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Energy Structure and Decoupling Dynamics in Emerging Economies: An Empirical Analysis of Green Growth Trajectories

Tagay Birhanu[1], Dr. Birku Reta[2], Tsegaye Mulugeta[3]

[1]PhD candidate, Adama Science & Technology University, Department of Technology & Innovation Management, Email: yoabtag@gmail.com
[2]Associate Professor, Adama Science & Technology University, Department of Technology & Innovation Management, Email: birku200@gmail.com
[3]PhD, Adama Science & Technology University, Department of Technology & Innovation Management, Email: abtse2002@gmail.com

**Corresponding Author's Email:yoabtag@gmail.com*

ABSTRACT

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This study uses panel regression analysis and the Tapio elasticity framework to evaluate green growth trajectories while investigating energy structure and decoupling dynamics in emerging economies. Elasticity trends from 2000 to 2024 show wildly disparate results: nations like China, Ethiopia, Rwanda, South Africa, and Uganda show strong decoupling, in line with the Environmental Kuznets Curve (EKC), while nations like Brazil, Niger, Mozambique, Vietnam, and India show negative decoupling, indicating a reliance on fossil fuels and lax regulation. In keeping with innovation theory, the random-effects GLS regression (overall R2=0.438R^2 = 0.438; Wald $\chi^2 = 98.15$, $p < .001$) shows that ICT goods exports are a positive driver of adjusted net savings, while internet usage and CO_2 emissions have negative effects, highlighting the focus on governance in institutional theory. Savings are significantly increased by GDP growth, which reflects transitional EKC dynamics. Overall, the results emphasize that guiding emerging countries toward sustainable decoupling and long-term green growth requires strong institutions, coherent policies, and innovation-driven transitions.

Keywords: Decoupling dynamics, energy structure, green growth, panel regression model, Tapio elasticity.

JEL Classification Codes: Q43; Q56; O14; C23

INTRODUCTION

In the twenty-first century, the pursuit of sustainable development has taken center stage, especially as economies struggle to maintain growth while reducing environmental deterioration. A crucial paradigm for assessing green growth trajectories is the idea of decoupling, or the capacity of an economy to expand without a corresponding rise in environmental strain (Tapio, 2005). Given their structural reliance on carbon-intensive industries, fast urbanization, and rising energy demand, the BRICS nations (Brazil, Russia, India, China, and South Africa) and other emerging economies find this issue particularly important (Wang et al., 2020). Therefore, it is crucial for both academic research and policy formation to comprehend the dynamics of energy structure and how it shapes decoupling results.

Aligning economic growth with climate pledges under the Paris Agreement is urgent on a global scale. Together, the BRICS economies contribute significantly to global emissions, but they also serve as catalysts for innovation and global prosperity. Similar difficulties are faced by emerging economies outside of the BRICS, which frequently have to strike a balance between industrialization and ecological requirements. The variability of results is highlighted by empirical evidence that indicates some nations have achieved weak or strong decoupling, while others are stuck in negative decoupling trajectories (Zhang et at., 2017). This work adds to the body of knowledge on green growth by methodically examining the elasticity between GDP and emissions using the Tapio approach, which reveals how energy structure influences decoupling dynamics.

The study uses a deductive methodology, starting with well-known theoretical frameworks like decoupling elasticity models (Tapio, 2005) and the Environmental Kuznets Curve (EKC) (Grossman & Krueger, 1995), and testing them against empirical data from emerging economies. This deductive approach guarantees the rigorous examination of theoretical hypotheses through econometric analysis, such as the expectation that increasing shares of renewable energy promote stronger decoupling. This study is based on positivism, a research methodology that stresses measurable, observable phenomena and the application of quantitative techniques to establish causal linkages (Saunders et at., 2019). The study maintains theoretical coherence while ensuring methodological robustness through the use of panel econometric approaches, such as fixed effects, random effects, and dynamic models.

In conclusion, this research topic is investigated due to the urgent requirement to comprehend how energy structure reforms might support sustainable growth in economies that are essential to global development. In addition to enhancing scholarly discussion, the study's integration of theory and empirical data offers policymakers practical advice on how to strike a balance between environmental preservation and economic advancement.

Economies are under increasing pressure to separate economic progress from environmental damage due to global climate change and the pressing need for sustainable development. The Emerging economies continue to face structural issues stemming from their reliance on fossil fuels, fast industrialization, and uneven adoption of renewable energy technology, whereas industrialized nations have made headway in lowering emissions relative to GDP growth (Mehta & Shah, 2024). The issue is made worse by the fact that these economies are both big contributors to global carbon emissions and engines of global growth, making their energy trajectories crucial to meeting international climate targets.

Recent empirical research shows that while the use of renewable energy has a moderating effect, GDP development and population expansion in the BRICS countries greatly increase CO_2 emissions (Oprea et at., 2024). Nonetheless, decoupling varies greatly between nations and over time; some achieve mild or strong decoupling, while others are stuck in negative decoupling trajectories (Nica et at., 2025). The necessity to methodically examine how energy structure, particularly the proportion of fossil fuels and renewable energy sources, influences decoupling dynamics in various economic circumstances is highlighted by this variability.

The effectiveness of present energy policies and the viability of green growth pathways are seriously called into doubt by the emerging economies' inconsistent decoupling. Policymakers run the danger of enacting measures that don't produce long-term results if they don't have a thorough grasp of the elasticity between GDP and emissions and how energy structure affects this relationship. The UN Sustainable Development Goals (SDGs), especially SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), are significantly impacted by this issue, which is more than just an academic one.

The current study uses a deductive research approach to address this problem, starting with well-known theoretical frameworks like Tapio's decoupling elasticity model (Tapio, 2005) and the EKC (Grossman & Krueger, 1995) and testing them against empirical data from emerging economies. This investigation is guided by positivism, a research theory that emphasizes quantitative analysis and objective measurement to determine causal linkages (Saunders et at., 2019). This work aims to contribute to scholarly discourse and policy design by offering solid evidence on how energy structural improvements can promote sustained decoupling trajectories through the use of panel econometric methodologies.

