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Economic Growth and Sustainable Development in Africa: An Application of Advanced Statistical and Econometric Methods

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« The aim is to propose a continental energy development framework that takes into account both renewable and non-renewable energy sources, ecology, and the technological advances of the coming decades».

C.A. DIOP (1974): 'The Economic and Cultural Foundations of a Federal State in Black Africa.

Dedication :

I dedicate

This thesis

To the roots and the peaks

Of my life

To my mother

Halima MOHAMED DAOUD

Acknowledgements :

At the conclusion of the work on this thesis, from which I have gained an unprecedented research experience over the course of several months, I solemnly wish to express my gratitude to the One who possesses the highest wisdom, the Supreme Giver, the Most Merciful, the Absolute Owner, the Subtle Benevolent... Praise be to Him.

I extend my most heartfelt words to my mother, Halima Daoud, to whom I can never find enough words to express all my gratitude.

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Glossary Of Abbreviations :

A/B

Adj	Adjusted
ANOVA	Analysis of Variance
ADF	Augmented Dicker Fuller
AR	Autoregressive
AIC	Akaike Information Criterion
BIC	Bayesian information Criterion

C/D

Chi-2	Chi- squared
Cons	Constant
Cont	Contribution
COS^2	Squared cosine
CAH	Hierarchical Ascendant Classification
CO_2	Carbon dioxide
CV	Coefficient of Variation
D/Diff	Differentiation
Dim	Dimension
DOLS	Dynamic Least Squares

E

EKC	Environnementale Kuznet Curve

F-I

First_qu First Quartile (25%)

GDP Gross Domestic Product

GNI Gross National Income

IGI Gini Coefficient

K/L

IV Instrumental Variables Methods

I3TSLS Three Stages Least Square with iterative

M

KMO Kaiser Mayer Olkin

LM Linear Model

MCO Ordinary Least Squares (OLS)

ML Maximum Likelihood

O

Min Minimum

Max Maximum

OPM Orthogonality Panel Model

P

OLS Ordinary Least Square

PCA Principal Component Analysis

PLS Partial Least Square

R/S

SD Standard Deviation

SE Sum of Squared Errors

Std Error Standart Errors

SAR Spatial Auteregressive

SO_2 Sulfur Dioxide

Sigma2e Error Variance

SUR Seemingly Unrelated Regression

T-Value Student value

T-W

TSLS Two Stage Least Square

NU United Nations

WCED World Commission on Environment and Development (UN)

Abstract:

This study investigates the relationships between economic growth, sustainable development, and environmental dynamics in Africa from 1960 to 2016. Using statistical and econometric techniques, we analyze the interaction between growth, physical capital, and human capital within the augmented Solow model.

A static, dynamic, and spatial approach is applied to examine the conditional convergence of African economies. Additionally, we explore the Kuznets Environmental Curve, assessing the relationship between economic growth and environmental degradation, particularly CO_2 emissions.

The findings highlight a continent with significant economic potential, influenced by both positive and negative effects of globalization, including the challenges of greenhouse gas emissions and income inequality.

The study offers new insights into the complex relationship between economic growth and sustainability in Africa.

Keywords: Economic Growth, CO_2 Emissions, Income Inequality, Sustainable Development, Africa.

General Introduction

Since the Industrial Revolutions, economic growth has rarely faced constraints as significant as those observed today (Nicholas Bloom, 2020). The adverse environmental impacts and the depletion of natural capital in recent years necessitate a reassessment of growth models to ensure long-term sustainability (Mark Edwards, 2021). In this context, concerns within the international community regarding climate change continue to escalate, particularly with respect to the potentially irreversible consequences of economic expansion driven by human activities. Against this backdrop, Ban Ki-moon was appointed on February 20, 2018, as the Director-General of the Global Green Growth Institute (GGGI), headquartered in Seoul, South Korea (János Pásztor, 2016). Under his leadership, the institute is tasked with developing strategies for environmentally sustainable development across its 28 member states, with Ethiopia being the only African nation represented (Mulatu Wubneh, 2020).

In 1987, the United Nations' World Commission on Environment and Development published the Brundtland Report, Our Common Future, which established the widely accepted definition of sustainable development (Justice Mensah, 2019): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

While this definition has been considered somewhat broad, it has undergone various refinements over time. Fundamentally, it highlights two major concerns: the depletion of natural resources and the environmental degradation resulting from human activities. These issues place the imperatives of sustainable development in continuous conflict with prevailing patterns of production and consumption. The concept of sustainable development, however, extends beyond mere environmental protection and the mitigation of greenhouse gas emissions (Justice Mensah, 2019). It encompasses a far more intricate framework than its basic definition may suggest. Sustainable development fundamentally demands an economic model that is efficient, socially equitable, and environmentally sound. Stated differently, economic growth must foster societal advancement while simultaneously safeguarding environmental integrity.

In this context, several critical research questions emerge: What is the current trajectory of economic growth in Africa? What are its key determinants, and to what extent do African economies exhibit absolute or conditional long-term convergence? Furthermore, what is the relationship between economic growth and CO_2 emissions in Africa, often categorized as a developing region? How can the persistent income disparities among African nations be explained?

To address these questions, this study will be structured into three key chapters. The first chapter will establish an analytical framework for understanding economic growth and sustainable development within the African context. The second chapter will provide a comprehensive review of the literature on economic growth and sustainability. Finally, the third chapter will present a methodological analysis aimed at formulating evidence-based economic policy recommendations.

