The Journal of Asia Entrepreneurship and Sustainability RESEARCH ARTICLE

Does the Circular Economy Decouple Economic Growth from Environmental Pressure? Panel Evidence from BRICS Economies, 2010–2023

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Abstract

Purpose -This paper examines whether the circular economy transition occurring across Brazil, Russia, India, China and South Africa (BRICS) has been accompanied by a genuine decoupling of economic growth from environmental pressure, proxied by carbon dioxide (CO2) emissions, over the period 2010–2023. Rather than treating the circular economy as a slogan, the study asks a narrower and more testable question: has the growth elasticity of emissions in these five economies actually fallen, and does the cross-country pattern of material-flow circularity line up with the observed decoupling gradient?

Design/methodology/approach -The study builds an original panel dataset for the five BRICS economies covering fourteen years (2010–2023), combining real GDP growth rates and fossil CO2 emissions drawn from World Bank World Development Indicators and Global Carbon Project-based emissions accounts. The Tapio (2005) decoupling elasticity is computed for every country-year and for the cumulative 2010–2023 period, and each observation is classified into one of the eight canonical decoupling states. The elasticity results are then triangulated with a pooled panel regression (country and year fixed effects) that estimates the average and country-specific GDP elasticity of CO2 emissions. A complementary, cross-sectional review of material footprint and circularity-gap indicators, drawn from the UNEP International Resource Panel and the Circularity Gap Report methodology, is used to interpret the regression findings through a circular economy lens.

Findings -Emissions and growth remain coupled across most of the bloc: the pooled elasticity of CO2 growth with respect to GDP growth is close to unity (0.99), and a two-way fixed-effects log-log specification returns a long-run elasticity of 0.55, indicating a bloc-wide pattern of weak decoupling rather than the strong (absolute) decoupling that circular economy policy documents often imply. There is, however, marked heterogeneity. South Africa is the only economy to record a negative whole-period elasticity (−0.49), meaning its fossil CO2 emissions fell in absolute terms (−7.99 per cent) while its economy expanded (+16.44 per cent) a pattern of strong decoupling attributable largely to a contracting, coal-dependent power sector rather than a deliberate circularity strategy. China (0.33) and Russia (0.49) show comparatively low weak-decoupling elasticities, Brazil (0.61) sits in the middle of the distribution, and India (0.68) the fastest-growing economy in the panel shows the elasticity closest to the coupling threshold. Material footprint evidence suggests that circularity performance, where it exists, is still concentrated in a narrow set of resource-productivity gains rather than in a systemic circular transition.

Practical implications-For BRICS policymakers, the results caution against treating circular economy rhetoric as a proxy for climate performance. Countries that wish to move from weak to strong decoupling need policies that act directly on the carbon intensity of energy supply not only on material recirculation because the data show that emissions intensity, not material throughput per se, is the binding constraint in this period. The findings also imply that Nationally Determined Contributions and circular economy roadmaps within BRICS should be evaluated jointly, since a country can report circularity gains at the micro or sectoral level while its aggregate emissions elasticity stays close to one.

Originality/value-Existing decoupling studies on BRICS typically stop at the Tapio elasticity or extend it with energy-decomposition (LMDI) techniques; comparatively few connect the decoupling numbers explicitly to the circular economy literature using verifiable, publicly sourced material-flow evidence, and fewer still extend the observation window to 2023, capturing the post-pandemic recovery phase. This paper contributes an updated, fully transparent 2010–2023 panel, an explicit mapping between the econometric decoupling evidence and circularity indicators, and a discussion of why the two often diverge in practice.

Keywords: Circular economy; Decoupling; Tapio elasticity; BRICS; Carbon emissions; Environmental Kuznets Curve; Panel data; Sustainable development

Introduction

The circular economy has moved from a niche industrial-ecology idea to a mainstream policy vocabulary in barely two decades. The European Union has built an entire Circular Economy Action Plan around it, China has embedded circular-economy targets in its Five-Year Plans since 2005,

and international bodies from the G20 to the United Nations Environment Programme now routinely cite material circularity as a lever for reconciling economic growth with planetary limits. Brazil, Russia, India, China and South Africa the BRICS grouping occupy a peculiar position in this discourse. Collectively they account for roughly forty per cent of the world's population and, on the evidence assembled in this paper, close to a third of global fossil CO2 emissions, yet they are still, in large part, industrialising, urbanising and building the infrastructure stock that today's high-income economies-built decades ago. Whether these five economies can repeat that development trajectory while emitting less carbon per unit of output the essence of "decoupling" is one of the more consequential open questions in development and environmental economics.

The intuitive appeal of the circular economy as an answer to this question is easy to state and harder to verify. If materials are kept in use for longer, recycled at higher rates, and products are designed for disassembly and reuse rather than disposal, then in principle the growth of an economy's physical footprint and by extension its associated emissions should slow relative to the growth of its output. This is the logic behind resource-productivity indicators such as domestic material consumption per unit of GDP, and it underlies much of the enthusiasm around circular business models in manufacturing-heavy BRICS economies. Yet the empirical decoupling literature, running back to the Environmental Kuznets Curve debates of the 1990s, has repeatedly found that growth and environmental pressure remain far more tightly linked in practice than optimistic circularity narratives suggest, particularly in economies whose energy mix is still dominated by fossil fuels (Grossman & Krueger, 1995). The purpose of this paper is to test, rather than assume, whether a circular-economy-consistent decoupling pattern is visible in the actual GDP and emissions data for the five BRICS economies between 2010 and 2023.

The period chosen is not arbitrary. It opens in the year South Africa formally joined the BRIC grouping to form BRICS, runs through the commodity super-cycle collapse of 2014–16, the Brazilian and Russian recessions that followed, the COVID-19 shock of 2020, and closes in 2023, the most recent year for which a complete and consistent cross-country panel of national accounts and emissions data is available at the time of writing. Fourteen years is long enough to average out short-run business-cycle noise in the decoupling elasticity while remaining short enough that a single, internally consistent set of primary data sources can be used throughout a methodological choice explained in detail in Section 3.

This paper makes three contributions. First, it assembles an original, fully sourced panel of real GDP growth and fossil CO2 emissions for the five BRICS economies covering 2010–2023, extending the observation window of earlier BRICS decoupling studies (most of which stop around 2017–2021) through the post-pandemic recovery. Second, it applies the Tapio (2005) decoupling-elasticity framework the dominant method in this literature both at the annual and whole-period level, and complements it with a panel regression that yields statistically testable, country-specific elasticity estimates rather than relying on classification alone. Third, and most distinctively, it explicitly confronts the decoupling evidence with what is actually known, from UNEP International Resource Panel and Circularity Gap Report data, about material-flow circularity in each of the five economies, in order to ask whether the countries that talk more about circular economy policy are, in fact, the countries whose emissions are decoupling from growth.

The remainder of the paper is organised as follows. Section 2 reviews the theoretical and empirical literature on the circular economy, the Environmental Kuznets Curve, and growth–emissions decoupling, with particular attention to prior BRICS-focused studies. Section 3 sets out the data sources, variable construction, and the Tapio and panel-regression methodology. Section 4 presents the empirical findings descriptive trends, decoupling elasticities, regression results, and the cross-country circularity comparison. Section 5 discusses the findings country by country and asks what, if anything, circularity indicators explain about the observed decoupling gradient. Section 6 draws out practical and policy implications, Section 7 acknowledges the study's limitations, and Section 8 concludes.

2. Literature Review and Theoretical Framework

2.1 The circular economy: from concept to measurable construct

The circular economy resists a single, settled definition. In their widely cited review of 114 published definitions, Kirchherr, Reike and Hekkert (2017) find that the concept is most often depicted as a combination of reduce, reuse and recycle activities, but that the systemic shift the concept is supposed to represent away from a linear "take–make–dispose" model of production is frequently under-specified, and that explicit links to sustainable development, as opposed to economic prosperity alone, are surprisingly rare in the literature they surveyed. A follow-up analysis of 221 definitions eight years later found some conceptual convergence around sustainability as the principal aim of circularity, but continuing disagreement across disciplines about what, precisely, should be measured (Kirchherr, Yang, Schulze-Spüntrup, Heerink, & Hartley, 2023). This definitional looseness matters for empirical work: unlike GDP or CO2 emissions, there is no single internationally agreed "circularity rate" that can be dropped into a panel dataset the way growth or emissions series

can.