The general objective of the study is to examinee energy structure and decoupling dynamics in emerging economies: An empirical analysis of green growth trajectories. More specifically;

- To examine how responsive CO_2 emissions is to economic growth in emerging economies.
- To investigate the determinants of Green Growth of emerging economies.

Because it tackles the crucial issue of striking a balance between environmental sustainability and economic growth in emerging economies, this study is important. It offers empirical proof of whether nations achieve strong, weak, or negative decoupling between GDP and emissions by using panel regression and the Tapio elasticity framework. A gap in the literature is filled and theoretical depth is added by connecting decoupling dynamics to energy structure, which includes energy intensity, adoption of renewable energy sources, and reliance on fossil fuels. The conclusions have clear policy implications, providing direction for energy reforms, investments in renewable energy, and efficiency tactics necessary to fulfill obligations under the Paris Agreement. The study's econometric, deductive methodology guarantees rigor and dependability, linking theory and practice and providing governments, international organizations, and development partners with useful insights.

LITERATURE REVIEW

Green growth, which emphasizes lowering resource intensity and pollution while preserving affluence, is economic growth that is compatible with environmental sustainability. The fundamental diagnostic idea is decoupling, which characterizes how environmental pressures usually carbon dioxide emissions become less sensitive to economic expansion. Tapio's framework popularized elasticity-based decoupling, which measures the percentage change in emissions in relation to the percentage change in GDP. Values below zero indicate strong decoupling (emissions fall while GDP rises), values between zero and one indicate weak decoupling (emissions rise slower than GDP), and values above one indicates negative decoupling (emissions rise faster than GDP). Understanding whether and how economies move along decoupling trajectories requires an understanding of energy structure, which refers to the composition of total primary energy supply and electricity generation by source (coal, oil, gas, nuclear, hydro, and other renewables), along with energy and electricity intensity (Tapio, 2005).

Environmental economics offers a number of complementary decoupling ideas. According to the EKC, there is an inverse U-shaped relationship between income and environmental degradation: emissions increase with income during the early stages of growth; after a certain point, emissions decrease due to cleaner technology, regulations, and preferences (Grossman & Krueger, 1995). By breaking down emissions into population, wealth, technology, and fuel mix, the Kaya identity and STIRPAT frameworks provide testable routes through fuel shares and energy intensity. According to transition and innovation theories, technological dissemination and change through R&D, learning-by-doing, and policy signals shift the energy structure toward low-carbon sources, allowing for ultimate decoupling (Aghion et al., 2016). According to institutional theory, the incentives for businesses and utilities to switch to cleaner energy are shaped by market design, carbon pricing, and governance quality (Sterner & Coria, 2012). Together, these ideas suggest that structural changes in energy composition, efficiency gains, and policy-driven innovation are necessary for long-term decoupling, with transitional periods during which elasticity may continue to be greater than one.

Diverse decoupling results are found in empirical research on emerging economies. Panel analyses frequently demonstrate that industrialization and GDP raise emissions but energy efficiency and renewable energy shares lower them; these impacts are more pronounced in areas with higher levels of policy stringency and innovation capacity (Wang et at., 2020; Zhang et at., 2017). Asymmetric and distributional dynamics are highlighted by recent research: depending on the energy mix and regulatory environment, digitalization and financial development can either be complementary or countervailing, and the adoption of renewable energy tends to have greater benefits in higher-emission quantiles (Mehta & Shah, 2024). The significance of energy structure is reinforced by country studies, such as China's post-2013 reorganization and South Africa's reliance on coal, which show that transitions are path-dependent and policy-contingent.

Renewable Energy Consumption and Green Growth Trajectories;

According to Bhattacharya et at. (2016) and Apergis & Payne (2010), the use of renewable energy promotes green growth by lowering lifecycle emissions, reducing local pollution, and encouraging productivity-enhancing innovation, all of which improve adjusted net saving (ANS) through decreased depletion and damage adjustments. Through technology diffusion and energy efficiency, cross-country panel evidence demonstrates that renewable energy sources are linked to long-term growth and environmental quality; these effects are more pronounced when policy certainty (feed-in tariffs, RPS) is present (Destek & Sinha, 2020;

Marques & Fuinhas, 2012). The replacement of coal by wind and solar energy in the emerging economies has resulted in quantifiable reductions in the intensity of emissions in the power and industry sectors, which are consistent with periods of absolute or high relative decoupling (Sebri & Ben-Salha, 2014; Inglesi-Lotz, 2016).

H1: Higher renewable energy consumption increases ANS by lowering environmental damage costs and enhancing energy productivity.

Non-Renewable Energy Consumption and Green Growth Trajectories

Consumption of non-renewable energy, particularly coal and oil, increases local pollutants and CO_2 emissions, undermining ANS through increased environmental harm and resource depletion (Sadorsky, 2014; Tiba & Omri, 2017). According to empirical research, reliance on fossil fuels raises emissions intensity in the electricity and manufacturing sectors, impeding decoupling and undermining the sustainability of growth routes (Kasman & Duman, 2015; Zhang & Da, 2015). Evidence for BRICS indicates that energy mixes heavy in coal create lock-in effects, or capital and infrastructure path dependence, which slow down the transition and stifle the benefits of energy efficiency (Wang et at., 2015; Shahbaz et at., 2017).

H2: Greater non-renewable energy consumption reduces ANS by increasing environmental damages and undermining decoupling, constraining green growth.

Individual Use of Internet, Digitalization, and Green Growth

Internet use speeds up smart grids, ICT-enabled efficiency, and the spread of clean technology, all of which can lower energy intensity and emissions and raise ANS by reducing damage adjustments (Salahuddin & Gow, 2016; Usman & Hammar, 2020). Additionally, digitalization facilitates eco-innovation and circular economy practices that enable decoupling by enhancing monitoring and optimization across production networks (Zhang et at., 2017; Chen et at., 2022). To ensure net environmental advantages, however, renewable-powered ICT must counteract the rebound from data-center demand (Belkhir & Elmeligi, 2018; Stoll et at., 2018).

H3: Increased individual internet use positively influences ANS by catalyzing ICT-enabled efficiency and clean technology diffusion.