🕮 General Objective:

The general objective of our research work is to better understand the interactions between the indicators of economic growth and sustainable development in Africa from 1960 to 2016.

🕮 Specific Objectives :

Our specific objectives are first to identify the relationship between physical capital, human capital, and economic growth in the African context, and then to examine the potential for absolute or conditional convergence among African economies.

In the context of studying environmental sustainability, we are interested in assessing the possibility of reducing greenhouse gas emissions, primarily CO_2, through the process of economic catch-up over the long term and testing a conditional convergence of CO_2 emissions in Africa.

Finally, we aim to better understand the impact of income inequality on economic growth in Africa.

Chapter 1 : Analytical Framework of Economic Growth and Sustainable Development in Africa

Introduction

Economic growth, as we have seen in its general concept, is simply understood as an increase, rise, or improvement in the level of economic activity. It is measured by a variety of economic indicators such as GDP, GNP, GNI, etc. However, their effectiveness seems quite limited in quantifying the interrelations between the economy and the environment, and vice versa. Moreover, this notion is often compared to an increase in the standard of living (Arthur Lermer, 1974). In truth, it does not necessarily indicate an improvement in the well-being of a population, although it could, in fact, lead to it during the process of growth. Furthermore, it is embedded in both a vicious and a virtuous cycle. Without ignoring its negative impact on the stock of natural capital, which questions the sustainability of development (Festus Fatai Adedoyin, 2021). Beyond pollution, economic growth is also responsible for the depletion of natural capital (Festus Fatai Adedoyin, 2021). Due to the pollution induced by growth through economic activity, it leads to the degradation of environmental quality, thus compromising the sustainability of natural capital. Indeed, some of the resources that constitute the stock of natural capital are non-renewable. The rate of exploitation of renewable resources is too high to ensure their regeneration (Mathis Wackernagel, 2002). In 2007, the Earth's capacity to regenerate was estimated at 11.9 billion hectares, well below the ecological footprint of human activity, which was around 18 billion hectares (Helmut Haberl, 2007).

In this chapter, we aim to present the analytical framework on the concept of economic growth and sustainable development in the African context.

I. Economic Growth in Africa

According to the African Development Bank (AfDB), Africa's GDP growth was projected at 3% in 2017, up from 2.2% in 2016, though lower than the initial forecast of 3.4% (Abdoul' Ganiou Mijiyawa, 2013). Additionally, growth was estimated at 3.7% in 2018, slightly below the initial projection of 4.2%. However, economic growth in Sub-Saharan Africa was expected to reach 2.4% in 2017, compared to 1.3% in 2016 (T.S. Jayne, 2018).

Driven by stable domestic demand, public investment in infrastructure, and a reduction in fiscal and current account deficits, Africa's economic growth remained robust. Moreover, the continent's overall performance appeared positive when compared to global economic growth, which was projected at 3.5% in 2017 and 3.6% in 2018 (Abdoul' Ganiou Mijiyawa, 2013).

The report attributes Africa's economic recovery mainly to the global economic rebound and the end of the commodity price downturn that had persisted since 2014. "Urgent and sustained efforts towards economic diversification and structural transformation are necessary to prevent repeated cycles of expansion and recession due to commodity price volatility," stated the latest African Economic Outlook report published in May 2017 (Franklin Obeng-Odoom, 2014).

Adjustments to previous forecasts followed the release of new data from key African economies, notably Nigeria, Algeria, and Egypt, which collectively account for nearly 50% of the continent's GDP and revised their projections downward for 2017 and 2018 (Adeleke Omolade, 2019). Additionally, strong domestic deman
contributed to sus

Chapter I: Analytical Framework of Economic Growth
and Sustainable Development in Africa

1. Economic Growth in East Africa

East Africa remains the fastest-growing region, with its growth rate increasing from 5.1% in 2016 to 5.4% in 2017 and 5.8% in 2018 (T.S. Jayne, 2018). Africa's economic outlook improved in 2017 compared to 2016 (AIMS, SCOPE AND AUTHOR GUIDELINES, 2017). This performance is expected to strengthen further through 2018, according to the African Development Bank (AfDB) in a revised growth forecast (Afreximbank – Creative Sector Development, 2020). Thus, East Africa continues to be the most dynamic growth region on the continent, with an estimated growth rate of 5.1% in 2016, projected to reach 5.4% in 2017 and 5.8% in 2018 (Dani Rodrik, 2016). This positive trend is primarily driven by high public infrastructure spending and strong domestic demand.

2. Economic Growth in North Africa

North Africa recorded the second-highest growth rate in Africa, at 3.1% in 2016, driven mainly by economic recovery in Egypt (4.3% growth) and Algeria (3 .3%) (Imen Mohamed Sghaier, 2021). The region's growth is projected to reach 3.1% in 2017 and 3.6% in 2018, supported notably by Morocco’s economic rebound, with an expected growth rate of 4.5% in 2017 and 3.9% in 2018 (Imen Kouki, 2013). However, the wolrd Bank warns of persistent political uncertainties and reduced oil production in Libya, which continue to

3

The growth of Southern Africa, on the other hand, remained mixed, at 0.9% in 2016, compared to 1.6% in 2015 (Channing Arndt, 2018). However, an expected improvement in South Africa's performance, with a growth rate of 0.3% in 2016, 1.2% in 2017, and 1.3% in 2018, is expected to boost the overall growth of the region (Channing Arndt, 2018). The region's growth is projected to reach 2% in 2017 and 2.3% in 2018, driven by increased mining production following a slight rise in commodity prices (Werner Kristjanpoller, 2016).

