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Sustainable Energy Transition, Energy Efficiency and Labour Market Dynamics in BRICS Economies: An Empirical Assessment of SDG 7, SDG 8 and SDG 13

Zrównoważona transformacja energetyczna, efektywność energetyczna i dynamika rynku pracy w gospodarkach BRICS: Empiryczna ocena Celów Zrównoważonego Rozwoju 7, 8 i 13

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Abstract
As the global shift toward cleaner energy accelerates, a critical question emerges: can sustainable energy transition foster decent employment or does it generate new labour market frictions? This study investigates how renewable energy transition and energy efficiency shape labour market dynamics across the BRICS economies, using a balanced panel of five countries from 2000–2023. The analysis integrates a composite Renewable Energy Transition Index (constructed via PCA), energy intensity and multidimensional institutional and demographic controls. A multi-method empirical strategy – fixed effects, two-stage least squares and method-of-moments quantile regression, captures both average and distributional effects, complemented by pre-/COVID-19 estimations to assess whether the pandemic altered the underlying relationships. The findings reveal that energy efficiency consistently enhances labour market outcomes, with this effect strengthening in the COVID-19 period. By contrast, renewable energy transition exerts heterogeneous and often adverse short-run impacts, particularly in weaker labour markets and in the full BRICS configuration, where Russia's inclusion amplifies transition frictions. However the situation for this country is now much more complicated, due to war with Ukraine, which begun in 2022. Education and governance mitigate some of these effects, with human capital providing the most stable moderating channel. Country-specific patterns show strong energy-labour linkages in Brazil and China, muted responses in India, persistent demographic pressures in South Africa and a significant bloc-level influence of Russia. By embedding SDG 7, SDG 8 and SDG 13 within a unified analytical framework and incorporating pandemic-related dynamics, this study offers novel evidence on how clean energy pathways interact with labour structures in emerging economies. The results highlight the importance of skills development, institutional capability and context-sensitive policy sequencing for aligning sustainable energy transition with inclusive and resilient labour markets.

Key words: BRICS economies, energy efficiency, governance quality, labour market dynamics, sustainable energy transition

Streszczenie

Wraz z przyspieszeniem globalnego przejścia na czystszą energię, pojawia się kluczowe pytanie: czy zrównoważona transformacja energetyczna może sprzyjać godnemu zatrudnieniu, czy też generuje nowe tarcia na rynku pracy? Niniejsze badanie analizuje, jak transformacja w zakresie odnawialnych źródeł energii i efektywność energetyczna kształtują dynamikę rynku pracy w gospodarkach BRICS, wykorzystując zrównoważony panel pięciu krajów z lat 2000–2023. Analiza integruje złożony Wskaźnik Transformacji w zakresie Odnawialnych Źródeł Energii (opracowany metodą PCA), intensywność energetyczną oraz wielowymiarowe kontrole instytucjonalne i demograficzne. Wielometodowa strategia empiryczna – efekty stałe, dwuetapowa metoda najmniejszych kwadratów i regresja kwantylowa metodą momentów – uwzględnia zarówno efekty średnie, jak i efekty dystrybucyjne, uzupełnione szacunkami sprzed pandemii COVID-19, aby ocenić, czy pandemia zmieniła podstawowe zależności. Wyniki pokazują, że efektywność energetyczna konsekwentnie poprawia wyniki na rynku pracy, a efekt ten nasila się w okresie pandemii COVID-19. Z kolei transformacja w kierunku odnawialnych źródeł energii wywiera heterogeniczne i często niekorzystne skutki krótkoterminowe, szczególnie na słabszych rynkach pracy oraz w pełnej konfiguracji BRICS, gdzie włączenie Rosji nasila tarcia transformacyjne. Sytuacja tego kraju stała się dodatkowo znacznie bardziej skomplikowana po wybuchu wojny z Ukrainą. Edukacja i zarządzanie łagodzą niektóre z tych skutków, a kapitał ludzki zapewnia najbardziej stabilny kanał moderujący. Wzorce specyficzne dla poszczególnych krajów wskazują na silne powiązania między energią a pracą w Brazylii i Chinach, stonowane reakcje w Indiach, utrzymującą się presję demograficzną w Republice Południowej Afryki oraz znaczący wpływ Rosji na poziomie bloku. Dzięki osadzeniu Celów Zrównoważonego Rozwoju 7, Celów Zrównoważonego Rozwoju 8 i Celów Zrównoważonego Rozwoju 13 w ramach ujednoliconych ram analitycznych oraz uwzględnieniu dynamiki związanej z pandemią, niniejsze badanie dostarcza nowych dowodów na to, jak ścieżki czystej energii oddziałują na struktury pracy w gospodarkach wschodzących. Wyniki podkreślają znaczenie rozwoju umiejętności, potencjału instytucjonalnego i kontekstowej sekwencji polityki dla powiązania zrównoważonej transformacji energetycznej z inkluzywnymi i odpornymi rynkami pracy.

Słowa kluczowe: kraje BRICS economies, efektywność energetyczna, jakość zarządzania, dynamika rynku pracy, zrównoważona transformacja energetyczna

1. Introduction

The global shift toward clean and sustainable energy has become one of the defining transformations of the twenty-first century, reshaping industrial systems, employment patterns, and development trajectories across both advanced and emerging economies. The urgency to transition from fossil fuels to renewable energy sources is reinforced by the mounting threats of climate change, volatile energy markets, and the growing international commitment to net-zero targets. Yet, this transformation is not merely an environmental or technological challenge; it is also a profound economic and social one. The sustainable energy transition reconfigures the structure of production, alters skill requirements, and redefines the nature of work, thereby creating new opportunities while exposing vulnerabilities within existing labour markets. For emerging economies such as the BRICS – Brazil, Russia, India, China, and South Africa, the intersection between clean energy expansion and employment generation is particularly critical. Together, these countries account for over 40 per cent of the world's population, a quarter of global GDP, and nearly half of global carbon emissions, positioning them as both major contributors to and potential leaders of global decarbonisation (Eti et al., 2023; Ahmad & Zhang, 2020). However in case of Russia the war with Ukraine is a complicated multi-layer new factor. First of all, war context brings destruction and changes in whole economy and society, not only energy sector. The consequences of war need further studies, especially when the conflict is finally over.

Despite impressive advances in renewable capacity, the pace and structure of transition across BRICS remain highly uneven. China has achieved remarkable progress through large-scale investments in solar, wind, and battery technologies, while Brazil has leveraged its extensive hydropower and bioenergy resources to sustain low-carbon development. Russia and India, by contrast, continue to rely heavily on fossil fuels, and South Africa's energy landscape remains dominated by coal, reflecting structural inertia and infrastructural constraints (Chandra Voumik & Sultana, 2022; Hlongwane & Khobai, 2025). The result is a heterogeneous landscape where some economies have successfully integrated renewables into industrial growth strategies, while others lag due to weak institutional frameworks, inadequate financing, and low technological diffusion (Chen & Lin, 2020; Beletskaya, 2022). These disparities have significant implications for employment and income distribution, as energy transition processes create and destroy jobs at different rates and in different sectors.

Empirical evidence demonstrates that renewable energy adoption tends to yield net positive employment effects globally, though these effects are moderate and uneven (García-García et al., 2020; Hanna et al., 2024). For instance, Proença and Fortes (2020) found that a 1 per cent increase in renewable capacity across EU countries generates a 0.48 per cent rise in employment, while Armiento et al. (2025) reported that global renewable energy industries created approximately 3.4 million new jobs between 2019 and 2022. However, such aggregate gains often conceal sectoral and spatial inequalities, as new employment opportunities are concentrated in renewable manufacturing, installation, and services, while losses are disproportionately borne by workers in carbon-intensive industries (Lynch et al., 2024; Grazini et al., 2024). In the BRICS context, these challenges are magnified by persistent skill mismatches, weak vocational training systems, and regional disparities in economic diversification. Studies indicate that hydropower and solar energy expansion in BRICS contributes positively to employment, ranging between 0.78 and 9.6 per cent, whereas wind and nuclear energy have shown more limited or even negative effects (Hlongwane et al., 2025). The unevenness of these outcomes underscores the need for policy coherence and labour adjustment mechanisms to mitigate the disruptive effects of green restructuring.

The central problem, however, lies in the limited empirical understanding of how sustainable energy transition influences labour market performance across the BRICS economies. While theoretical and case-based research has documented the potential complementarities between SDG 7 (Affordable and Clean Energy) and SDG 8 (Decent Work and Economic Growth), empirical evidence linking renewable energy indicators with employment dynamics remains fragmented, particularly in developing and emerging contexts (Fonseca et al., 2020; Pearse & Bryant, 2021). Most studies are confined to correlation analyses or high-income regions, offering little insight into the causal pathways through which renewable energy, energy efficiency, and institutional quality jointly shape employment, job quality, and productivity in the BRICS bloc (García-García et al., 2020; Hanna et al., 2024). Moreover, the literature reveals persistent neglect of mediating factors such as governance, education, and financial development, that influence the magnitude and direction of employment effects (Qin et al., 2023; Adepoju et al., 2022). Without a multidimensional, comparative approach, it is difficult to determine whether the green transition in BRICS economies can deliver the dual goals of energy sustainability and inclusive labour market outcomes.

This study aims to bridge this knowledge gap by empirically assessing how sustainable energy transition influences labour market performance across BRICS economies. Broadly, it seeks to integrate energy transition indicators such as renewable energy consumption, energy intensity, and energy efficiency with labour market variables including employment, unemployment, and productivity. Specifically, it addresses three interrelated questions: What is the impact of renewable energy transition on labour market performance in BRICS economies? Through which channels do education and governance moderate this relationship? And how heterogeneous are the employment effects of energy transition across BRICS economies and time horizons? By providing empirical evidence on these questions, this study contributes to understanding how cleaner energy pathways can stimulate decent employment while managing transition-related trade-offs.

The study's contribution is both theoretical and practical. Theoretically, it extends the Green Growth and Just Transition frameworks by embedding them within the empirical realities of emerging economies, highlighting how institutional quality, skill formation, and policy coordination shape the social dimensions of decarbonisation (Bowen et al., 2012; Ding et al., 2024). Empirically, it introduces a multidimensional analytical framework that captures the heterogeneity of energy–labour interactions across BRICS countries, providing a richer understanding of the co-evolution of energy and employment systems. Practically, its findings will inform policy efforts aimed at balancing the objectives of environmental sustainability and labour inclusivity. By illuminating how energy transition can be leveraged to advance both SDG 7 and SDG 8, this study contributes to the global discourse on equitable pathways toward sustainable growth in emerging economies.

Furthermore, given the centrality of climate mitigation to global energy transition efforts, this study also aligns its framework with SDG 13 (Climate Action). Renewable energy adoption, energy efficiency improvement, and reduced energy intensity represent key pathways through which BRICS economies can contribute to climate neutrality. As such, the transition dynamics investigated in this study extend beyond labour market and energy access considerations (SDG 7 and SDG 8) to the broader climate responsibility agenda embedded in SDG 13.

2. Review of literature

2.1. Theoretical and conceptual framework

The theoretical and conceptual foundations linking sustainable energy transition and labour market performance are best understood within the interrelated frameworks of the Sustainable Development Goals, particularly SDG 7 (Affordable and Clean Energy) and SDG 8 (Decent Work and Economic Growth). The growing body of literature reveals that the energy transition, underpinned by the diffusion of renewable technologies, interacts dynamically with employment patterns, skill formation, and industrial restructuring, shaping the trajectory of sustainable development. Within this nexus, SDG 7 facilitates the adoption of renewable energy sources that reduce carbon intensity and foster clean industrial processes, while SDG 8 emphasises decent job creation, productivity enhancement, and inclusive economic growth. Together, these goals capture the multidimensional implications of energy transition on employment generation, skill transformation, and labour market resilience.

Empirical evidence demonstrates predominantly positive yet complex linkages between sustainable energy transition and labour market outcomes. Studies consistently report that renewable energy deployment yields net job creation globally, though the magnitude of these effects remains modest (Pablo García-García et al., 2020). The integration of clean energy technologies stimulates new employment opportunities across production chains while demanding new skill sets aligned with digitalisation, automation, and environmental management (Boone et al., 2023; Martin Černý et al., 2024). These dynamics underpin the synergy between SDG 7 and SDG 8, as shown in the European Union, where renewable electricity expansion enhanced both energy sustainability and labour productivity (Swain et al., 2020). However, the transition also produces short-term disruptions, such as job displacement in carbon-intensive industries and regional inequalities, as highlighted in the coal phase-out cases of Germany and South Africa (Hägele et al., 2022).