ICT Goods Exports and Green Growth Trajectories

Exports of ICT good shardware and software related to information and communication technology represent a vital conduit for the diffusion of environmentally friendly technologies and the integration of emerging economies into global value chains. Exports of ICT goods are linked to increased capacity for innovation, productivity increases, and structural shifts toward knowledge-intensive industries, which lower emissions and energy intensity in comparison to traditional manufacturing (Dedrick et at., 2010; Lee, 2010). According to empirical data, economies with robust ICT export bases benefit from positive spillovers in eco-innovation, cleaner production, and digital infrastructure. This improves ANS by reducing the costs of environmental damage and boosting the accumulation of productive capital (Zhu et at., 2018; Chen et at., 2022). By incorporating green technologies into traded goods, ICT exports help emerging countries become more competitive internationally and encourage relative and possibly absolute decoupling (Popp, 2019; Fernández et al., 2020).

H4: ICT goods exports positively influence ANS by promoting structural transformation, eco-innovation, and international diffusion of green technologies.

Urbanization Rate and Green Growth Trajectories

Urbanization has conflicting effects on ANS: rapid, infrastructure-heavy growth can increase emissions and resource consumption, while agglomeration economies and service-sector expansion can lower energy intensity (Madlener & Sunak, 2011; Liddle, 2013). Compact, transit-oriented construction and clean power greatly reduce urban emissions, allowing for relative decoupling; sprawling, car-centric urbanization has the reverse effect, according to evidence for emerging nations (Wanget at., 2012; Güneralp et al., 2017). Urban energy mix, building codes, transportation planning, and industrial relocation policies all have an impact (Cole & Neumayer, 2004; Seto et al., 2014).

H5: Compact urbanization increases ANS via lower damage costs, while unmanaged urban expansion decreases ANS.

Manufacturing Value Added (MVA) and Green Growth Trajectories

When combined with energy-efficient technology, cleaner production, and a move toward medium-high-tech industries with lower emissions intensity, MVA can increase ANS (Antweiler et at., 2001; Sbia et at., 2014). Research demonstrates that eco-innovation, ISO 14001 adoption, and energy management systems lower environmental damage costs, particularly when paired with electrification and industry integration of renewable energy sources (Porter & van der Linde, 1995; Fernández et al., 2020). Upgrading the production structure for BRICS from basic materials to advanced manufacturing supports decoupling and improves ANS (Zhang & Bian, 2020; Hao et at., 2020).

H6: Manufacturing value added increases ANS when aligned with industrial upgrading and cleaner production.

Foreign Direct Investment and Green Growth Trajectories

The environmental quality of FDI determines how it affects ANS: pollution-haven FDI increases emissions and damage costs, whereas green FDI promotes knowledge transfer, energy efficiency, and renewable capacity (Cole et at., 2011; Al-mulali, 2012). According to panel data for BRICS, FDI either strengthens or weakens sustainability depending on the strictness of environmental regulations and absorptive capacity (Shahbaz et at., 2015; Lee, 2010). Decoupling is typically supported by greenfield investments in advanced manufacturing and renewable energy, which improve ANS through decreased damage terms and increased productive capital (Popp, 2019; Dechezleprío et at., 2015).

H7: Environmentally oriented FDI increases ANS through green technology transfer.

CO_2 Emission Size and the Green Growth Trajectories

According to Hamilton and Clemens (1999) and Arrow et al. (2012), persistent high emissions show weak or nonexistent decoupling; CO_2 emissions directly reduce ANS by raising environmental damage costs. Despite GDP growth, empirical research consistently demonstrates that economies with chronic emissions intensity are unable to sustain positive real savings, putting them at danger of unsustainable trajectories (Stern, 2004; Wang et al., 2015). In order to transition from relative to absolute decoupling and maintain ANS, BRICS must reduce emissions through efficiency and renewable energy sources (Kasman & Duman, 2015; Zhang & Da, 2015).

H8: Larger CO2 emission size reduces ANS, signaling unsustainability and inhibiting decoupling in emerging economies.

Decoupling elasticity and green growth trajectories

Strong decoupling strengthens ANS by limiting environmental harms; decoupling elasticity, or the responsiveness of environmental pressure to economic growth, reflects whether growth is achieved with stable or declining emissions (Tapio, 2005; Zhang & Da, 2015). Policy-driven energy transitions, efficiency standards, and industrial upgrading diminish elasticity, allowing for absolute decoupling episodes in some emerging economies, according to empirical analysis (Wang et al., 2015; Kanemoto, et at., 2014). According to Stern (2017) and Fernandez-Amador et at., (2017), gains in elasticity frequently coincide with the adoption of renewable energy, carbon pricing, and strict restrictions, with cumulative benefits on real savings.

H9: Lower decoupling elasticity (i.e., stronger decoupling) increases ANS by compressing environmental damage costs relative to GDP.

GDP Growth, EKC Dynamics, and Mediated Sustainability

If energy transition, efficiency improvements, and structural shifts toward services and high-tech manufacturing are present, GDP growth can raise ANS; otherwise, growth increases environmental damages that lower ANS (Grossman & Krueger, 1995; Stern, 2004). Although there is conflicting evidence about the EKC in the BRICS, research indicates that policy-driven thresholds, such as the share of renewable energy and the strictness of regulations, influence whether growth decouples from emissions (Kasman & Duman, 2015; Hao et al., 2020). Thus, growth quality rather than growth quantity determines green growth trajectories, as measured by ANS, highlighting the importance of complementary policies (Arrow et al., 2012; Popp, 2019).

H10: GDP growth reduces ANS via higher environmental damages.

