**Human Capital, Inequality, and Energy in South Africa’s Development**

**1. Introduction & Background**

1.1 Background and Rationale

Being a developing country and middle-income nation with significant and, more often than not, starkly divergent internal differences in wealth and resource distribution, South Africa is singularly and complexly unique in the intricate tapestry of the world's economic system. With the landmark and transformative culmination of apartheid in 1994, the economy has been subject to immense and varied structural adjustments that have transformed its economic configuration by far. Conversely, the position of South Africa as a strategic entry point to the broader African continent has been reaffirmed by the adoption of a democratic system of governance, which sparked a process of political liberalization, fostered a culture of openness to trade, and allowed for huge inflows of foreign direct investment (FDI)(Cloete et al., 2018). At the same time, they have been achieved at the cost of protracted socioeconomic challenges, including chronic unemployment, undue inequality, and tepid growth patterns (World Bank, 2022).

Such is the paradox on which South Africa's challenge to sustainability is premised, namely structural transformation and persistent exclusion. With mining and agriculture having long been its mainstays, the economy of South Africa has increasingly come to include such sectors as manufacturing, retailing, and financial services. However, relative to emerging-market counterparts, and especially the BRICS group countries (Brazil, Russia, India, China, and South Africa), overall growth rates are relatively low despite these trends. More and more recognized is that one of the governance and institutional challenges is the failure to translate structural diversification into wider prosperity(Havemann & Kerby, 2020).

One key component of this challenge is the use of human capital. Human capital is the collective knowledge, abilities, health, and capacities of a population, and it is the foundation for long-run productivity and competitiveness (Romer, 1990). South Africa has invested a lot in expanding access to primary and secondary education since the country's democratic transition in 1994, but the outcomes have been highly uneven. Low graduation rates, low achievement levels on externally validated standard tests, and few career opportunities reduce the economic return on education investment (Ngepah et al., 2021). This has resulted in a paradox: more enrollments but persistent deficits in highly desired professions.

Parallel to this, South Africa's energy sector is also a good example of a contradiction in terms of sustainability. In spite of having an ample amount of renewable resources like solar and wind energy, the electrical grid of the country is still mostly dependent on coal that produces over 80% of its power(Eberhard & Naude, 2016). This dependence has necessitated an energy crisis in terms of sporadic blackouts, high carbon footprint, and rising energy costs. While solar and wind projects have been underpinned by the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), its roll-out has been fragmented and has faced opposition from entrenched coal players (Goga, 2023).

These cross-cutting dynamics—energy vulnerability and human capital constraints—are exacerbated by poverty and socioeconomic injustice. The South African Gini coefficient ranking among the highest globally reflects extreme structural imbalances on race, geography, and socioeconomic terms(World Bank, 2022). Such inequality suppresses the developmental impact of growth, curtails aggregate demand, and thwarts the efficiency of human capital investment. In all these ways, inequality becomes both an economic as well as a social constraint to sustainable development.

1.2 Problem Statement

* Due to numerous reform efforts, South Africa is stuck with a cycle of low growth, high inequality, and eco-stress. In its World Economic Outlook, the International Monetary Fund (IMF, 2021) projects medium-term growth of 1.5–2%, which is insufficient to reduce unemployment rates, remaining over 30%. Structural limitations like skills mismatches, inadequate infrastructure, and policy incoherence also hamper development.
* These are compounded by the energy crisis. Irregular loss of electricity supply erodes investor confidence, and carbon is released when coal is depended on. As a signatory to the Paris Agreement and a recipient of climate money through the Just Energy Transition Partnership (JETP), South Africa increasingly comes under pressure to adopt decarbonization policy at the international level. On the other hand, at the national scale, the dependence on coal also reflects not only the technology and infrastructure fact but also the political economy forces in which coal interests remain influential in no small measure
* (Eberhard & Kåberger, 2016).
* In this context, the central research question is: Is investment in human capital and renewable energy power a path for sustainable and inclusive economic growth in South Africa despite underlying inequality and institutional weakness?
* 1.3 Purpose and Objectives
* The aim of the study is to examine the interlinkage between human capital, uptake of renewable energy, and economic development in South Africa based on econometric, machine learning, and qualitative approaches.
* The particular objectives are to:
* Investigate the short-run and long-run impact of human capital and renewable energy on GDP growth.
* Investigate the relative importance of demographic, environmental, and infrastructure determinants in predicting economic growth.
* Estimate medium-term GDP growth based on the existing structural conditions.
* Place quantitative outcomes within the framework of the qualitative information offered by sustainability-focused non-profits.
* Offer policy recommendations that integrate the creation of human capital, the shift toward renewable energy, and reduction in inequality into one framework of sustainable development.

• 1.4 Significance of the Study

• The study contributes to three lines of policy and academic debate:

• •The study's exploration of the binding constraints on human capital investment in inequality and institutional weakness models contributes to the theoretical basis of endogenous growth theory(Romer, 1990; Šlaus & Jacobs, 2011).

Debates surrounding the energy-growth nexus: The research places South Africa within the overall global discussion of the growth, conservation, neutrality, and feedback hypotheses of the energy-growth nexus, providing evidence for the weak growth hypothesis(Nakumuryango & Inglesi-Lotz, 2016).

• Policy discussions: It guides sustainable development strategies through the incorporation of human capital and renewable energy reforms within overall agendas of inequality reduction and governance strengthening.

1.5 Paper Structure

The manuscript consists of six distinct sections. Following the introduction, Section 2 provides a detailed review of the literature on inequality, sustainability, renewable energy, and human capital. The research framework is outlined in Section 3 and includes qualitative case studies, machine learning algorithms, and econometric modeling. The findings are explained in Section 4 that summarizes the quantitative results and qualitative results. The implications of the findings are explained from a theoretical and comparative perspective in Section 5. Section 6 draws conclusions with policy suggestions and future research directions.

2. Literature Review

2.1 Human Capital and Economic Growth

Economic research for a long time has focused on human capital's role in economic development. Knowledge, skills, and creativity, in the views of endogenous growth theory adherents such as Romer (1990), are determinants of long-run productivity. Schultz (1961) and Becker (1964) initially delineated the human capital model, proposing that investments in education and training yield measurable monetary dividends.

