusion from both prior African methane studies [7,8], neither of which tested a sample broader than six countries or checked whether their nonlinear estimates survived the removal of high-leverage observations. Where Model D's quadratic term appeared nominally significant, it was generated entirely by 3 of 53 countries at the extreme of the income distribution, precisely the failure mode Stern's critique identifies as endemic to the EKC literature [9]. The canonical per-capita specification the field's own standard form showed no nonlinearity at all, reinforcing that this is not a specification-dependent artifact.

Population, in contrast, showed a stable, near-unit elasticity ($\approx 1.06\text{--}1.17$) across every STIRPAT-style specification tested, including across the formal pre/post-1995 stability check. This is not a mechanical or trivial finding: York et al. [6] report a strikingly similar population elasticity (1.149) for global CO₂ using the same framework, suggesting a genuine, externally-corroborated empirical regularity proportional scaling of emissions with population rather than an artifact specific to this sample or gas.

These results bear directly on the broader green growth debate that motivates this study. Hickel and Kallis's influential review [2] finds no global empirical evidence that absolute decoupling of GDP from resource use or emissions occurs at a pace consistent with climate targets, and argues that decoupling claims embedded in policy including, by extension, the Sustainable Development Goals [1] are not well supported by the available evidence. The present analysis extends this question to a specific gas, region, and policy instrument: African methane and the Global Methane Pledge. The finding is consistent with the wider decoupling skepticism in [2]: growth does not appear to carry an automatic methane dividend in this sample, whether through a simple linear channel or an eventual EKC-style turning point. Within the sustainability-transformations framing that emphasizes context-specific, deliberately governed pathways rather than assumed, growth-driven trajectories [3], this is an argument for treating methane mitigation as a distinct transformation target requiring its own governance and investment, not an anticipated by-product of economic development.

Policy implications

These results speak directly to the Global Methane Pledge's implicit theory of change for its African signatories. If methane emissions do not predictably track GDP neither monotonically nor via an eventual income-driven turning point then neither “grow now, mitigate later” nor “degrowth will resolve emissions” describes this sample's actual dynamics. Sector-specific, growth-independent mitigation fossil-fuel leak detection and flaring reduction, livestock management, landfill-gas capture [14,15] remains justified on its own technical merits regardless of a country's growth trajectory, and should not be deprioritized pending, or predicated on, any particular development pathway.

Limitations

All associations reported are conditional correlations from an observational panel, not causal estimates; two-way fixed effects address time-invariant confounding and common shocks but not time-varying endogeneity or reverse causality, which prior cointegration-based studies [7] suggest may exist. EDGAR, as a bottom-up inventory, carries greater uncertainty for data-sparse, non-OECD countries [12], uncertainty not propagated into the confidence intervals reported here. The GDP panel is unbalanced (44 of 53 countries fully covered); two-way fixed-effects estimation accommodates this without bias under standard assumptions not separately tested here. With 53 country clusters, cluster-robust inference is in the range generally considered adequate in the applied econometrics literature [13], though we did not implement a wild-cluster bootstrap as a further check, which would be a reasonable addition for future work. Finally, a single-region, single-gas null result cannot resolve the global green growth debate; it contributes one rigorously-tested data point to a question that, per the transformations literature [3], must be answered context by context rather than assumed to generalize in either direction.

Conclusion

Testing both the Environmental Kuznets Curve and STIRPAT frameworks, in both linear and quadratic form, with explicit fragility and structural-stability checks absent from prior African methane studies, this analysis finds no credible evidence that economic growth predicts methane emissions trajectories in Africa, whether directly or through an eventual income-driven turning point. Population is the one variable robustly associated with methane growth across every test applied. These findings add a rigorously-tested, region- and gas-specific data point to the wider empirical debate over whether growth-compatible environmental transformation can be assumed rather than governed [2,3]. Methane policy for Africa including under the Global Methane Pledge

should be built on sector-specific mitigation levers rather than assumptions about the continent's growth trajectory.

Materials and Methods

Data sources

Monthly CH₄ emissions (Gg) were obtained from the EDGAR Community GHG Database, 2025 release, IPCC 2006 sector taxonomy [10], and aggregated to annual country totals, 1970–2024. Population (SP.POP.TOTL) and GDP, constant 2015 US\$ (NY.GDP.MKTP.KD) were obtained from the World Bank World Development Indicators [11]. As a bottom-up emissions inventory, EDGAR carries known, larger uncertainty for data-sparse, non-OECD countries [12], a general limitation of the source data addressed further in the Discussion.

Sample construction

The analytical sample comprises 53 sovereign African countries, derived from EDGAR's regional grouping after excluding four non-sovereign territories (Mayotte, Réunion, Saint Helena, Western Sahara) and correcting a regional-grouping error that had conflated UN M49 Western and Middle/Central Africa. Population data are complete for all 53 countries across the full period; GDP data are complete for 44 of 53 countries across the full 1970–2024 period, with partial early-period gaps for the remaining 9. The regression sample uses all available complete-case country-years (N=2,765) rather than restricting to the balanced 44-country subset, since two-way fixed-effects estimation accommodates an unbalanced panel without bias, provided missingness is not systematically related to the outcome conditional on the fixed effects a standard assumption we do not further test here and note as a limitation.