The transmission channels between renewable energy and labour markets operate through several mechanisms. First, renewable energy investments generate direct employment in installation, manufacturing, and maintenance, with spillover effects on supporting industries (Hlongwane and Khobai, 2025; Hanna et al., 2024). Second, they foster skill transformation by increasing demand for higher educational attainment and technical competencies in engineering, data analytics, and environmental management (Boone et al., 2023). Third, renewable technologies enhance industrial competitiveness by stimulating innovation and improving resource efficiency (Caglar et al., 2023). Lastly, they contribute to improved employment outcomes through economic diversification, particularly in emerging economies such as the BRICS, where renewable energy expansion modifies production structures and reduces energy intensity (Zhu et al., 2025; Ofori et al., 2024).

From a theoretical standpoint, the Green Growth Theory and the Just Transition framework jointly elucidate these interactions. Green Growth Theory posits that environmental sustainability and economic development are mutually reinforcing when policy instruments promote investment in low-carbon technologies and human capital (Bowen et al., 2012). It underscores that employment creation in green sectors can offset losses in traditional energy industries, provided that market and institutional mechanisms are well-aligned. Conversely, the Just Transition framework emphasises equity, worker protection, and inclusivity in managing the socio-economic disruptions associated with the energy shift (Ding et al., 2024; Wilgosh et al., 2022). Together, these frameworks highlight that while energy transition can advance growth and employment, its success depends on policies that ensure social fairness, skill adaptability, and economic competitiveness.

In the context of BRICS economies, these frameworks are particularly relevant given the scale of industrial transformation and the persistence of fossil fuel dependency. Renewable energy diffusion in these economies has been found to promote economic restructuring, enhance energy efficiency, and generate new green employment opportunities (Huo et al., 2025). Nonetheless, sustaining these gains requires deliberate investment in education, reskilling, and institutional mechanisms that align labour markets with evolving green technologies. Thus, sustainable energy transition emerges not only as a pathway to environmental resilience but also as a transformative driver of inclusive labour market outcomes, aligning the dual objectives of SDG 7 and SDG 8 through innovation, competitiveness, and social equity.

2.2. Empirical insights into the dynamics of energy transition in BRICS economies

Empirical evidence on energy transition in BRICS economies reveals substantial heterogeneity in renewable energy consumption, installed capacity, and energy intensity, reflecting the diversity in resource endowments, institutional quality, and policy commitment across the bloc. China continues to lead renewable energy deployment globally, driven by strong industrial policy and massive investments in solar and wind technologies, while Russia and Brazil have leveraged hydropower and bioenergy resources to sustain their low-carbon trajectories (Eti et al., 2023). In contrast, India and South Africa remain constrained by infrastructural deficits and heavy dependence on coal, slowing the pace of energy transition despite growing policy attention (Chandra Voumik & Sultana, 2022). The literature consistently highlights that differences in economic structure, technological capabilities, and policy instruments largely explain the uneven development of renewable energy across BRICS economies.

Studies examining long-term energy transition trends project that the BRICS group will play an increasingly pivotal role in the global energy landscape by 2040, with renewable capacity expansion expected to offset a significant share of fossil fuel demand (Ahmad & Zhang, 2020). Yet, despite this optimistic projection, energy intensity levels remain high in several BRICS countries, suggesting that structural inefficiencies and carbon lock-ins continue to hinder the decoupling of growth from emissions. Empirical analyses further reveal that technological innovation acts as a critical enabler of renewable adoption, with China's advancements in photovoltaic and battery technologies serving as a benchmark for other emerging economies (Eti et al., 2023). These technological spillovers have begun to reshape industrial energy demand, but their diffusion remains uneven, with institutional and infrastructural bottlenecks limiting scalability in India, Brazil, and South Africa.

Policy design and infrastructure readiness play an equally decisive role in shaping the pace of renewable energy adoption. Evidence from cross-country comparisons demonstrates that market-based mechanisms such as quota systems with certificate trading, competitive tendering, and targeted fiscal incentives deliver stronger renewable outcomes than general tax relief or non-binding targets (Hille & Oelker, 2023). However, the success of these instruments depends heavily on supporting grid infrastructure and coordination among key actors. In China, grid density limitations and transmission constraints have slowed renewable integration despite large installed capacities (Chen & Lin, 2020), while similar challenges persist in South Africa due to inadequate investment in grid modernisation and maintenance. Comparative evidence from Sweden shows that renewable diffusion thrives when policy, institutions, and adopter networks co-evolve through feedback mechanisms that link infrastructure provision to technology adoption (Palm, 2022). These findings imply that in BRICS economies, policy effectiveness must be viewed as a systemic outcome of institutional design, technological innovation, and infrastructure alignment rather than isolated policy measures.

Financial development and institutional quality emerge as critical determinants of renewable energy expansion across BRICS and other developing contexts. Empirical analyses covering large cross-country datasets demonstrate that deeper financial systems facilitate green investment flows and accelerate clean energy transition (Qin et al., 2023). Nonetheless, green projects often face higher capital costs estimated at 30 per cent above conventional investments, due to perceived risks and limited market maturity (Škare et al., 2023). Institutional quality, encompassing governance effectiveness and regulatory stability, consistently correlates with faster renewable adoption (Vatamanu & Zugravu, 2023; Uzar, 2020; Satrianto et al., 2024). Yet financing barriers persist in lower-income BRICS members, where weak financial intermediation constrains renewable project viability. Targeted interventions, including credit guarantees, concessional loans, and subsidy frameworks, have proven effective in reducing financing constraints and widening clean energy access (Shittu et al., 2024).

The empirical literature suggests that the dynamics of energy transition in BRICS economies are shaped by a complex interplay of policy design, technological diffusion, infrastructural readiness, and institutional quality. While progress is evident, particularly in China and Brazil, sustained investment in innovation systems, financial inclusion, and grid modernisation remains imperative for achieving deep decarbonisation and inclusive energy access within the bloc.

2.3. Stylised facts and renewable energy transition pathways in BRICS economies (2000–2023)

Building on the preceding empirical insights on the dynamics of energy transition (Section 2.2), this section presents descriptive evidence illustrating how renewable energy development has evolved across BRICS economies from 2000 to 2023. Using country-level data on installed capacity disaggregated by energy type, the figures (1–5) highlight temporal trends, structural compositions, and diversification patterns. The analysis complements earlier findings in the literature by revealing not only the magnitude of progress but also the heterogeneity and structural imbalances that shape the renewable energy transition across BRICS economies.

Figure 1 presents the aggregate renewable energy mix across BRICS economies between 2000 and 2023. The total installed capacity expanded from approximately 220 GW in 2000 to over 1,900 GW in 2023, representing an average annual growth rate of 9.4 percent. Hydropower, which accounted for about 76 percent of total renewable capacity in 2000, declined to 41 percent by 2023, as solar and wind energy gained prominence. Solar capacity alone rose from less than 5 GW in 2000 to more than 700 GW in 2023, while wind energy increased from roughly 8 GW to 470 GW during the same period.

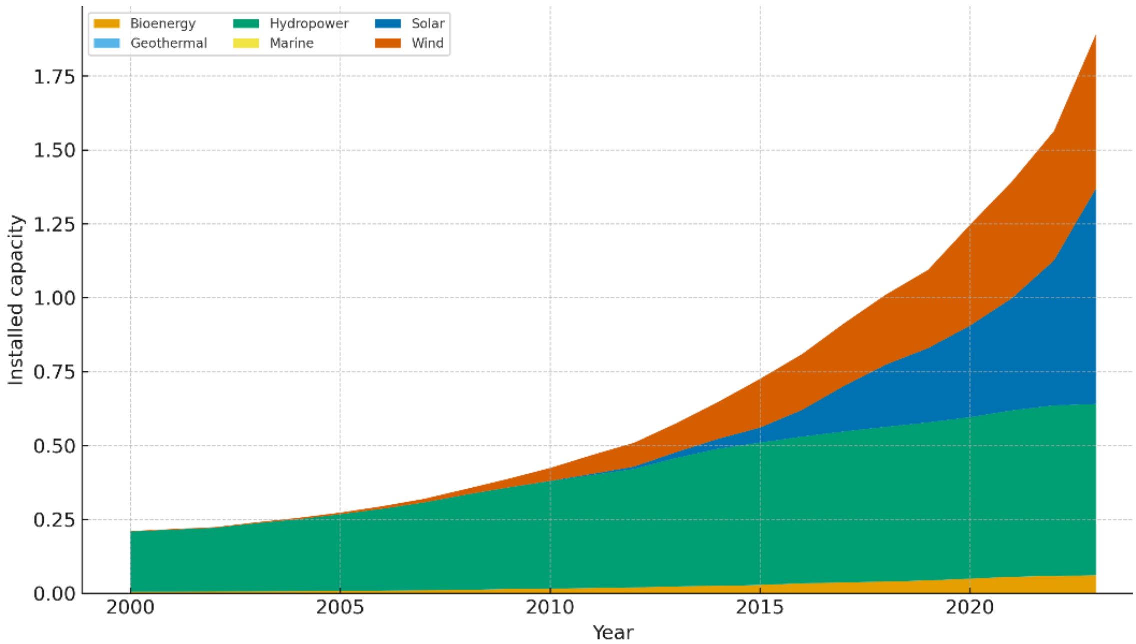

Figure 1. BRICS Renewable Energy Mix over Time, source: Authors' Illustration using data from IRENA

This structural shift aligns with Eti et al. (2023), who identified a pronounced post-2010 diversification led by China and India through large-scale investments in solar and wind technologies. However, the magnitude of expansion observed in this dataset suggests an even faster rate of transition than previously documented, underscoring the accelerating policy and technological momentum across BRICS. Bioenergy and geothermal resources contributed modestly, particularly in Brazil, supporting earlier evidence that resource-specific endowments still influence renewable portfolios across developing economies (Ahmad & Zhang, 2020).

Figure 2 compares the growth trajectories of total renewable installed capacity among BRICS nations. China remains the dominant contributor, increasing from approximately 110 GW in 2000 to around 1,200 GW by 2023, representing 63 percent of the bloc's total renewable capacity. India's installed capacity rose from 25 GW to nearly 250 GW, while Brazil expanded from 70 GW to 160 GW. South Africa grew from a modest 1.2 GW in 2000 to 40 GW by 2023, whereas Russia's capacity increased only marginally from 45 GW to 60 GW.

These figures reinforce the asymmetric pace of transition reported by Chandra Voumik and Sultana (2022), who emphasised that infrastructural constraints and coal dependency slow renewable adoption in India and South Africa. Yet, the sharp post-2015 acceleration in India and South Africa revealed here suggests a narrowing of this gap, signalling incremental policy effectiveness. The relative stagnation of Russia's capacity, however, corroborates findings by Hille and Oelker (2023) that policy inertia and weak institutional commitment continue to impede renewable diffusion in resource-abundant economies.

Collectively, the figure demonstrates that China and India drive the group's renewable expansion, Brazil maintains steady but sector-specific growth, South Africa is emerging as a late adopter, and Russia lags significantly behind – a pattern consistent with the structural heterogeneity highlighted in earlier empirical reviews.

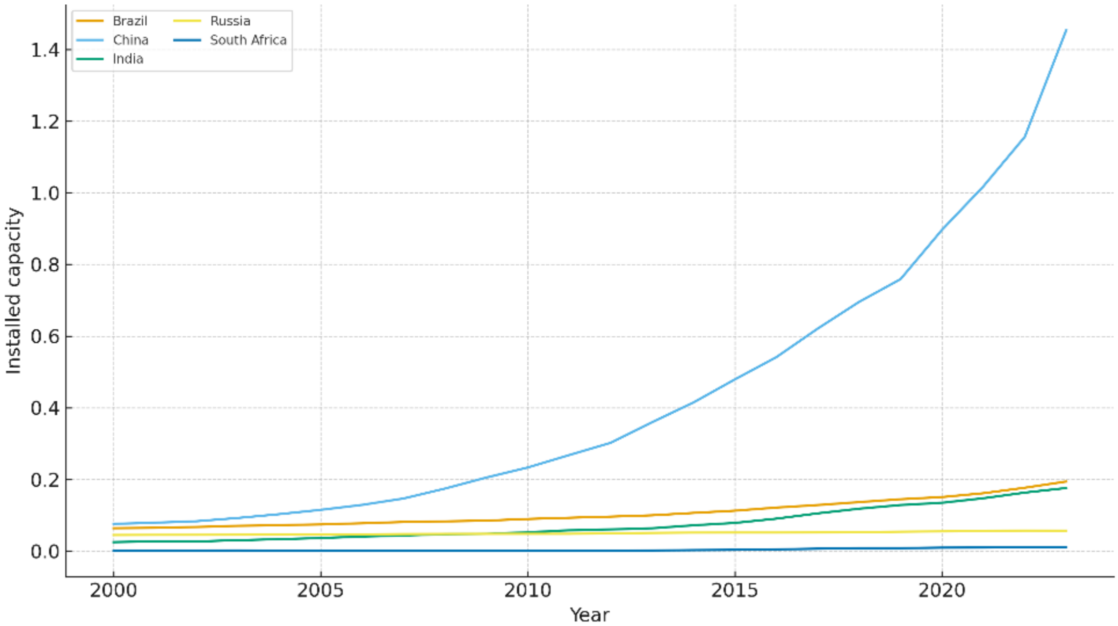

Figure 2. Total Renewable Installed Capacity by Country, source: Authors' Illustration using data from IRENA

Figure 3 provides a cross-sectional snapshot of the renewable energy composition for 2023. Brazil remains overwhelmingly dependent on hydropower (≈79%), complemented by bioenergy (≈11%) and wind (≈9%). Russia's renewable portfolio is 92 percent hydropower, with nascent wind and solar sectors comprising less than 5 percent. China exhibits the most diversified structure—hydropower (35%), solar (32%), and wind (28%), reflecting its strong industrial policy orientation and technological self-sufficiency (Eti et al., 2023). India follows with solar (43%), wind (36%), and hydropower (18%), while South Africa's mix is dominated by solar (58%) and wind (34%).

