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An Empirical Investigation of Threshold Effects on the Relationship between Sustainable Energy and Trade Balance in Africa

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ABSTRACT

This study assesses the impact of energy resource depletion on the trade balance of 52 African countries from 1990 to 2023, considering key factors such as external debt, energy prices, and CO_2 emissions. Employing a threshold regression model (PTR), the analysis distinguishes three regimes of energy depletion to examine how fossil fuel dependence affects economic sustainability. The results show that countries undergoing an energy transition experience a gradual improvement in their trade balance thanks to the integration of renewable energies, although debt and energy prices remain major obstacles. This study highlights the importance of sustainable energy policies to enhance long-term economic resilience in African countries.

Keywords: Energy Sustainability, Energy Depletion, Threshold Panel Regression Model
JEL Classifications: Q42, C24, O55

1. INTRODUCTION

The issue of sustainability, as approached through the impact of renewable energies on economic growth, has been extensively discussed for decades. The subject, whose initial foundations date back to John Stuart Mill (1848), in Principles of Political Economy, where he suggests a stationary state in which economic growth ceases to preserve natural resources, has gained significant momentum since 2015 with the establishment of the 17 SDGs for a more sustainable world by 2030. This renewed interest reflects the recognition of climatic and ecological challenges not only on growth but also on human survival, particularly with the development of 'finitude capitalism' practices.

The subject of sustainability is interdisciplinary due to its economic and social impacts. Studies and methodologies employed are diverse. Badeeb et al. (2020), Zahoor et al. (2020), Ayimadu et al. (2024), and Amin et al. (2024) have highlighted the necessity of a transition towards green growth through technological innovation, digital technologies, renewable energies, and human capital, while questioning the validity of the Environmental Kuznets Curve (EKC) in natural resource-dependent economies.

Mahmood et al. (2020) and Lei et al. (2020) have shown, for their part, that globalization intensifies resource exploitation and pollution, but that technological innovation can mitigate these effects. Other studies have focused on analyzing the impact of renewable energies on growth and CO_2 emissions, revealing varied effects depending on the level of economic development (Khanniba et al., 2020; Gharnit et al., 2021).

Antolín-López and José (2019) and Zhang et al. (2024) have endeavored to study the role of financial markets and

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green investments in the transition towards a sustainable economy.

Energy transition, as well as energy and environmental sustainability, are now major priorities for the global economy, particularly for developing countries facing specific challenges related to their energy dependence and natural resource management. In this context, Africa stands out for its unique position: Although the continent has abundant energy resources, its economies remain particularly exposed to energy price fluctuations and trade imbalances (Kahia et al., 2019).

The issue of energy sustainability in Africa is embedded in a global perspective that intertwines energy security, economic development, and trade stability. As highlighted by Pang et al. (2024), the depletion of natural resources poses a growing threat to global energy security. This situation is particularly critical for African countries, which must balance their development ambitions with the sustainable management of their natural resources.

The existing literature has primarily focused on the interaction between renewable energy and economic growth (Busu, 2020; Tugcu et al., 2012), often neglecting the impact of energy sustainability on the trade balance. However, the work of Ben Jebli et al. (2015) has opened up new perspectives by analyzing the relationship between renewable energy consumption and international trade, although their approach remains limited to a linear modeling framework.

This study offers an original perspective on the relationship between the trade balance and energy sustainability. By incorporating adjusted net saving as a measure of resource depletion and utilizing a panel threshold regression model (PTR), developed by Hansen (1999) and Wang (2015), we are able to capture the complex and non-linear dynamics between these variables.

The urgency of climate change and the volatility of energy prices have highlighted the need for this research. As demonstrated by Moreno and García-Álvarez (2017), fossil fuel price fluctuations have a profound impact on developing economies, particularly in Africa where the challenge lies in balancing energy transition with economic growth.

Our analysis covers 52 African countries from 1990 to 2023, providing a comprehensive overview of continental trends while acknowledging the heterogeneity of national experiences. By incorporating environmental and economic indicators such as renewable energy consumption, CO_2 emissions, and external debt, we offer a more nuanced understanding of the relationship between energy sustainability and trade balances.

This paper is organized into four sections. The first section reviews the existing literature on energy sustainability and its economic implications. The second section outlines the methodology and data, which include stationarity tests and the application of a panel threshold regression (PTR) model. The third section presents empirical results, focusing on the varying impacts of different energy depletion regimes. Finally, the fourth section concludes by summarizing the key findings and providing policy recommendations for African countries.