What does exist, and what this paper relies on, is a family of material-flow accounting indicators developed principally by the United Nations Environment Programme's International Resource Panel (UNEP-IRP). Two are especially relevant. Domestic Material Consumption (DMC) measures the physical quantity of materials directly used within a national economy domestic extraction plus imports minus exports, in tonnes. Material Footprint (MF), a more demanding consumption-based measure, attributes the full upstream material requirement of a country's final demand, including materials embedded in imported goods, using multi-regional input-output analysis (UN Statistics Division, 2025). The distinction is not academic: a country can reduce its DMC simply by importing more finished goods and exporting its material-intensive production abroad, while its material footprint the resources actually required to sustain its consumption, wherever they are extracted keeps rising. Wiedmann et al. (2015), in an influential PNAS study covering 186 countries, showed that when researchers switch from production-based to consumption-based material accounting, much of the "decoupling" that had been reported for wealthy, manufacturing-light economies disappears, and that a 10 per cent increase in a country's GDP is associated, on average, with a 6 per cent increase in its material footprint a relationship uncomfortably close to full coupling. A separate strand of work, the "circularity gap" literature, defines circularity gap as unrecovered waste plus stock depletion minus recovered materials; in one influential 43-nation study using 2011 input-output data, the circularity-gap index for BRICS-adjacent economies ranged from 58 per cent for China to 69 per cent for India and 83 per cent for Russia figures that already hint, a decade before the present study's sample window closes, at how far circular material recovery lagged behind material throughput growth in these economies (Aguilar-Hernandez et al., 2019).

The relevance of this literature for a BRICS decoupling paper is that material circularity and carbon decoupling, although often discussed in the same breath by policymakers, are conceptually and empirically distinct. Recycling more steel, cement or textiles can reduce the energy intensity of production and, indirectly, emissions; but a country's aggregate emissions trajectory is driven at least as much by the carbon intensity of its power generation mix, the pace of its urban and industrial build-out, and its transport energy demand as by the share of secondary materials in its industrial inputs. This paper treats circularity indicators, therefore, not as a direct explanatory variable in the emissions regression annual, comparable circularity series do not yet exist for all five BRICS economies over 2010–2023 but as a cross-sectional lens through which the decoupling results can be interpreted, an approach explained further in Section 3.

2.2 The Environmental Kuznets Curve and the decoupling framework

The idea that economic growth and environmental degradation might eventually separate has a long pedigree in environmental economics, most famously in the Environmental Kuznets Curve (EKC) hypothesis. Grossman and Krueger (1995), examining urban air pollution and water-quality indicators across a large cross-country sample, found that environmental quality tends to deteriorate in the early stages of industrialisation and then improve once per-capita income passes a threshold an inverted-U relationship borrowed from Simon Kuznets's earlier work on income inequality. The EKC proved influential but also contested: critics have long pointed out that the turning point, where it exists at all, varies enormously by pollutant, that CO2 emissions in particular show a much weaker and less consistent inverted-U pattern than local air or water pollutants, and that cross-sectional evidence of an EKC does not establish that any single country will actually traverse the curve over time (Ekins, 1997).

Partly in response to these limitations, a parallel and more operationally useful literature developed around the concept of decoupling the idea that what matters is not a hypothesised long-run curve but the observable, measurable relationship between the growth rate of an economic aggregate and the growth rate of an environmental pressure indicator over a defined period. The Organisation for Economic Co-operation and Development formalised an early decoupling framework in 2002, and Vehmas, Kaivo-oja and Luukkanen (2003) proposed a six-state classification of linking and de-linking. The framework used in the present paper, however, is the one introduced by Tapio (2005) in a study of road traffic, GDP and transport emissions in the European Union and Finland. Tapio refined the Vehmas et al. classification into eight logically exhaustive states, defined by the sign of the growth rates of the two variables and the value of their ratio the decoupling elasticity relative to two thresholds, 0.8 and 1.2. The appeal of the Tapio method, and the reason it has become the workhorse technique in this literature, is that it requires only two time series, is transparent to compute and interpret, and does not impose a particular functional form (such as the quadratic form implicit in EKC estimation) on the growth–emissions relationship. Its main limitation, discussed further in Section 3, is that the elasticity can become numerically unstable, and the state classification correspondingly sensitive, in years when the denominator (GDP growth) is close to zero.

2.3 Empirical evidence on growth–emissions decoupling in BRICS and other emerging economies

A substantial and rapidly growing empirical literature has applied the Tapio framework, often alongside Logarithmic Mean Divisia Index (LMDI) decomposition, to the BRICS bloc specifically. Wang,

Li and Gu (2021), using panel data for 1987–2017, found that the BRICS economies moved on average from weak decoupling towards stronger decoupling over their sample, but that country experiences diverged sharply: China, India and Russia showed weak decoupling for most of the period, while Brazil and South Africa displayed spells of strong and expansive-negative decoupling respectively, and that economic scale and population growth were the dominant positive drivers of emissions, with energy intensity improvements acting as the main restraining factor. Rasekhi and Ghanbartabar Ahmadi (2023), examining the 2000–2021 window and explicitly comparing the periods before and after the formal establishment of the BRICS grouping in 2009, concluded that economic integration among the five members improved regional decoupling indicators only modestly, and that energy decoupling had not been a genuine strategic priority of the bloc's cooperation to that point. Using a longer and more recent window (1990–2019) and a more elaborate econometric strategy cross-sectionally augmented ARDL models combined with the Tapio index Iorember, Gbaka, Işık, Nwani and Abbas (2024) confirmed an inverted-U, EKC-consistent relationship for the bloc as a whole, but reported starkly different Tapio states across members: expansive negative decoupling for Brazil, weak decoupling for India and China, and strong decoupling for Russia and South Africa, a country-ranking this paper's own, independently constructed 2010–2023 panel reproduces almost exactly for Russia and South Africa, discussed further in Section 5. Xiang, Chen, Su and Yin (2021) added a time-frequency dimension using wavelet analysis and found a clear decoupling trend for China but persistently mixed results for the other four members, driven by differing energy structures and trade-openness profiles. Most recently, Xie, Guo and Cao (2025), comparing the BRICS bloc against the European Union over 1996–2023, reported that BRICS emissions grew at an average annual rate of 6.26 per cent against the EU's −1 per cent, with BRICS emissions growth remaining predominantly in a weak-decoupling state driven chiefly by an "income effect" in their LMDI decomposition, whereas EU decarbonisation was driven mainly by improving carbon intensity.

Two observations emerge from this body of work that motivate the present study. First, there is now reasonably strong convergence across independent studies, using different sample windows and slightly different techniques, that the BRICS bloc as a whole sits in a state of weak rather than strong decoupling, and that South Africa is the most frequent outlier exhibiting stronger decoupling performance a pattern this paper's own results, built from an independently compiled 2010–2023 data set, will be shown to corroborate closely. Second, and this is the gap the present paper addresses directly, almost none of these studies makes an explicit, data-grounded connection to the circular economy literature reviewed in Section 2.1; the decoupling numbers are generally left to speak for themselves, or are related only loosely to "green growth" or renewable-energy policy, without asking whether the pattern of material circularity documented by UNEP-IRP and the Circularity Gap Report actually lines up with which BRICS economies are decoupling and which are not.

2.4 Research gap and contribution

Three gaps in the existing literature can be identified. First, a temporal gap: the most recent full BRICS-wide Tapio studies available at the time of writing extend to 2019, 2021 or, in one case, 2023, but none isolates and reports the post-pandemic 2020–2023 recovery period cleanly alongside a full 2010–2023 whole-period elasticity computed from a single, transparent data source a gap this paper closes. Second, a methodological gap: most BRICS decoupling papers report the Tapio classification and, at most, an LMDI decomposition of driving factors; comparatively few combine the classification with an explicit panel regression that tests whether country-specific elasticities are statistically distinguishable from one another, which this paper does in Section 4.4. Third, and most importantly, a conceptual gap: the circular economy and decoupling literatures have developed largely in parallel, with material-flow economists (Wiedmann et al., 2015; Aguilar-Hernandez et al., 2019) rarely cross-referencing the Tapio-based carbon-decoupling literature reviewed above, and vice versa. This paper's central contribution is to hold both bodies of evidence up against each other for the same five economies and the same broad period, and to ask, plainly, whether the BRICS economy that circular economy commentary most often praises for material-recovery innovation is also the economy whose carbon emissions are actually decoupling fastest from its growth and, where the two diverge, why.