This composition largely mirrors the policy and resource asymmetries documented by Ahmad and Zhang (2020), who found that hydro-based economies such as Brazil and Russia exhibit slow diversification relative to technology-driven systems like China and India. The present evidence, however, shows greater compositional balance in India and China than previous studies, suggesting that recent policy reforms, including competitive renewable tenders and grid expansion programmes, have begun to yield tangible structural results (Chen & Lin, 2020).

The figure also reinforces the conclusion by Chandra Voumik and Sultana (2022) that solar energy has emerged as the cornerstone of renewable transition across late adopters, especially in South Africa, due to favourable solar irradiance and government procurement schemes.

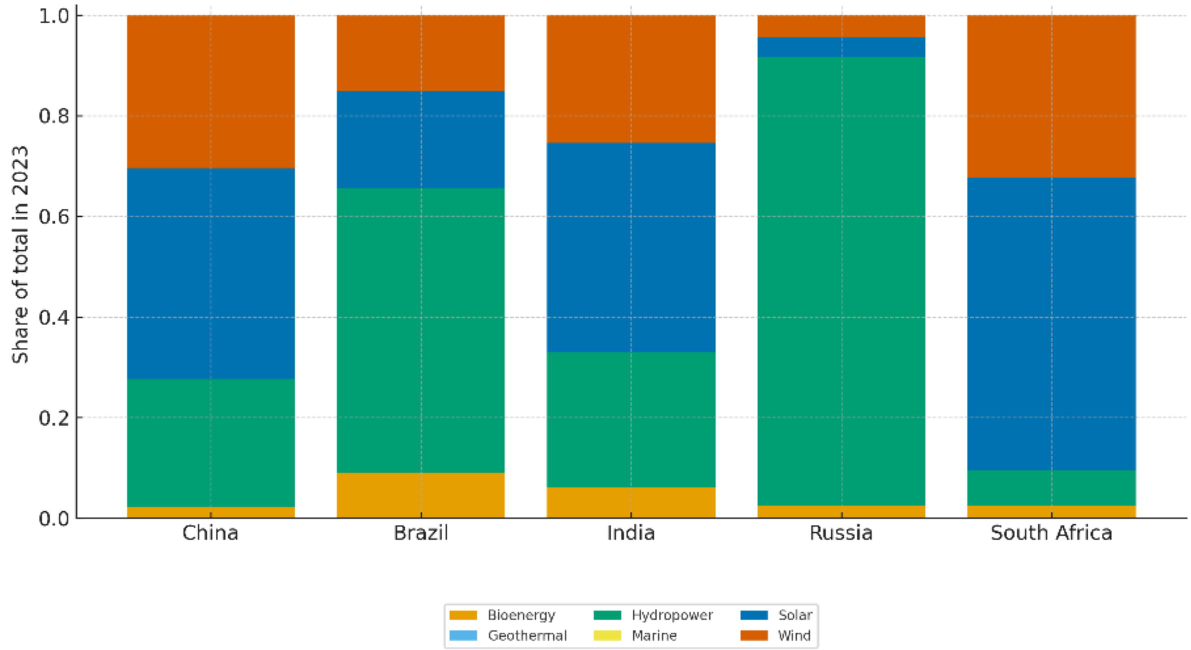

Figure 3. Energy-Mix Shares by Country in 2023, source: Authors' Illustration using data from IRENA

Figure 4 traces the evolution of renewable energy diversification using the Herfindahl–Hirschman Index (HHI). All BRICS economies had high HHI scores above 0.85 in 2000, indicating strong reliance on hydropower. By 2023, China's index declined to 0.39, while India's fell to 0.42, reflecting rapid diversification through solar and wind integration. Brazil's HHI decreased modestly from 0.92 to 0.71, consistent with its partial inclusion of bio-energy and wind, while South Africa's HHI dropped sharply from 0.96 to 0.54 after 2012. Russia's value remains high at 0.88, confirming its limited technological diversity.

These results validate the argument of Hille and Oelker (2023) that policy and institutional mechanisms, such as renewable auctions and tariff schemes, strongly shape diversification outcomes. However, the steep decline in HHI for China and India exceeds earlier projections by Ahmad and Zhang (2020), implying accelerated technological diffusion and improved energy governance. The persistence of high concentration in Russia echoes Vatamanu and Zugravu's (2023) finding that weak institutional quality and regulatory volatility impede renewable market diversification.

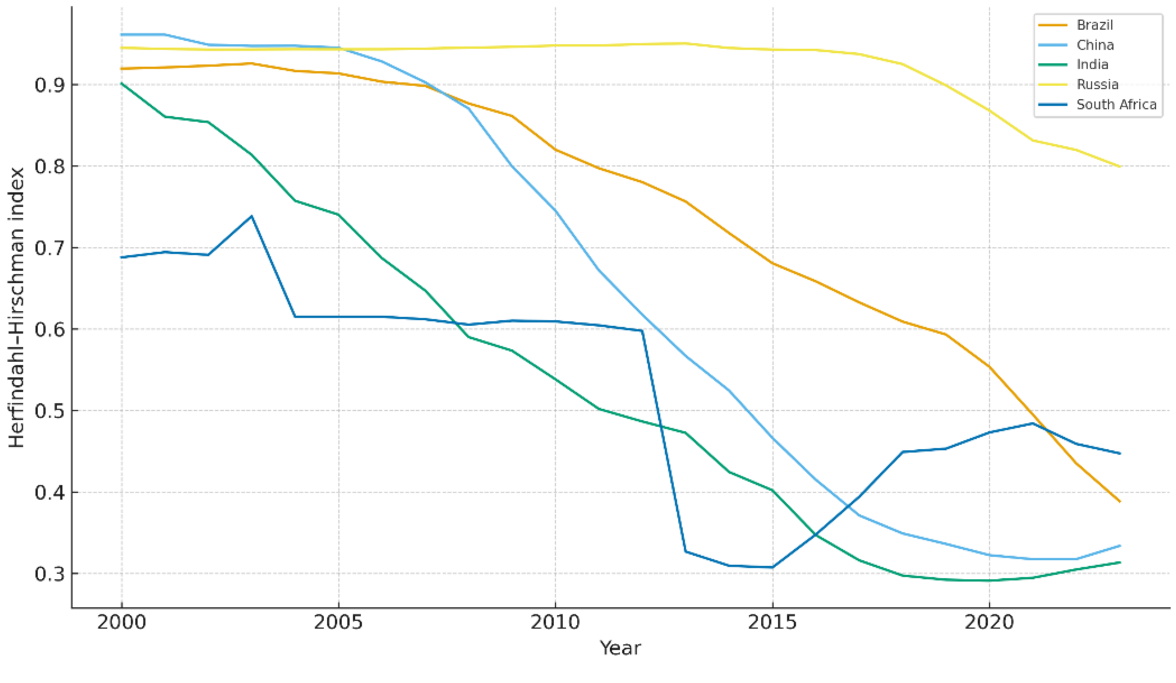

Figure 4. Diversification of the Renewable Energy Mix (HHI Index), source: Authors' Illustration using data from IRENA

Hence, while diversification is improving in most BRICS economies, the extent and pace remain closely linked to the coherence of policy instruments, infrastructure investment, and financial readiness, as also noted by Qin et al. (2023).

Figure 5 summarises the compound annual growth rates (CAGR) of installed capacity by energy type. Solar energy recorded the highest average growth—23.4% in China, 21.7% in India, and 19.6% in South Africa, followed by wind energy with 17.3% in China and 14.2% in India. Hydropower showed moderate increases of 3.5% in China and 2.8% in Brazil, while bioenergy grew steadily in Brazil at 4.6% per year.

These findings align with Eti et al. (2023), who underscored China's and India's dominance in renewable technology diffusion, but they also demonstrate that the speed of solar and wind expansion in the 2015–2023 period has exceeded earlier projections. The growth patterns confirm that technological innovation and industrial policy act as primary accelerators of renewable adoption, echoing the conclusions of Ahmad and Zhang (2020) and Shittu et al. (2024) on the catalytic role of innovation systems and targeted financing mechanisms. The negligible growth in Russia's non-hydro sectors reiterates structural inertia, consistent with Uzar (2020), who observed that institutional rigidity impedes green investment momentum.

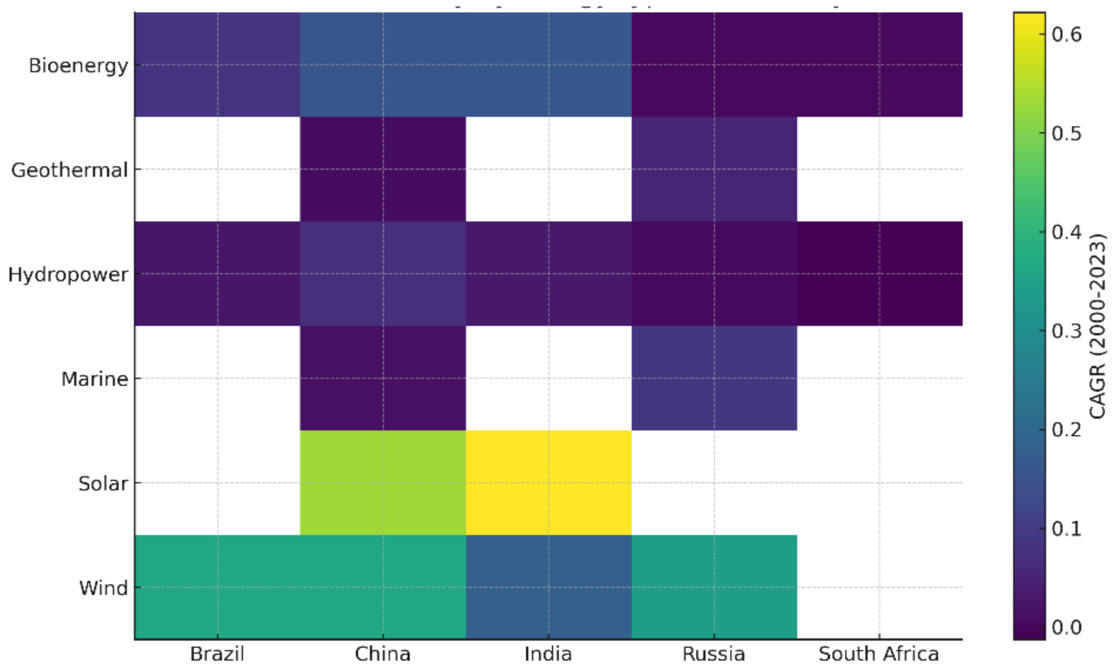

Figure 5. Growth Intensity by Energy Type and Country (CAGR 2000–2023), source: Authors' Illustration using data from IRENA

2.4. Synthesis and implications

The stylised facts derived from Figures 1–5 confirm and, in several respects, extend existing empirical insights on energy transition in BRICS economies. Total renewable capacity across the bloc rose by over 1.6 TW between 2000 and 2023, with China and India jointly accounting for almost 80 percent of the incremental growth. Diversification indices show significant progress in China, India, and South Africa, corroborating findings that strong institutional frameworks and financing depth underpin renewable success (Qin et al., 2023; Vatamanu & Zugravu, 2023). Nevertheless, Brazil and Russia remain structurally constrained by dependence on hydropower and insufficient diversification.

These results illustrate both convergence and divergence with prior studies: while they confirm the dominance of China and India, they reveal greater intra-group heterogeneity and faster recent diversification than earlier research suggested. The evidence therefore advances understanding of BRICS' renewable transition by contextualising aggregate progress within a detailed technological and temporal framework. In sum, the renewable energy pathways of BRICS economies demonstrate clear progress toward SDG 7 and SDG 13, but with persistent disparities reflecting differences in policy maturity, institutional strength, and infrastructural readiness.