2. LITERATURE REVIEW

Most studies have assessed the impact of renewable energy (RE) on GDP growth. Kahia et al. (2019) highlighted a bidirectional relationship between economic growth, renewable energy consumption, trade, FDI, and CO_2 emissions in the MENA region, while Busu (2020) demonstrated using ARDL that various RE sources positively influence EU growth. Tugcu et al. (2012) compared RE and non-RE in G7 nations, concluding a bidirectional relationship between economic growth and both energy types.

Domac et al. (2005) outlined a theoretical model for how RE can stimulate GDP by fostering business growth, creating jobs, and reducing energy imports, thereby influencing economic growth and trade both directly and indirectly.

Chien and Hu (2008) showed using SEM that renewable energy boosts GDP primarily through capital formation, not trade. Ben Jebli et al. (2015) found short-term causality from renewable energy to trade in sub-Saharan Africa, but a long-term bidirectional relationship.

Bousnina and Gabsi (2023) found a long-term positive link between renewable energy consumption and the current account balance in OECD countries using an ARDL model. While the short-term impact was insignificant, they argued that reducing energy imports improves both the current account and environmental quality.

Bildirici and Kayıkçı (2022) and Idris et al. (2022) found a long-term positive link between renewable energy and the current account balance in OECD countries. Opeyemi et al. (2019) found a negative relationship in Sub-Saharan Africa but suggested that policy improvements could reverse this trend.

The energy transition poses both environmental and economic challenges, given fossil fuels' dominance in the global energy mix. The risk of energy insecurity is a major concern. Pang et al. (2024) found that depleting natural resources exacerbates energy security risks, as shown by CS-ARDL and PMG-ARDL models.

Other studies have examined the impact of fossil fuel price fluctuations on developing countries dependent on these resources. Moreno and Garcia-Álvarez (2017) found that changes in the prices of natural gas, coal, and oil can directly affect household electricity prices, as production costs are generally passed on to the wholesale electricity market. Such an effect can have implications for the trade balance of energy-importing countries. This paper investigates the link between the current account balance and energy resource depletion in 52 African countries. By analyzing economic and environmental factors over 1990-2023, we aim to shed light on the challenges and opportunities for sustainable energy management and economic stability in these countries.

3. DATA AND METHODOLOGY

3.1. Data

Using a comprehensive dataset of economic and environmental variables, this study investigates the interrelationships between the current account balance, energy consumption patterns, and CO_2 emissions. Variables definitions and data sources are detailed in the Table 1.

The choice of the total trade balance rather than the energy balance enables a more comprehensive analysis of economic sustainability in Africa. It integrates both natural resource dependencies, economic diversification, and the ability of countries to finance their energy transition. By highlighting the interactions between trade, investment, and energy policy, this approach allows for a better understanding of the obstacles and levers for a sustainable transition in 52 African countries, listed in the following Table 2.

The analysis of descriptive statistics for the variables included in this study provides important information about their distribution and variation. These statistics are summarized in the Table 3.

Descriptive statistics reveal a high degree of heterogeneity among the countries studied. The current account balance (CAB) is, on average, in deficit (−7.04% of GDP), with significant variations across countries (ranging from −75.60% to 80.78%). The share of renewable energy (RE), meanwhile, reached an average of 61.83% over the period considered, but varies widely, with some countries being almost entirely dependent on fossil fuels (1%) while others rely primarily on renewable sources (98.3%).

Adjusted energy savings (ea) show a variable exploitation of energy resources, with values ranging from 47.67% (significant depletion) to 94%. CO_2 emissions per capita (co2_em), on the other hand, are relatively low on average (0.38 tons), but they vary up to nearly 3.89 tons, reflecting differences in economic and energy structures. The statistics on external debt (debt_ext) show an average of 44.28% of GDP, a debt that can reach up to 533.34%, signaling a marked dependence on external borrowing for some countries. However, energy prices (price_energy) show moderate volatility, with an average index of 69.31, ranging between 23.20 and 138.20. These disparities indicate specific dynamics for each country and justify the use of econometric models capable of capturing these structural differences.

3.2. Methodology

Standard panel data models often rely on the assumption of homogeneous coefficients. However, this assumption may be restrictive, especially when dealing with heterogeneous data. Panel threshold regression (PTR) models, proposed by Hansen (1999) and Wang (2015), provide a more flexible framework by allowing for multiple regimes and accommodating heterogeneity in the data.