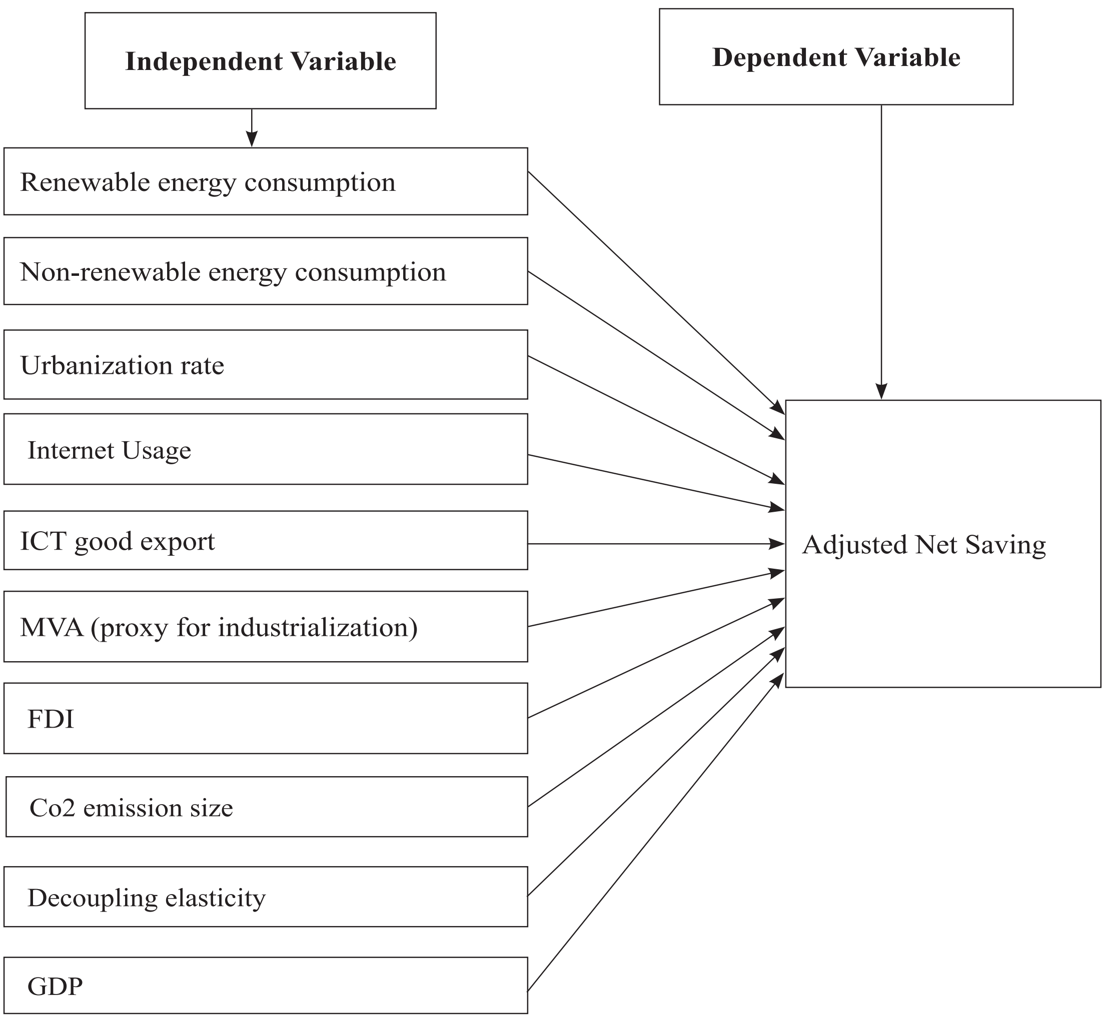
Despite growing research on decoupling and energy transitions, several gaps remain. First, panel methods are rarely applied in cross-country studies, with most analyses focusing on average effects and overlooking distinctions between short-run adjustments and long-run equilibrium responses to energy structure changes. Second, multi-country data on emerging economies often treats energy structures superficially, failing to differentiate electricity mix from primary energy or account for transitional externalities such as mineral depletion in renewable supply chains, which affect sustainability metrics like adjusted net savings. Third, structural driver estimates may be biased because cross-country spillovers through trade, technology diffusion, and integrated energy markets are seldom incorporated. Finally, few studies integrate policy tools with elasticity-based decoupling measures in a unified empirical design, limiting practical insights for green growth. This study addresses these gaps by combining Tapio elasticity, disaggregated energy variables, dynamic panel estimators, and policy indicators from emerging economies.

Conceptual framework

In order to investigate how energy architecture and socioeconomic factors influence green growth in emerging economies, this dissertation combines decoupling theory with sustainability economics. Adjusted Net Savings (ANS), which accounts for both environmental costs and capital accumulation, is a proxy for green growth. Empirical data indicates that by reducing emissions intensity and promoting eco-innovation, the use of renewable energy, ICT diffusion, and ICT goods exports improve ANS. On the other hand, by increasing ecological costs and decreasing decoupling, reliance on non-renewable energy, fast urbanization, and high CO2 emissions threaten ANS. Industrial upgrading, regulatory quality, and technology transfer further influence sustainability results, while factors including manufacturing value added, foreign direct investment, and GDP growth have context-specific consequences. To determine if economic growth coincides with a decrease in environmental stresses, the framework uses decoupling elasticity. In general, it suggests that energy transition, digitization, industrial restructuring, and cogent policy-driven decoupling must work together to achieve sustainable green growth in emerging economies.

Figure1

The conceptual framework of the study is presented as below;



Source: Developed by the researcher by reviewing different literature

RESEARCH METHODOLOGY

The positivist research ethic used in this work places a strong emphasis on observable phenomena, objective measurement, and the application of quantitative techniques to determine causal linkages (Saunders, et at., 2019). Because the study looks into quantifiable factors like GDP, CO_2 emissions, and energy structure shares and aims to test theories based on well-established theories of decoupling and green growth, positivism is acceptable.

The study uses a deductive methodology, starting with theoretical frameworks like Tapio's elasticity model (Tapio, 2005) and the EKC (Grossman & Krueger, 1995). These theories serve as the foundation for the formulation of hypotheses, which are then empirically examined using panel data from the emerging economies. Deduction permits empirical confirmation while guaranteeing that conclusions are based on theory. The design is comparative, longitudinal, and quantitative: Numerical data (GDP, emissions, energy shares) were employed in the quantitative analysis. In order to identify patterns, the longitudinal design spans several years (2000–2024). In contrast, the comparative design looks at how the decoupling trajectories of emerging economies differ.