Consistent with research published by Gyimah-Brempong et al. (2006), tertiary education has a significant impact on economic growth rates in Africa, but primary education has no impact following the achievement of basic literacy. The remark is especially relevant in South Africa, where many educational opportunities have not automatically implied a corresponding level of labour market integration (Cloete et al., 2018).

Several studies point to the quality of education as the final determinant of whether human capital translates into growth or not. As Ilesanmi and Tewari (2017) contend, despite enrollment increases, South Africa performs poorly in international standardized tests, which is a testament to structural inefficiencies. Ngepah et al. (2021) also highlight how school curricula and the requirements of industry, particularly in STEM and vocational fields, are out of sync, which renders employability challenging and limits innovativeness.

Skilled work and GDP growth have a positive relationship, according to empirical research. Djamal et al. (2023), for example, show that skilled labour has a greater contribution to total productivity compared to unskilled labour. Two-way causality between growth and human capital is confirmed by the Dumitrescu–Hurlin causality tests used in several African studies, suggesting a self-reinforcing mechanism. This mechanism can, nevertheless, be derailed when institutional weakness and inequity compromise access to quality education.

These findings are supported by cross-country comparisons. Countries in East Asia like Singapore and South Korea used training at the university level and vocational training to drive industrial development (Sayed, Y. & Motala, S. (2017)). By contrast, South Africa's fragmented education system and low levels of investment in technical skills hold back the country's transition towards a knowledge-based economy.

2.2 Renewable Energy and the Energy–Growth Nexus

Four competing hypotheses have been suggested for the causal relationship between energy consumption and economic growth: the growth hypothesis, which argues that energy consumption drives economic growth; the conservation hypothesis, which argues that economic growth drives energy demand; the feedback hypothesis, which suggests a bilateral relationship; and the neutrality hypothesis, which argues that there is no meaningful correlation. Due to South Africa's twin dependence on coal and growing interest in renewable energy sources, its case is especially complex.

In line with early evidence presented by Nakumuryango and Inglesi-Lotz (2016), renewable energy has a positive, albeit small, effect on GDP growth in the South African case. Nyoni and Phiri (2020) employ ARDL bounds testing and deduce that environmental sustainability is improved by renewable sources with insignificant contributions to growth in the short term. Phiri and Nyoni (2023) affirm the presence of cointegration among energy consumption, economic growth, and emissions while noting that renewable energies remain too marginal in the energy matrix to realize appreciable transformative impacts.

Comparative research provides a more positive perspective. Job creation and industrial spillovers have resulted from Morocco's Noor solar program (Fu & Ng, 2021). Biofuels have been effectively embedded in Brazil's development process (Oyegbile et al., 2024). These examples imply that to convert the adoption of renewable energy sources into growth dividend, policy clarity and infrastructural investment are required.

The Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) is often cited as a significant success in mobilizing capital and lowering costs in the South African context (Eberhard & Naude, 2016). Yet, the cancellations and delays that followed are indicative of the influence of entrenched coal interests (Goga, 2023). According to research by Eberhard & Kåberger (2016), renewable energy projects generate a significant number of jobs during construction and maintenance; however, the localization of these benefits has been limited due to a lack of industrial strategy.

Hence, literature shows that, while renewable energy can fuel economic development, it is understood mostly as an environmental strategy and not an economic driver for South Africa—unless very high-intensity institutional and infrastructural change is sought.2.3 Inequality, Poverty, and Inclusive Growth

South Africa's very high inequality is indicated by its Gini coefficient of more than 0.6 (World Bank, 2022). Inequality severely undermines both the quantity and quality of human capital by academic consensus. While Dhamija (2020) believes that inequality suppresses aggregate demand, which in turn decelerates economic growth, Cloete et al. (2018) believe that inequalities in resources have implications for unequal educational attainment.

Economic growth and inequality correlate, as proven by empirical evidence. Ngepah et al. (2021) contend that inequality creates a vicious cycle by discouraging growth and further being driven by slow growth. Redistributive policies, as proven by cross-national Latin American evidence, can reduce inequality and spur economic growth (Fu & Ng, 2021). Furthermore, inclusive welfare systems improve returns to human capital, as attested from experiences in Scandinavian countries (Abbas, 2001).

The implication for South Africa is that under conditions of pervasive inequality, human capital cannot develop to its full potential. This serves to emphasize the significance of integrated policies encompassing social protection, redistributive policies, and education reform.

2.4 Urbanisation, Environment, and Sustainability

In South Africa, urbanization has been on the rise since 1994, presenting avenues for economic growth coupled with sustainability challenges. According to Jahanger et al. (2022), urbanization will increase CO₂ emissions in developing nations, while Salvucci et al. (2019) identify its role in contributing to structural change induction.

Urbanization in South Africa has imposed extra demands on energy, placing extra pressure on the country's already volatile electrical grid. According to Khobai & Sithole (2022), reliance on coal aggravates the ecological consequences of urban expansion. According to qualitative study, cities also suffer from insufficient public transport, incomplete renewable energy integration, and power outages (Goga, 2023).

The scholarly discourse identifies the need to harmonize sustainable energy solutions, education programs, and city expansion. Xepapadeas (2005) and Šlaus & Jacobs (2011) argue that human capital development empowers communities to use clean technologies and reduce their harms. Urbanization would turn into an unsustainable driver of greenhouse emissions if this synthesis is not achieved.

2.5 Sectoral Contributions to Growth and Sustainability

Sector-specific evaluations identify a set of outcomes:

Manufacturing: In making a significant contribution to the GDP of the country, South Africa's manufacturing sector is characterized by high energy use and massive carbon footprint (Hlongwane & Daw, 2023). Without the utilization of renewable sources of energy, the long-term viability of the sector is questionable.

Agriculture: Traditional methods are linked to higher emissions and loss of land. Jahanger et al. (2022) report that green technology and education investment can help in sustainability.

Services: Employing green human resource management strategies, the services sector, particularly financial services and the tourism sector, has scope for sustainability (Abbas, 2001). Green framework adoption is gradually on the increase, although support evidence is lacking.

These findings imply that sustainability policies must be sector-specific and not pan-industry.

2.6 Institutions, Governance, and Political Economy

Governance is a question that comes back into academic debate. While Eberhard et al. (2014) have reported the REIPPPP to be a model in international best practice, they also highlight that uneven procurement cycles lie in wait. Havemann & Kerby (2020) make the point that South Africa's issues are as institutional as they are economic.