3.2.1. Single-threshold model

In these models, the endogenous variable y is determined by several different non-dynamic relationships. Under a two-regime threshold, the regression model is expressed as follows:

$$y_{it} = \mu_i + \alpha_1 X_{it} I(q_{it} < c) + \alpha_2 X_{it} I(q_{it} \geq c) + \varepsilon_{it} \quad (1)$$

Where μ_i is the vector of individual fixed effects, $X_{it} = (X_{it}^1, ..., X_{it}^k)$ is the matrix of k variables exogenous not containing any lagged endogenous variable, and $\alpha = (\alpha^2., \alpha^k)$ et ε_{it} is iid $(0; \sigma_\varepsilon^2)$. The index i = 1...,N denotes the individual dimension and the index t = 1...,T denotes the time dimension. q_{it} it is the threshold variable. The transition from one regime to another requires comparing the situation of a transition factor q_{it} it with respect to the value of a threshold c.

This modeling approach allows for the definition of a panel with multiple different regimes, each defined by a linear dynamic. When the change indicator exceeds the threshold $q_{it} < c$, even very slightly, the process is described by the first regime defined using the slope coefficients. Conversely, if $q_{it} \geq c$, the process is described by a second regime.

Testing for a threshold effect is the same as testing whether the coefficients are the same in each regime. Using Hansen's (2000) bootstrap method, we test the null hypothesis of linearity against the alternative hypothesis of a threshold effect:

Table 1: Definitions and data sources

Codes	Variables	Definitions	Sources
Sbc	trade balance by GDP	Balance trade in US$ at current prices in millions per GDP (constant 2015 US$)	UNCTAD
Rec	Renewable energy consumption (% of total final energy consumption)	Renewable energy consumption is the share of renewable energy in total final energy consumption.	WB
Ea	Adjusted savings: energy depletion (% of GNI)	Energy depletion is the ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at 25 years). It covers coal, crude oil, and natural gas.	WB
co2_em	CO_2 emissions (metric tons per capita)	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.	WB
debt_ext	External debt stocks, total (DOD, current US$) by GDP	Total external debt is debt owed to nonresidents repayable in currency, goods, or services. It is the sum of public, publicly guaranteed, and private nonguaranteed long-term debt, short-term debt, and use of IMF credit. Data are in current U.S. dollars.	WB
price_energy	Energy price	annual indices, 2010=100, 1960 to present, real 2010 US dollars	WB Commodity Price

$$\begin{cases} H_0 : \alpha_1 = \alpha_2 \\ H_1 : \alpha_1 \neq \alpha_2 \end{cases}$$

3.2.2. Multiple-thresholds model

If there are multiple thresholds (that is, multiple regimes), we estimate the model sequentially. Thus, a model with multiple thresholds can be written as follows, we use a double-threshold model as an example.

$$y_{it} = \mu + \alpha_1 X_{it}(q_{it} < c_1) + \alpha_2 X_{it}(c_1 \leq q_{it} < c_2) + \alpha_3 X_{it}(c_2 \geq q_{it}) + \mu_{it} + \varepsilon_{it} \quad (2)$$

here c_1 and c_2 are the thresholds refers that divide the equation into three regimes with coefficients α_1, α_2, and α_3.

The threshold-effect test is also sequential; that is, if we reject the null hypothesis in a single-threshold model, then we must test the double-threshold model. The null hypothesis is a single-threshold model, and the alternative hypothesis is a double-threshold model. The bootstrapping design for this is similar to that in the single-threshold model, (Chan, 1993).

4. RESULTS, INTERPRETATION, AND DISCUSSION

4.1. Results of the PTR Model Estimation

To evaluate the effect of the chosen variables on the trade balance, with energy depletion as the threshold variable, equation (3) can be expressed as follows:

Table 2: Sample of African countries selected

Lesotho	Djibouti	Egypt
Cabo Verde	Rwanda	Somalia
Seychelles	Tunisia	Zimbabwe
Sao Tome and Principe	Ethiopia	Mali
Gambia	Guinea-Bissau	Central African
Eritrea	Liberia	Mauritania
Mozambique	Malawi	Benin
Mauritius	Sierra Leone	Ghana
Comoros	Niger	South Africa
Senegal	Burkina Faso	Cameroon
Morocco	Uganda	Eswatini
Namibia	Madagascar	Algeria
Chad	Congo, Dem, Rep	Gabon
Cote d'Ivoire	Libya	Angola
Nigeria	Congo	Botswana
Zambia	Guinea	Equatorial Guine
Burundi	Kenya	
Togo	Tanzania, United	