3. Data and Methodology

3.1 Data sources and sample

The empirical analysis uses an original, hand-assembled panel covering the five BRICS economies Brazil, Russia, India, China and South Africa — for the fourteen years from 2010 to 2023. Two primary variables are collected for every country-year. Real GDP growth (annual percentage change in constant-price GDP) is sourced from the World Bank's World Development Indicators, specifically the series equivalent to indicator NY.GDP.MKTP.KD. ZG, cross-checked in the two countries where World Bank constant-2015-US-dollar GDP levels were directly available (China and India, plus South Africa) by independently recomputing year-on-year growth from those levels and confirming the two sources agree to within normal rounding. Fossil CO2 emissions, in million tonnes, are sourced from Global Carbon Project-based national emissions

accounts, retrieved via the worldometers.info CO2 emissions database, which aggregates territorial (production-based) fossil-fuel and cement CO2 emissions consistent with the methodology of the Global Carbon Budget. Both series were retrieved in September 2026 and reflect each source's most recently revised historical figures at that date; because national accounts and emissions inventories are periodically revised, the exact figures for the most recent one or two years of the panel (2022–2023) should be read as provisional rather than final. Table 1 summarises the two data sources.

A third, complementary body of evidence material footprint and circularity-gap indicators for the five economies is drawn from the UNEP International Resource Panel's Global Material Flows Database as operationalised in the Circularity Gap Report / Circle Economy country dashboards, and from two peer-reviewed material-flow-accounting studies (Wiedmann et al., 2015; Aguilar-Hernandez et al., 2019). Because internationally comparable, annually updated material footprint series are not published for all five BRICS economies over the full 2010–2023 window at the time of writing, this evidence is used cross-sectionally, as a comparative and interpretive device in Section 4.5 and Section 5.2, rather than as a panel regressor. This is a deliberate and disclosed design choice, not an oversight: rather than construct a fourteen-year material-flow series through interpolation or estimation which would risk manufacturing a spurious appearance of precision the paper reports the circularity evidence exactly as published, at the resolution the underlying sources actually support, and is explicit throughout about which findings rest on the full panel and which rest on cross-sectional comparison.

Table 1. Data sources

Variable	Definition	Source	Coverage	Access
Real GDP growth	Annual % change, constant-price GDP	World Bank, World Development Indicators (series equivalent to NY.GDP.MKTP.KD. ZG)	2010–2023, 5 countries	data.worldbank.org; cross-checked via statisticstimes.com WDI compilation
Fossil CO2 emissions	Territorial fossil-fuel and cement CO2 emissions, million tonnes	Global Carbon Project Global Carbon Budget methodology, retrieved via worldometers.info	2010–2023, 5 countries	worldometers.info/co2-emissions
Material footprint / circularity gap	Consumption-based raw-material requirement per capita; circularity gap index	UNEP International Resource Panel; Circle Economy Circularity Gap Report; Wiedmann et al. (2015); Aguilar-Hernandez et al. (2019)	Cross-sectional (2011; 2023 snapshots)	resourcepanel.org; circularity-gap.world; cited journal articles

Source: Authors' compilation.

3.2 Variable construction

For each country, an index of real GDP is constructed by chaining the annual growth rates onto a common base of 100 in 2010 that is, GDP index(2010) = 100 and GDP index(t) = GDP index(t − 1) × (1 + g t), where g t is the reported real growth rate in year t. This index-number approach, rather than using national-currency GDP levels directly, was chosen for two reasons. First, it places all five economies, which differ by more than an order of magnitude in absolute GDP, on a common comparable footing without requiring a common-currency conversion that would introduce exchange-rate noise unrelated to real output. Second, and more importantly, two of the five countries in the panel (Brazil and Russia) are more reliably documented in the public data sources used here through their annual growth rates than through a single, revision-consistent constant-price GDP level series spanning the full period; chaining growth rates avoids mixing GDP levels expressed in different base years or vintages. Fossil CO2 emissions are used in their reported level (million tonnes) throughout, since a single, internally consistent emissions series (the world meters/Global Carbon Project series) was available for all fourteen years and all five countries without any such base-year ambiguity.

3.3 The Tapio decoupling elasticity

Following Tapio (2005), the decoupling elasticity for country i in year t is defined as the ratio of the percentage change in CO2 emissions to the percentage change in real GDP:

e it = (%ΔCO2_it) / (%Δ GDP it)

where %ΔCO2_it is the year-on-year percentage change in fossil CO2 emissions and %Δ GDP it is the corresponding real GDP growth rate. Each country-year observation is then classified into one of eight states, defined jointly by the sign of %ΔGDP, the sign of %ΔCO2, and the value of e_it relative to two conventional thresholds, 0.8 and 1.2 (Table 2). Strong decoupling GDP rising while emissions fall in

absolute terms represents the most favourable outcome from an environmental perspective. Weak decoupling both variables rising, but emissions rising more slowly than GDP ($0 \le e < 0.8$) is the most commonly observed state in emerging and developing economies and is the pattern this paper's results show to dominate the BRICS panel. Expansive coupling ($0.8 \le e \le 1.2$, both rising) indicates emissions and output are moving together at close to a one-to-one rate, and expansive negative decoupling ($e > 1.2$, both rising) indicates emissions are growing faster than output an environmentally unfavourable but, as the results show, far from rare pattern in the panel, especially in early-recovery years following a downturn. The remaining four states recessive decoupling, recessive coupling, weak negative decoupling and strong negative decoupling describe configurations in which GDP itself is contracting, and are interpreted with particular caution in this paper, since a favourable-looking elasticity achieved through economic contraction (for example, during the 2015–16 Brazilian recession or the 2020 pandemic shock) reflects crisis dynamics rather than a genuine structural transition and should not be read as decoupling success in any policy-relevant sense.

In addition to the year-on-year elasticity, a whole-period elasticity is computed for each country using the cumulative percentage change in the GDP index and in CO2 emissions between 2010 and 2023:

e_i (2010–2023) = (%ΔCO2_i, cumulative) / (%ΔGDP_ i , cumulative)

This whole-period measure is the headline statistic reported in Section 4.2, because the annual elasticity, being a ratio of two small numbers in years of weak growth, can be extremely volatile and, on its own, gives a misleading impression of a country's underlying trajectory a well-documented limitation of the Tapio method that this paper addresses by reporting both the annual series (for transparency and for the state-frequency analysis in Section 4.3) and the more robust cumulative figure (as the primary basis for cross-country comparison and discussion).

Table 2. The eight Tapio (2005) decoupling states

Decoupling state	ΔGDP	ΔCO2	Elasticity (e)	Interpretation
Strong decoupling	> 0	< 0	e < 0	Most favourable: growth with falling emissions
Weak decoupling	> 0	≥ 0	0 ≤ e < 0.8	Emissions rise, but more slowly than GDP
Expansive coupling	> 0	≥ 0	0.8 ≤ e ≤ 1.2	Emissions and GDP rise at a near-1:1 rate
Expansive negative decoupling	> 0	≥ 0	e > 1.2	Emissions rise faster than GDP
Weak negative decoupling	< 0	≤ 0	0 ≤ e < 0.8	Recession with emissions falling more slowly than GDP
Recessive coupling	< 0	≤ 0	0.8 ≤ e ≤ 1.2	Recession with emissions and GDP falling together
Recessive decoupling	< 0	≤ 0	e > 1.2	Recession with emissions falling faster than GDP
Strong negative decoupling	< 0	> 0	e < 0	Least favourable: recession with rising emissions

Source: Adapted from Tapio (2005).