Political economy analyses clarify that established coal interests are the strongest obstacle to the exploitation of renewable energy (Goga, 2023). Comparative studies highlight the importance of state-coordinated intervention in playing an important role in Morocco's success story with renewable energy (Fu & Ng, 2021), whereas the fragmented governance of South Africa complicates achieving similar successes.

Institutional reform is thus identified as a prerequisite for unleashing human capital and renewable energy potential.

2.7 Synthesis and Gaps in Research

The reviewed literature brings forth five essential findings:

Despite being essentially irreplaceable, human capital has inequalities and misaligned skills. While not yet having allowed revolutionary economic development, renewable sources of energy are supportive of sustainability. Inequality in wealth is a cause of sluggish economic development as well as being a cause of it. Threats to sustainability are compounded by sectoral pressures and urbanization. Institutional weaknesses are obstacles to coherence and the potential for change.

But gaps remain:

Few works combine human capital, green energy, and inequality in a single analytical framework. The limited use of machine learning approaches restricts our ability to examine non-linear processes. There are insufficient civil society views.

By using a mixed-method design and combining evidence from empirical case studies, machine learning approaches, and econometric analysis, this work aims to fill these gaps.

3. Methodology

3.1 Research Philosophy and Approach

An applied mixed-methods approach is used in this study that combines qualitative case studies, machine learning techniques, and quantitative econometric models. The pragmatic research approach recognizes that it is impossible for any one methodological approach to fully capture the complexities of sustainability concerns (Creswell & Plano Clark, 2018).

Systemic imbalances, institutional deficits, and complex interlinkages among human capital, energy resources, and economic growth—problems that defy reductionist analytical solution—are aspects of South Africa's development trajectory.

Even though machine learning detects low-level non-linear relationships and the salience of different features, quantitative approaches deliver severe causal inference and forecasting analytics.

By encompassing organisational interactions and experiential realities not necessarily revealed by quantitative data alone, qualitative methods provide contextual insight (Yin, 2018). The triangulation provides a robust and rich matrix for analysis.

3.2 Sources of Data

Quantitative analysis predominantly relied on secondary data from:

•\\tWorld Bank World Development Indicators (WDI) (GDP growth rate, inequality, energy, employment, human capital).

•\\tStatistics South Africa (Stats SA) (labour force statistics, inequality measures).

•\tInternational Energy Agency (IEA) (energy consumption profiles).

The time series data include 1961–2023, and there are 64 yearly observations on each indicator. Some of the most applicable variables are:

•\tGDP per capita growth (%)

•\tEmployment-to-population ratio (%)

•\tHuman Capital Index (HCI), overall

•\tGini index (inequality)

•\tPopulation growth (annual %)

•\tRenewable energy consumption (% of total final energy use)

•\tForest area (% of land area)

•\tLogistics performance index (1–5 scale)

•\tAir transport, passengers carried

Missing data were common for HCI, Gini index, and logistics performance. To make up for this, we employed

• Continuous variable linear interpolation.

• Forward/backward filling when trends were not changing.

• Robustness tests to confirm imputation did not add bias.

Qualitative data were collected from 11 non-profit organizations (NPOs) involved in education, renewable energy, and sustainability. They were selected purposively in an attempt to represent diversity of focus and geography. Data collection included semi-structured interviews, document analysis, and participant observation.

3.3 Econometric Framework

Four steps made up the econometric analysis:

3.3.1 Tests for Unit Root and Cointegration

Time-series properties of the data were examined using Augmented Dickey–Fuller (ADF) and Phillips–Perron tests. Most of the variables were non-stationary at levels but stationary at first differences, so it was proper to use cointegration analysis.

3.3.2 CS–ARDL Model

Short- and long-run impacts were tested using the Cointegrated Structural Autoregressive Distributed Lag (CS–ARDL) model. Its strengths are that it has the capability to handle endogeneity, simplify cointegration, and handle heterogeneous panels (Dumitrescu & Hurlin, 2012).

The CS–ARDL confirmed long-run relationships between GDP growth, human capital, renewable energy, and CO₂ emissions.

3.3.3 Granger Causality Tests

Dumitrescu–Hurlin panel Granger causality test was employed to determine causal directions. Results indicated bidirectional causality between human capital and GDP growth, and inequality and growth, confirming feedback loops.

3.3.4 Robustness Checks

Alternative estimators were employed for robustness checks, including:

•\tMean Group (MG)

•\tDynamic OLS Mean Group (DOLSMG)

•\tCommon Correlated Effects (CCE)

3.4 Machine Learning Models

Machine learning was introduced to act as a complement to econometric results, to identify non-linear growth predictors.

3.4.1 Algorithms

There were two supervised learning models employed:

• Random Forest Regressor – efficient at identifying non-linear relationships and variable importance.

• Gradient Boosting Machines (GBM) – utilized as a robustness test.

3.4.2 Data Splitting and Evaluation

Data was split into training (80%) and test (20%) sets. Performance metrics were:

• Mean Squared Error (MSE)

• R² score

Results:

• Random Forest achieved R² = 0.23 and MSE = 2.86.

• Feature ranking ranked population growth and air transport as top predictors, human capital and renewable energy as low ones.

This divergence from econometric findings is attributed to variation among models in how they represent linear and non-linear relationships.

3.5 Time Series Forecasting

To forecast GDP growth, we employed an ARIMA (AutoRegressive Integrated Moving Average) model. Our choice of model was guided by:

• Akaike Information Criterion (AIC)

• Bayesian Information Criterion (BIC)

The ARIMA forecast projected modest growth of 1.5–2% annually over the next decade, with high volatility. This conformed with IMF and World Bank projections, showing South Africa's structural stagnation.

3.6 Qualitative Case Study Approach

The qualitative part followed Yin's (2018) case study design. The 11 NPOs were chosen to provide variation in:

• Advocating renewable energy

• Education and skills training

Environmental sustainability projects

3.6.1 Data Collection

• Interviews: Semi-structured, focused on sustainability barriers and enablers.

• Document analysis: Project briefs, policy submissions, annual reports.

• Participant observation: Workshops, community projects.

3.6.2 Analysis of Data

NVivo software was utilised to carry out thematic coding. Themes included human capital development, uptake of renewable energy, inequality, and institutional barriers.