Source: Authors

$$sbc_{it} = \mu + \alpha_{11} ea_{it} + \alpha_{12} rec_{it} + \alpha_{13} co2_{it} + \alpha_{14} debt\_ext_{it} + \alpha_{15} price\_energy_{it} I(ea<k1) + \alpha_{21} ea_{it} + \alpha_{22} rec_{it} + \alpha_{23} co2_{it} + \alpha_{24} deb\_ext_{it} + \alpha_{25} price\_energy_{it} I(k1 \leq ea < k2) + \alpha_{31} ea_{it} + \alpha_{32} rec_{it} + \alpha_{33} co2_{it} + \alpha_{34} debt\_ext_{it} + \alpha_{35} price\_energy_{it} I(k_{r-1} \leq ea) + ui + \varepsilon_{it} \quad (3)$$

Where i denotes the individual and t represents time, (ea) corresponds to the threshold variable q, used to divide each sample into groups, also called 'regimes', is the matrix of explanatory variables, including renewable energy consumption, energy price, external debt, CO_2 emissions, and energy depletion, α_1 et α_2, α_3 are the coefficients to be estimated for the 3 regimes. µi is the country-specific fixed effect. The random variable is a regression error, and k_1 et k_2 et k_{r-1} are the threshold levels to be estimated.

To address the issue of heteroscedasticity in the regression errors, our model is generated using the generalized least squares (GLS) method. Furthermore, before evaluating the threshold model, we test for non-linearity and the existence of a threshold effect between the trade balance and energy depletion. We reject the null hypothesis of no threshold effects in the model using the P-values from the bootstrap method proposed by Hansen (1999), repeated 300 times for each panel threshold test. The test results show that the test statistic for a double threshold is significant at the 0.0067 level, as shown the Table 4, indicating that our model admits three regimes.

The threshold effects analysis reveals a significant double threshold, validated by the bootstrap method with a P = 0.0067, which confirms the existence of three distinct regimes in the model. The statistical tests reinforce the robustness of this approach, and the estimates of the threshold values with their confidence intervals are presented in Table 5.

For robustness, we employ the locally weighted scatterplot smoothing (LOWESS) method to analyze the correlation between the trade balance and energy depletion. LOWESS, a nonparametric smoothing approach, allows us to identify the best-fitting curve describing the relationship between these two variables. As Figure 1 shows, this relationship is nonlinear, suggesting the existence of a threshold effect. An inflection point appears at −1.49% and 16.07%. The first interval concerns countries with a depletion rate below −1.49%, the second covers values between −1.49% and 16.07%, and the last corresponds to countries where depletion exceeds 16.07%. This analysis reveals that the relationship between energy depletion and the trade balance does not evolve uniformly. The identification of inflection points indicates that distinct thresholds exist depending on the rate

Table 3: Descriptive statistics

Variables	Obs	Mean	Standard deviation	Min	Max
Sbc	1,768	−7.038054	17.76203	−75.606	80.77768
rec	1,768	61.83214	30.11953	1	98.3
ea	1,768	2.743296	10.7653	−47.67013	94.0731
co2_em	1,768	0.3791436	0.3085021	0.061126	3.89246
debt_ext	1,768	44.27655	44.46116	0	533.3426
price_energy	1,768	69.30787	34.32134	23.1965	138.201

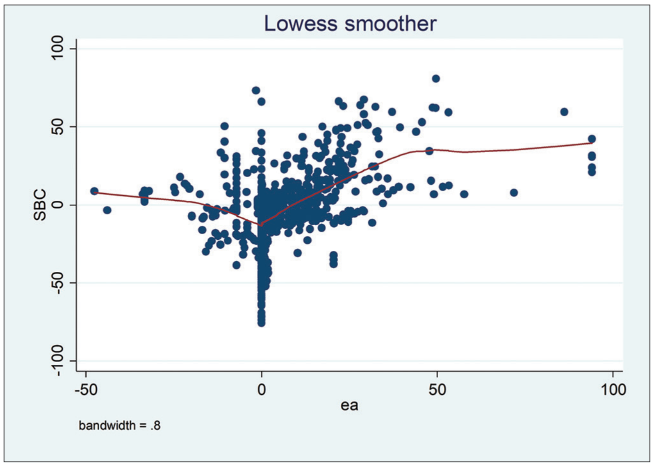
Table 4: Threshold effect test (Bootstrap=300)

Seuil	RSS	MSE	Fstat	Prob	Crit10	Crit5	Crit1
Single	/	/	/	/	/	/	/
Double	1.30e+05	74.9687	73.06	0.0067	32.4962	44.1533	65.5362
Triple	1.23e+05	71.1384	93.36	0.5067	147.7038	168.0486	202.3054

Table 5: Threshold values

Model	Threshold	Lower bound	Upper bound
Th_21	16.0749	15.6774	18.5540
Th_22	−1.4110	2.0433	−1.8977

Figure 1: Relationship between trade balance and energy resource depletion



Source: Authors, output Stata

of resource depletion, suggesting that the impact of resource depletion on the trade balance varies according to the intensity of this depletion.