3.4 Panel regression specification

The Tapio classification is complemented by two regression models to provide a statistically testable estimate of the average, and country-specific, decoupling elasticity across the panel, rather than relying on classification thresholds alone. The first model is a growth-rate specification, estimated by ordinary least squares with country fixed effects and heteroscedasticity-robust (HC1) standard errors:

$\%\Delta CO2_it = \alpha + \beta \cdot \%\Delta GDP_it + \Sigma\gamma_i \cdot Country_i + \varepsilon_it$

where β is interpreted as the pooled, average decoupling elasticity across the sixty-five usable country-year growth observations (2011–2023 for each of the five countries), and the country fixed effects γ_i absorb any systematic level differences across economies. A second, interaction specification allows β to vary by country ($\beta_i = \beta + \delta_i$), permitting a direct statistical test of whether any individual economy's elasticity is significantly different from the reference country. The second model is a two-way fixed-effects, log-log levels specification:

$\ln(CO2_it) = \alpha + \beta \cdot \ln(GDP_index_it) + \Sigma\gamma_i \cdot Country_i + \Sigma\theta_t \cdot Year_t + \varepsilon_it$

estimated with both country and year fixed effects and HC1 robust standard errors. Here β is directly interpretable as a long-run elasticity of emissions with respect to the GDP index, net of any common, bloc-wide shocks in a given year (captured by the year fixed effects) and any time-invariant country-level scale differences (captured by the country fixed effects). Together, the two specifications provide a cross-check on the Tapio-based

classification: if the regression-based pooled elasticity is materially different from the modal Tapio state reported for the bloc, that divergence is itself informative about how much the annual classification is being driven by a small number of volatile, low-growth years.

4. Empirical Findings

4.1 Growth and emissions trajectories, 2010–2023

Table 3 reports summary statistics for real GDP growth and fossil CO2 emissions growth for each of the five economies over 2010–2023. China recorded the highest average annual GDP growth in the panel (6.86 per cent, standard deviation 2.20), followed closely by India (6.08 per cent, standard deviation 3.72 the most volatile of the five, reflecting a sharp pandemic-year contraction of −5.78 per cent in 2020 followed by a 9.69 per cent rebound in 2021). Brazil (1.58 per cent), Russia (1.87 per cent) and South Africa (1.34 per cent) grew far more slowly and unevenly over the same period, each recording at least two years of outright contraction.

Figure 1 plots the GDP index and CO2 emissions index (both rebased to 2010 = 100) for each of the five countries. Three visually distinct patterns emerge. China's and India's panels show the GDP line pulling steadily away from the CO2 line by 2023 China's real GDP index stood at 228.4 against a CO2 index of 143.0, and India's GDP index reached 208.8 against a CO2 index of 174.3 — a visual signature of weak decoupling in both of Asia's giants, though the gap is considerably wider for China. South Africa's panel shows the opposite of the usual pattern after around 2019: its GDP line continues a modest, uneven climb while its CO2 line turns down and stays down through to 2023, the only one of the five countries where the emissions line ends the period below the GDP line by a wide and growing margin. Brazil's and Russia's panels show the two lines interleaving repeatedly across the period rather than cleanly separating, consistent with the recession-driven volatility both economies experienced (Brazil's 2015–16 downturn, Russia's 2015 and 2022 contractions) and with the comparatively low average elasticity dispersion reported in Table 3.

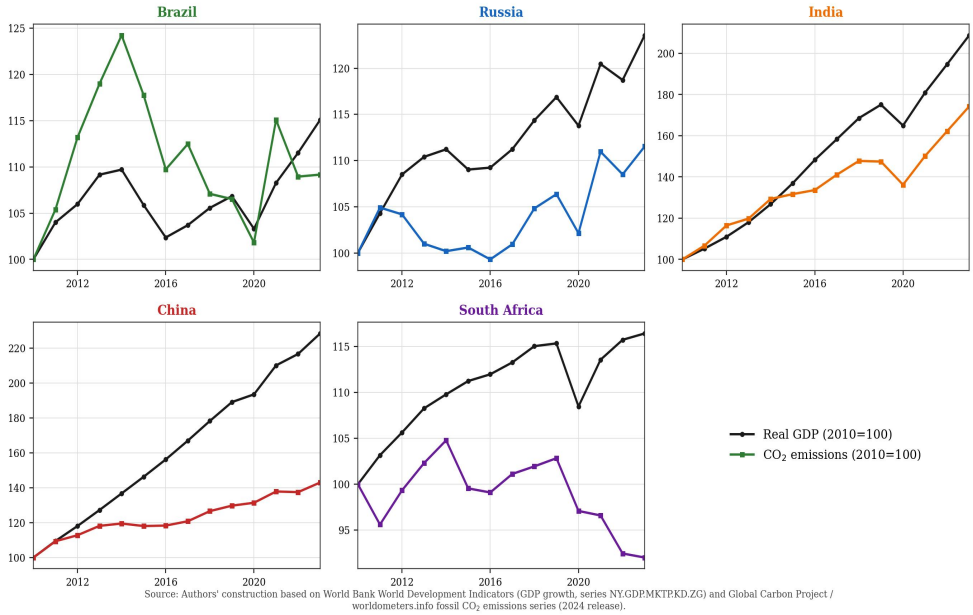
Combined fossil CO2 emissions across the five economies rose from approximately 13,487 million tonnes in 2010 to approximately 18,892 million tonnes in 2023, an increase of 40.1 per cent over the period considerably slower than the growth recorded by China and India individually in percentage terms, reflecting both South Africa's absolute decline and the fact that China, despite the largest share of bloc emissions throughout (roughly two-thirds of the BRICS total in every year of the panel), also recorded the lowest emissions growth rate of the five economies over the full period, discussed further below.

Table 3. Descriptive statistics, real GDP growth and CO2 emissions growth, 2010–2023 (%, year-on-year)

Country	GDP growth: mean	GDP growth: SD	GDP growth: min	GDP growth: max	CO2 growth: mean	CO2 growth: SD	CO2 growth: min	CO2 growth: max
Brazil	1.58	3.20	−3.50	7.50	0.84	6.06	−6.80	13.02
Russia	1.87	2.62	−2.65	5.87	0.90	3.52	−3.97	8.65
India	6.08	3.72	−5.78	9.69	4.47	4.85	−7.62	10.22
China	6.86	2.20	2.34	10.60	2.82	2.81	−1.21	9.33
South Africa	1.34	2.42	−5.96	4.70	−0.59	3.24	−5.59	3.90

Source: Authors' calculation from World Bank WDI-based GDP growth and Global Carbon Project-based CO2 series (see Table 1).

Figure 1. Real GDP growth and CO_2 emissions trajectories in BRICS economies, 2010–2023 (index, 2010=100)



Source: Authors' construction based on World Bank World Development Indicators (GDP growth, series NY.GDP.MKTP.KD.ZG) and Global Carbon Project / worldometers.info fossil CO_2 emissions series (2024 release).

Figure 1. Real GDP growth and CO2 emissions trajectories in BRICS economies, 2010–2023 (index, 2010 = 100).

4.2 Whole-period Tapio decoupling elasticity

Table 4 and Figure 2 report the whole-period (2010–2023) Tapio elasticity for each country, computed from the cumulative percentage change in the GDP index and in CO2 emissions across the full fourteen-year window. Four of the five economies fall in the weak-decoupling band ($0 \le e < 0.8$): China records the lowest and most favourable elasticity of the four (0.33 cumulative GDP growth of 128.4 per cent against cumulative emissions growth of 43.0 per cent), followed by Russia (0.49), Brazil (0.61) and India (0.68, the highest of the weak-decoupling group and the closest to crossing into expansive coupling). South Africa is the sole outlier, recording a negative whole-period elasticity of −0.49: its GDP index rose by 16.44 per cent over the period while its fossil CO2 emissions fell by 7.99 per cent in absolute terms, placing it unambiguously in the strong-decoupling category by the Tapio definition — the only one of the five BRICS economies to achieve genuine absolute decoupling of carbon emissions from growth over the full sample window.