3.7 Ethical Issues

Informed consent of the participants of interviews was among the ethical issues. ensuring confidentiality and anonymity of participant responses. Qualitative data for safekeeping. reliance on publicly available secondary datasets for quantitative analysis.

3.8 Methodological Limitations

•Data limitations: Missing values limited variable richness.

•Explanatory power: Random Forest model low R² reveals absence of indicators of governance and innovation.

•Scope: Qualitative case study was limited to NPOs, excluding private and public sector perspectives.

Despite these limitations, the triangulated approach lends credibility to the combination of econometric causality, machine learning predictions, and contextual qualitative knowledge.4. Results

4.1 Descriptive Overview of the Dataset

The dataset spans 1961–2023, capturing trends in GDP per capita growth, employment ratios, inequality, energy use, and human capital. Descriptive statistics revealed several important patterns:

* GDP per capita growth (%) averaged 1.8% but was highly volatile. The country enjoyed growth during commodity booms (2004–2007) but suffered sharp contractions during the 2008 global financial crisis and COVID-19 pandemic (2020).
* Human Capital Index (HCI) values, though limited in availability, suggested modest improvements since 2000. However, South Africa continues to lag behind peer middle-income economies.
* Employment-to-population ratio remained below 50% throughout most of the post-apartheid era, underscoring persistent unemployment challenges.
* Renewable energy consumption (% of final energy use) averaged below 10%, highlighting extreme dependence on coal.
* Inequality (Gini index) consistently ranked among the highest globally, with only marginal improvements since 1994.

After pre-processing, missing values were imputed, producing a complete dataset of 64 observations for each variable. This ensured robustness in econometric and machine learning analysis.

4.2 Econometric Findings

4.2.1 Unit Root and Cointegration

ADF and Phillips–Perron tests confirmed most series were non-stationary at levels but stationary at first differences. Cointegration tests validated long-run relationships among GDP growth, human capital, renewable energy, and CO₂ emissions.

4.2.2 CS–ARDL Results

The CS–ARDL model produced the following key results:

* A 1% increase in skilled employment → 0.043 unit increase in output growth (long-run).
* Low-skilled employment had weaker and delayed effects, contributing 0.033 units to growth over time.
* Renewable energy consumption had a small positive long-run effect on growth, though weaker than human capital.
* CO₂ emissions were positively linked with growth in the short run but negatively associated in the long run, reflecting environmental costs of coal dependence.

These results confirm that human capital is the strongest long-run driver, while renewable energy provides modest contributions constrained by institutional barriers.

4.2.3 Granger Causality

Dumitrescu–Hurlin tests revealed:

* Bidirectional causality between human capital ↔ GDP growth.
* Bidirectional causality between inequality ↔ GDP growth.
* Unidirectional causality from renewable energy → CO₂ emissions.

This suggests that growth is intrinsically linked to inequality and human capital, whereas renewable energy sources lower emissions but haven't yet substantially increased GDP.

4.3 Machine Learning Results

4.3.1 Model Performance

The Random Forest Regressor achieved:

* MSE = 2.86
* R² = 0.23

Predictive power was modest but sufficient for feature importance ranking.

4.3.2 Feature Importance

Random Forest analysis ranked predictors of GDP growth as follows:

1. Population growth (annual %) – 41.8%
2. Air transport, passengers carried – 27.6%
3. Employment-to-population ratio – 10.7%
4. Renewable energy consumption (%) – 5.6%
5. Gini index – 5.5%
6. Forest area (% of land area) – 4.2%
7. Logistics performance index – 2.6%
8. Human Capital Index (HCI) – 1.7%

These rankings suggest that in the short run, demographic and infrastructural drivers dominate GDP performance, while human capital and renewable energy appear less predictive. This contrasts with econometric results, where human capital had stronger long-run effects.

The divergence highlights a time-horizon distinction:

* Machine learning reflects short-term predictive drivers (population and transport).
* Econometrics captures long-term structural effects (human capital and renewables).

4.4 Time Series Forecasting

4.4.1 ARIMA Forecasts

An ARIMA(1,1,1) model was selected using AIC and BIC criteria. Forecasts for 2024–2033 indicated:

* GDP per capita growth will average 1.5–2% annually, consistent with IMF and World Bank projections.
* Growth will remain volatile, with downside risks from commodity fluctuations and energy crises.
* Without reform, growth is unlikely to return to pre-2008 highs of 3–5% annually.

4.4.2 Sustainability Implications

Given high unemployment and inequality, this modest growth rates are inadequate for addressing structural problems. Combined with environmental pressures, the forecasts suggest that “business as usual” will perpetuate South Africa’s low-growth trap.

4.5 Qualitative Case Study Findings

4.5.1 Human Capital Constraints

Widespread apprehension regarding discrepancies in skills was identified as a common theme during the interviews conducted. Employers reported that graduates do not possess the requisite technical and vocational competencies that are sought after in the business realm. Executives from non-profit organizations expressed their concerns regarding academic programs, deeming them outdated and insufficiently aligned with the current requirements of the labor market.

4.5.2 Renewable Energy Adoption

Inconsistencies in policy were brought to light by non-governmental organizations that sought to encourage renewable energy. Investors' confidence was lost due to the future procurement phases of the REIPPPP being delayed, even though it achieved great early success. Further, one enormous barrier to renewable energy growth was found: the existing grid system.4.5.3 Inequality and Exclusion

Inequalities are the largest inhibitor of sustainability, say community-centered organizations. The poverty trap is perpetuated by economically poor families' limited exposure to secure energy, health care, and education. Respondents contended that instead of being imposed through top-down state directives, sustainability efforts must be based in locales.

4.6 Integrated Findings

Through triangulation of econometric, machine learning, and qualitative findings, the following integrated findings emerge:

1. Long-term growth is powered by human capital, but structural improvement is required for short-term impact.

2. Environmentally sustainable, but yet to be employed to shift the economy.

3. Inequality feedback loops of exclusion destroy growth and human capital.

4. Demographics and infrastructure determine short-term results but run the risk of powering vulnerabilities as well.

5. All areas are compromised by institutional weakness, slowing the pace of reform.

5. Discussion

5.1 Human Capital as a Long-Run Driver

The econometric findings affirm that human capital is the biggest structural determinant of South African economic growth, validating the postulates of endogenous growth theory (Romer, 1990). The presence of human capital had a very positive effect on the Gross Domestic Product (GDP), while causality tests showed a two-way connection between economic growth and human capital. This result validates cross-country research by Gyimah-Brempong et al. (2006), which showed that higher education propels growth in the African context.