As a preliminary step to estimating the three regimes for each country group, we conducted Levin-Lin-Chu (LLC) and Im-Pesaran-Shin (IPS) unit root tests (Table 6). The results of these tests confirm that all variables are stationary and integrated of the same order.

After conducting the required stationarity tests, which confirmed that all variables are stationary at the first difference (I(1)), it is necessary to examine the relationships between variables in the different regimes in more detail. To this end, we employ the generalized least squares (GLS) estimation method, which effectively addresses potential heteroscedasticity and autocorrelation issues in panel data. This approach, suitable for complex models, allows us to obtain more robust and reliable estimates of the effects of adjusted savings on the trade balance in the three identified regimes. The results of this estimation are presented in Table 7.

4.2. Interpretation

Regimes 1 and 3 are both marked by substantial fossil fuel depletion. However, they differ in that the first regime experiences net economic losses due to the massive depletion of energy resources, as revenues fail to cover extraction costs or the loss of natural capital. In contrast, the last regime, characterized by a high (ea), suggests that excessive exploitation of energy resources poses long-term economic risks if resource management is not sustainable.

The countries included in both regimes are those that are rich in energy resources (oil, coal and natural gas) and economically dependent on fossil fuels, and where the extraction of these resources and the consequent income is not reinvested in sectors that enable sustainable growth.

4.2.1. Regime 1: ea<−1.41

The first regime is characterized by a substantial depletion of energy resources (negative ea), which significantly harms the country's trade balance. The revenues from energy exports fail to adequately improve the trade balance as they are offset by the economic costs of depletion, leading to a negative net benefit and a deterioration of the trade balance.

Countries such as Chad, Congo, the Democratic Republic of Congo (DRC), Côte d'Ivoire, Gambia, and Tanzania, which are subject to this regime, have been unable to effectively reinvest export earnings into sustainable sectors. Their economies are heavily reliant on fossil fuel exports, as exemplified by Chad and Congo, which are oil-exporting nations. This overreliance on a single commodity leaves them vulnerable to economic shocks, such as fluctuations in oil prices. Similarly, mineral-rich countries like the DRC and Côte d'Ivoire face the same challenge of a narrow economic base.

The positive impact of (rec) on the trade balance suggests that developing renewable energy sources can help these countries diversify their energy mix and mitigate the negative effects of (ea), although investment levels remain inadequate. The significant positive correlation between (CO_2) and the trade balance indicates a high degree of energy dependence and a lack of stringent environmental regulations. The mining and petroleum sectors are major contributors to CO_2 emissions due to their energy-intensive production processes. The absence of an energy transition strategy and weak environmental regulations allow these countries to maximize export revenues but at the cost of environmental degradation and the depletion of natural resources. This unsustainable situation arises from the failure to internalize environmental costs.

While debt may not have a direct impact on the trade balance under regime 1, it plays a pivotal role in the economy and natural resource management, particularly in the context of dwindling energy resources. This energy dependence and lack of economic diversification force these countries to rely heavily on borrowing to finance their deficits. Unfortunately, poor resource allocation and a lack of investment in sustainable sectors hinder their ability to service their debt in the long run, exposing them to the risk of debt crises and macroeconomic instability.

Table 6: Unit root test

Variables	LLC	Probability	(IPS)	Probability	Stationarity
Sbc	−2.31**	0.0104	−9.7055***	0.0000	I (0)
Rec	−4.61***	0.0000	−3.31***	0.0005	I (0)
Ea	−6.01***	0.0000	−9.67***	0.0000	I (0)
co2_em	−1.65**	0.0492	−7.79***	0.0000	I (0)
debt_ext	−6.94***	0.0000	−24.55***	0.0000	I (0)
price_energy	−4.69***	0.0000	−2.12**	0.0168	I (0)

***Stationary at the 1% level ** Stationary at the 5% level

Table 7: Estimation of the effect of adjusted savings on the trade balance

Dependent V.	Regime 1		Regime 2		Regime 3	
SBC	ea<−1,411		−1,411<ea<16.074		ea>16.074	
Independent V.	**Coefficient**	**T-statistic**	**Coefficient**	**T-statistic**	**Coefficient**	**T-statistic**
rec	0.811***	5.62	0.128***	10.28	−0.089	−1.32
ea	−0.332**	−2.18	1.7281***	17.94	0.451***	4.26
co2_em	49.756***	3.46	−2.891**	−2.45	2.433	0.30
debt_ext	0.029	0.24	−0.018***	−2.64	0.024	0.24
price_energy	0.214***	4.59	−0.100***	−10.61	0.257***	4.54
Constant	−91.215***	−6.55	−11.833***	−8.61	−11.01	−1.08
Number of observations	107		1517		144	

***Statistically significant at the 1% level. **Statistically significant at the 5% level.

While energy prices have a substantial positive effect on these countries' trade balances, they also expose these economies to the risks associated with volatile energy markets, particularly oil price shocks.