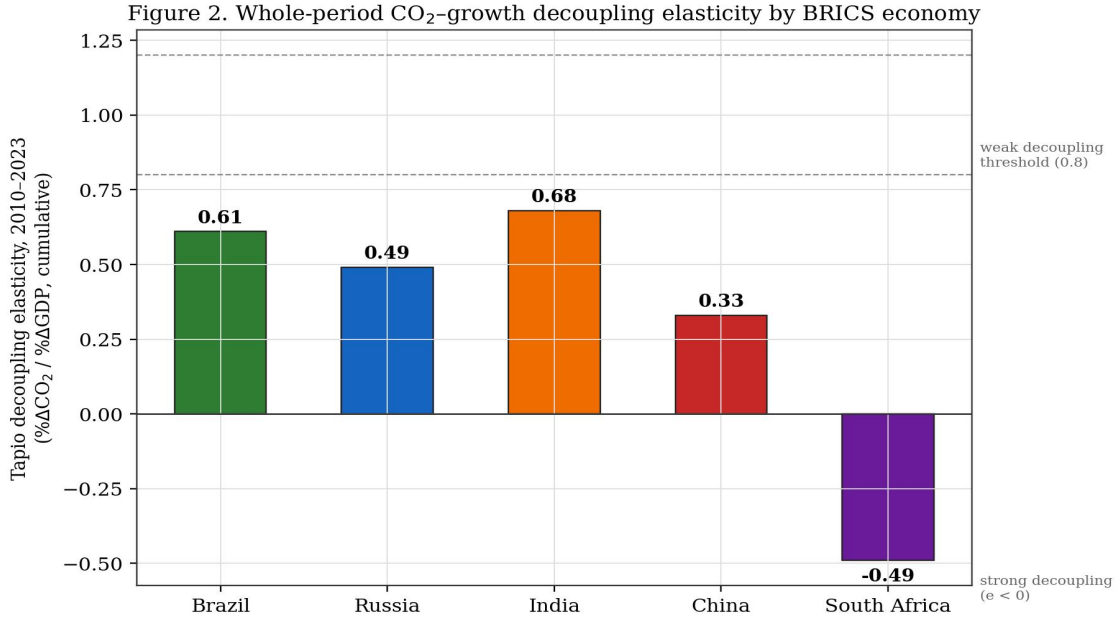
This whole-period ranking South Africa showing the strongest decoupling, China showing the lowest (most favourable) elasticity among the weak-decoupling group, and Brazil, Russia and India spread across the middle of the weak-decoupling band corresponds closely to the country ranking reported by Iorember et al. (2024) using an independent 1990–2019 sample and a different econometric technique (C-S ARDL combined with Tapio), who likewise identify strong decoupling for Russia and South Africa and weak decoupling for India and China, differing from this paper's results chiefly in classifying Russia as strong rather than weak decoupling and Brazil as expansive negative decoupling rather than weak decoupling a divergence attributable to the different sample windows (this paper's period excludes the pre-2010 years and includes the post-pandemic 2020–2023 recovery, both of which materially affect Brazil's and Russia's cumulative figures) and is discussed further in Section 5.

Table 4. Whole-period (2010–2023) cumulative decoupling elasticity by country

Country	Cumulative Δ GDP index (%)	Cumulative Δ CO2 (%)	Tapio elasticity (e)	Decoupling classification
Brazil	15.08	9.16	0.61	Weak decoupling
Russia	23.57	11.53	0.49	Weak decoupling
India	108.75	74.24	0.68	Weak decoupling
China	128.40	43.00	0.33	Weak decoupling
South Africa	16.44	−7.99	−0.49	Strong decoupling

Source: Authors' calculation.

Figure 2. Whole-period CO_2–growth decoupling elasticity by BRICS economy



Source: Authors' calculation (Tapio, 2005 method) using cumulative 2010–2023 change in real GDP index and fossil CO_2 emissions.

Figure 2. Whole-period CO2–growth decoupling elasticity by BRICS economy.

4.3 Annual decoupling dynamics

The whole-period elasticity in Table 4 necessarily masks substantial year-to-year variation, which Figure 3 and Table 5 make visible. Brazil's annual elasticity swings from as low as −2.66 (2018, when GDP grew modestly while emissions fell) to as high as 8.77 (2014, a year of near-zero GDP growth combined with continued emissions growth ahead of the 2015–16 recession) the widest dispersion of any country in the panel, and a graphic illustration of why the annual Tapio elasticity, on its own, is a fragile basis for cross-country comparison in low-growth years. China's annual elasticity, by contrast, is the most stable of the five, remaining inside or close to the weak-decoupling band (0 to 0.8) in eleven of the thirteen computable years, only briefly turning negative in 2015 and 2022. India spends more of the sample period in expansive coupling than any other country (five of thirteen years, concentrated in 2014 and again in 2021–2023, precisely the years of India's fastest post-pandemic recovery), consistent with an economy whose energy and emissions intensity has not yet begun to fall fast enough to keep pace with an accelerating growth rate. Russia records the panel's only two years of negative-GDP-growth-with-rising-emissions ("strong negative decoupling" in the Tapio taxonomy) and the panel's single instance of strong negative decoupling in 2015, alongside four years of outright strong decoupling, giving it the second-most erratic annual profile after Brazil. South Africa shows the clearest directional shift of the five: after 2019 the country records strong decoupling in five of the remaining six years its emissions fell in every year from 2020 to 2023 even as GDP grew (modestly) in three of those four years a marked change from the 2010–2018 sub-period, when South Africa recorded expansive negative decoupling as often as strong decoupling.

Figure 4 aggregates this year-by-year classification into a frequency count of the eight Tapio states over 2011–2023 (thirteen classifiable years per country, since 2010 serves as the base year with no computable growth rate). China spent ten of its thirteen years in weak decoupling, the most concentrated single-state distribution of any country in the panel. South Africa spent six years in strong decoupling and only one in weak decoupling, the mirror image of China's profile. Brazil's thirteen years are the most dispersed across categories: six years of expansive negative decoupling, three of strong decoupling, three of recessive decoupling, and one of weak decoupling no single state accounts for even half of its sample years. India spent five years in expansive coupling, more than any other country, alongside four years of weak decoupling. Russia's profile is the most evenly spread of the five, with no single state accounting for more than four years.

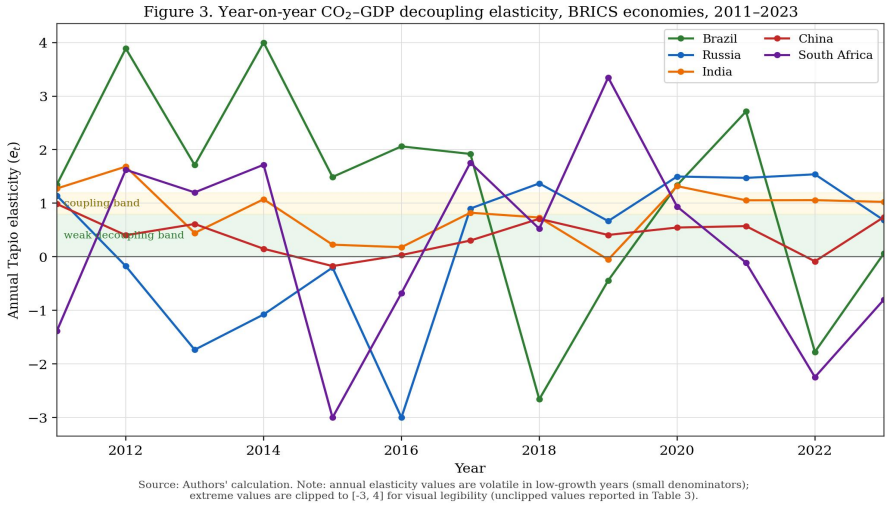


Figure 3. Year-on-year CO2–GDP decoupling elasticity, BRICS economies, 2011–2023.