2.5. Sustainable energy transition and labour market adjustments

The evolving discourse on sustainable energy transition and labour market adjustments underscores an intricate interplay between renewable energy expansion, employment dynamics, and structural shifts within economies. Across theoretical and empirical studies, the green transition is associated with net positive employment outcomes, although these gains are modest and unevenly distributed across regions and sectors. García-García et al. (2020)

observed a consistent yet small rise in employment following renewable energy adoption, while Proença and Fortes (2020) quantified a 0.48 per cent employment increase for every 1 per cent growth in renewable capacity within the EU. Similarly, global workforce data reveal the addition of 3.4 million jobs between 2019 and 2022, primarily in renewables, energy efficiency, and clean technology industries (Armiento et al., 2025). These findings suggest that sustainable energy transition stimulates aggregate employment while driving structural changes that demand labour reallocation and skill adaptation.

Within the BRICS economies, energy transition generates distinctive labour market patterns shaped by economic structure, technological readiness, and institutional capacity. Empirical studies indicate that renewable energy expansion yields mixed but largely positive effects on employment. Hlongwane et al. (2025) found that hydropower and solar energy contribute between 0.78 and 9.60 per cent to employment growth, whereas wind and nuclear energy exhibit more limited or negative effects. Beletskaya (2022) highlighted that BRICS countries are prioritising policies to foster labour market inclusiveness, while Zhao and Rasoulinezhad (2022) demonstrated that improving resource efficiency accelerates both employment and green growth. Despite this progress, significant disparities persist in renewable deployment and workforce absorption, particularly in South Africa and India, where fossil fuel dependency and skill shortages constrain transition outcomes. These findings imply that targeted labour market interventions, such as retraining and social protection policies, are essential to mitigate transitional unemployment and promote equitable participation in green sectors.

The dual impact of the green transition is increasingly evident. On one hand, it offers new opportunities for employment creation in renewable energy manufacturing, installation, and maintenance. On the other, it induces structural displacement as carbon-intensive sectors contract and automation reshapes production processes. Studies show that the global transition could yield a 0.3 per cent net job increase (Malerba & Wiebe, 2020), yet such aggregate gains mask the vulnerability of workers in declining fossil fuel industries (Lynch et al., 2024; Grazini et al., 2024). Geographic and occupational mismatches exacerbate these challenges, with new jobs often concentrated in different regions or requiring higher skill levels than those being lost (Hanna et al., 2024). Moreover, many emerging green jobs, particularly in construction and maintenance, remain characterised by wage instability and limited career progression (Malerba et al., 2020).

Human capital development emerges as a decisive factor in maximising the employment benefits of energy transition. The existing evidence suggests substantial gaps in education, technical expertise, and vocational training relevant to renewable industries. Adepoju et al. (2022) observed limited research and policy engagement on human capital formation in the energy sector, underscoring the need for systemic investment in workforce capacity. De Rosa et al. (2024) found that human capital accumulation significantly drives renewable energy adoption, particularly through enhanced vocational education and regional training programmes. In the UK and EU, Cook and Elliott (2025) documented critical skill shortages in renewable-related occupations, while Arcelay et al. (2021) emphasised the necessity of integrating digital competencies such as artificial intelligence and the Internet of Things into training frameworks. Albertz and Pilz (2025) further reported that discussions on green vocational education are expanding across Asia-Pacific and Africa, reflecting a growing recognition of its strategic importance.

Collectively, the literature affirms that sustainable energy transition reshapes labour markets through both opportunity creation and structural disruption. The BRICS experience demonstrates that employment outcomes depend on the capacity to align technological diffusion, educational reforms, and labour policies. Thus, ensuring a just and inclusive transition requires not only investment in clean technologies but also deliberate strategies to cultivate adaptable, skilled, and resilient workforces capable of sustaining long-term green growth.

2.6. Exploring the interconnections between SDG 7 and SDG 8: emerging gaps and future research pathways

The interconnections between SDG 7 (Affordable and Clean Energy) and SDG 8 (Decent Work and Economic Growth) have become a central theme in recent empirical and theoretical debates on sustainable development, particularly within the context of the BRICS economies. The literature increasingly highlights that the transition toward cleaner energy sources can generate substantial employment opportunities while simultaneously driving industrial restructuring and productivity enhancement. Fonseca et al. (2020) found strong complementarities between clean energy expansion and decent work creation, suggesting that renewable energy deployment can stimulate inclusive economic growth. However, these synergies coexist with significant trade-offs. As Pearse and Bryant (2021) observed, renewable energy transitions often reorganise labour structures, influencing job quality, employment stability, and the nature of collective bargaining. Evidence from Germany and South Africa shows that coal phase-outs, although environmentally beneficial, produce employment shocks and income disparities if not managed through coherent policy frameworks and retraining strategies (Hägele et al., 2022). Similarly, Coscieme et al. (2020) cautioned that unqualified pursuit of growth under SDG 8 can offset environmental progress under SDG 7, reinforcing the need for policy coordination between economic and ecological priorities.

Empirical studies on BRICS economies show both convergence and heterogeneity in energy transition outcomes. China and Brazil have achieved impressive renewable capacity expansion and corresponding labour absorption, while India, Russia, and South Africa face challenges arising from infrastructure gaps, skills shortages, and policy inconsistencies (Eti et al., 2023; Chandra Voumik & Sultana, 2022). Hlongwane et al. (2025) quantified these disparities, reporting that hydropower and solar energy contribute positively to employment ranging from 0.78 to 9.60 per cent, whereas wind and nuclear energy have more limited effects. Economic growth and renewable investment together explain up to 37 per cent of employment creation across the bloc, underscoring the catalytic role of sustainable energy in labour market performance. Yet, these gains remain uneven and often concentrated in energy-intensive or service-related industries, where informal work and low wages persist. Beletskaya (2022) and Zhao and Rasoulinezhad (2022) emphasised that maintaining labour market inclusiveness in BRICS requires aligning resource efficiency with targeted employment and social protection policies.

While empirical results generally support a net positive relationship between renewable energy expansion and employment growth, significant research gaps remain. García-García et al. (2020) identified the scarcity of studies exploring the causal mechanisms linking energy transition indicators – such as renewable generation, energy efficiency, and energy intensity – to labour market outcomes. Likewise, Hanna et al. (2024) noted the lack of standardised metrics on job quality, skill composition, and gender disparities in green employment, which limits cross-country comparability. Existing econometric evidence, such as Proença and Fortes (2020), demonstrates only modest employment elasticities (0.48 per cent increase for every 1 per cent rise in renewable capacity), while studies like Füllemann et al. (2020) confirm net positive effects without fully capturing sectoral displacement or automation risks. Furthermore, analyses in developing contexts remain sparse, with limited attention to institutional quality, financial development, and policy coherence as mediating factors in the energy–employment nexus.

Human capital development and skill formation have become defining elements of the sustainable energy transition, determining how effectively economies adapt to shifting production structures and new patterns of employment. Yet, as Adepoju et al. (2022) observed, policy engagement in developing renewable-sector skills remains limited, constraining the ability of economies to fully benefit from green transformation. De Rosa et al. (2024) highlighted that investment in education and vocational training is essential for sustaining renewable adoption and mitigating structural unemployment, while studies in advanced economies by Cook and Elliott (2025) and Arcelay et al. (2021) emphasised the growing demand for upskilling and digital competencies in areas such as artificial intelligence and Internet-of-Things-enabled energy systems. Albertz and Pilz (2025) similarly noted that green vocational education is gaining momentum in emerging regions, marking a global shift towards skills-based transition strategies. However, within the BRICS economies, these dimensions remain empirically underexplored. Existing studies tend to focus on aggregate employment outcomes without examining how renewable energy expansion, efficiency improvements, and industrial restructuring interact with human capital formation and labour adaptability. This study seeks to address these gaps by empirically assessing how sustainable energy transition influences labour market performance across BRICS countries. By integrating indicators of renewable energy consumption, energy intensity, and employment outcomes within a cross-country analytical framework, it provides deeper insight into how cleaner energy pathways can foster inclusive employment, enhance workforce capabilities, and balance the dual objectives of SDG 7 and SDG 8 in the context of rapidly transforming emerging economies.

3. Methodology

3.1. Theoretical framework

This study is anchored on two complementary frameworks: the Green Growth Theory and the Just Transition Framework. The Green Growth Theory provides the conceptual foundation for linking sustainable energy transitions to long-run economic performance. It argues that economies can sustain growth while reducing environmental degradation through renewable energy expansion, energy efficiency improvements, and technological innovation. Within the Sub-Saharan African context, where dependence on fossil-fuel-based energy systems coexists with structural labour market vulnerabilities, the theory highlights how investments in renewable capacity and energy efficiency can stimulate new markets, enhance productivity, and generate decent employment opportunities. By capturing both renewable energy transition and energy intensity reduction, the empirical model operationalises the central mechanisms of green growth.

The Just Transition Framework complements this perspective by focusing on the distributive and social justice dimensions of the energy transition. While green growth emphasises the economic viability of clean energy pathways, just transition interrogates the inclusiveness of these pathways by addressing potential displacement, skills mismatch, and social inequality. It calls for deliberate mechanisms such as re-skilling, social protection, and equitable policy design to ensure that the transition towards a green economy promotes job security and inclusivity. Integrating this framework allows the study to assess whether renewable energy adoption and energy efficiency improvements in Sub-Saharan Africa translate into inclusive labour market outcomes in line with Sustainable Development Goals 7 and 8. Together, these theoretical perspectives establish a coherent analytical foundation, combining economic efficiency with social equity.

3.2. Data description, measurement and source

The empirical analysis draws on a balanced panel of BRICS countries observed between 2000 and 2023. The sample covers all five countries: Brazil, China, Indonesia, Russia and South Africa. This scope provides a rich platform for examining country heterogeneity in the relationship between energy transition, energy efficiency, and labour market outcomes.

The study period of 2000–2023 spans several major global structural shifts that have implications for both energy transition and labour market dynamics. Notably, the adoption of the United Nations Sustainable Development Goals (SDGs) in 2015 and the signing of the Paris Agreement in the same year marked a decisive pivot toward global climate action and clean energy commitments. These policy milestones reshaped national strategies across the BRICS economies, particularly in the areas of renewable energy deployment, energy efficiency, and carbon mitigation. Additionally, the COVID-19 pandemic introduced further discontinuities after 2020. Recognising these transitions, the empirical design accounts for temporal heterogeneity by clearly distinguishing between the pre-COVID (2000–2018) and the COVID-19 (2019–2023) periods while also acknowledging the relevance of the 2015 policy realignments for interpreting the evolution of energy and labour indicators.

Although the study covers all BRICS economies in a balanced panel, the empirical strategy is not restricted to aggregate estimation. We estimate three complementary models: (i) a full-sample BRICS panel, (ii) country-specific regressions that capture domestic structural heterogeneity, and (iii) pre-COVID vs COVID estimations. This multi-level design ensures that important country-specific dynamics are not obscured by aggregation, directly addressing concerns about reliance on broad measures.

Table 1. Data description and measurement, s*ource: Authors' compilation*

Variable	Description	Measurement	Expected Sign	Source
Labour Market Dynamics (LMD	Indicators capturing the performance and structural shifts of the labour market, with a focus on employment opportunities and inclusiveness.	Employment-to-population ratio, % of population ages 15+	+	WDI
Renewable Energy Transition Index (RETI)	A composite indicator capturing the degree of transition towards renewable energy. It reflects both the supply and consumption sides of renewable energy adoption.	Measurement: Constructed using Principal Component Analysis (PCA) from renewable energy installed capacity (% of total installed capacity) and renewable energy consumption (% of total final energy use) in Stata. Higher values denote greater reliance on renewable energy sources.	+	Authors' construct
Energy Intensity (ENINT)	proxy for energy efficiency and environmental sustainability	Energy use kg of oil equivalent per $1,000 GDP constant 2015 PPP	–	WDI
GDP per Capita		Constant 2015 US$	+	WDI
Population (POP)	The total number of people residing within a country, regardless of legal status or citizenship.	Population, total	+	WDI
Education Level	Indicator of human capital development reflecting the level of access to and quality of education.	Expected Year of Schooling	+	UNESCO / WDI
Governance Effectiveness (GOV)	Indicator of human capital development reflecting the level of access to and quality of education.	WGI governance effectiveness index –2.5 to +2.5	+	WGI
Regulatory quality (REQ)	This indicator captures perceptions of the government's ability to formulate and implement sound policies and regulations that permit and promote private sector development.	The index ranges from –2.5 (weak) to +2.5 (strong) governance performance.	+	WGI

Labour market dynamics, the dependent variable, are proxied by the employment-to-population ratio (percentage of population ages 15 and above) obtained from the World Development Indicators (WDI). The core explanatory variable is the Renewable Energy Transition Index (RETI), a composite index constructed by the authors using principal component analysis (PCA) from renewable energy installed capacity and renewable energy consumption, where higher scores denote stronger renewable energy reliance. Energy efficiency is proxied by energy intensity (energy use in kilograms of oil equivalent per US$1,000 GDP, constant 2015 PPP), sourced from the WDI. Additional controls include GDP per capita, population, education (measured by expected years of schooling from UNESCO/WDI), and governance effectiveness (sourced from the Worldwide Governance Indicators). Table 1 provides the description, measurement, expected signs, and data sources for all variables.