Overreliance on fossil fuel exports, coupled with insufficient revenues to compensate for resource depletion, creates long-term economic vulnerabilities. These countries have limited economic diversification and underinvest in renewable energy, making them susceptible to fluctuations in energy prices. Furthermore, poor external debt management exacerbates their economic and environmental instability.

4.2.2. Regime 3: ea≥16.074

Regime 3 encompasses Angola, Benin, Nigeria, Equatorial Guinea, Gabon, Algeria, Egypt, Libya, and all countries from regime 1 excluding Chad. In contrast to regime 1, countries in regime 3 have demonstrated greater efficiency in managing their resources, resulting in positive trade balances despite the continued heavy reliance on fossil fuels, with a (ea) exceeding 16.074%. This suggests that the generated revenues can provide some short-term sustainability, although they remain exposed to risks of energy insecurity and price volatility over the longer term.

The energy transition is still incomplete and insufficient, with countries largely dependent on fossil fuel exports, even though efforts have been made to develop renewable energy sources, such as solar energy in Algeria and solar and wind energy in Egypt. However, these initiatives are relatively small-scale, and investments in renewable energy have yet to yield significant returns, thus impeding the transition to a more sustainable energy economy in these countries.

The insignificant negative coefficient of (rec) indicates that region 3 countries face significant structural barriers to fully integrating low-carbon energy sources into their energy mix. Despite these challenges, CO_2 emissions remain high due to carbon-intensive industries and the substantial efforts required to reduce their carbon footprint and transition to cleaner energy sources. The region's energy rents have shielded its countries from the significant effects of external debt on their trade balances, enabling them to maintain fiscal stability. However, the volatility of energy prices exposes these countries to the risk of increased borrowing, particularly during periods of price decline. Therefore, to foster sustainable growth, energy diversification is essential to mitigate the risks associated with price fluctuations.

Despite positive net adjusted savings indicating profitable exploitation of energy resources, regime 3 countries remain heavily reliant on fossil fuels. This lack of diversification exposes these economies to vulnerabilities. Transitioning to renewable energy sources is therefore crucial to enhance their resilience against economic and climate shocks.

4.2.3. Regime 2: −1,411≤ea<16.074

His regime encompasses 51 African countries in the sample, excluding Chad. These countries are undergoing an energy transition, implementing policies to reduce their reliance on fossil fuels while aiming to integrate renewable energy sources. Although they have made progress, their energy performance remains moderate. Their economies are still dependent on fossil fuels but show a growing interest in diversification. These countries seek to balance their trade accounts while decreasing their reliance on energy imports. While continuing to exploit fossil resources, regime 3 countries do so at a less intensive rate compared to regime 1. Their energy resource depletion indicator (ea) falls between the high values of regime 1 and the very high values of regime 3, reflecting a more sustainable approach to resource exploitation. This shift is driven by a growing awareness of the economic and environmental risks associated with over-exploiting fossil fuels.

The positive impact of energy savings (ea) is reflected in a significant improvement in the trade balance and a decrease in reliance on fossil fuel imports. This regime demonstrates intermediate levels of energy efficiency, as countries begin to increase their consumption of renewable energy sources. This trend highlights a growing diversification of the energy mix and a reduced dependence on fossil fuels.

While the coefficient for renewable energy consumption (rec) is positive and statistically significant, its magnitude is considerably smaller than in regime 1. This suggests that renewable energy sources continue to have a beneficial impact on the trade balance, although this effect is less pronounced. This is because these countries are in a transitional phase, gradually increasing their share of renewable energy consumption in the overall energy mix, but not yet to a point where it significantly alters the trade balance. Conversely, the negative coefficient for CO_2 emissions indicates that reducing these emissions is associated with an improvement in the trade balance, likely due to the shift towards cleaner energy sources.

From a sustainability standpoint, a substantial reduction in energy resource depletion, leading to increased energy savings (ea), significantly improves the trade balance. This indicates that energy efficiency measures reduce the consumption of imported fossil fuels, a critical goal for long-term sustainability. This regime is arguably the most sustainable, as countries demonstrate improving energy efficiency while gradually transitioning to renewable energy sources. This combination is essential for both energy and economic sustainability. Decreasing CO_2 emissions further support the notion that these countries are moving towards more sustainable practices.