4. West Africa's economic growth

In West Africa, a region where oil production plays a central role in the economy, growth significantly declined from 0.5% in 2015 to 0 .4% in 2016 (Chinazaekpere Nwani, 2016). This downturn was primarily due to the economic recession in Nigeria, which heavily impacted the region's overall performance. However, countries such as Sierra Leone, Togo, Côte d'Ivoire, and Senegal achieved notable growth during this period. Nigeria, accounting for 72.4% of West Africa's total GDP, experienced a contraction of 1.5% in 2016. In contrast, the combined economies of Sierra Leone, Togo, Côte d'Ivoire, and Senegal, representing approximately 10% of the regional GDP, grew at an average rate of 6% (Chinazaekpere Nwani, 2016). Looking ahead, West Africa's growth is projected to improve, with forecasts of 2.5% in 2017 and 4% in 2018. This anticipated rebound is largely attributed to a recovery in Nigeria's oil production and an increase in commodity prices (John C. Anyanwu, 2015).

5. Croissance économique en Afrique Centrale

Central Africa experienced subdued economic growth, primarily due to the underperformance of Equatorial Guinea and Chad, whose economies contracted by 7.3% and 6 .4% respectively (Diadié Diaw, 2013). Additionally, the Republic of Congo also faced a contraction of 2.4%. However, updated data from the Bank indicates that the Central African Republic is expected to achieve growth rates of 1.6% in 2017 and 3.1% in 2018. These figures, though positive, are modest and fall short of the April projections, which had anticipated a growth rate of 2.6% (Christian-Lambert Nguena, 2014).

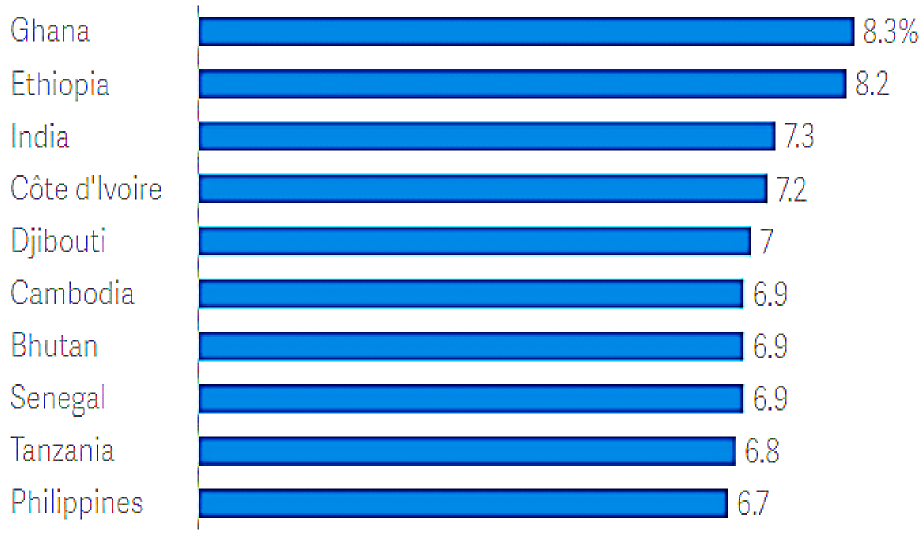


Figure 1. African Economic Growth in the World, World Bank, 2018.

The graph above illustrates the prominence of the economic dynamism of African countries across the world (figure 1). With a growth rate of 8.3%, Ghana will be the leader of the most dynamic economies in the world in 2018, followed by Ethiopia, according to World Bank forecasts. Economic recovery continues across sub-Saharan Africa: 1.3% in 2016, 2.4% in 2017, and a forecast of 3.2% in 2018 (figure 1). The economic recovery continues for sub-Saharan Africa, according to forecasts published by the World Bank on January 10th. Notably, the rise in commodity prices has led the continent to regain prospects of an expanding economy, following the 2008 global economic crisis. The engines of Africa's economic dynamism are located in West Africa (Senegal) and East Africa (Djibouti and Ethiopia) Furthermore, none of the ten most vigorous sub-Saharan African economies are oil producers, except for Ghana, a modest exporter. The sectors of agriculture and infrastructure are the driving forces of growth in these countries. These growth rates of over 8%, 7%, and 6% do not, however, impress some Africans (figure 1). Most African economies are still creating too few jobs to sustainably reduce unemployment and address the persistent inequalities (Dani Rodrik, 2016).