In line with the sustainability orientation of this study, all variables are aligned with relevant Sustainable Development Goals. The Renewable Energy Transition Index (RETI) is directly linked to SDG 7.2 on expanding renewable energy and SDG 13.2 on integrating climate mitigation policies. Energy intensity (ENINT) supports SDG 7.3, which promotes improved energy efficiency, and contributes to SDG 13.3, which strengthens adaptive and mitigation capacity. Labour market dynamics (LMD) correspond to SDG 8.3 and SDG 8.5, reflecting decent work and inclusive growth dimensions. Education and governance variables serve as enabling factors for progress under SDG 7.a, SDG 8.3, and SDG 13.b. This integrated mapping ensures that the empirical framework simultaneously advances SDG 7, SDG 8, and SDG 13 without fragmenting the conceptual alignment.

SDG 13 (Climate Action) is inherently linked to sustainable energy transition through emissions reduction, energy efficiency improvements, and clean technology deployment. Renewable energy expansion directly reduces dependence on carbon-intensive fuels, while declining energy intensity contributes to mitigation pathways. Incorporating SDG 13 into the analytical framework ensures that labour market outcomes are interpreted not only as economic consequences but also as components of the broader climate transition agenda.

For the purpose of econometric differentiation, the study defines **pre-COVID** as the period **2000–2019**, representing the structural baseline before pandemic-induced disruptions. The **COVID** period is defined as **2019–2023**, reflecting the years in which labour markets and energy systems began adjusting to the shock. This classification follows the WHO's formal declaration timeline.

3.3. Model specification

The empirical model investigates the relationship between renewable energy transition, energy efficiency, and labour market dynamics in Sub-Saharan Africa, while accounting for education, governance, and demographic pressures. The baseline specification is expressed as:

$$LMD_{it} = \alpha + \beta_1 RETI_{it} + \beta_2 X_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (1)$$

where LMD_{it} denotes labour market dynamics in country i at time t, $RETI_{it}$ is the renewable energy transition index, X_{it} represents the vector of controls, μ_i captures country-specific heterogeneity, λ_t controls for time-fixed effects, and ϵ_{it} is the error term.

Building on this structure, the study employs a log-log specification to allow interpretation of coefficients as elasticities:

$$\ln LMD_{it} = \alpha + \beta_1 \ln RETI_{it} + \beta_2 \ln ENINT_{it} + \beta_3 \ln EDU_{it} + \beta_4 \ln GOV_{it} + \beta_5 \ln REQ_{it} + \beta_6 \ln GDPPC_{it} + \beta_7 \ln POP_{it} + \gamma_1 (\ln RETI \times \ln GOV)_{it} + \gamma_2 (\ln RETI \times \ln EDU)_{it} + \mu_i + \epsilon_{it} \quad (2)$$

Where $\ln LMD_{it}$ denotes the logged labour market outcome for country i at time t; $\ln RETI_{it}$ is the logged Renewable Energy Transition Index; $\ln ENINT_{it}$ represents the logged energy intensity; $\ln EDU_{it}$ captures the logged education indicator; $\ln PGDP_{it}$ is logged GDP per capita; $\ln GOV_{it}$ reflects the logged governance indicator; $\ln GOV_{it}$ reflects the logged regulatory quality and $\ln POP_{it}$ denotes the logged total population. Finally, the interaction terms $(\ln RETI \times \ln GOV)_{it}$ and $(\ln RETI \times \ln EDU)_{it}$ are incorporated to assess the moderating roles of governance and education in shaping the effect of renewable energy transition on labour market dynamics.

This specification captures both the direct effects of renewable energy transition and energy efficiency on labour market outcomes, and the moderating roles of governance and education. The interactive terms test whether institutional quality and human capital amplify or constrain the employment effects of renewable energy adoption.

3.4. Estimation technique

The empirical strategy adopts a multi-layered estimation pathway to ensure robustness. First, the fixed-effects estimator serves as the benchmark, exploiting within-country variation while controlling for unobserved heterogeneity across countries. Second, two-stage least squares (2SLS) estimation is employed to address potential endogeneity concerns arising from reverse causality between labour market outcomes and renewable energy transition. Appropriate instruments are selected based on theoretical relevance and statistical validity. Finally, the method of moments quantile regression (MM-QR) is applied to examine heterogeneous effects across the conditional distribution of labour market outcomes. This approach captures whether the impact of renewable energy transition and energy efficiency varies across countries with different levels of employment performance, thereby providing a more comprehensive view of distributional dynamics.

Given the structural shocks associated with the Russia–Ukraine conflict beginning in February 2022, a separate estimation excluding Russia is conducted to address potential distortions. This step also mitigates the impact of the reduced reliability of Russian data post-2022, thereby improving the credibility of the comparative analysis.

Through a comprehensive estimation framework that includes full-sample BRICS analysis, country-specific regressions, a four-country sample excluding Russia, and the Method of Moments Quantile Regression (MM-QR), the study provides robust and nuanced evidence on how sustainable energy transition and energy efficiency influence labour market dynamics. This comprehensive analytical approach strengthens the empirical relevance of the findings and reinforces their implications for the attainment of SDG 7, SDG 8, and SDG 13.

4. Results and discussion

4.1. Result presentation

4.1.1. Descriptive statistics

The descriptive statistics presented in Table 2 provide an overview of the main variables underpinning the dynamics between sustainable energy transition, energy efficiency, and labour market performance across Sub-Saharan Africa. Labour market dynamics (LMD) has a mean value of 61.73 and a standard deviation of 12.60, with a range between 30.84 and 85.84. This distribution indicates substantial variation across countries, reflecting differences in employment structures, industrial capacities, and policy implementation relating to SDG 8 (decent work and economic growth). The observed variability suggests that while some countries have made progress in improving labour market conditions, others continue to struggle with unemployment and underemployment challenges.

Renewable energy transition index (RETI) exhibits a mean close to zero, with values ranging from -7.29 to 0.99 and a standard deviation of 1.16. The wide dispersion highlights uneven progress in renewable energy adoption across the region. While a few countries have taken notable steps towards cleaner energy sources, many remain dependent on conventional fossil-based systems, constraining the attainment of SDG 7 (affordable and clean energy).

Energy intensity (ENINT) averages 6.60, indicating a relatively high level of energy use per unit of output, which reflects inefficiencies in production and limited adoption of energy-efficient technologies. The variation from 0.9 to 26.91 implies that some economies are transitioning towards more efficient energy systems, whereas others still exhibit substantial wastage and dependence on traditional energy practices.

Educational attainment (EDU) presents a mean of 9.72 years with moderate variability, suggesting improvements in human capital development but also persistent disparities in access to quality education. Government effectiveness (GOV), has an average value of 1.29, indicating moderate governance performance across Sub-Saharan Africa. The wide variation in scores (ranging from 0.12 to 3.15) highlights pronounced disparities in administrative capacity, policy implementation, and institutional reliability among countries in the region. These variations are critical for labour market dynamics, as stronger institutions tend to foster a more predictable policy environment, enhance regulatory quality, and improve the effectiveness of labour and energy market reforms. Conversely, weaker institutional frameworks can constrain job creation by discouraging investment, undermining contract enforcement, and limiting the success of renewable energy initiatives that require long-term policy stability.

Overall, these statistics demonstrate considerable divergence among Sub-Saharan African countries in terms of economic performance, human capital, and energy transition indicators. This heterogeneity underscores the need for differentiated, context-specific policy frameworks to ensure that sustainable energy transitions contribute effectively to inclusive growth and job creation in line with SDGs 7 and 8.

Table 2. Descriptive statistics, *source: Authors' computation*

Variable	Mean	Std. dev.	Min	Max
LMD	55.73719	8.348787	36.798	71.771
RETI	1.15E-09	1.157197	-1.08478	4.641932
ENINT	134.7999	43.87216	74.5066	220.872
EDU	13.34192	1.756581	8.33	15.79
GOV	0.97054	0.341177	0.287538	1.807912
REQ	1.863083	0.360347	0.86	2.82
PGDP	2.85E+12	3.92E+12	2.2E+11	1.8E+13
POP	6.01E+08	5.83E+08	47000000	1.40E+09

4.1.2. Correlation analysis

The correlation matrix in Table 3 reveals important relationships among the key variables. Labour market dynamics (lnLMD) shows a moderate positive correlation with renewable energy transition (lnRETI) at 0.216 and a stronger positive correlation with energy intensity (lnENINT) at 0.393. This suggests that higher energy utilisation and incremental shifts toward renewable energy are associated with more active labour markets, possibly through energy-led industrialisation and employment generation. However, lnLMD is negatively correlated with GDP per capita (–0.611), education (–0.441), and government effectiveness (–0.177), indicating that increases in income, educational attainment, and government spending do not automatically translate into proportional labour market improvements.

A strong positive correlation is observed between lnLMD and population (0.580), which aligns with the labour-abundant nature of Sub-Saharan African economies where growing populations contribute to larger labour forces but not necessarily to productive employment. The high negative correlation between lnPGDP and lnRETI (–0.629) further illustrates that countries with higher per capita incomes tend to have lower renewable energy shares, suggesting a continued reliance on non-renewable energy sources in more industrialised economies.

The overall correlation structure highlights complex interdependencies between economic development, energy transition, and labour outcomes. The patterns suggest that while renewable energy adoption contributes positively to labour market activity, structural factors such as educational quality and fiscal efficiency may moderate the extent to which energy transition supports inclusive growth.

Table 3. Correlation analysis, source: Authors' computation

	lnLMD	**lnRETI**	**lnENINT**	**lnEDU**	**lnGOV**	**lnREQ**	**lnPGDP**	**lnPOP**
lnLMD	1.000							
lnRETI	0.304	1.000						
lnENINT	-0.028	-0.777	1.000					
lnEDU	-0.307	0.126	-0.641	1.000				
lnGOV	-0.338	0.092	0.015	-0.188	1.000			
lnREQ	-0.440	-0.239	0.011	0.090	0.508	1.000		
lnPGDP	0.770	0.510	-0.168	-0.179	-0.029	-0.479	1.000	
lnPOP	0.539	0.697	-0.172	-0.405	0.182	-0.485	0.802	1.000

4.1.3. Cross-sectional dependence test

To evaluate the existence of contemporaneous correlation across cross-sectional units, the Pesaran (2004) test of cross-sectional dependence (CD) was conducted. The result, reported in Table X, shows that the null hypothesis of cross-sectional independence cannot be rejected at conventional significance levels (Pesaran's CD = 1.689, p = 0.0912). This outcome indicates an absence of significant cross-sectional dependence among the panel units. In addition, the average absolute value of the off-diagonal elements of the cross-sectional correlation matrix (0.245) suggests only weak interdependence across units.

Given these findings, the assumption of cross-sectional independence is deemed valid. Therefore, the study can confidently proceed with the application of first-generation unit root tests, which rely on the independence of cross-sectional units. This provides a robust basis for subsequent panel data estimations and inference.

4.1.4. Panel unit root tests

The unit root results presented in Table 4 indicate that most variables are non-stationary at levels but become stationary after first differencing, confirming their integration of order one, I(1). Both the CADF and CIPS statistics show that variables such as RETI, ENINT, and PGDP become significant at the 1% level after first differencing. Education (EDU) and government effectiveness (GOV) demonstrate mixed stationarity patterns, being stationary at levels under CADF but requiring first differencing under CIPS. The Labour market dynamics index (lnLMD) attains stationarity only after first differencing, implying persistence in employment outcomes over time. These findings justify the use of cointegration and long-run estimation techniques that accommodate a mixture of I(0) and I(1) variables, ensuring that both short-term dynamics and long-term equilibrium relationships are appropriately captured in the analysis.

Table 4. Panel unit root result, source: Authors' computation

Variable	**LLC Test**		**IPS Test**	
	I(0)	**I(1)**	**I(0)**	**I(1)**
lnLMD	0.454	-2.818***	0.7335	-8.305***
lnRETI	-1.271	-7.007***	2.6692	-7.059***
lnENINT	-1.879**		0.6510	5.628***
lnEDU	-0.3840	3.449***	1.4164	-4.530***
lnGOV	-1.2251	-1.934**	-0.6413	-9.230***
lnREQ	-3.404***		-1.6348**	
lnPGDP	-0.7329	-4.153***	1.9961	-8.859***
lnPOP	-2.194**		-1.4207*	

4.1.5. Panel cointegration test

The cointegration results summarised in Table 5 confirm the existence of a long-run equilibrium relationship among the study variables. The Pedroni test statistics—including the Modified Phillips–Perron t (7.4851, p = 0.0000) and Phillips–Perron t (–3.5816, p = 0.0002)—are highly significant, rejecting the null hypothesis of no cointegration. The Kao test further supports this finding, with all versions of the Dickey–Fuller statistics significant at the 1% and 5% levels.