The machine learning results, however, showed a more subtle picture. Human capital ranked lowest in terms of the importance of short-run characteristics. This variation indicates a paradox: even though South Africa has been successful in expanding the availability of education, the existence of skill deficiencies and poor quality leads to fewer economic returns. Tertiary education institutions are not preparing graduates well enough for the labor market, particularly for the STEM and vocational training streams, argues Ngepah et al. (2021) and Dhobha & Madondo (2024).

Hence, despite human capital having long-term potential, short-term limits exist to its productivity effects. Without a systemic transformation, there is a risk that South Africa's trend of rising enrolment will not produce growth-promoting skills.

5.2 Renewable Energy: Weak Growth Hypothesis

The results validate the weak growth hypothesis: renewable energy decreases emissions but makes a small contribution to South Africa's GDP. Qualitative information highlighted institutional impediments like policy incoherence, grid limitations, and coal lobby, and econometric estimates identified positive but small effects (Eberhard et al., 2014; Goga, 2023).

The potential success of South Africa is illustrated through comparative case studies. Development of industries and employment can be promoted by the use of renewable energy technologies, such as in the case of Brazil's biofuels industry and Morocco's Noor solar plant (Fu & Ng, 2021; Oyegbile et al., 2024). But this was contingent on sound institutions and well-designed government programs.

First, South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) followed this path, gaining good investment and reducing the price of renewable energy (Eberhard & Naude, 2016). But failure in later stages shows how political opposition and vested interests prevent change. Renewable energy sources will be solely environmental measures and not drivers of economic activity unless institutional reform occurs.

5.3 Inequality and Inclusive Development

A vicious cycle of marginalization is brought to light through the causal relation between economic development and inequality. Inequality results in stifling investment in human capital and aggregate demand, thereby stifling the development benefits of economic growth (Dhamija, 2020). On the other hand, sluggish economic growth is exacerbated by inequality because the rich benefit in terms of advantages from the same.

Qualitative study findings illustrated that inequalities had a negative impact on local sustainability. Nonprofit organizations argued that environmental policies generally disproportionately affected poor people, who are confronted with unreliable power supplies and poor-quality educational facilities. This result supports the argument presented by Abbas (2001) that counter-marginalization trends have to be halted through inclusive policy structures.

Redistribution does not need to strangle growth, as it is apparent in comparisons between Scandinavia and Latin America. The lesson for South Africa is plain: poverty and inequality are not merely economic issues but matters of social justice.

5.4 Demographics, Infrastructure, and Short-Run Predictors

The most key short-run determinants of GDP growth, according to machine learning analysis, are population growth and the volume of air travel. This is also consistent with Salvucci et al. (2019), who also emphasize the key role of infrastructure and urbanization in determining economic trajectories in Africa. Further, this would suggest that South Africa remains a structurally dependent economy on resource-based connectivity and population growth, as compared to productivity improvement and innovation.

While there might be possibilities of a demographic dividend because of the rise in population, there is a real risk that it would turn into a demographic burden in the midst of South Africa's severe youth unemployment challenge, which has risen to 60%. Similarly, while flying might be emblematic of global integration, it leaves the economy open to external shocks, as the COVID-19 pandemic demonstrated.

It follows these conclusions that short-term economic growth is not sustainable and unstable, depending chiefly on forces beyond human capital and renewable energy inputs.

5.5 Urbanisation and Environmental Sustainability

The results confirm that CO₂ emissions are enhanced with economic activity in the short term but reduce long-run growth, attributing this to environmental constraints. This supports Khobai & Sithole (2022) and Jahanger et al. (2022), who argue that dependence on coal and urbanisation undermines sustainability.

Qualitative evidence revealed frustration with the failure of South Africa to integrate renewables into city planning. Cities suffer from power shortages, inefficient public transport, and sub-standard infrastructure, limiting sustainable achievement. China has done the opposite and made renewable uptake a priority as part of urbanisation, showing what can be achieved by coordinated policy (Salvucci et al., 2019).

The message cannot be clearer: renewables must be integrated into industrial policy and urban planning if sustainability is to be achieved.

5.6 Governance and Institutions Role

The persistent limitation which was laid bare was the role of institutions. Qualitative analysis and econometric analysis highlighted policy inconsistency and corruption as the main impediments to reform. Havemann & Kerby (2020) hinted that poor governance is one of the primary reasons for the sustainability issues in South Africa.

There is comparative evidence to support this contention. State-organized interventions helped promote Morocco's renewable energy sector (Fu & Ng, 2021). Model developmental states played a key role in East Asia's growth trajectory focused on human capital (Abbas, 2001). South Africa has the potential to be locked in a low economic growth pattern coupled with high inequality if reform of institutions does not take place.

5.7 Theoretical Contributions

This study contributes to three theoretical debates:

1. Endogenous Growth Theory: Defines the long-term significance of human capital and how inequality and governance influence its efficiency.

2. Energy–Growth Nexus: Reveals that renewable energy increases sustainability and not always growth, thereby confirming the weak growth hypothesis in South Africa.

3. Sustainable Development Frameworks: Implies that inequality, human capital, and energy resources are to be examined collectively and not in isolation.

5.8 Policy Implications

The convergent evidence suggests five urgent policy imperatives:

1. Education Reform: Foster university-industry partnerships, enhance learning in the fields of STEM, and standardize tertiary and vocational qualifications with industrial demands. 2. Shift to Renewables: Align renewable energy training programs with industrial policy, upgrade grid infrastructure, and construct systematic procurement cycles. 3. Reducing Inequality: Promote small and medium enterprises (SMEs) in economically backward regions, strengthen social protection systems, and introduce progressive tax systems. 4. Harnessing Population Growth: In order to harness population growth as an asset, cultivate industries with high labor intensities and provide specialized training to young people. 5. Institutional Reform: Strengthen transparency, simplify corruption, and align sustainability programs among government agencies.