Drawing on the resource curse theory, these countries appear to be in a transitional phase, recognizing the risks associated with overreliance on natural resources and seeking to diversify their economies. They are implementing policies to reduce fossil fuel dependency, leading to increased energy savings and a growing share of renewable energy. Nevertheless, escaping the resource curse typically requires institutional reforms that promote investment in non-energy sectors and renewable energy. Countries in this regime may have initiated such reforms, as evidenced by the implementation of large-scale renewable energy projects in Tunisia, Morocco, South Africa, Egypt, Ethiopia, Rwanda, Nigeria, Ghana, and Zambia.

Côte d'Ivoire has a modestly expanding energy sector. While still reliant on energy imports, the country is striving to diversify its energy mix through investments in renewable energy sources. However, the country's geo-economics position can pose challenges, as relationships with various partners (Europe, China) are crucial for its energy strategy. In contrast, Tanzania has a more balanced energy sector and aims to bolster its domestic energy production. Nevertheless, geopolitical fragmentation can constrain the availability of financing for energy projects, particularly from international institutions.

The combined negative impacts of external debt and high energy prices expose countries undergoing energy transitions to significant vulnerabilities. High levels of external debt limit fiscal space for productive investments and constrain the ability to improve the current account balance. Meanwhile, elevated energy prices increase import costs and erode export competitiveness, further weakening the current account. This underscores the critical need for sound debt management and accelerated investments in renewable energy to reduce fossil fuel dependence, stabilize the current account, and enhance economic resilience.

4.3. Discussion: Country Migration Across Energy Regimes

Sustainability is closely linked to the balance between energy efficiency, the adoption of renewable energy sources, and the management of associated costs. Figure 2 shows a strong positive correlation between the trade balance and energy resource depletion in African countries, suggesting that countries with significant energy extraction are more susceptible to the 'Dutch disease'.

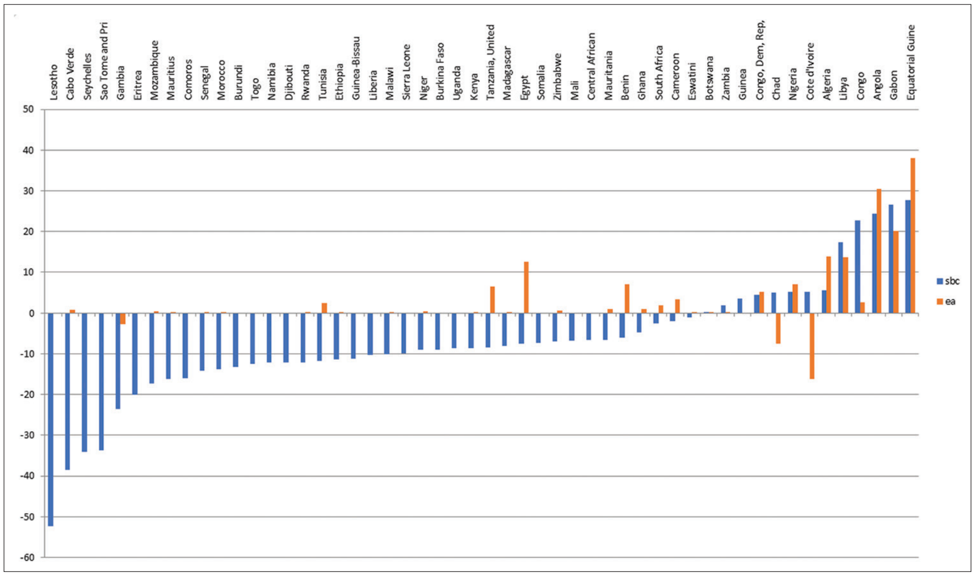
As predicted by the 'Dutch disease' theory, countries with trade deficits tend to have lower rates of energy depletion, which can result in deindustrialization and overreliance on commodity exports, as observed by Corden and Neary (1982).

This figure highlights the sustainability challenges posed by development models heavily reliant on natural resource extraction, emphasizing the need for economic diversification to foster more sustainable growth.

Nevertheless, our analysis reveals that countries frequently shift between different energy regimes over time. These transitions are often driven by economic, political, technological, or environmental factors. Energy transitions are complex, non-linear processes, particularly in developing or rapidly changing economies. Countries may experience multiple regimes shifts before achieving a stable energy system, as their energy transitions are influenced by economic conditions, investments, and policy choices.