These results imply that, despite short-run fluctuations, the variables: Labour market dynamics, renewable energy transition, energy intensity, economic growth, education, and government effectiveness, tend to move together in the long run. This long-run relationship highlights the structural interdependence between sustainable energy transition and labour market outcomes in Sub-Saharan Africa. Policies that promote renewable energy use, enhance energy efficiency, and strengthen fiscal and educational systems can therefore contribute to long-term improvements in labour productivity and employment quality in alignment with SDGs 7 and 8.

Table 5. Panel cointegration result, source: Authors' computation

	Statistic		**p-value**
Pedroni test for cointegration			
Modified Phillips–Perron t	1.9933		0.023
Phillips–Perron t	-3.7459		0.000
Augmented Dickey–Fuller t	-3.228		0.001
Kao test for cointegration			
Modified Dickey–Fuller t	-3.9588		0.000
Dickey–Fuller t	-2.3448		0.010
Augmented Dickey–Fuller t	-2.9346		0.002
Unadjusted modified Dickey–Fuller t	-3.3774		0.000
Unadjusted Dickey–Fuller t	-2.2018		0.014

4.1.6. Summary

Overall, the preliminary analyses confirm that the data structure is suitable for panel-based long-run estimations. The results collectively indicate that energy transition and efficiency dynamics are deeply intertwined with economic growth, educational progress, and government spending in shaping Sub-Saharan Africa's labour market outcomes.

4.2. Estimation results across methods

4.2.3. Fixed-Effects (FE) Estimation

The Hausman specification test ($\chi^2 = 86.66$, $p = 0.0000$) confirms that the fixed-effects estimator is consistent and preferred over the random-effects model. This indicates that country-specific effects are correlated with the explanatory variables, making the FE approach appropriate for the baseline analysis.

Using labour market dynamics (LMD) as the outcome variable, the full-sample fixed effects results for the BRICS countries reported in Table 6, show that energy intensity (lnENINT) exerts a negative and significant influence at −0.137 ($p < 0.05$). This supports the expectation that improvements in energy efficiency strengthen labour outcomes, consistent with complementarities between SDG 7 and SDG 8. The renewable energy transition index (lnRETI) is also negative and significant at −0.283 ($p < 0.05$), indicating that the adjustment costs of shifting the energy mix can create short-term pressures in the labour market. Education (lnEDU) displays a negative but weak effect at −0.152 ($p < 0.10$), while governance effectiveness (lnGOV) is positive and significant at 0.0316 ($p < 0.05$), reflecting the role of institutional capability in supporting labour systems. Regulatory quality (lnREQ) carries a negative and significant coefficient at −0.0796 ($p < 0.05$). GDP per capita (lnPGDP) is not significant, although population size (lnPOP) is negative and significant at −0.356 ($p < 0.01$), suggesting demographic pressures on labour absorption. The RETI–education interaction remains positive and significant at 0.0987 ($p < 0.05$), implying that stronger human capital can help mitigate transition-related labour disruptions.

The estimation results must be interpreted within the context of the Russia–Ukraine war, which began on 24 February 2022. This conflict has altered Russia's labour market dynamics, energy pricing structures, and data transparency. As noted by international data agencies, post-2022 macroeconomic and energy statistics from Russia exhibit reduced reliability. This challenge justifies the decision to estimate Russia separately and compare results between the full-sample BRICS panel and the four-country panel excluding Russia. The divergence in results underscores how conflict-induced distortions shape the bloc's aggregate behaviour.

A second estimation excludes the Russian Federation in order to assess the performance of the BRICS bloc without the influence of a country currently experiencing war-related distortions. The comparison shows notable shifts. The negative effect of the renewable energy transition index (lnRETI) becomes smaller in magnitude (−0.177) and loses statistical significance, indicating that Russia's inclusion contributed substantially to the short-term transition frictions observed in the full sample. The relationship between energy intensity and labour dynamics also weakens markedly, with the coefficient on lnENINT approaching zero (−0.0002) and becoming insignificant, suggesting that the energy efficiency–labour link is less consistent among Brazil, India, China, and South Africa.

Education (lnEDU) remains negative at −0.172, and governance effectiveness (lnGOV) remains positive at 0.00721, but both are statistically insignificant. Regulatory quality (lnREQ) also loses significance (−0.00563), indicating that the institutional variables drive much of their explanatory power from the full five-country configuration. Population size (lnPOP) retains a negative and significant coefficient at −0.341 ($p < 0.05$), which shows that demographic pressures remain important within the four-country sample. The interaction terms also shift: the RETI–education coefficient (0.0698) remains positive but becomes insignificant, suggesting that the moderating role of human capital is weaker when Russia is excluded.

Overall, the comparative results show that the energy transition variables and institutional indicators are more influential in the full BRICS sample than in the reduced sample. Russia's removal reduces the significance of key transition and institutional effects, signalling that national conditions linked to conflict exposure, energy structure, and governance capacity materially shape the combined behaviour of the bloc. The findings imply that policy alignment across BRICS is uneven, and that the labour market implications of the renewable energy transition are more pronounced when Russia is included in the analysis.

Country-specific patterns reveal sharp heterogeneity. For Brazil, lnENINT is strongly negative and significant at −1.389 ($p < 0.01$), lnREQ is negative and significant at −0.344 ($p < 0.05$), and lnPOP is negative and significant at −0.507 ($p < 0.05$). For China, lnENINT remains negative and significant at −0.503 ($p < 0.05$), lnREQ is positive and significant at 1.107 ($p < 0.01$), while the RETI–REQ interaction is negative and significant at −0.986 ($p < 0.01$). This combination suggests that stronger regulatory quality coincides with better labour outcomes on average, but additional renewable penetration yields weaker marginal gains for employment unless complementary adjustments occur in labour and product markets. For India, coefficients are small and generally insignificant, pointing to a more neutral short-run mapping between energy covariates and LMD. In Russia, lnPGDP is positive and significant at 0.136 ($p < 0.01$), highlighting income-driven labour improvements. In South Africa, lnPOP is negative and significant at −2.074 ($p < 0.05$), signalling demographic headwinds for job creation.

Table 6. Fixed Effect (FE) full sample and sub-regional estimates, source: Authors' computation

	(1)	(2)	(3)	(4)	(4)	(4)	(7)
VARIABLES	**FULL SAMPLE**	**FULL SAMPLE EXCLUDING RUSSIA**	**BRAZIL**	**CHINA**	**INDIA**	**RUSSIA**	**SOUTH AFRICA**
lnRETI	-0.283**	-0.177	-6.956	1.389	0.267	-4.558	-1.519
	(0.127)	(0.185)	(9.635)	(1.685)	(0.552)	(5.132)	(2.292)
lnENINT	-0.137**	-0.000219	-1.389***	-0.503**	0.0505	-0.0105	-0.0266
	(0.0630)	(0.0832)	(0.262)	(0.174)	(0.0828)	(0.0649)	(0.200)
lnEDU	-0.152*	-0.172	-1.199	-0.0624	0.0169	1.858	1.364
	(0.0839)	(0.122)	(4.559)	(0.581)	(0.0859)	(2.153)	(1.396)
lnGOV	0.0316**	0.00721	-0.386	-0.176	-0.00274	-0.0584	-0.468
	(0.0155)	(0.0411)	(0.309)	(0.269)	(0.0254)	(0.229)	(0.427)
lnREQ	-0.0796**	-0.00563	-0.344**	1.107***	-0.00646	0.0548	0.720
	(0.0356)	(0.0641)	(0.120)	(0.261)	(0.0558)	(0.524)	(1.045)
lnPGDP	-0.0441	-0.00718	0.100	-0.200	-0.0329	0.136***	0.566
	(0.0298)	(0.0404)	(0.134)	(0.114)	(0.0313)	(0.0440)	(0.334)
lnPOP	-0.356***	-0.341**	-0.507**	0.0236	-0.0271	0.00712	-2.074**
	(0.0867)	(0.134)	(0.222)	(0.199)	(0.131)	(0.0823)	(0.731)
lnRETI_GOV	-0.0127	0.00999	0.380	0.130	-0.132	-0.0479	-0.355
	(0.0114)	(0.0235)	(0.262)	(0.195)	(0.112)	(0.207)	(0.277)
lnRETI_REQ	-0.0177	-0.0341	1.256	-0.986***	0.0150	0.0803	0.306
	(0.0313)	(0.0463)	(1.053)	(0.239)	(0.184)	(0.489)	(0.731)
lnRETI_EDU	0.0987**	0.0698	2.485	-0.301	-0.114	1.688	0.581
	(0.0422)	(0.0582)	(3.565)	(0.596)	(0.210)	(2.019)	(0.755)
Constant	13.31***	11.36***	20.70*	10.83**	5.462*	-4.802	22.07*
	(1.732)	(2.417)	(10.10)	(4.187)	(3.025)	(5.787)	(10.33)
Observations	120	96	24	24	24	24	24
R-squared	0.688	0.724	0.894	0.950	0.986	0.960	0.883
Number of c_id	5	4	1	1	1	1	1

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

4.2.4. Two-Stage Least Squares (2SLS) Estimation

The 2SLS estimates in Table 7 address endogeneity and reveal strong state dependence in labour market dynamics (LMD), with the lagged dependent variable remaining positive and significant in both the full BRICS sample (0.881, $p < 0.01$) and the reduced sample excluding Russia (0.693, $p < 0.01$). This persistence is consistent with the fixed effects model, where structural and institutional forces were already shown to influence labour outcomes. The dynamic framework therefore reinforces the earlier conclusion that labour market conditions in the BRICS region evolve gradually and are shaped by accumulated past performance.

A key similarity with the fixed effects model is the behaviour of the energy transition and energy efficiency variables. Under fixed effects, lnRETI and lnENINT were significant in the full sample but lost significance when Russia was excluded. The 2SLS results display the same pattern. In the full sample, country-specific effects in

Brazil and China show meaningful links between the energy transition and labour outcomes. Once Russia is removed, the coefficients on lnRETI and lnENINT become small and insignificant, indicating that the reduced four-country bloc does not show a strong or consistent renewable–labour or efficiency–labour relationship. This convergence across estimators strengthens the interpretation that Russia contributes materially to identifying transition-related labour effects in the aggregated BRICS configuration. Institutional variables exhibit a similar trajectory. Under fixed effects, governance effectiveness and regulatory quality mattered for labour outcomes in the full sample but weakened considerably when Russia was omitted. The 2SLS results confirm this pattern. In the full sample, Brazil and China show significant institutional effects through governance and regulation, including moderating terms such as RETI–GOV and RETI–REQ. After excluding Russia, these institutional channels all lose statistical significance, mirroring the fixed effects finding. The convergence suggests that the strength of institutional transmission mechanisms at the bloc level is closely tied to the full five-country structure.

The RETI–EDU interaction remained an important feature of the full-sample fixed effects model, indicating that human capital helped soften transition-related labour frictions. In the 2SLS estimates, this result also appears in China, where the interaction is positive and significant. When Russia is excluded, the interaction remains positive but becomes insignificant, which again parallels the weakening of the effect under fixed effects. The pattern suggests that the labour-enhancing role of education in the energy transition is more detectable when the full BRICS composition is retained. Population dynamics also move in the same direction as the fixed effects model. Under fixed effects, lnPOP was negative and significant in the full sample, capturing absorption pressures. The 2SLS estimates confirm this mechanism for Brazil and show a similar negative sign for the four-country sample, although with reduced significance. This supports the interpretation that demographic pressures are more salient when the full BRICS bloc is analysed.

The main point of departure between the 2SLS and fixed effects results concerns the role of GDP per capita. While lnPGDP was insignificant in the static fixed effects model, it emerges as a significant predictor for China and Russia under 2SLS, indicating that income-led improvements become more pronounced once endogeneity is addressed. This suggests that the static model may understate the contribution of economic growth to labour outcomes in some countries due to unmodelled feedback effects.