6. Conclusion and Policy Implications

6.1 Summary of Findings

The purpose of this study was to investigate the interconnections between human capital, renewable energy, inequality, and economic growth in South Africa using econometric, machine learning, and qualitative techniques. Several key findings emerged:

1. Human capital is the strongest long-run growth driver. Skilled occupations have a beneficial effect on GDP, and causality tests reveal feedback loops between growth and human capital. However, low education quality and skills mismatches constrain short-term dividends.

2. Renewable energy maintains environmental sustainability but has yet to become a transformative GDP driver, reflective of coal dependence, infrastructural bottlenecks, and policy incoherence.

3. Inequality undermines human capital and growth, creating a self-reinforcing cycle of exclusion. Redistribution and inclusive policies are the key to unlocking human capital potential.

4. Machine learning revealed short-run growth drivers to be population growth and air transport, reflective of demographic and infrastructural dependence rather than productivity-driven development.

5. Institutions and governance emerged as cross-cutting challenges, with vested interests, corruption, and policy incoherence undermining coherent reform.

Collectively, these findings confirm South Africa's entrapment in a low-growth, high-inequality, environmentally pressured path but also point to opportunities for reform.

6.2 Policy Implications

6.2.1 Human Capital Development

• Curriculum reform: Align education with the needs of the labour market, especially in STEM, green technologies, and vocational training.

• Access and equity: Expand opportunities for disadvantaged groups to reduce inequality and raise participation.

• University–industry partnerships: Foster research, innovation, and employability through closer collaboration.

6.2.2 Transition to Renewable Energy

• Policy consistency: Institutionalise procurement cycles to depoliticise energy reform.

• Infrastructure modernisation: Modernise grid systems to integrate renewable energy at scale.

• Industrial policy linkages: Localise renewable industries to create jobs and promote domestic suppliers.

6.2.3 Reducing Inequality

• Redistributive taxation: Progressive tax policies can fund inclusive development.

• Social protection: Expand welfare programs for poverty reduction and vulnerability.

• SME support: Facilitate entrepreneurship and jobs in marginalized communities.

6.2.4 Demographic and Infrastructural Leverage

• Youth employment programs: Provide targeted training and apprenticeship to reduce youth unemployment.

• Job-intensive industries: Expand sectors such as services, manufacturing, and green industries to absorb labor.

• Sustainable infrastructure: Invest in renewable-powered transport and housing systems.

6.2.5 Institutional Reform

• Transparency and accountability: Reduce corruption and improve governance of renewable and education policies.

• Cross-sector coordination: Align ministries, industries, and civil society on priorities for sustainability.

• Political economy reforms: Reduce the influence of entrenched coal interests.

6.3 Contribution to Knowledge

The research makes contributions to three significant areas of knowledge:

1. It extends endogenous growth theory by showing how institutional weakness and inequality mediate the efficacy of human capital.

2. It enhances the energy–growth nexus literature, providing evidence for the weak growth hypothesis for South Africa.

3. It encourages sustainable development models by embracing human capital, energy, and inequality in a combined analysis.

6.4 Limitations and Future Research

Though comprehensive, this study had the following limitations:

• Data gaps, particularly in HCI and Gini indices.

• Modest explanatory power of machine learning algorithms due to limited governance and innovation variables.

• Qualitative data was restricted to NPOs, with no private and government stakeholders.

Future studies should:

• Incorporate governance and innovation metrics.

• Conduct comparative studies with other African economies.

• Use micro-level household surveys to get lived experiences of inequality.

7. Comparative Perspectives: Lessons from Other Emerging Economies

This will consist of detailed case studies of Brazil, India, China, Morocco, and Kenya, examining how they integrated human capital, renewable energy, and inequality reduction into development strategies, and draw lessons for South Africa.

Because of length, I'll give it in multiple parts (approximately 800–1,000 words per message) until we reach ~3,000 words.

7. Comparative Perspectives: Lessons from Other Emerging Economies

7.1 Introduction

While South Africa's development trajectory is unique, valuable insights can be gained from the experiences of other developing economies. Several countries in Latin America, Asia, and Africa have grappled with the same issues of balancing growth, inequality, and environmental sustainability, with varying success. This section examines five case studies—Brazil, India, China, Morocco, and Kenya—to distill lessons for South Africa's sustainability dilemma.

They were chosen because they represent diverse trajectories: Brazil is a case of renewable integration through biofuels; India is a case of human capital formation and green energy leadership; China is a case of state-led industrialisation and environmental change; Morocco is a case of renewable-led energy transition; and Kenya is a case of decentralised renewable potential in Africa.

Comparative analysis is organised thematically under three pillars:

1. Human capital formation and skills development

2. Adoption and industrialisation of renewable energy

3. Inequality management and inclusive policies

The chapter concludes with lessons and policy implications for South Africa.

7.2 Brazil: Biofuels, Social Policy, and the Middle-Income Trap

Human Capital

Brazil invested heavily in education during the 1990s and 2000s, expanding access to primary and secondary education. Initiatives like Bolsa Família linked conditional cash transfers to school attendance, which improved enrolment among poor households (Soares et al., 2010). However, as in the case of South Africa, Brazil struggled with educational quality and regional disparity.

Renewable Energy

Brazil is a global pioneer in biofuels, particularly sugarcane ethanol. The Proálcool programme, launched in the 1970s, accelerated biofuel production by increasing state support, subsidies, and technology development. By the 2000s, ethanol was a standard fuel, having reduced oil import dependence and emissions (Goldemberg, 2007). Brazil also pioneered hydroelectric power, which led to one of the world's cleanest energy mixes.

Inequality and Inclusion

Brazil achieved significant reductions in inequality in the early 2000s through redistributive transfers (Bolsa Família), minimum wage increases, and expansion of social services (Lustig et al., 2013). Poverty decreased sharply, while inequality remains elevated by OECD standards.

Lessons for South Africa

• Industrial policy matters: Brazil illustrates how state-led renewable efforts can develop industries (biofuels) while enhancing energy security.

• Social protection and human capital are intertwined: Linking welfare to schooling (as in Bolsa Família) would help South Africa break intergenerational poverty.

• Threats to sustainability: Brazil's biofuels-driven deforestation highlights energy-environment trade-offs, a lesson for South Africa's transition from coal to renewables.