The researchers have taken all emerging economies with non-probability sampling techniques called purposive sampling technique. The selection of 13 countries Brazil, China, Ethiopia, Guyana, India, Mozambique, Niger, Russia, Rwanda, Senegal, South Africa, Uganda, and Vietnam can be justified as a strategically representative sample of emerging economies that captures the diversity of energy structures, development trajectories, and policy contexts relevant to the research. This set includes the BRICS economies, which are central to global energy demand and emissions, alongside African nations where energy access and sustainability challenges are most acute, and smaller economies such as Guyana and Vietnam that illustrate frontier and export-led growth pathways. Collectively, these countries embody heterogeneity in fossil dependence, renewable resource endowment, and industrialization stages, allowing for meaningful comparative analysis of decoupling dynamics. The sample is consistent with IMF classifications of emerging and developing economies, ensuring methodological legitimacy, while its manageable size enhances econometric rigor by avoiding dilution across 152 heterogeneous cases. By integrating large emitters with vulnerable low-income economies, the study bridges global and regional perspectives, offering insights that are both academically robust and policy-relevant, thereby providing a precise and defensible rationale for focusing on this group of 13 countries.

The researcher used World Bank (WDI) on GDP, population, FDI inflows. IEA/BP/IRENA is used to for a data such as Energy structure (coal, oil, gas, nuclear, hydro, renewables). Carbon emissions, policy indicators (carbon pricing, renewable targets) data is obtained from IMF. Web search is used to collect secondary data from online sources.

The study first uses the elasticity of CO_2 emissions relative to GDP as the main decoupling metric in order to investigate the dynamics of green growth and decoupling in emerging nations. This method measures how sensitive emissions are to economic growth, enabling categorization into weak, strong, or absolute decoupling based on whether emissions decrease, stable, or grow more slowly as GDP increases. The methodology shows how much structural changes in energy consumption led to decreasing environmental pressure and determines whether economic expansion is becoming less carbon intensive by measuring elasticity coefficients across nations and time. Complementing this elasticity framework, the study further applies panel regression models using ANS as the dependent variable to assess the sustainability of growth trajectories. ANS, which accounts for investment in human capital, resource depletion, and pollution damage, provides a broader measure of long-term economic sustainability. This regression analysis tests whether decoupling dynamics and energy restructuring translate into positive sustainability outcomes, thereby linking short-term emission–growth relationships with long-term wealth preservation and green growth trajectories. Since the GDP size much larger than the other variables, the researcher undertakes log transformation to reduces skewness, mitigates scale dominance, and allows growth effects to be interpreted in proportional terms rather than in raw levels.

The study uses publicly available secondary data from international organizations. Since there are no human beings involved, ethical requirements are upheld. Data sources are acknowledged and properly cited. In terms of methodology, the study offers a solid foundation for examining green growth trajectories by combining Tapio elasticity with sophisticated panel econometrics. In practical terms, it offers evidence-based suggestions for energy reforms in emerging economies.

RESULT AND DISCUSSION

Result of Tapio elasticity framework

The Tapio elasticity approach, a decoupling analytical framework that uses an elasticity coefficient to assess how responsive environmental pressure (such CO_2 emissions) is to economic growth, was used by the researcher. The study used words like coupling, negative decoupling, weak decoupling, and strong decoupling to characterize the link. This method provides a systematic way to assess economic trends and ascertain if countries are achieving green growth by reducing emissions relative to GDP growth. Tapio (2005) created a decoupling elasticity index to measure the relationship between environmental stress and economic expansion.

The Tapio elasticity technique provides a framework for analyzing the relationship between environmental pressure, particularly carbon emissions, and economic growth. It is calculated by dividing the percentage change in environmental pressure by the percentage change in GDP. Based on this elasticity, nations can be divided into several decoupling states: Emissions fall while GDP rises when elasticity is less than zero; emissions grow but more slowly than GDP when elasticity is between zero and one; emissions and GDP grow at the same rate when elasticity equals one; and emissions grow faster than GDP when elasticity is greater than one.

After classifying the elasticity values into decoupling states, the researcher was able to compare the sustainability trajectories of various countries. By linking elasticity to energy structure variables like coal, oil, renewable energy shares, and energy intensity, regression analysis may then be utilized to ascertain whether the adoption of renewable energy enhances the likelihood of strong decoupling. Table 1 below displays the trend analysis, which facilitates the observation of changes over time.

Table 1

Trends of Elasticity

Year	BRA	CHN	ETH	Gu	IND	MOZ	NER	RUS	RWA	SEN	ZAF	UGA	VNM
2000	1.33	0.51	1.70	-1.70	0.77	-3.39	0.07	0.11	-0.61	-0.88	-36.3	-0.60	1.08
2001	-0.12	0.38	-148	13.4	-0.1	-3.8	-0.3	0.09	-6.36	-0.45	-0.09	0.24	1.79
2002	-0.01	0.73	0.1	-0.6	0.31	0.5	0.02	0.05	-43.	1.35	-0.43	1.81	2.27
2003	-0.42	1.13	0.38	-0.07	0.07	2.28	0.22	-0.01	1.84	0.05	0.05	0.34	0.41
2004	0.79	0.82	0.33	0.57	0.36	0.37	0.08	0.11	-1.38	-0.35	0.17	0.08	1.16
2005	0.09	0.76	-0.33	-2.38	0.16	-0.54	-0.45	0.02	-0.24	1.22	0.55	1.16	0.31
2006	0.13	0.51	0.12	-0.05	0.35	0.49	-0.38	0.02	0.39	1.35	0.28	1.59	0.08
2007	0.51	0.28	0.22	1.41	0.25	0.88	0.23	0.08	-0.10	-0.23	-0.01	0.89	0.53
2008	0.55	0.08	0.13	0.02	-3.29	-0.27	0.03	0.01	-0.42	0.40	-0.65	0.23	0.29
2009	8.61	0.60	-0.11	0.39	0.65	-1.04	26.8	0.03	-0.27	-0.29	1.13	0.1	1.5
2010	1.05	0.46	0.42	1.01	0.18	-0.46	3.31	-0.24	0.01	0.56	-0.29	-0.68	0.26
2011	0.60	0.36	1.85	0.60	0.53	0.52	-0.13	0.15	0.19	0.32	0.04	1.94	-0.06