Country-specific patterns reveal sharp heterogeneity. For Brazil, lnENINT is strongly negative and significant at −1.389 ($p < 0.01$), lnREQ is negative and significant at −0.344 ($p < 0.05$), and lnPOP is negative and significant at −0.507 ($p < 0.05$). These results are consistent with the full-sample fixed effects findings, where energy efficiency, regulatory quality, and population pressures played meaningful roles in shaping labour outcomes. Brazil's strong negative energy efficiency effect mirrors the fixed effects result that lnENINT exerts downward pressure on LMD in the broader BRICS configuration. For China, lnENINT remains negative and significant at −0.503 ($p < 0.05$), lnREQ is positive and significant at 1.107 ($p < 0.01$), while the RETI–REQ interaction is negative and significant at −0.986 ($p < 0.01$). This combination parallels the fixed effects pattern where regulatory institutions influence labour outcomes, although the direction of the regulatory quality effect differs. The positive regulatory effect is consistent with the fixed effects result that governance capability strengthens labour conditions; however, China's negative RETI–REQ interaction highlights a point of departure, that increased renewable penetration yields weaker marginal gains when regulatory constraints tighten, unless complementary adjustments occur in labour and product markets.

For India, coefficients are small and generally insignificant, pointing to a more neutral short-run mapping between energy covariates and LMD. This resembles the reduced-sample fixed effects results, where energy transition variables lost significance, and it reinforces the interpretation that India's labour response to energy and institutional shifts is more muted relative to other BRICS members. In Russia, lnPGDP is positive and significant at 0.136 ($p < 0.01$), highlighting income-driven labour improvements. This aligns with the departure observed in the 2SLS full-sample comparison, where GDP per capita becomes important once endogeneity is addressed, departing from its insignificance in the fixed effects model. Russia's economic structure and conflict-related distortions contribute to the stronger detectability of transition and institutional effects in the full-sample models. In South Africa, lnPOP is negative and significant at −2.074 ($p < 0.05$), signalling demographic headwinds for job creation. This aligns closely with the fixed effects pattern where population pressures negatively affected LMD across the BRICS. South Africa's large and growing labour force therefore reinforces the population–labour absorption mechanism observed in both the fixed effects and 2SLS frameworks.

Overall, the 2SLS results align closely with the core narrative established under fixed effects. Both estimators indicate that renewable transition effects, energy efficiency, and institutional quality play stronger roles in the full BRICS sample than in the reduced configuration. The main departure arises in the income–labour relationship, which becomes more visible under 2SLS. Apart from this, the two models tell a broadly consistent story: Russia's inclusion strengthens the detectability of transition and institutional influences on labour outcomes, while its exclusion reveals a less uniform pattern among the remaining four countries.

Table 7. Two-Stage Least Square (2SLS) full sample and sub-regional estimates, source: Authors' computation

	(1)	(2)	(2)	(3)	(4)	(5)	(6)
VARIABLES	**FULL SAMPLE**	**FULL SAMPLE EXCLUDING RUSSIA**	**BRAZIL**	**CHINA**	**INDIA**	**RUSSIA**	**SOUTH AFRICA**
lnRETI	0.818	-1.530	-23.50	-5.024*	6.412	-15.30	-9.377
	(1.052)	(1.650)	(22.35)	(2.602)	(12.96)	(12.53)	(11.88)
L.lnLMD	0.881***	-0.376	0.0478	0.500***	-0.378	0.0413	-0.0112
	(0.179)	(0.327)	(0.168)	(0.186)	(0.696)	(0.195)	(0.830)
lnENINT	0.139	-0.253	-1.239***	0.340	0.365	-0.00393	-0.398
	(0.273)	(0.370)	(0.189)	(0.231)	(0.669)	(0.0672)	(0.387)
lnEDU	-0.0462	-0.0201	-8.727	-2.608**	0.657	6.314	3.960
	(0.117)	(0.0462)	(10.16)	(1.179)	(1.354)	(5.206)	(4.290)
lnGOV	0.0334	-0.207	-0.442*	0.214	-0.00410	0.197	-1.267
	(0.0399)	(0.241)	(0.242)	(0.256)	(0.0619)	(0.342)	(1.076)
lnREQ	-0.0877	-0.0533	-1.147	0.935***	0.204	-0.648	3.997
	(0.0579)	(0.0463)	(1.384)	(0.193)	(0.548)	(0.900)	(5.027)
lnPGDP	0.0682	-0.277	0.253	0.285**	0.000222	0.151***	0.489
	(0.125)	(0.190)	(0.209)	(0.136)	(0.124)	(0.0423)	(0.445)
lnPOP	-0.147	-0.0294	-0.628***	-0.128	-0.439	-0.0106	-1.112
	(0.104)	(0.0624)	(0.188)	(0.144)	(0.821)	(0.0763)	(1.130)
lnRETI_GOV	0.0310	0.212	0.424**	-0.152	0.248	0.179	-0.818
	(0.0328)	(0.308)	(0.210)	(0.185)	(0.872)	(0.306)	(0.671)
lnRETI_REQ	-0.149	0.495	0.736	-0.565***	-0.463	-0.557	2.469
	(0.130)	(0.512)	(1.196)	(0.134)	(0.876)	(0.823)	(3.239)
lnRETI_EDU	-0.254	0.693***	8.393	1.933**	-2.493	5.885	2.917
	(0.342)	(0.140)	(7.954)	(0.952)	(5.086)	(4.898)	(3.606)
Observations	115	92	23	23	23	23	23
R-squared	0.688	0.659	0.947	0.978	0.837	0.939	0.781
Number of c_id	5	4	1	1	1	1	1

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

4.2.5. Method-of-Moments Quantile Regression (MM-QR)

Table 8 (MM-QR) shows that effects vary across the conditional distribution of LMD. At the lower quantile (Q25), lnRETI is negative and significant at −0.921 ($p < 0.05$) and lnENINT is negative and significant at −0.331 ($p < 0.05$), indicating that weaker labour markets are more exposed both to transition frictions and to inefficiency.

Table 8. Method-of-Moments Quantile Regression (MM-QR), source: Authors' computation

VARIABLES	(3)	(4)	(5)
	qtile__25	**qtile__5**	**qtile__75**
lnRETI	-0.921**	-0.609	-0.249
	(0.449)	(0.379)	(0.433)
lnENINT	-0.331**	-0.219*	-0.0889
	(0.142)	(0.119)	(0.134)
lnEDU	-0.727***	-0.683***	-0.632***
	(0.183)	(0.157)	(0.183)
lnGOV	-0.189***	-0.133***	-0.0680*
	(0.0469)	(0.0370)	(0.0397)
lnREQ	0.290**	0.167*	0.0239
	(0.123)	(0.0997)	(0.110)
lnPGDP	0.0754***	0.0975***	0.123***
	(0.0266)	(0.0224)	(0.0254)
lnPOP	0.0678	0.00676	-0.0638
	(0.0549)	(0.0445)	(0.0490)
lnRETI_GOV	-0.0133	-0.00622	0.00196
	(0.0304)	(0.0262)	(0.0305)
lnRETI_REQ	0.221**	0.209***	0.196**
	(0.0895)	(0.0774)	(0.0901)
lnRETI_EDU	0.261*	0.164	0.0509
	(0.145)	(0.122)	(0.140)
Constant	3.835***	3.867***	3.904***
	(1.019)	(0.882)	(1.026)
Observations	120	120	120

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Education and governance are negative and significant across Q25, Q50, and Q75, with magnitudes that attenuate toward the upper quantile, which is consistent with delayed pay-offs from human capital and institutional reforms within the sample window. Regulatory quality is positive and significant at Q25 and Q50, 0.290 ($p < 0.05$) and 0.167 ($p < 0.10$), respectively, while income is positive and significant across all quantiles, rising from 0.075 ($p < 0.01$) at Q25 to 0.123 ($p < 0.01$) at Q75. The RETI–REQ interaction is positive and significant at the lower and median quantiles, 0.221 ($p < 0.05$) and 0.209 ($p < 0.01$), and remains positive at Q75, 0.196 ($p < 0.05$). The RETI–EDU interaction is weakly positive at Q25, 0.261 ($p < 0.10$), but not significant at higher quantiles. Overall, institutions and skills are more effective at unlocking labour benefits from renewables among lower-performing labour markets, even though the direct lnRETI effect remains negative at the bottom of the distribution.

4.2.6. Pre- COVID-19 and COVID-19 dynamics: FE and 2SLS

Table 9 separates the pre- and COVID periods. In FE, lnENINT is negative and significant pre-COVID at −0.088 ($p < 0.10$) and becomes larger in magnitude COVID at −0.794 ($p < 0.10$), showing that efficiency gains are increasingly linked to labour improvements in the recovery phase. Education turns from negative and significant pre-COVID at −0.398 ($p < 0.01$) to a positive but insignificant estimate COVID. The RETI–GOV interaction is negative and significant pre-COVID at −0.0467 ($p < 0.01$) but becomes positive and insignificant COVID. In FE, RETI–REQ is positive and significant pre-COVID at 0.104 ($p < 0.01$) and negative and weakly significant COVID at −0.454 ($p < 0.10$), indicating a reconfiguration of regulatory effects during the recovery.

The 2SLS specifications confirm strong persistence in LMD before and after the pandemic, with lagged LMD at 0.628 ($p < 0.01$) pre-COVID and 0.402 ($p < 0.01$) COVID. Energy intensity is negative and significant in both periods, with a much larger magnitude COVID at −0.989 ($p < 0.01$) compared with −0.174 ($p < 0.10$) pre-COVID. Governance becomes negative and significant COVID at −0.163 ($p < 0.05$), while the RETI–GOV interaction turns positive and significant at 0.134 ($p < 0.05$). These patterns suggest that, in the recovery phase, public administration may have been retargeted toward enabling the conversion of renewable progress into labour outcomes, while efficiency improvements became a stronger channel linking SDG 7 to SDG 8.

Table 9 FE and 2SLS estimation with pre and during/COVID-19 dynamics

VARIABLES	**(1)**	**(2)**	**(3)**	**(4)**
	FE_Pre-Covid	**FE_COVID**	**2SLS_Pre-Covid**	**2SLS_COVID**
lnRETI	-0.172	-0.958	-0.727	-3.006
	(0.137)	(1.525)	(0.611)	(2.202)
lnENINT	-0.0880*	-0.794*	-0.174*	-0.989***
	(0.0528)	(0.406)	(0.103)	(0.267)
lnEDU	-0.398***	0.407	-0.0995	0.608*
	(0.0837)	(0.412)	(0.125)	(0.321)
lnGOV	-0.00419	-0.152	-0.0341	-0.163**
	(0.0158)	(0.120)	(0.0298)	(0.0768)
lnREQ	0.0107	0.0671	-0.0561	0.153
	(0.0368)	(0.248)	(0.0668)	(0.161)
lnPGDP	0.0444	0.0993	-0.0612	0.164
	(0.0315)	(0.284)	(0.0415)	(0.214)
lnPOP	-0.342***	-0.928	-0.102	-0.323
	(0.0752)	(0.916)	(0.0828)	(0.851)
lnRETI_GOV	-0.0467***	0.143	-0.0125	0.134**
	(0.0124)	(0.0877)	(0.0116)	(0.0564)
lnRETI_REQ	0.104***	-0.454*	0.109	-0.295
	(0.0317)	(0.227)	(0.0945)	(0.190)
lnRETI_EDU	0.0420	0.316	0.233	0.982
	(0.0456)	(0.494)	(0.197)	(0.711)
L.lnLMD			0.628***	0.402***
			(0.169)	(0.137)
Constant	10.90***	22.05		
	(1.394)	(25.35)		
Observations	95	25	90	25
R-squared	0.755	0.690	0.822	0.751
Number of c_id	5	5	5	5

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

4.2.7. Synthesis and policy-relevant insights for SDG 7 and SDG 8

Three conclusions emerge. First, higher energy efficiency is consistently associated with stronger LMD. This result is robust across methods, is strongest in Brazil, and intensifies COVID. Second, renewable transition has heterogeneous short-run labour effects. Full-sample FE and lower-quantile results show negative contemporaneous associations, signalling transition frictions. Interactions with education and regulatory quality are often positive in weaker labour markets, showing that skills and supportive regulation help convert renewable progress into employment. The Chinese estimates illustrate this duality most clearly: regulatory quality improves average labour outcomes, the RETI–EDU interaction is positive, yet the RETI–REQ interaction is negative, signalling the need to align tighter regulation with labour market flexibility and targeted skills. Third, governance capacity matters, but its role is context-dependent. In Brazil, the RETI–GOV complementarity is beneficial under 2SLS, while COVID 2SLS in the full sample shows a positive RETI–GOV interaction that was absent before the pandemic.

Country-tailored strategies follow from these patterns. Brazil should continue to prioritise efficiency gains and strengthen administrative linkages between renewable investment and employment programmes. China should combine regulatory tightening with active labour policies and skill upgrading to avoid near-term crowding out. India's neutral coefficients suggest that enabling conditions and sectoral reforms, rather than a single lever, are likely pivotal. Russia's income-led gains point to macro stabilisation as a key complement to the energy transition. South Africa's negative population effects call for active labour market policies and sectoral renewal to absorb a growing workforce while the electricity system stabilises.