Table 5. Annual Tapio decoupling elasticity and classification, 2011–2023

Year	Brazil	Russia	India	China	South Africa
2011	1.35 (END)	1.14 (EC)	1.28 (END)	0.99 (EC)	-1.38 (SD)
2012	3.89 (END)	-0.17 (SD)	1.68 (END)	0.40 (WD)	1.62 (END)
2013	1.71 (END)	-1.73 (SD)	0.45 (WD)	0.61 (WD)	1.20 (END)
2014	8.77 (END)	-1.08 (SD)	1.07 (EC)	0.15 (WD)	1.72 (END)
2015	1.49 (RD)	-0.20 (SND)	0.23 (WD)	-0.17 (SD)	-3.79 (SD)
2016	2.06 (RD)	-6.73 (SD)	0.18 (WD)	0.03 (WD)	-0.68 (SD)
2017	1.92 (END)	0.90 (EC)	0.82 (EC)	0.30 (WD)	1.76 (END)
2018	-2.66 (SD)	1.37 (END)	0.73 (WD)	0.71 (WD)	0.52 (WD)
2019	-0.44 (SD)	0.67 (WD)	-0.05 (SD)	0.41 (WD)	3.35 (END)
2020	1.34 (RD)	1.50 (RD)	1.32 (RD)	0.55 (WD)	0.94 (RC)
2021	2.71 (END)	1.47 (END)	1.06 (EC)	0.57 (WD)	-0.11 (SD)
2022	-1.78 (SD)	1.54 (RD)	1.06 (EC)	-0.08 (SD)	-2.24 (SD)
2023	0.06 (WD)	0.68 (WD)	1.02 (EC)	0.74 (WD)	-0.80 (SD)

Notes: e = Tapio elasticity. SD = strong decoupling; WD = weak decoupling; EC = expansive coupling; END = expansive negative decoupling; RD = recessive decoupling; RC = recessive coupling; SND = strong negative decoupling; WND = weak negative decoupling. Source: Authors' calculation.

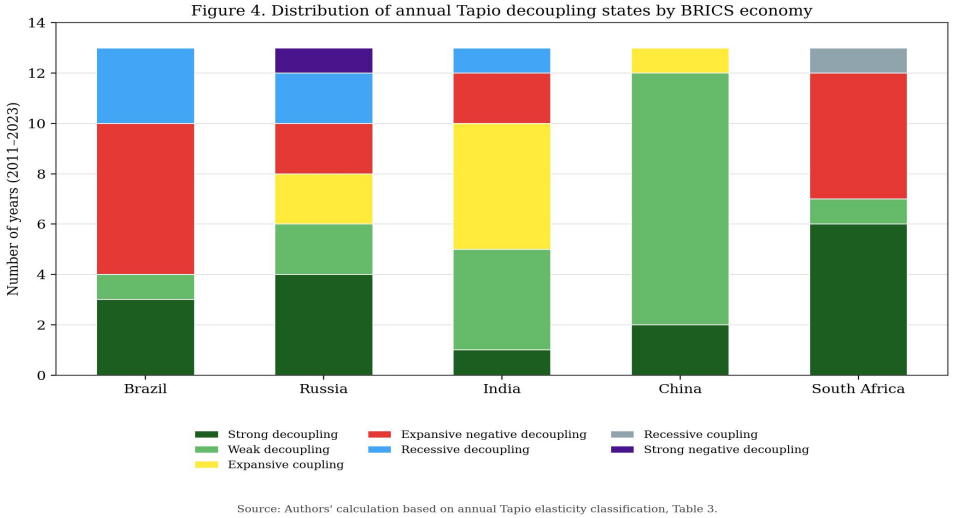


Figure 4. Distribution of annual Tapio decoupling states by BRICS economy, 2011–2023.

4.4 Panel regression evidence

Table 6 reports the results of the three panel regression models set out in Section 3.4. In the pooled growth-rate model with country fixed effects (Model 1), the estimated coefficient on GDP growth is 0.990 (robust standard error 0.127, $p < 0.001$), meaning that, averaging across the five economies and pooling all sixty-five usable country-year observations, a one-percentage-point increase in GDP growth is associated with a very nearly equal,

0.99-percentage-point increase in CO2 emissions growth an average pooled elasticity close to unity, and closer to the expansive-coupling boundary than the modal weak-decoupling classification reported in Section 4.2 might suggest. This apparent tension is informative rather than contradictory: it reflects the fact that the annual, growth-rate-based pooled regression is more heavily influenced by high-frequency, business-cycle-driven co-movement between output and emissions (which tends to push the estimated elasticity towards one) than the whole-period cumulative elasticity, which nets out short-run fluctuations and better reflects the structural, trend decoupling that policy is usually concerned with. The model's R^2 of 0.514 indicates that GDP growth alone, without any additional controls, explains just over half of the year-on-year variation in emissions growth across the panel a substantial share for a bivariate specification, underscoring how tightly linked output and emissions growth remain across BRICS even after accounting for country fixed effects.

The two-way fixed-effects log-log specification (Model 2), which uses GDP and emissions levels rather than growth rates and nets out any common year-specific shocks across the bloc, returns an estimated long-run elasticity of 0.554 (robust standard error 0.065, $p < 0.001$) a figure that sits almost exactly at the midpoint of the four country-level whole-period elasticities reported in Table 4 for the weak-decoupling economies (Brazil 0.61, Russia 0.49, India 0.68, China 0.33), and comfortably inside the 0–0.8 weak-decoupling band. This levels-based estimate, which is far less sensitive to single-year volatility than either the annual Tapio classification or the pooled growth-rate regression, is treated in this paper as the most reliable single summary statistic for the bloc's structural decoupling elasticity over 2010–2023: it confirms that the BRICS economies, taken together, have been decoupling emissions from growth, but only weakly — for every one per cent of additional cumulative output, emissions have risen by a little over half a per cent, not by the much smaller or negative figure that a "strong decoupling" or circular-economy-driven narrative would predict.

The interaction model (Model 3) tests whether individual countries' elasticities differ significantly from Brazil, the reference category. Only the South Africa interaction term is statistically significant (coefficient −0.963, $p = 0.035$), confirming, in a formal statistical sense, what the whole-period and annual evidence in Sections 4.2 and 4.3 already suggested: South Africa's decoupling elasticity is significantly lower than the other four BRICS economies' at conventional confidence levels, while the differences between Brazil, China, India and Russia, although all point in the expected direction (each interaction term is negative, indicating a lower elasticity than Brazil), are not statistically distinguishable from one another given the panel's modest time dimension ($T = 13$ per country). This is an important qualification: with only thirteen annual growth observations per country, the panel regression has limited statistical power to detect anything but the largest cross-country differences, and the China–Brazil or India–Brazil elasticity gaps, while economically sizeable in the whole-period figures of Table 4, cannot be confirmed as statistically distinct from zero with the same confidence as the South Africa result.

Table 6. Panel regression results: decoupling elasticity of CO2 emissions with respect to GDP

	Model 1: Pooled growth-rate (country FE)	**Model 2: Two-way FE, log-log levels**	**Model 3: Country-interaction (growth-rate)**
GDP growth / ln(GDP index)	0.990*** (0.127)	0.554*** (0.065)	1.443*** (Brazil, reference) (0.378)
China interaction	—	—	−0.647 (n.s.) (0.509)
India interaction	—	—	−0.454 (n.s.) (0.399)
Russia interaction	—	—	−0.412 (n.s.) (0.472)
South Africa interaction	—	—	−0.963** (0.456)
Country fixed effects	Yes	Yes	Yes
Year fixed effects	No	Yes	No
Observations	65	70	65
R^2	0.514	0.999	0.545

Notes: Heteroscedasticity-robust (HC1) standard errors in parentheses. *** p<0.01, ** p<0.05, n.s. = not significant at the 10% level. Model 2's very high R^2 reflects the inclusion of country and year fixed effects in a levels (rather than growth-rate) specification and should not be compared directly with the R^2 of Models 1 and 3.

4.5 The circular economy dimension: a cross-country comparison

Table 7 assembles the cross-sectional material-flow evidence discussed in Section 2.1 for the five BRICS economies, drawn from the UNEP-IRP-based Circularity Gap Report country dashboards and from the two peer-reviewed material-flow studies cited above. Brazil's material footprint stood at 19.8 tonnes per capita in 2023, the second highest of the five economies for which comparable figures could be sourced and well above both the global average (12.6 tonnes per capita) and the widely cited "safe" sustainability benchmark of around 8 tonnes per capita, driven overwhelmingly (64 per cent) by biomass associated with Brazil's large agricultural and livestock sector (Circle Economy / Circularity Gap Report dashboard, 2024). China's material footprint, while not directly comparable in the same units in the sources consulted here, has been documented as roughly twice that of the United States and around four times that of Japan or India in absolute terms, with construction materials overwhelmingly non-metallic minerals for cement and aggregate accounting for some sixty per cent of the total, a footprint composition consistent with a still rapidly urbanising, infrastructure-building economy (Wiedmann et al., 2015). Using an independent circularity-gap metric computed for a 2011 baseline, Aguilar-Hernandez et al. (2019) find that Russia records the highest circularity gap of any of the three BRICS economies in their sample (83.4 per cent, meaning that only about one-sixth of Russia's generated waste, stock depletion and disposed materials were being recovered back into the economy), against 69.2 per cent for India and 58.2 per cent for China, the most favourable of the three.