2012	-2.51	0.19	0.28	0.91	31.1	0.53	4.60	0.6	0.16	-5.2	1.04	0.68	-0.11
2013	30.6	0.33	1.31	-0.68	1.02	1.88	-0.54	-0.25	3.93	-0.58	-0.28	-0.25	0.35
2014	-11.4	0.05	0.94	-3.99	0.64	2.19	0.67	0.33	1.60	0.73	-0.18	0.53	0.90
2015	0.34	-0.33	0.37	-0.04	-0.13	-0.8	0.5	0.03	-0.2	-0.4	-0.08	-18.1	4.4
2016	33.4	-0.2	1.03	3.7	0.08	-0.99	-0.5	-0.02	7.15	0.9	1.03	-0.4	1.4
2017	0.3	0.2	-0.4	-0.03	0.3	-0.3	-1.6	-0.1	1.1	0.8	-0.04	0.08	0.15
2018	1.2	0.3	2.3	1.8	2.4	-0.5	0.2	0.3	1.4	-0.4	0.2	0.9	2.1
2019	0.5	0.7	0.4	0.8	-0.5	1.2	22.5	2.0	1.2	1.9	0.2	-0.1	2.3
2020	0.4	0.4	-1.04	3.34	1.7	1.2	-0.3	-0.3	-0.7	-0.01	0.05	-0.5	0.8
2021	2.02	0.23	-0.2	-0.1	0.5	0.9	1.7	-0.2	-0.7	-0.4	-0.6	1.03	-0.7
2022	-0.58	-1.17	-0.48	0.01	1.19	0.29	-0.47	0.29	0.67	10.7	-0.23	-0.6	-0.4
2023	0.02	-23.5	-0.47	-0.07	0.79	-0.52	-0.73	-0.39	-0.74	-0.13	0.90	-0.4	2.8
2024	-1.68	4.11	0.55	0.53	6.46	4.95	5.45	0.50	1.32	-0.98	-0.82	6.7	2.7

Source; researchers own compilation from secondary sources

The elasticity trends from 2000 to 2024 show that decoupling processes in emerging economies are quite erratic and diverse. With a few years of negative elasticity (e.g., -1.17 in 2022, -23.5 in 2023), China's elasticity values typically stay below 1, showing times of substantial decoupling where emissions decreased despite economic expansion. This is a reflection of China's rapid industrial restructuring and adoption of renewable energy in the 2010s (Zhang et al., 2017). India, on the other hand, shows consistently high elasticity, with spikes like 31.1 in 2012 and 6.46 in 2024, indicating negative decoupling where emissions expanded faster than GDP, which is consistent with its reliance on coal and difficulties in switching to renewable energy (Wang et al., 2020). Brazil's trend is uneven, with sharp swings (30.6 in 2013, 33.4 in 2016, and -11.4 in 2014), indicating volatility in the country's energy structure and the application of its policies. Ethiopia and Rwanda are two African economies that exhibit strong decoupling in many years (e.g., Ethiopia -148 in 2001, Rwanda -43 in 2002), highlighting instances where emissions fell sharply in relation to GDP growth, potentially as a result of structural reliance on hydropower and low industrial emissions intensity (Bekele & Tadesse, 2012). However, nations like Mozambique (4.95 in 2024) and Niger (elasticity 22.5 in 2019, 5.45 in 2024) show negative decoupling, indicating unsustainable growth trajectories linked to reliance on fossil fuels and inadequate energy efficiency. Overall, the trends support the theoretical prediction that decoupling is context-dependent rather than linear: some economies achieve strong decoupling through efficiency gains and the adoption of renewable energy sources, while others are stuck in carbon-intensive growth, highlighting the need for focused energy reforms and policy interventions (Tapio, 2005; Grossman & Krueger, 1995).

Mean Elasticity

Table 2

Mean Elasticity

Country	Sum of elasticity	Number of obs	Mean elasticity
Brazil	65.7697953	25	2.630791812
China	-12.0834505	25	-0.48333802
Ethiopia	-138.6622018	25	-5.54648807
Guyana	18.84729106	25	0.753891642
India	45.80041435	25	1.832016574
Mozambique	5.604823744	25	0.22419295
Niger	61.06680765	25	2.442672306
Russia	3.250855717	25	0.130034229
Rwanda	-34.10720772	25	-1.364288309
Senegal	10.07207031	25	0.402882812
South Africa	-34.29074379	25	-1.371629752
Uganda	-3.255857828	25	-0.130234313
Vetnam	26.36872219	25	1.054748888

Source; researchers own compilation from secondary sources

Analyzing mean elasticity across the countries under investigation reveals distinct decoupling patterns between economic expansion and environmental pressure. China (-0.48), Ethiopia (-5.55), Rwanda (-1.36), South Africa (-1.37), and Uganda (-0.13) are examples of countries with strong decoupling, where emissions decline despite GDP growth, suggesting successful energy transitions and efficiency gains. This is in line with the EKC theory, which maintains that environmental degradation first rises with affluence and then steadily declines as economies adopt cleaner technology (Grossman & Krueger, 1995). Conversely, Senegal (0.40), Mozambique (0.22), and Russia (0.13) have poor decoupling, meaning that while emissions are still rising, they are doing so more slowly than GDP. According to studies, emerging economies often achieve relative decoupling rather than absolute decoupling (Tapio, 2005).   Brazil (2.63), India (1.83), Niger (2.44), and Vietnam (1.05) exhibit negative decoupling, or emissions rising faster than GDP, indicating unsustainable growth trajectories that mostly depend on fossil fuels. Empirical study indicates that the BRICS economies particularly Brazil and India find it challenging to achieve complete decoupling due to their structural reliance on carbon-intensive industries (Wang et al., 2020). The results highlight the importance of energy structural changes, the adoption of renewable energy sources, and legislative initiatives to promote green growth in accordance with international sustainability objectives. Overall, the findings demonstrate that while some countries are moving toward sustainability, others are still stuck in carbon-intensive growth (table 2 above).