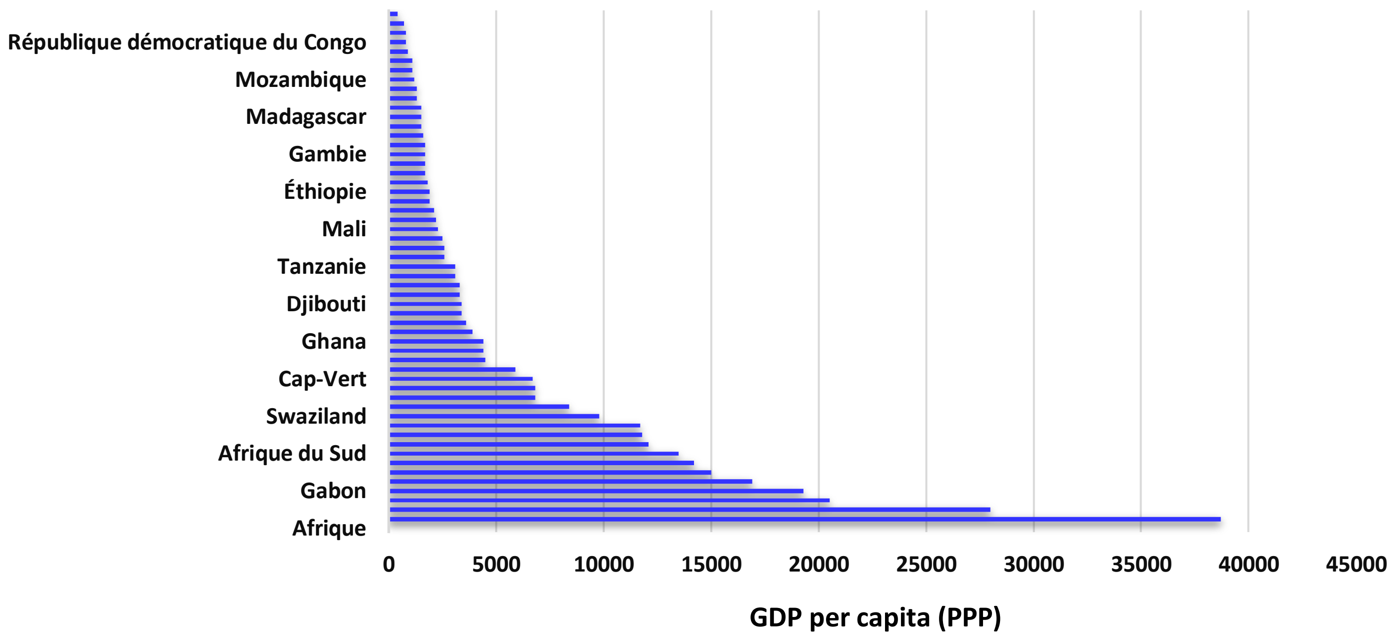


Figure 2. GDP by Purchasing Power Parity in Africa, World Bank, 2016.

The chart above illustrates the ranking of GDP by Purchasing Power Parity (PPP) in Africa according to the World Bank data (Figure 2). At the top of the 2016 ranking are Equatorial Guinea (1), followed by Seychelles (2), Mauritius (3), Gabon (4), Botswana (5), Algeria (6), Libya (7), South Africa (8), Egypt (9), Namibia (10), Tunisia (11), Swaziland (12), Morocco (13), Angola (14), Republic of Congo (15), Cape Verde (16), Nigeria (17), Sudan (18), Mauritania (19), Ghana (20), Zambia (21), Côte d'Ivoire (22), Kenya (23), Djibouti (24), Sao Tome and Principe (25), Cameroon (26), Lesotho (27), Tanzania (28), Senegal (29), Chad (30), Sahrawi Arab Democratic Republic (31), Mali (32), Benin (33), Uganda (34), Rwanda (35), Ethiopia (36), Burkina Faso (37), Sierra Leone (38), South Sudan (39), Gambia (40), Zimbabwe (41), Guinea-Bissau (42), Togo (43), Madagascar (44), Comoros (45), Guinea (46), Eritrea (47), Mozambique (48), Niger (49), Malawi (50), Liberia (51), Democratic Republic of Congo (52), Burundi (53), Central African Republic (54), and finally Somalia (55) (Figure 2).

II. Carbon Dioxide (CO^2) Emissions in Africa

According to the World Bank's definition, carbon dioxide emissions are those that result from the combustion of fossil fuels and cement production. They include carbon dioxide emissions produced during the consumption of solid fuels. Indeed, carbon dioxide (CO_2) is the primary greenhouse gas in its natural state, being colorless, inert, and non-toxic (João Gomes, 2007). However, its lifespan in the atmosphere is approximately 100 years (Eric Ray, 2017). Carbon dioxide (CO_2) is produced when carbon compounds are burned in the presence of oxygen. Due to human activities, the concentration of CO_2 in the atmosphere has steadily increased, particularly by 30% over the last two centuries. Agriculture and forestry are estimated to contribute 12% of carbon dioxide emissions. Carbon constantly undergoes transfers between these various environments (Junling Huang, 2012).