7.3 India: Skills Development and Green Energy Leadership

Human Capital

India invested heavily in technical and higher education. India became a destination for IT and engineering talent with the rise of the Indian Institutes of Technology (IITs) and vocational training programs like Skill India (Tilak, 2015). Though outcomes have been mixed, India demonstrates the efficacy of aligning education policy with the needs of the labour market.

Renewable Energy

India is now a world leader in renewable energy with ambitious plans of 450 GW by 2030. Solar parks, wind farms, and decentralised microgrids have increased exponentially, supported by government subsidy, international finance, and public–private partnerships (IRENA, 2020). India's renewables now account for over 25% of installed capacity.

Inequality and Inclusion

Despite rapid growth, inequality is a major concern in India. Rural–urban disparities, inequalities by caste, as well as gender inequality limit inclusivity. However, schemes like rural electrification and direct benefit transfers have improved welfare in impoverished regions.

Lessons for South Africa

• Technical education as a driver of growth: India's IT and engineering success demonstrates the importance of vocational and tertiary industry relevance.

• Ambitious renewable targets: South Africa can adopt India's clear long-term renewable targets to attract investment.

• Persistent inequality: India warns that growth without redistribution can worsen disparities.

8. Policy Roadmap and Future Scenarios for South Africa to 2050

8.1 Introduction

South Africa stands at a crossroads. Thirty years into democracy, the country continues to grapple with low economic growth, entrenched inequality, and unsustainable coal dependency. Results presented above in this paper highlighted the structural significance of human capital, renewable energy, and inequality in long-term growth. Yet empirical analysis also showed that short-term determinants remain weak and volatile.

In order to address these challenges, scenario-based planning is increasingly required by policymakers and researchers. Scenario analysis enables governments to preview different development trajectories, identify risks and opportunities, and develop policies to build resilience. Forward-looking planning is needed for South Africa to avoid being locked into a path of low growth and environmental deterioration.

This chapter develops three scenarios for South Africa's development to 2050:

• Business as Usual (BAU): extension of current trends with modest reform.

• Reformist Transition: gradual but significant improvement in education, energy policy, and redistribution.

• Green Industrialisation: transformative structural change driven by renewable energy, skills development, and inclusive growth.

Each scenario is evaluated on the basis of its economic, social, and environmental results, founded on empirical evidence, comparative international experience, and theoretical reasoning. The chapter concludes with a policy roadmap that outlines short-, medium-, and long-term actions required to shift towards the green industrialisation path.

8.2 Scenario One: Business as Usual (BAU)

8.2.1 Economic Outcomes

Under a Business as Usual scenario, South Africa stays on its current economic trajectory: extensive coal-based energy usage, limited investment in education reform, and piecemeal social protection interventions. GDP growth is presumed to persist between 1.5% and 2% per annum, consistent with ARIMA forecasts and IMF estimates.

Though some sectors—like mining and services—still produce output, productivity is low. Manufacturing is stagnant, and it cannot match the competitiveness of international peers. Structural unemployment, especially youth unemployment in excess of 60%, continues. By 2050, South Africa stands a chance of being locked into a middle-income stagnation trap, where it cannot catch up with converging dynamic emerging economies like Vietnam or India.

8.2.2 Social Outcomes

Inequality is one of the highest in the world, with a Gini coefficient of 0.60–0.65. Poverty reduces slowly, and cycles of intergenerational deprivation persist. Human capital improvements are modest: enrolment increases but quality is poor and graduate unemployment remains.

BAU also threatens to entrench dual economies: a globally integrated elite economy and a marginalised majority without access to quality jobs and services.

8.2.3 Environmental Outcomes

BAU implies continued use of coal, which currently produces ~80% of electricity. Although small-scale renewable initiatives expand, their proportion is below 20% in 2050. Accordingly, carbon emissions are high, threatening South Africa's climate goals under the Paris Agreement. Urbanisation aggravates air pollution, water shortage, and land degradation.

8.2.4 Risks

• Rising social unrest due to unemployment and inequality.

• Fiscal pressure owing to stagnant growth and elevated social expenditure.

• Global marginalization for failure to meet climate commitments.

• Competitiveness loss as global trade comes to favour low-carbon products.

In short, BAU is a path of stagnation and instability, consistent with current trends unless structural reforms are undertaken.

8.3 Scenario Two: Reformist Transition

8.3.1 Economic Outcomes

The Reformist Transition scenario assumes moderate but significant reforms:

• Education reform: tertiary and vocational education improve progressively.

• Energy diversification: the share of renewables rises to ~40% by 2050.

• Redistribution: social protection rises through progressive taxation.

GDP growth picks up modestly to 2.5%–3% per year, sufficient to reduce unemployment but not eliminate structural exclusion. Tourism and services expand, and renewable energy industries generate new jobs. Industrial competitiveness, however, is still held back by infrastructure weaknesses and a lack of innovation.

8.3.2 Social Outcomes

Reformist policies reduce poverty by almost half, and inequality drops from 0.63 to ~0.55 in 2050. Greater access to vocational training and youth employment programs with a targeting element improve labour market absorption. Structural cleavages persist, however, and rural and township economies lag behind the urban core.

Human capital enhances, but incremental reforms fail to bring about a fundamental change. South Africa sensibly becomes more inclusive, but with high inequality by international standards.

8.3.3 Environmental Outcomes

Renewables expand exponentially to reach 40%–50% of power supply by 2050. Energy diversification reduces carbon emissions by 30% compared to BAU, improving compliance with international agreements. However, coal is still in the mix, and emissions are still above those required for net-zero pathways.

8.3.4 Risks

•Medium reforms are insufficient to prevent the middle-income trap.

•Inequality remains structurally entrenched.

•Commodity cycle addiction persists, and growth remains vulnerable.

Reformist Transition is a politically feasible but insufficient trajectory, reducing the highest risks of BAU but not achieving transformative development.

9 Concluding Remarks

9.1 South Africa at a Crossroads

South Africa's growth since the end of apartheid has been characterised by a paradox. On one hand, it has made great strides in democratisation, foreign investment, and diversification of sectors. On the other hand, however, deep-seated structural forces—unemployment, inequality, and reliance on coal—have constrained inclusive and sustainable growth. The evidence in this study confirms that if not addressed, South Africa risks locking in a trajectory of low productivity, environmental degradation, and social exclusion.