Overall, the BRICS experience shows that joint progress on SDG 7 and SDG 8 requires: sustained efficiency improvements, careful sequencing of renewable deployment with human capital and regulatory readiness, and country-specific policy mixes that address distributional differences revealed by the quantile results.

4.3. Discussion of results

This study set out to examine how sustainable energy transition and energy efficiency shape labour market dynamics in the BRICS economies, and how these relationships are conditioned by education and governance within the broader framework of SDG 7 and SDG 8. The analysis integrated indicators of renewable energy transition, energy intensity and income with a composite measure of labour market dynamics, exploiting fixed effects, 2SLS and method-of-moments quantile regression, complemented by pre and COVID-19 splits and the exclusion of Russia as a robustness check. Three results stand out. First, higher energy efficiency, captured by lower energy intensity, is consistently associated with stronger labour market performance, with this effect intensifying in the pandemic period. Second, the renewable energy transition exerts heterogeneous and frequently adverse short run effects on labour market dynamics, with negative coefficients in the full-sample fixed effects model and at the lower quantiles, indicating transition frictions that are more pronounced in weaker labour markets. Third, education, governance effectiveness and regulatory quality operate as key mediating channels: the interaction between renewable transition and education supports labour outcomes in the full sample, while the interactions with governance and regulatory quality alternately amplify or dampen labour effects depending on the institutional context and time horizon. The 2SLS results reveal strong state dependence in labour markets and show that income-led improvements become more visible once endogeneity is addressed, whereas the exclusion of Russia reduces the statistical strength of transition and institutional variables, underscoring the bloc's internal asymmetries. In combination, these findings offer novel evidence on how the SDG 7–SDG 8 nexus operates in large emerging economies, both on average and across the distribution of labour market performance.

These results are broadly consistent with, yet extend, existing empirical and conceptual work on energy transition and labour markets. Global studies have shown that renewable energy expansion tends to yield modest net employment gains and positive but small employment elasticities, while still generating structural shifts that require labour reallocation (García-García et al., 2020; Proença & Fortes, 2020; Armiento et al., 2025). Evidence from the European Union indicates that renewable electricity deployment can support productivity and decent work, though the gains are contingent on institutional and sectoral conditions (Swain et al., 2020; Fonseca et al., 2020). At the same time, research on coal phase-outs in Germany and South Africa has emphasised the social and regional dislocation that accompanies decarbonisation when not supported by coherent labour market and social protection policies (Hägele et al., 2022; Pearse & Bryant, 2021). Within the BRICS context, prior work has highlighted the heterogeneity of renewable pathways, with China and Brazil leading diversification and capacity growth, and India and South Africa constrained by infrastructure, coal dependence and policy gaps (Eti et al., 2023; Chandra Voumik & Sultana, 2022; Huo et al., 2025). The stylised facts on rapid solar and wind growth and improving diversification in parts of the bloc, alongside persistent concentration and institutional inertia in others, align with evidence that policy design, technological capabilities, financial depth and institutional quality shape renewable outcomes (Ahmad & Zhang, 2020; Qin et al., 2023; Vatamanu & Zugravu, 2023; Shittu et al., 2024). The present findings contribute to this literature by linking these differentiated energy trajectories directly to labour market dynamics, and by identifying conditions under which education and governance attenuate or exacerbate transition frictions. They also respond to calls for more causal evidence on the energy–employment nexus, particularly in emerging economies (García-García et al., 2020; Hanna et al., 2024).

The mechanisms suggested by the results resonate with Green Growth and Just Transition perspectives. Improvements in energy efficiency appear to release productive resources, strengthen competitiveness and support more resilient labour demand, consistent with the idea that low-carbon technologies can sustain growth and employment when embedded in appropriate policy frameworks (Bowen et al., 2012; Caglar et al., 2023; Zhao & Rasoulinezhad, 2022). The stronger COVID association between efficiency and labour market dynamics suggests that, in recovery periods, reducing energy waste becomes an even more important channel through which SDG 7 reinforces SDG 8. By contrast, the predominantly negative short run coefficients on renewable transition, especially at the lower quantiles of labour performance, are in line with evidence that the restructuring of carbon-intensive activities induces transitional unemployment, regional imbalances and skill mismatches (Hägele et al., 2022; Malerba & Wiebe, 2020; Grazini et al., 2024). The quantile results show that these frictions are most acute in weaker labour markets, where firms and workers may have less capacity to adjust. Yet, the positive interactions between renewable transition and education, and between renewables and regulatory quality in certain parts of the distribution, indicate that when human capital and institutions are aligned, the same transition can yield more favourable labour outcomes, echoing findings on the importance of skills and institutional readiness for capturing green employment gains (Boone et al., 2023; De Rosa et al., 2024; Cook & Elliott, 2025; Albertz & Pilz, 2025).

The policy implications are therefore non-trivial for governments, social partners and development institutions interested in harnessing the energy transition for decent work in BRICS economies. First, the consistent benefits of energy efficiency suggest that policies that lower energy intensity, including support for technological upgrading, industrial retrofits and resource-efficient production, may offer a relatively low-risk route to joint progress on SDG 7 and SDG 8. Second, the heterogeneity of renewable-labour effects implies that renewable deployment must be sequenced with labour market policies, education and vocational reforms if it is to generate broad-based employment rather than pockets of opportunity amid localised dislocation. Evidence that renewable investments create direct jobs in installation, manufacturing and maintenance, and generate spillovers across supply chains, is well established (Hlongwane et al., 2025; Hanna et al., 2024; Hlongwane & Khobai, 2025), but global assessments also show that many of these jobs remain precarious and spatially concentrated (Malerba et al., 2020; Lynch et al., 2024). The present findings reinforce that, in BRICS economies, the capacity to translate renewable investments into durable, high-quality employment depends on the interplay between energy policy, skill systems and institutional quality, in line with Just Transition arguments that emphasise fairness, inclusion and worker protection (Ding et al., 2024; Wilgosh et al., 2022).

A key strength of this study lies in its multi-method empirical strategy and explicit focus on SDG 7–SDG 8 interactions in large emerging economies. By combining fixed-effects, 2SLS and method-of-moments quantile regression, the analysis uncovers not only average relationships but also distributional effects and dynamic patterns. The inclusion of interaction terms between renewable transition and education, governance and regulatory quality allows the study to move beyond aggregate energy and labour indicators to identify moderating channels that are directly relevant for policy. The separation of pre and COVID-19 periods shows that these relationships are time-varying and sensitive to macroeconomic shocks, while the comparison between full BRICS and BRICS without Russia highlights the influence of conflict exposure and structural differences on bloc-wide conclusions. These features respond to empirical gaps in the literature that has often treated energy and employment outcomes in isolation or at highly aggregated levels (García-García et al., 2020; Füllemann et al., 2020).

At the same time, several limitations should be acknowledged. The composite measure of labour market dynamics cannot fully capture dimensions of job quality, informality, gender inequality and wage dispersion that are central to debates on decent work and Just Transition (Fonseca et al., 2020; Coscieme et al., 2020). Data constraints also prevent systematic sectoral or regional disaggregation within each country, which limits the analysis of distributional impacts and of the specific vulnerabilities of workers in coal regions or informal segments, issues emphasised in studies of coal phase-out and structural change (Hägele et al., 2022; Pearse & Bryant, 2021). While the 2SLS approach mitigates endogeneity concerns, it cannot fully address all forms of unobserved heterogeneity, especially where policy shocks, financial constraints or institutional reforms simultaneously affect energy and labour outcomes (Qin et al., 2023; Škare et al., 2023). In addition, although the quantile regressions offer valuable insights into the distribution of effects, they are estimated on a relatively small country panel, which calls for cautious interpretation of magnitudes. These caveats suggest that the estimates should be viewed as robust directional evidence rather than precise causal parameters.

Taken together, the findings indicate that sustainable energy transition and energy efficiency can contribute meaningfully to improved labour market dynamics in BRICS economies, but the synergy between SDG 7 and SDG 8 is conditional, path dependent and institutionally mediated. Efficiency improvements appear to provide the most robust channel through which clean energy goals support decent work, while the labour effects of renewable deployment depend crucially on education, governance quality and the timing of reforms. For policymakers and international partners, the results point to the need for integrated strategies that combine support for renewable and efficiency investments with sustained investment in human capital, vocational education and labour market institutions, alongside tailored measures for countries and regions facing structural constraints (Beletskaya, 2022; Zhao & Rasoulinezhad, 2022; Huo et al., 2025). Future research should deepen this agenda by employing sectoral and micro-level data to examine job quality, gender and spatial disparities in green employment, and by exploring more explicitly the roles of financial systems, digital technologies and vocational education in mediating the energy–labour nexus (Adepoju et al., 2022; De Rosa et al., 2024; Arcelay et al., 2021). Advancing this line of inquiry will be essential for designing transition pathways that deliver not only cleaner energy systems, but also more inclusive, resilient and decent labour markets in line with the ambitions of the 2030 Agenda.

The empirical findings also carry important implications for SDG 13, as the observed improvements in renewable energy transition and reductions in energy intensity contribute directly to climate mitigation pathways in BRICS economies. Countries demonstrating stronger progress in RETI and energy efficiency also exhibit more stable labour market outcomes, suggesting that climate-oriented energy reforms can generate broader socio-economic benefits. The results therefore reinforce the synergy between climate action and inclusive development, highlighting that sustained investment in clean energy and efficiency is not only an environmental imperative but also a catalyst for resilient employment structures within the BRICS bloc.

5. Conclusion

This study examined how sustainable energy transition and energy efficiency shape labour market dynamics in BRICS economies, and how these relationships are conditioned by education and governance within the SDG 7 and SDG 8 framework. By integrating indicators of renewable energy transition, energy intensity and income with a composite measure of labour market dynamics, and applying fixed effects, two stage least squares, method of moments quantile regression and pre and COVID-19 splits, the study addressed three questions: the impact of renewable transition on labour outcomes, the moderating roles of human capital and institutions, and the heterogeneity of effects across countries, time horizons and segments of the labour market distribution.

Three core findings emerge. First, higher energy efficiency, reflected in lower energy intensity, is consistently associated with stronger labour market performance, and this relationship becomes more pronounced in the pandemic period. Efficiency improvements therefore appear to provide the most reliable channel through which progress on clean energy supports decent work. Second, the labour effects of renewable energy transition are heterogeneous and often adverse in the short run. Negative coefficients in the full sample fixed effects estimates and at the lower quantiles indicate that transition frictions are most acute in weaker labour markets and in contexts marked by structural and conflict related disruptions. Third, education, governance effectiveness and regulatory quality act as critical mediating mechanisms. Interactions between renewable transition and education, governance and regulation show that where human capital and institutions are aligned, the labour market consequences of the transition become less disruptive and, in some cases, more favourable. The strong state dependence evident in the dynamic models and the weakening of energy and institutional effects when Russia is excluded underline the importance of path dependence and structural asymmetries within the bloc.

These results matter for both analytical and policy reasons. Analytically, they demonstrate that the linkage between SDG 7, SDG 8 and SDG 13 in large emerging economies is conditional and context specific rather than automatic. For policymakers, social partners and development institutions, the findings suggest that accelerating energy efficiency, through technological upgrading, industrial retrofits and more resource efficient production, offers a relatively low risk route to strengthening labour outcomes while advancing clean energy goals. At the same time, the evidence that renewable deployment can weaken labour market dynamics in the short term, particularly in more fragile labour markets, highlights the need to sequence renewable investments alongside active labour market policies, vocational and higher education reforms, and institutional strengthening. Governments in BRICS countries, as well as international partners, stand to benefit from using these insights to design country specific transition strategies that integrate energy policy, skills development and labour market institutions rather than treating them as separate agendas.

The study's empirical design, spanning multiple estimators, interaction terms and pre-COVID and COVID-19 dynamics, provides a rigorous platform for these conclusions but also points to clear avenues for further research. The composite index of labour market dynamics cannot fully reflect job quality, informality, gender and spatial inequalities that are central to the decent work agenda and to just transition debates. Future work should therefore combine this type of cross-country analysis with sectoral and micro level data to identify which workers, sectors and regions bear the greatest adjustment costs and where the largest employment gains materialise. There is also scope to explore explicitly how financial systems, digital technologies and green vocational education mediate the energy labour nexus in BRICS and other emerging regions. Advancing this research agenda will be critical for shaping transition pathways that achieve not only cleaner energy systems, but also more inclusive, resilient and productive labour markets in line with the aspirations of the 2030 Agenda.

By explicitly integrating SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), and SDG 13 (Climate Action), this study highlights the interconnected nature of clean energy transition, labour market performance, and climate resilience in BRICS economies. The findings underscore the importance of coordinated institutional reforms, human capital development, and targeted policy sequencing to ensure that clean energy pathways deliver both employment benefits and long-term climate mitigation outcomes. Now the biggest challenge is the war between Russia and Ukraine which final consequences are still unpredictable.

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