Adhering to the theory of the resource curse (Fleming et al., 2015; Yaduma, 2018; Dell'Annoa and Maddah, 2022; Kpognon, 2022; Sanjeev et al., 2024), resource-rich countries (oil, gas) are often trapped in regimes 1 and 3, characterized by low energy efficiency and a strong dependence on fossil fuels. Those undertaking reforms to diversify their energy mix and improve their energy efficiency migrate towards regime 2, but this transition remains fragile and subject to economic and political cycles. For example, Nigeria and Angola oscillate between regimes 2 and 3 depending on oil prices and economic reforms. Chad and the DRC, on the other hand, remain in regime 1, due to low diversification and marked energy inefficiency. Furthermore, political instability, government changes, and subsidy policies (e.g., for renewable energies) can shift a country from one regime to another. In this sense, South Sudan, dependent on oil, suffers repeated economic crises due to

Figure 2: Adjusted trade balance and energy savings



price volatility and internal conflicts. In line with the abundance theory, which explains migration between regimes and the inability of a successful energy transition in African countries, the Resource Dependence Theory demonstrates that resource-rich countries remain trapped in an export-oriented model that hinders their energy diversification. The path dependence theory supports the hypothesis that past choices in energy infrastructure strongly influence the current trajectory. Similarly, the theory of extractive and inclusive institutions (Acemoglu et al., 2001) emphasizes that weak institutions prevent the transition to a more sustainable regime. However, we note that dependence on multinational corporations and international creditors limits the room for maneuver of African countries in their energy transition and is likely to accentuate their oscillation from one regime to another. Thus, migration between energy regimes is influenced by a multitude of economic, political, and structural factors. Resource-rich countries often remain stuck in inefficient energy regimes, but political reforms and targeted investments can enable them to gradually emerge from the resource curse. However, this transition remains fragile and strongly influenced by economic cycles and geopolitical dynamics.

The Democratic Republic of Congo (DRC), while endowed with abundant natural resources, has failed to leverage these assets for sustainable development. Internal conflicts, corruption, and inadequate infrastructure have hindered efforts to diversify the economy and improve energy efficiency, leaving the country trapped in a low-development state. In the DRC, resource exploitation is often characterized by a lack of transparency, with profits flowing out of the country and providing limited benefits to the local population.

Despite having a robust agricultural sector, Côte d'Ivoire's offshore oil reserves and limited energy diversification impede substantial energy savings. The country vacillates between energy regimes 1 and 2, despite its potential in renewable energy, with occasional periods operating under regime 2.

Despite having fewer natural resources than the previously mentioned countries, The Gambia and Tanzania also experience the negative impacts of the resource curse. Their economies are heavily reliant on extractive and energy-intensive industries, such as mining in Tanzania, which has limited the potential for investment in energy efficiency and economic diversification.

5. CONCLUSION

This research investigates the non-linear relationship between energy resource depletion, external debt, and energy prices on the trade balance of 52 African countries from 1990 to 2023. The findings reveal three distinct energy depletion regimes, indicating varying degrees of energy dependence and economic resilience.

Findings indicate that the depletion of energy resources, volatile energy prices, and external debt management exacerbate trade imbalances and intensify geo-economics and geopolitical fragmentation in African countries. Countries that are heavily reliant on fossil fuels are particularly susceptible to external shocks, reinforcing their dependence on foreign creditors and hindering their integration into regional value chains. Moreover, the study reveals disparities in energy transition strategies across the continent, with some countries lagging behind in adopting renewable energy sources, while others, although more advanced, still face challenges in ensuring long-term economic sustainability.

The polarization between energy exporters and importers poses significant challenges to the development of regional energy policies, impeding cooperation and collective action. Addressing these challenges requires a comprehensive overhaul of national and regional strategies to mitigate fragmentation, foster an inclusive and sustainable energy transition, and enhance economic resilience through diversification and improved natural resource governance.

This study highlights the need for policy reforms to address the challenges posed by energy transition and debt management in African countries. By implementing policies that promote efficient energy transitions and sound debt management, policymakers can enhance economic resilience and foster sustainable growth. Moreover, integrating renewable energy sources into national energy strategies can reduce dependence on fossil fuels and attract sustainable investments, aligning with global efforts towards a low-carbon future (IRENA, 2022).

The findings of this study underscore the need for further efforts to enhance the economic and environmental sustainability of African countries. Implementing policies that facilitate energy transition and support investments in sustainable infrastructure, technological advancements, and human capital development can significantly improve energy efficiency and reduce environmental impacts. Such strategies are essential for stabilizing local economies and fulfilling international commitments on sustainable development and climate change mitigation (Boţa-Avram et al., 2024).

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