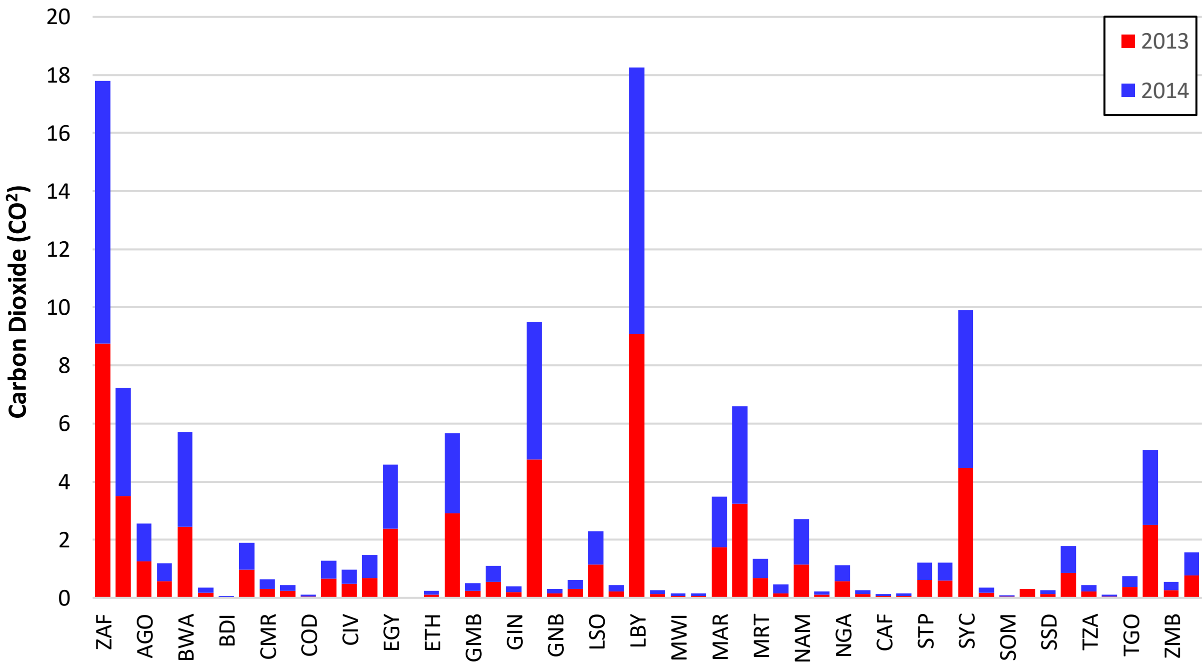


Figure 3. CO2 Emissions in 2013 and 2014 from African Countries, World Bank, 2014.

1. CO_2 Emissions in North Africa

Libya is the leading polluter in North Africa, despite being an oil producer and a member of OPEC. Its carbon dioxide (CO2) emissions amounted to 9.08 and 9.18 tons per capita in 2013 and 2014, respectively, totaling more than 18 tons per capita over two years. During the same period, Egypt contributed more than 4 tons per capita, while Tunisia and Morocco each contributed over 5 tons per capita (Mohamed, 2013).

2. CO_2 Emissions in West Africa

Some West African countries, notably Côte d'Ivoire, Togo, and Mauritania, emitted between 2013 and 2 tonnes, averaging ju lower than that of th

3. CO_2 Emissions in East Africa

In East Africa, carbon dioxide (CO2) emissions per capita for the period 2013 to 2014 are estimated at less than 1 ton per capita, particularly for Ethiopia (a country increasingly relying on renewable energy), Kenya, and Somalia (Nicholas M. Odhiambo, 2017)

4. CO_2 Emissions in Southern Africa

Southern African countries such as South Africa and Angola have carbon dioxide (CO2) emissions per capita exceeding 17 tons per capita over two years and more than 7 tons of CO2 per capita, respectively. After the Northern countries, those in Southern Africa represent the second most polluted region in Africa (Petra Maritz, 2019).

III. Income Inequality: The Case of Africa

The reduction of poverty and the achievement of the Sustainable Development Goals (SDGs) require committed efforts to address the challenge of income inequality while simultaneously achieving decisive progress in African countries. According to a study published by the United Nations Development Programme (UNDP) titled "Income Inequality in Sub-Saharan Africa: Diverging Trends, Determinants, and Consequences," income inequality in African countries stems from several factors (John C. Anyanwu, 2016). These include the highly dualistic structure of the economy, where income-generating sectors such as multinationals and the extractive sector have a limited capacity to generate jobs compared to the informal sector, where most workers earn much lower wages. Other factors include the high concentration of physical capital, human capital, and land, particularly in East and Southern Africa economies, as well as the limited redistributive role of the state, often manifesting through the "resource curse," urban bias in public policies, and ethnic and gender inequalities (John Page, 2015).

In principle, the study of inequality focuses more on the complete distributions of income and synthesizes the results using inequality indicators (Gini, Theil, Atkinson, Hoover, deciles, Theil-Hoover, etc., (Sourushe Zandvakili, 2008). However, income inequality can be measured between countries on a continental or international level. The most commonly used index is the Gini index, which ranges from 0 to 1: 0 represents perfect equality, while 1 represents absolute inequality. In Africa, the inequality index is evaluated at 45.1, compared to a global average of about 38 (John C. Anyanwu, 2016). This shows that the continent is relatively highly unequal, with many African countries exceeding the global average, thereby presenting an inequality index greater than 38.