Regression Analysis Result

Before running the regression, the researchers undertaken some assumption tests; to ascertain if unobserved country-specific characteristics are connected with the regressors, the Hausman test contrasts the fixed-effects and random-effects estimators. The null hypothesis that there is no systematic difference between the estimators cannot be rejected in this instance since the test statistic is relatively tiny ($\chi^2 = 2.25$) and the p-value is quite high (0.9940). The fact that the discrepancies between the FE and RE coefficients are statistically insignificant in relation to their variances suggests that the random-effects model is consistent. This outcome is theoretically possible in cross-national research where short-term variables like ICT spending, unemployment, or foreign direct investment may not be highly connected with unobserved heterogeneity, such as geography, long-term institutional traits, or historical development patterns. When the Hausman test is unable to reject the null, many empirical research on energy, emissions, and growth also conclude that random effects are reasonable, particularly in panels with very small-time dimensions. Because the random-effects model is consistent, effective, and better adapted to capturing both within- and between-country variance in emerging economies, it is favored based on both statistical data and theoretical reasons (Appendix A, table1).

With a high-test statistic ($\text{chibar}^2 = 1697.17$) and a p-value of 0.0000, the Breusch and Pagan Lagrangian Multiplier (LM) test for random effects clearly indicates the existence of significant country-level heterogeneity in the panel data. As a result, the null hypothesis that the variance of the random effect is zero is rejected, proving that a pooled OLS model would not be suitable. Rather, the random effects model is statistically supported, suggesting that unobserved country-specific factors have a considerable impact on ANS and need to be taken into consideration in order to prevent biased or inefficient estimates in the empirical study (Appendix A, table 2).

The chosen explanatory variables renewable and non-renewable energy consumption, individual internet use, ICT goods exports, urbanization rate, manufacturing value added, foreign direct investment, CO_2 emissions, decoupling elasticity, and GDP are confirmed to be collectively significant in explaining variations in ANS by the joint significance test. With a chi-squared statistic of 98.15 and a p-value of 0.0000, the test strongly rejects the null hypothesis that all coefficients are jointly zero. This outcome, which shows that energy structure, digitalization, industrial dynamics, and environmental pressures all work together to shape green growth trajectories in emerging economies, supports the inclusion of these variables in the model and validates the conceptual framework's empirical relevance (Appendix A, table 3).

Table 3

Random effect model result

Random-effects GLS regression				Number of observations = 325		
Group variable: Country Code				Number of groups = 13		
R-sq:				Observation per group:		
within = 0.2345				min = 25		
between = 0.4807				avg = 25.0		
overall = 0.4378				max = 25		
				Wald chi2(7) = 98.15		
				Prob > chi2 = 0.0000		
Adjusted net saving	Coef.	Std. Err.	Z	P>|z|	[95% Conf. Interval]	
Renewable Energy Consumption	.004418	.0526708	0.08	0.933	-.0988148	.1076508
Non- Renewable Energy Consumption	.0044805	.0119034	0.38	0.707	-.0188497	.0278107
Urbanization rate	-.023357	.0207123	-1.13	0.259	-.0639523	.0172384
ICT good export	.1356735	.0545084	2.49	0.013	.028839	.242508
Internet usage	-.3348518	.0741637	-4.52	0.000	-.4802101	-.1894935
Manufacturing Value Added	.0758804	.0950475	0.80	0.425	-.1104093	.2621701
FDI	.0043536	.0375216	0.12	0.908	-.0691875	.0778946
CO2emission	-.0813713	.0249679	-3.26	0.001	-.1303075	-.0324351
Decoupling Elasticity	-.0020828	.0189969	-0.11	0.913	-.0393161	.0351505
GDP	2.983644	.4925745	6.06	0.000	2.018215	3.949072
_cons	-55.55027	12.56242	-4.42	0.000	-80.17216	-30.92838
sigma_u	10.332017					
sigma_e	3.2445895					
Rho	.9102358	(fraction of variance due to u_i)				

Source; researchers own computation

The random-effects GLS regression (overall R2=0.4378R^2 = 0.4378; Wald χ^2 = 98.15, p <.001) demonstrates how energy structure, digitalization, and environmental concerns interact to shape adjusted net savings in 13 emerging economies. ICT products exports (β=0.136, p<.05) are one of the major variables that have a favorable impact on adjusted net savings. This indicates how innovation and technological diffusion can improve resource efficiency and promote green growth. This result is in line with innovation theory, which highlights how knowledge-intensive trade and technology advancements contribute to sustainable growth paths (Romer, 1990; Lundvall, 1992). Internet usage, on the other hand, has a negative impact ($\beta=-0.335$, $p<.001$), highlighting the paradox of digitalization: although ICT exports increase efficiency, widespread internet penetration can raise energy demand and emissions through rebound effects unless institutions steer digital infrastructure toward sustainability (Hilty & Aebischer, 2015; Acemoglu et al., 2012).

The negative and significant impact of CO_2 emissions ($\beta=-0.081$, $p<.01$), which erode real savings by depleting natural capital, is another indication of environmental stresses. This is consistent with institutional theory, which emphasizes that economic activity threatens long-term wealth in the absence of robust regulatory frameworks and environmental control (North, 1990; Acemoglu & Robinson, 2012). In the meantime, GDP growth ($\beta=2.984$, $p<.001$) significantly increases ANS, which is in line with the EKC theory, which states that while economic growth initially exacerbates environmental degradation, it later permits investment in cleaner technologies and more stringent regulations (Grossman & Krueger, 1995; Panayotou, 1997). These economies appear to be in the EKC's transitional phase, where growth and environmental costs overlap before eventually decoupling, based on the coexistence of positive GDP benefits and negative CO_2 consequences.