Two observations follow from placing Table 7 alongside the decoupling results of Sections 4.2–4.4. First, the country with the most favourable carbon-decoupling performance in this paper's panel South Africa is not the country most frequently associated in the wider circular economy literature with material-recovery innovation; the material-footprint evidence available for South Africa in the sources consulted is comparatively thin, and the country's strong decoupling result, discussed further in Section 5.1, appears far more closely tied to structural change in its electricity sector than to any documented circularity transition. Second, China despite recording the lowest circularity-gap index (the most favourable of the three economies for which a comparable metric exists) and the most stable, consistently weak-decoupling emissions profile in the panel still carries, by a wide margin, the largest absolute material footprint of the group, an apparent tension that is best read as evidence that resource productivity (material input per unit of output) and absolute material or carbon throughput are simply different things, and that a country can improve markedly on the former while continuing to grow the latter. This distinction, elaborated further in the Discussion, is central to why this paper treats "circular economy" and "carbon decoupling" as related but analytically separate questions rather than as a single, interchangeable policy outcome.

Table 7. Cross-sectional material-flow and circularity indicators for BRICS economies

Country	Material footprint (tonnes per capita, latest available year)	Circularity gap index (%, 2011 baseline)	Notable feature	Source
Brazil	19.8 (2023)	n/a in source	64% of footprint is biomass (agriculture/livestock); second-highest per-capita footprint among the five	Circle Economy / Circularity Gap Report dashboard (2024)
Russia	n/a (comparable per-capita figure not available in sources consulted)	83.4 (2011)	Highest circularity gap of the three countries with comparable data; only ~17% of waste/stock depletion recovered	Aguilar-Hernandez et al. (2019)
India	n/a (comparable per-capita figure not available in sources consulted)	69.2 (2011)	Mid-range circularity gap; lowest per-capita material footprint historically among BRICS	Aguilar-Hernandez et al. (2019); Wiedmann et al. (2015)
China	Largest absolute footprint of the five (~2x the US, ~4x Japan/India, 2008 baseline)	58.2 (2011)	Lowest (most favourable) circularity gap of the three comparable countries; 60% of footprint is construction minerals	Wiedmann et al. (2015); Aguilar-Hernandez et al. (2019)
South	n/a (comparable	n/a in source	Thinly documented in the	—

Africa	per-capita figure not available in sources consulted)		material-flow literature relative to the other four members	

Notes: Figures are drawn from cross-sectional snapshots reported in the cited sources and are not strictly comparable across countries owing to differing reference years and methodological vintages; they are reported here for qualitative, comparative interpretation only, and are not used as panel regressors (see Section 3.1).

5. Discussion

5.1 Country narratives

Brazil's weak-decoupling elasticity of 0.61 conceals two very different sub-periods. Between 2010 and 2014, Brazil's GDP and emissions rose together at close to a one-to-one rate (a pattern the annual data classify mostly as expansive negative decoupling), driven by a commodity-fuelled expansion of agriculture, mining and associated energy demand. The 2015–16 recession then produced two years of what the Tapio taxonomy labels "recessive decoupling" emissions fell alongside contracting output which, consistent with the methodological caution flagged in Section 3.3, should not be read as an environmental achievement so much as a by-product of a deep macroeconomic contraction triggered by the Petrobras corruption scandal and a collapsing term of trade. The post-2017 recovery years show a more genuinely favourable pattern, with 2018, 2019 and 2022 all classified as strong decoupling (positive growth, falling emissions), suggesting some structural improvement plausibly linked to Brazil's already low-carbon electricity mix, which is unusually hydro-dominated among large emerging economies but the 2021 post-pandemic rebound (expansive negative decoupling, elasticity 2.71) shows how quickly that progress can reverse when growth resumes sharply after a shock.

Russia's whole-period elasticity of 0.49 is the second-most favourable in the weak-decoupling group, but its annual profile is the most erratic apart from Brazil's, reflecting an economy whose growth path over 2010–2023 was repeatedly disrupted by external shocks largely unrelated to any environmental or circularity policy: the 2014–15 oil-price collapse and associated sanctions, the 2020 pandemic, and the 2022 sanctions regime following the invasion of Ukraine, which produced a rare contraction in an energy-exporting economy alongside continuing, if reduced, emissions. Whatever decoupling appears in Russia's aggregate figures over this period is difficult to disentangle from these repeated external shocks and cannot, on the evidence assembled here, be confidently attributed to a deliberate circular-economy or decarbonisation strategy; indeed, Russia records the highest circularity-gap index of any economy with comparable data in Table 7 (83.4 per cent), suggesting comparatively limited material-recovery infrastructure relative to its BRICS peers.

India presents perhaps the most policy-relevant case in the panel. With the fastest average real GDP growth of the five economies bar China, and an elasticity (0.68) that sits closest to the coupling threshold of any country still classified as weak decoupling, India's results illustrate the central tension facing large, still-industrialising economies: five of its thirteen classifiable years fall in expansive coupling, concentrated precisely in the years of fastest growth (2014, 2017, 2021–2023), indicating that as India's growth rate accelerates, its emissions growth rate tends to accelerate almost in step. This is not a criticism specific to India it is close to the textbook pattern one would expect from an economy still building out basic electricity access, transport infrastructure and urban housing stock but it does mean that India's much-discussed renewable energy and circular economy policy initiatives had not, by 2023, visibly bent the aggregate emissions-growth elasticity down towards the more favourable figures recorded by China or Russia over the same window.

China's results are, in one sense, the most reassuring in the panel and, in another, the most cautionary. China records the lowest (most favourable) whole-period elasticity (0.33) and the most stable annual profile, spending ten of thirteen years in weak decoupling consistent with a large, well-documented programme of energy-intensity reduction, renewable and nuclear capacity expansion, and, since the mid-2000s, an explicit national circular economy policy framework embedded in successive Five-Year Plans. Yet China's cumulative emissions growth over the period (43.0 per cent) is, in absolute tonnage terms, by far the largest of any BRICS economy an increase of roughly 3,915 million tonnes of CO2 between 2010 and 2023, more than eight times the combined 2010 emissions of Brazil and South Africa. Weak decoupling, even sustained over fourteen years at a relatively favourable elasticity, is still compatible with a very large absolute increase in emissions when it is achieved on top of the fastest-growing large economy in the sample; this is precisely the distinction between relative and absolute decoupling that the wider EKC and material-footprint literature (Wiedmann et al., 2015) repeatedly stresses and that circular economy communications, which tend to foreground relative efficiency gains, can obscure.

South Africa stands apart from the other four economies on almost every measure reported in this paper. It is the only BRICS member to record a negative whole-period Tapio elasticity, the only one whose CO2 emissions in 2023 were lower in absolute terms than in 2010, and the only one for which the country-specific coefficient in the panel

regression (Model 3) is statistically distinguishable from the bloc average. The turning point in South Africa's annual profile after 2019 corresponds closely to a well-documented period of severe, prolonged electricity supply constraints ("load shedding") imposed by the state utility Eskom's ageing and increasingly unreliable coal-fired generation fleet, alongside a stagnant, at times contracting, energy-intensive mining and manufacturing sector. Read in this light, South Africa's strong decoupling result over 2010–2023 looks considerably less like the product of a deliberate, successful circular-economy or decarbonisation strategy and considerably more like an involuntary reduction in energy-intensive economic activity caused by chronic infrastructure failure — a distinction of real importance for policymakers elsewhere in the bloc who might otherwise be tempted to read South Africa's headline elasticity as a template to emulate rather than, in large part, a cautionary tale about what happens when power-sector investment fails to keep pace with demand.