1. Gini Index in Africa

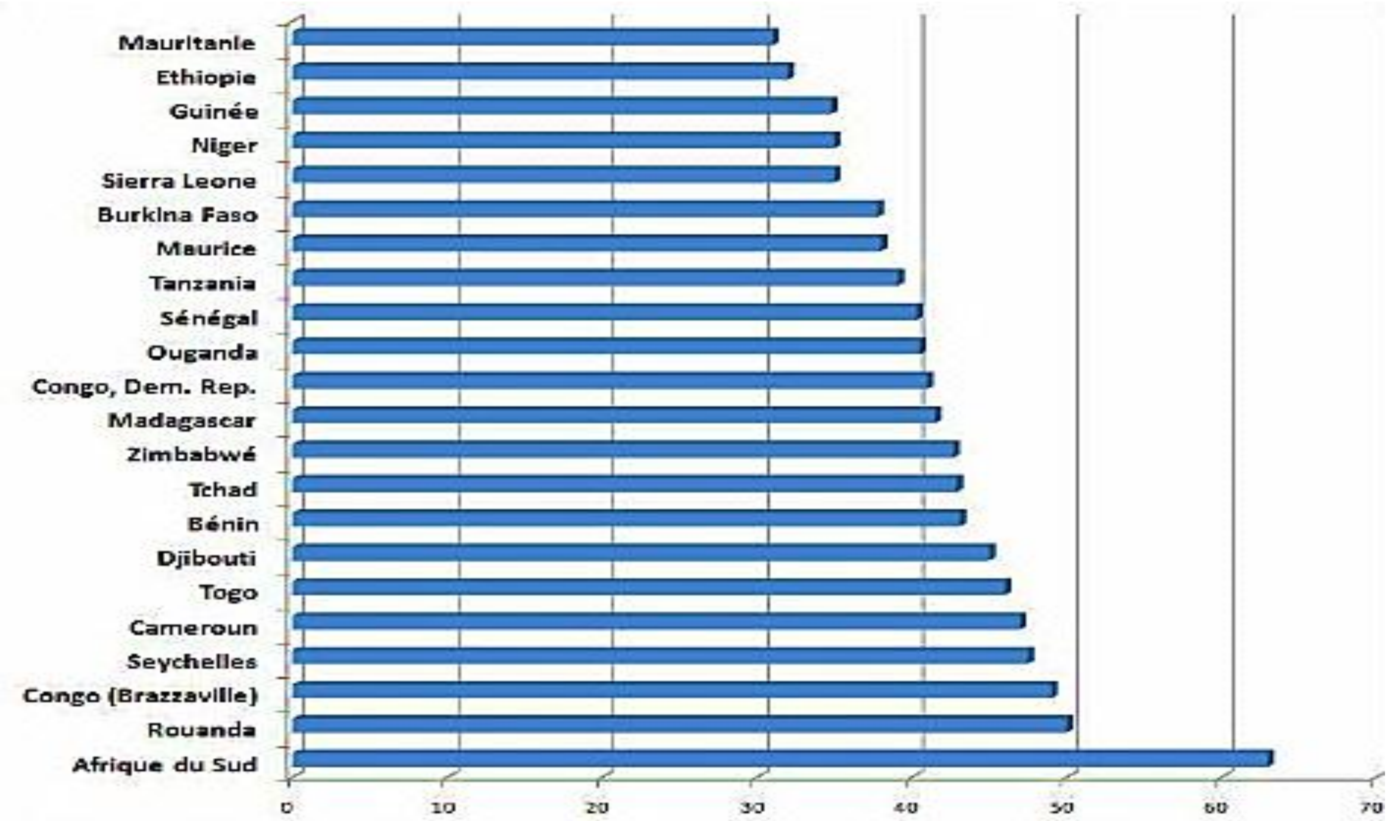


Figure 4. Gini Index in Africa, World Bank, 2016.

Figure 4 shows the ranking of African countries in terms of income inequality. Measured by the Gini index, there is considerable heterogeneity between countries. In fact, South Africa is the most unequal country with a Gini coefficient well above 50 (indicating relatively very high inequality). In contrast, Mauritania is ranked with a Gini index near 30 (indicating relatively low inequality), which is below the global average (Figure 4). This is the best score in Africa for income equality among the 23 African countries featured in the World Bank's report on income distribution, published in early October 2016. Moreover, with a Gini index close to 31, Mauritania, with a population of about 4 million and an estimated per capita income of $1,260, is a model for Africa in terms of income distribution (John C. Anyanwu, 2016). It stands as one of the more equal countries in a continent where income inequality remains a critical issue in many countries. For the 2016 ranking, other countries that need to improve include Ethiopia (with a Gini coefficient of 33), Guinea (34), Niger (35), Sierra Leone (36), Burkina Faso (37), and Mauritius (38) (Figure 4).