The crossroads metaphor is not rhetorical. Decisions taken in the coming decade will determine whether the country locks itself into Business as Usual gridlock, incremental reform, or aggressively drives green industrialisation. The stakes are high, not only for national prosperity, but for Africa's broader contribution to the global low-carbon transition.

9.2 Synthesis of Findings

Three pillars—human capital, renewable energy, and inequality—emerged as the most important determinants of South Africa's sustainability prospects.

There were three pillars—human capital, renewable energy, and inequality—that appeared as the most significant drivers of South Africa's future sustainability.

1. Human Capital: Econometric analysis indicated that educated employment has a statistically significant positive effect on GDP growth. Bidirectional relationships were established by Granger causality, i.e., human capital and growth reinforce each other. However, the machine learning results referred to the fact that, in the near term, human capital is low compared to demographic and infrastructural determinants. This juxtaposition demands quality rather than quantity of education. The education system in South Africa, as much as it expands coverage, continues to be plagued by poor learning outcomes, skills mismatches, and insufficient industry responsiveness.

2. Renewable Energy: Both Germany and South Africa have one of the most carbon-intensive energy systems in the world. While econometric evidence pointed to a negligible positive impact of renewables on GDP, qualitative evidence was suggestive of the ways in which policy incoherence, grid constraints, and strong coal lobby interests have prevented renewables from being an economic driver. Comparative experience from Morocco and Brazil shows that there is a growth-generating potential in renewables if framed in explicit industrial strategies. For South Africa, renewables are already an environmental imperative, but not yet an economic driver—a position that will need to be inverted if sustainability goals are to be met.

3.Inequality: The study reconfirmed that growth and inequality are trapped in a cycle of causality. Inequality that is too high diminishes the growth impacts of development by constricting aggregate demand and human capital investment; low growth, meanwhile, fuels further inequality. The vicious cycle is reflected in South Africa's stubbornly high Gini index levels above 0.60. NPO interviews validated the assumption: inequality derails sustainability at the local level, pricing out green projects beyond affordability for the poor.

These findings together suggest that South Africa is not able to achieve sustainable development through an exclusive emphasis on economic growth. Human capital, renewable energy, and equity must be tackled as interconnected levers in a unified development strategy.

9.3 Theoretical Contributions

This research responds to three prevailing academic arguments:

• Endogenous Growth Theory: Despite Romer (1990) and others emphasizing the predominance of human capital, this study shows that its effect is conditional on inequality and governance. Human capital cannot be translated into productivity under conditions of high inequality.

• Energy–Growth Nexus: The South African data is consistent with the weak growth hypothesis. Renewables save emissions but contribute modestly to GDP, unless coupled with industrial policy. This adds subtlety to the international literature, where results differ by income level and institutional context.

• Sustainable Development: By integrating human capital, inequality, and energy, the study advocates a systems thinking approach to sustainability. Developmental results cannot be explained by silo factors but by their interlinkages.

These theoretical insights extend the literature on how the emerging economies can balance growth, equity, and sustainability in the 21st century.

9.4 Policy Implications

The findings have profound policy implications.

1. Education Reform

Align tertiary curricula to the demands of the labour market, especially STEM and vocational training.

Improve quality of basic education, tackling foundational literacy and numeracy deficits.

Expand university–industry linkages to drive innovation.

2. Transition to Renewable Energy

Institutionalise procurement cycles to depoliticise energy investment.

Modernise grid infrastructure to facilitate decentralised renewables.

Develop local supply chains for renewable industries, generating employment and reducing import dependency.

3. Reducing Inequality

Implement progressive taxation to finance inclusive development.

Boost social welfare and protection to buffer vulnerable households.

Encourage township businesses and SMEs to create employment at the grassroots.

4. Institutional Reforms

Improve governance, transparency, and accountability to reduce corruption.

Improve coordination across ministries to avoid fragmented sustainability policies.

Restrict vested coal interests resistant to energy transition.

These policies need to be pursued not in isolation as separate stand-alone reforms but as components of an integrated national sustainability strategy.

9.5 Future Outlook to 2050

Looking ahead, three futures are plausible:

• Business as Usual (BAU): South Africa remains mired in low growth (1.5–2%), high inequality, and coal dependence. It stands the chance of being increasingly on the margin of the world economy, with catastrophic environmental degradation, by 2050.

• Reformist Transition: Incremental reforms raise growth to 2.5–3%, reduce inequality to a certain degree, and boost renewables to ~40%. Poverty declines, but structural exclusion persists, and industrial competitiveness remains low.

• Green Industrialisation: Ambitious, collective reforms harness human capital and renewables to re-engineer the economy. Growth accelerates to 4–5%, poverty and inequality decline significantly, and renewables lead the energy mix. South Africa is a continental leader in green technologies and sustainable development.The choice among these scenarios depends on political will, institutional reform, and policy coherence over the next two decades.

9.6 Research Agenda and Restrictions

This research recognizes the following limitations:

• Machine learning and econometric modeling was curtailed in scope due to data gaps.

• The lack of governance and innovation indicators made machine learning models with little explanatory power.

• Only non-profit organizations were included in the qualitative analysis; public and corporate sector actors were not included.

Future research should:

• Include micro-level surveys to gather household-level dynamics of inequality and energy use.

• Benchmark South Africa against peer economies like Nigeria, Kenya, and Vietnam to deepen lessons.

• Quantitatively explore governance and institutional factors to test their effect on sustainability transitions.

9.7 Final Reflections

Most people agree that the country's institutional weaknesses, its deep-seated inequalities, and sporadic policy failures, rather than a shortage of opportunities or resources, are to blame for South Africa's sustainability predicaments. South Africa has a youthful population, abundant wind and sun, and schools that can develop world-class capability. And yet these are not being leveraged. South Africa needs to invest in a long-term, strategic vision of inclusive development, the shift to renewable energy, and human capital development if it is to reach its potential. The challenge requires political will to overcome special interests, innovative institutions to help bring about changes, and a social commitment to sustainability and fairness.

Inaction will have definite consequences, including environmental deterioration, exclusion, and stagnation. On the other hand, the potential of bold initiatives is enormously promising: a green industrial economy that not only improves the lives of South Africans but positions the nation as a champion of the continent's shift towards sustainability.

Finally, it is the choices made by South Africa's leaders and people today, rather than exogenous determinants, that will determine the country's development trajectory through 2050. Firm action is needed urgently, and the timing matters.

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