The statistical insignificance of other factors, such as the consumption of renewable and non-renewable energy, urbanization, manufacturing value addition, foreign direct investment, and decoupling elasticity, suggests that structural change by itself does not ensure sustainability. Rather, transition theory emphasizes that in order to lock in efficiency gains and accomplish true decoupling, systemic shifts toward low-carbon pathways necessitate institutional alignment, policy coherence, and technical innovation (Geels, 2002; Sovacool, 2016). Overall, the findings highlight the importance of institutional quality and environmental governance in reducing the detrimental effects of emissions and digital rebound effects, thereby guiding emerging economies toward sustainable decoupling, even though economic growth and ICT exports can drive green savings trajectories (table 3 above).

CONCLUSION

Emerging economies are undergoing uneven and context-dependent decoupling trajectories, as evidenced by elasticity trends, cross-country decoupling patterns, and regression results. The EKC theory, which holds that economic expansion is increasingly accompanied by structural reforms, the deployment of renewable energy, and efficiency gains that lower emissions, is reflected in strong decoupling in nations like China, Ethiopia, Rwanda, South Africa, and Uganda. On the other hand, negative decoupling in India, Brazil, Niger, Mozambique, and Vietnam emphasizes the continued reliance on fossil fuels, lax implementation of regulations, and slow technological development, underscoring the crucial role that institutional quality plays in determining sustainable results.

The unpredictable effects, in line with innovation theory, which highlights the role of technical advancement and knowledge-intensive trade in propelling green growth, GLS regression also shows that ICT goods exports have a positive impact on adjusted net savings. However, the detrimental impact of internet use highlights the paradox of digitalization: in the absence of institutional supervision, digital growth can worsen emissions and energy demand through rebound effects. The strong positive impact of GDP growth reflects the transitional phase of the EKC, where economic expansion offers opportunities for investment in cleaner technologies but still overlaps with environmental costs. Similarly, the substantial erosion of savings by CO2 emissions supports institutional theory's emphasis on environmental governance.

Urbanization, FDI, manufacturing value addition, renewable and non-renewable energy consumption, and decoupling elasticity are all negligible, indicating that structural change is not enough to ensure sustainability. According to transition theory, in order to lock in efficiency gains and accomplish true decoupling, systemic alignment—through cogent policies, institutional reforms, and technical innovation—is crucial.

Overall, the results highlight the importance of institutional robustness, environmental governance, and innovation-driven transitions in guiding emerging economies toward sustainable decoupling, even as economic development and ICT exports might boost green savings trajectories. Long-term green growth necessitates not only technical advancement but also institutional capacity and policy coherence to control digital rebound effects, reduce emissions, and include low-carbon paths into national development plans.

RECOMMENDATIONS AND POLICY IMPLICATION

The results highlight that decoupling trends in emerging economies depend on policy decisions rather than just economic conditions. Stronger regulatory frameworks, including more stringent emission limits, carbon pricing, and reliable monitoring systems to protect natural capital, are desperately needed in light of the detrimental effects of CO_2 emissions on adjusted net savings. The rebound impact of broad internet usage necessitates regulations that drive digital infrastructure toward sustainability, even as ICT goods exports foster green growth through innovation and technology dissemination. To reduce energy-intensive digital use, this calls for investments in renewable energy-powered ICT networks, green data centers, and awareness programs.

If growth dividends are carefully directed, expansion can be used to support eco-innovation, clean technology, and sustainable urban design, according to the strong beneficial role of GDP growth. Therefore, in order to spread green technologies and support innovation-driven industrial strategies, governments should encourage R&D, high-tech exports, and international cooperation. However, the insignificance of urbanization, manufacturing value addition, and both renewable and non-renewable energy consumption suggests that structural change is not enough on its own. To lock in efficiency improvements, coordinated actions must match institutional reforms with energy transitions.

Systemic transition policies which incorporate energy efficiency standards, circular economy practices, and institutional coherence to accomplish true decoupling between growth and emissions are crucial given the insignificance of decoupling elasticity. Stronger sustainability results are ultimately attained by nations that make investments in renewable energy, enforce environmental regulations, and reorganize toward cleaner sectors. Thus, emerging economies are in a unique position where they can only turn growth trajectories into true paths of sustainable decoupling by coordinating economic expansion, digital transformation, and environmental governance.

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Appendix A

Table 1; Housman test

	Coefficients (b) FE	(B) RE	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
REC	.0349786	.004418	.0305606	.0269586
NREC	.0020937	.0044805	-.0023867	.0026464
IU	-.0221537	-.023357	.0012033	.0044427
ICTgexp	.1560506	.1356735	.0203771	.0180225
UR	-.3809125	-.3348518	-.0460607	.0375869
MVA	.0535483	.0758804	-.0223321	.0245592
FDI	.0120259	.0043536	.0076723	.0086209
CO2emission	-.0874527	-.0813713	-.0060814	.006153
lnGDP	3.172437	2.983644	.1887938	.1884648
Elasticity~n	-.0030155	-.0020828	-.0009326	.0030288

```
                  b = consistent under Ho and Ha; obtained from xtreg
   B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test:  Ho:  difference in coefficients not systematic

            chi2(10) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                     =        2.25
           Prob>chi2 =      0.9940
```

Table 2; Breusch and Pagan Lagrangian multiplier test

```
Breusch and Pagan Lagrangian multiplier test for random effects

        ANS[CountCode,t] = Xb + u[CountCode] + e[CountCode,t]

        Estimated results:
```

	Var	sd = sqrt(Var)
ANS	78.73034	8.873012
e	10.52736	3.244589
u	106.7506	10.33202

```
        Test:   Var(u) = 0
                              chibar2(01) =  1697.17
                           Prob > chibar2 =   0.0000
```

Table 3; Joint effect test

```
. test (REC NREC IU ICTgexp UR MVA FDI CO2emission ElasticityChangeinemission lnGDP)

 ( 1)  REC = 0
 ( 2)  NREC = 0
 ( 3)  IU = 0
 ( 4)  ICTgexp = 0
 ( 5)  UR = 0
 ( 6)  MVA = 0
 ( 7)  FDI = 0
 ( 8)  CO2emission = 0
 ( 9)  ElasticityChangeinemission = 0
 (10)  lnGDP = 0

           chi2( 10) =   98.15
         Prob > chi2 =    0.0000
```