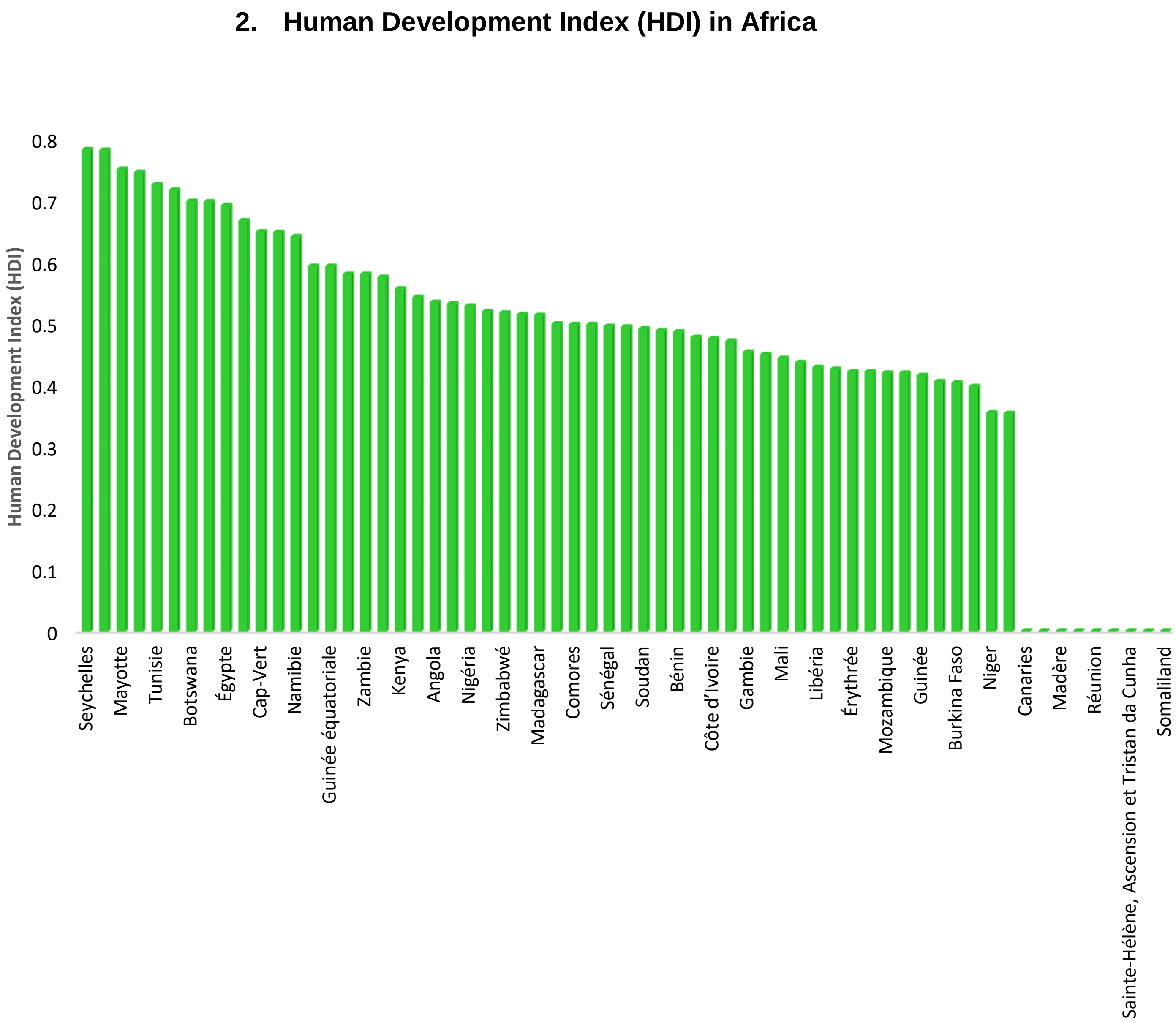


Figure 5. Human Development Index in Africa, UNDP, 2015.

Figure 5 illustrates the Human Development Index (HDI) in Africa. This indicator was established in 1990 by the United Nations Development Programme (UNDP) to serve as a measure of human development. According to the 2011 formula, it is calculated by the geometric mean of the products of the indices for longevity, education level, and income level (Carmen Herrero, 2012). However, the value was calculated using the arithmetic mean in 2005. In the 2015 ranking, Seychelles ranks first, followed by Mauritius, Mayotte, Algeria, Tunisia, Libya, Botswana, Gabon, Egypt, South Africa, Cape Verde, Morocco, Namibia, Congo, Equatorial Guinea, Zambia, Ghana, Sao Tome and Principe, Kenya, etc. However, this ranking is not exhaustive due to missing values (Pascal Bovet, 2006). For comparison, we also provide the 2016 HDI ranking in Africa, which is much more complete. In ascending order of HDI value, we have:

1 - Seychelles (63rd), 2 - Mauritius (64th), 3 - Algeria (83rd), 4 - Tunisia (97th), 5 - Libya (102nd), 6 - Botswana (108th), 7 - Gabon (109th), 8 - Egypt (111th), 9 - South Africa (119th), 10 - Cape Verde (122nd), 11 - Morocco (123rd), 12 - Namibia (125th), 13 - Congo (135th), 14 - Equatorial Guinea (135th), 15 - Ghana (139th), 16 - Zambia (139th), 17 - Sao Tome & Principe (142nd), 18 - Kenya (146th), 19 - Swaziland (148th), 20 - Angola (150th), 21 - Tanzania (151st), 22 - Nigeria (152nd), 23 - Cameroon (153rd), 24 - Zimbabwe (154th), 25 - Mauritania (157th), 26 - Madagascar (158th), 27 - Rwanda (159th), 28 - Comoros (160th), 29 - Lesotho (160th), 30 - Senegal (162nd), 31 - Uganda (163rd), 32 - Sudan (165th), 34 - Togo (166th), 35 - Benin (167th), 36 - Malawi (170th), 37 - Côte d'Ivoire (171st), 38 - Djibouti (172nd), 39 - Gambia (173rd), 40 - Ethiopia (174th), 41 - Mali (175th), 42 - DRC (176th), 43 - Liberia (177th), 44 - Guinea-Bissau (178th), 45 - Eritrea (179th), 46 - Sierra Leone (179th), 47 - Mozambique (181st), 48 - South Sudan (181st), 49 - Guinea (183rd), 50 - Burundi (184th), 51 - Burkina Faso (185th), 52 - Chad (186th), 53 - Niger (187th), and finally, 54 - Central African Republic (188th).

Conclusion :

Economic growth and sustainable development are gaining momentum in Africa, with a global economic dynamism. This phenomenon, unseen for decades, describes an emerging reality. Some African countries are surpassing the growth rates of major Western powers, primarily by increasing investments and infrastructure development in their countries, aside from Ghana and Nigeria, oil-producing nations that have been weakened by the fall in oil prices. Despite the vast potential in natural capital for certain countries like Libya or the Democratic Republic of the Congo, political instability continuously hinders their growth prospects.

Studies from the African Development Bank (ADB) highlight significant economic activity in East Africa, which is among the highest growth rates in the world, as seen in Ethiopia and Djibouti. This "spring of economic growth" is also embracing North Africa, West Africa, Central Africa, and Southern Africa. It is clear that the economic model of developed countries associates substantial economic growth with degrading air pollution. The higher the standard of living driven by growth, the more carbon dioxide per capita is emitted. This is true for countries like South Africa, Nigeria, Libya, Seychelles, Equatorial Guinea, Mauritius, and others.