5.2 Does circularity explain the decoupling gradient?

Bringing together Sections 4.4 and 4.5, the honest answer this paper's evidence supports is: only partially, and not in the direction popular circular-economy narratives often assume. If a straightforward circular-economy story were correct more circularity leads mechanically to more decoupling one would expect the country with the most favourable circularity-gap index in Table 7 (China, at 58.2 per cent) to also show the most favourable carbon-decoupling elasticity, and it very nearly does (China's 0.33 is the lowest, most favourable elasticity in the panel). But the country with the outright best decoupling outcome the only true strong decoupler, South Africa is the one economy in the panel for which comparable circularity evidence could not be located in the sources consulted here, and whose favourable emissions trajectory, as argued in Section 5.1, appears to be driven overwhelmingly by an energy-supply crisis rather than by any documented circular-economy transition. Conversely, Russia records the least favourable circularity-gap index of the three economies with comparable data (83.4 per cent) yet a mid-range decoupling elasticity (0.49), better than Brazil's or India's.

The pattern that does emerge consistently across both bodies of evidence is that carbon intensity of the energy system, rather than material circularity narrowly defined, appears to be the dominant proximate driver of the decoupling gradient observed in this panel. China's relatively favourable emissions elasticity coincides with the most aggressive documented programme, among the five economies, of grid decarbonisation and energy-intensity reduction (even as its material footprint, driven by construction, remains the largest in absolute terms); South Africa's favourable elasticity coincides with an involuntary contraction of coal-fired generation; India's less favourable elasticity coincides with continued heavy reliance on coal to meet still-growing electricity demand. Material circularity recycling rates, product-life extension, industrial symbiosis plausibly matters for the trajectory of material footprint and for resource security, and the Chinese and Brazilian evidence in Table 7 suggests it is not unrelated to emissions outcomes, but on the evidence assembled in this paper it is not, on its own, doing the heavy lifting in explaining which BRICS economies are decoupling their carbon emissions from growth and which are not. This is an important corrective to policy discourse that sometimes treats "circular economy" and "climate mitigation" as near-synonyms: the data examined here suggest they are, at most, loosely and unevenly correlated policy objectives that happen to share some common levers (energy and materials efficiency) but that require, in large part, distinct policy instruments a point taken up directly in Section 6.

6. Practical Implications

Three practical implications follow for policymakers and firms operating within the BRICS bloc. First, circular economy roadmaps and Nationally Determined Contributions under the Paris Agreement should be evaluated and reported jointly, not treated as separate policy tracks whose progress can be inferred from one another. A country can report genuine, verifiable gains in recycling rates or material productivity as China arguably has while its aggregate carbon-emissions elasticity remains well short of the strong decoupling that climate stabilisation ultimately requires; conversely, an economy can show a favourable emissions elasticity, as South Africa does in this paper's data, for reasons that have little to do with circularity policy and that are unlikely to be either durable or replicable by design. Investors, multilateral lenders and domestic regulators assessing a BRICS economy's "green" credentials should therefore ask for both metrics, not infer one from the other.

Second, the evidence that carbon intensity of electricity generation appears to be the dominant proximate driver of the decoupling gradient observed here implies that, within a constrained policy budget, BRICS governments seeking to move from weak towards strong decoupling are likely to see a larger and faster payoff from accelerating renewable and low-carbon generation capacity and retiring or repowering the oldest, least efficient coal-fired plant than from circular-economy measures targeted narrowly at material recirculation, however valuable the latter may be for other objectives such as resource security, air-quality co-benefits, and reducing exposure to volatile international commodity markets. This is not an argument against circular-economy policy the case for it on resource-security and local-

pollution grounds is largely untouched by this paper's findings but it is an argument against over-stating its likely near-term contribution to the specific problem of carbon decoupling relative to power-sector decarbonisation.

Third, for India specifically the economy in this panel furthest from strong decoupling despite among the most ambitious documented renewable-capacity targets in the bloc the results suggest that the sheer pace of underlying economic and infrastructure growth is, for now, outrunning the rate at which emissions intensity can plausibly be reduced through supply-side measures alone, implying a continuing and probably growing role for demand-side efficiency (building codes, industrial process efficiency, transport electrification) alongside continued renewable build-out, if India's elasticity is to move durably below the 0.8 weak-decoupling threshold rather than oscillating around it, as the 2021–2023 data in this paper suggest it has so far continued to do.

7. Limitations and Future Research Agenda

This study has several limitations that should temper how its findings are used. First, and most importantly, fossil CO2 emissions are a partial, if standard and widely used, proxy for "environmental pressure"; the analysis does not cover land-use emissions, non-CO2 greenhouse gases, water stress, biodiversity loss or local air pollution, any of which might show a materially different decoupling pattern from the one reported here, and a genuinely comprehensive circular economy assessment would ideally examine several of these dimensions jointly. Second, the material footprint and circularity-gap evidence used in Section 4.5 is cross-sectional rather than a full annual panel, for the reasons explained in Section 3.1; while this is a deliberate and disclosed choice made to avoid manufacturing false precision through interpolation, it does mean the paper cannot formally test, with the same panel-regression rigour applied to the GDP–emissions relationship, whether year-on-year changes in circularity indicators are statistically associated with year-on-year changes in the decoupling elasticity a natural and valuable extension once comparable annual UNEP-IRP series become available for all five economies over a common window. Third, the panel regression's statistical power is constrained by its modest time dimension (thirteen usable annual growth observations per country), which is why only the South Africa country-interaction term achieves conventional statistical significance in Model 3 despite economically meaningful differences visible in the whole-period elasticities of Table 4; a longer panel, or a pooled cross-BRICS-plus-comparator sample, would allow sharper statistical discrimination between the other four countries' elasticities. Fourth, the study relies on nationally reported and internationally compiled secondary data (World Bank national accounts and Global Carbon Project-based emissions inventories) which are periodically revised, particularly for the most recent one to two years of any panel; the 2022–2023 figures used here should accordingly be treated as provisional pending future data vintages. Finally, as emphasised throughout the Discussion, this paper documents statistical association and plausible proximate mechanisms energy-mix composition, macroeconomic shocks rather than establishing causal identification of the effect of circular-economy policy specifically on carbon decoupling; a causal research design, for instance exploiting the staggered introduction of specific circular-economy regulations or targets across BRICS economies, is a natural next step for future work.

8. Conclusion

This paper set out to test, rather than assume, whether the circular economy transition under way across Brazil, Russia, India, China and South Africa has been accompanied by a genuine decoupling of economic growth from carbon emissions over 2010–2023. Using an original, transparently sourced panel and the Tapio (2005) elasticity framework, cross-checked against a two-way fixed-effects panel regression, the answer is a qualified and unevenly distributed "partly." At the bloc level, emissions and growth remain closely linked a pooled long-run elasticity of 0.55 confirms weak, not strong, decoupling and only one of the five economies, South Africa, has achieved outright strong decoupling over the full period, for reasons this paper argues are more plausibly attributable to an energy-supply crisis than to a deliberate circularity strategy. China shows the most consistently favourable relative decoupling trend among the four weak-decoupling economies, but also by far the largest absolute increase in emissions, underlining that relative efficiency gains and absolute environmental pressure are analytically distinct outcomes that a single "circular economy" narrative can too easily conflate. India, the fastest-growing large economy in the panel, shows the least favourable decoupling elasticity of the five, a reminder that the scale and pace of still-unfinished industrialisation and infrastructure build-out continues, for now, to outweigh the decoupling effect of any efficiency or circularity gains being achieved concurrently.

The cross-sectional circularity evidence assembled in Section 4.5, read against these results, suggests that material-flow circularity and carbon decoupling, while conceptually related and sharing some common policy levers, are empirically distinct outcomes across the BRICS bloc over this period, most plausibly connected to each other through the intermediating channel of energy and industrial efficiency rather than through material recirculation narrowly defined. For researchers, this argues for treating circular economy metrics and carbon

decoupling metrics as complementary but non-substitutable indicators in any assessment of a country's sustainable development trajectory. For policymakers across BRICS, it argues for continuing to prioritise the decarbonisation of electricity and industrial energy supply as the most direct lever on the specific problem of carbon–growth decoupling, while pursuing circular economy policy on its own, separate merits resource security, waste reduction, local environmental quality rather than as a presumed proxy for climate performance. As the BRICS grouping continues to expand its membership and its share of global output, getting this distinction right in both research and policy design is likely to matter more, not less, over the decade ahead.

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