Panel regression models

The primary analysis estimates two-way (country and year) fixed-effects models of the form $\ln(\text{CH}_{4i}) = \alpha_i + \lambda_t + f(\text{GDP}_i) + \varepsilon_{it}$, where α_i are country fixed effects, λ_t are year fixed effects, and $f(\cdot)$ is either linear (Models A, B) or quadratic (Models C, D) in $\ln(\text{GDP})$, with Models

250 B and D additionally including $\ln(\text{Population})$. A parallel set of models (E, F) tests the canonical
 251 per-capita EKC specification directly: $\ln(\text{CH}_4 \text{ per capita})$ as a function of $\ln(\text{GDP per capita})$,
 252 linear and quadratic. Estimation used the within (iterative alternating-projections demeaning)
 253 transformation, appropriate for an unbalanced panel, with cluster-robust standard errors by country
 254 [13] to account for arbitrary within-country serial correlation. A variance inflation factor was
 255 computed on the within-transformed regressors to rule out collinearity between $\ln(\text{GDP})$ and
 256 $\ln(\text{Population})$ as an alternative explanation for any attenuation of the GDP coefficient.

257 **EKC turning-point robustness check**
 258 For each quadratic specification, the implied turning point (the value of $\ln(\text{GDP})$ at which the
 259 estimated relationship changes sign) was computed as $-\beta_1/(2\beta_2)$. The proportion of country-years
 260 exceeding this turning point, and the specific countries contributing them, were identified directly.

261 As a robustness check absent from prior African methane-EKC studies, Model D was re-estimated
 262 after excluding the countries responsible for all above-turning-point observations, to test whether
 263 the quadratic term's significance depends on their inclusion.

264 **Non-parametric shape check**
 265 Within-transformed $\ln(\text{CH}_4 \text{ per capita})$ and $\ln(\text{GDP per capita})$ were binned into deciles of GDP
 266 per capita, examining whether the pattern of decile means shows a coherent monotonic-rise-then-
 267 fall shape independent of the parametric quadratic functional form.

268 **Structural stability test**
 269 A pooled specification adding $\text{GDP} \times \text{post-1995}$ and $\text{Population} \times \text{post-1995}$ interaction terms to
 270 Model B tested whether either coefficient differs significantly before versus after the continental
 271 CH_4 trajectory's independently-identified 1995 structural break (identified via changepoint
 272 analysis in a related companion study using the same underlying emissions panel). This formal
 273 interaction test, rather than a simple pre/post sample split, is the statistically appropriate approach

to testing parameter stability, since it retains the full sample's statistical power rather than halving it.

Software

All analyses were performed in Python 3 (pandas, NumPy, SciPy). No pre-built implementation of the two-way fixed-effects estimator with cluster-robust standard errors was available in the analysis environment; this was implemented directly from Cameron and Miller [13] and validated by convergence diagnostics on the demeaning transformation (S1 Code).

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We further appreciate colleagues and research peers who provided discussions and constructive intellectual feedback during the development of the study. The authors are responsible for the analytical approach, statistical analyses, interpretation of results, and conclusions presented in this manuscript.

Author Contributions

Conceptualization: Afeez Olabisi Yusuf. Data curation: Kofoworola Funmilayo Odutayo. Formal analysis: Ahmed Olaniyi Yusuf. Methodology: Peter Adedayo Oladetuyi. Writing – original draft: Peter Adedayo Oladetuyi. Writing – review & editing: Kofoworola Funmilayo Odutayo, Ahmed Olaniyi Yusuf, Peter Adedayo Oladetuyi.

Data Availability Statement

All data and code required to reproduce the findings reported in this manuscript are provided as Supporting Information (S1 Data, S1 Code) and are additionally available at <https://doi.org/10.5281/zenodo.22973129>. The package includes the fully merged, analysis-ready country-year panel (EDGAR CH₄ emissions merged with World Bank WDI population and GDP data, 53 African countries, 1970–2024) and a single Python script that reproduces every table and statistic reported in this manuscript deterministically (no stochastic procedures are used). Raw source data (EDGAR Community GHG Database, World Bank World Development Indicators) are third-party data, both licensed CC BY 4.0, and their full provenance, retrieval details, and original files are documented in a companion repository for a related manuscript using the same underlying source panel, cited in the Supporting Information.

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Competing Interests

The authors have declared that no competing interests exist.

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Supporting Information

S1 Data. Analysis-ready country-year panel (CH₄ emissions, population, GDP; 53 African countries, 1970–2024) used to produce every table in this manuscript. (CSV)

S1 Code. Single Python script reproducing every table and statistic reported in the manuscript from S1 Data, deterministically. (PY)

S1 Table. Full decile-binned non-parametric check output (mean within-transformed ln(CH₄ per capita) and ln(GDP per capita) by GDP-per-capita decile). (CSV)