The analysis of income inequality in Africa confirms that the continent remains highly unequal, which is not consistent with sustainable development. According to the International Monetary Fund (IMF) study, following Stiglitz's article (Nobel Prize in Economics in 2001) on inequality and growth in OECD countries, it is clear that countries with significant economic growth also face pollution and income inequality. Indeed, South Africa, Seychelles, and Mauritius are both growth drivers, polluters, and highly unequal in terms of income distribution in Africa.

Chapter 2 : Chapter 2: Literature Review on Economic Growth and Sustainable Development

Introduction

Stimulating economic growth while mitigating incurred debts, several developing countries, particularly in Africa, have adopted, under the auspices of international organizations such as the International Monetary Fund (IMF) and the World Bank, an open-door policy since the early 1980s (Ching-Cheng Chang, 2012). This approach aligns with structural adjustment programs, GATT agreements, and more recently, regional accords under the World Trade Organization (WTO). However, from an ecological standpoint, this trend risks exacerbating the strain on an already fragile planet, further burdened by industrialized nations (Kevin P. Gallagher, 2009). Moreover, the World Meteorological Organization (WMO) revealed that atmospheric carbon dioxide (CO_2) concentrations reached a record level in 2016. Over the past 25 years, the frequency of weather-related disasters, such as floods and droughts, has doubled. This escalation partly explains why Africa experiences the highest drought-related mortality rates globally. Conversely, flooding remains the most prevalent disaster in North Africa (Adeoluwa Akande, 2017). Additionally, Africa must intensify efforts to combat income inequality to enhance citizens' living standards and achieve the Sustainable Development Goals (SDGs).

This context frames our study on economic growth and sustainable development in Africa during the specified period. In the introductory terms of this chapter, we will address, in the first section, a literature review on economic growth, examining the relationship between economic growth and CO_2 emissions on one hand, and between economic growth and income inequality on the other. In the second section, we will also explore their empirical reviews with a view to modeling appropriate frameworks for economic growth and sustainable development, conducting empirical estimations and tests on a panel of 54 African countries, excluding Western Sahara, which is not recognized by the UN and lacks available data.

I. Theoretical Reviews on Economic Growth and Sustainable Development

1. Theoretical Review on Economic Growth

In the long-term perspective, Robert Solow developed the first neoclassical growth model in 1956, considering four variables: production, technological progress, capital, and labor (Robert M. Solow, 1994). Firms combine labor and capital to produce goods. They use household savings to invest and increase production capacities. Therefore, the more the economy saves, the more firms can accumulate capital (figure 6). Consequently, in the absence of technological progress, growth gradually tends toward zero, and the economy may eventually reach a point where production no longer increases but stagnates. Solow thus reinforces the classical idea that the economy converges toward a stationary state.

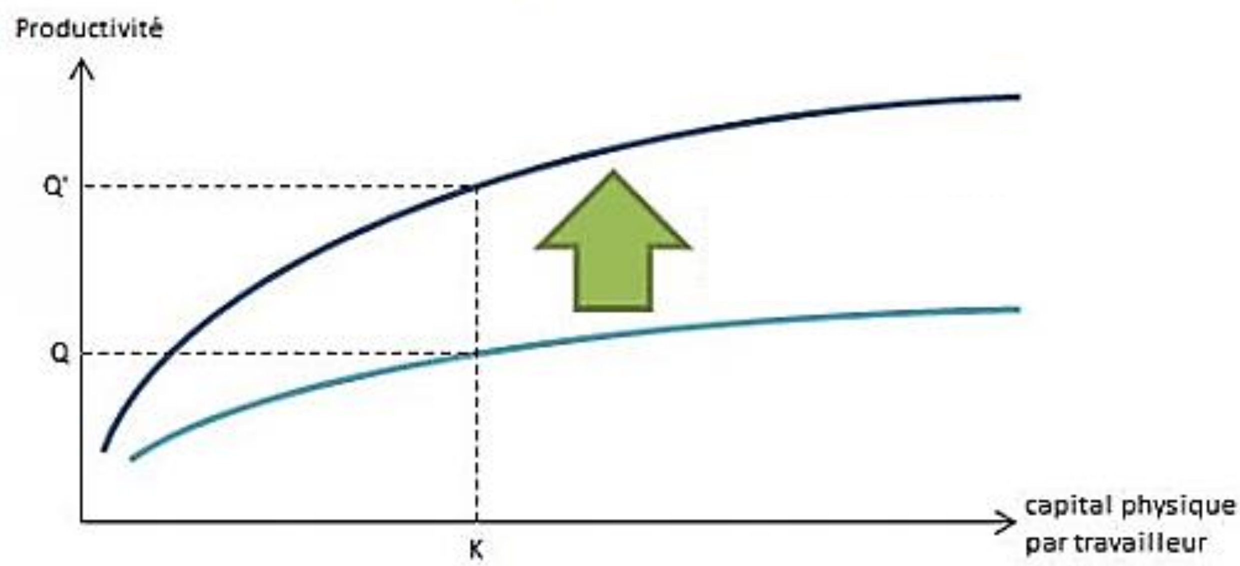


Figure 6. Solow Curve.

2. Theoretical Review on CO_2 Emissions

Grossman and Krueger (1991) study the possibility of applying the Kuznets curve to the field of the environment (Remigijus Čiegis, 2008). Although it is controversial, it does not directly derive from Kuznets' work. Moreover, various indicators from different domains, such as health, water, or air pollution, also show an inverted "U" curve at the early stages of economic development: environmental concerns and the rise in pollution are often overlooked, which go hand in hand with industrialization (Yunpeng Luo, 2014). The Kuznets curve (based on the work of Simon Kuznets (1955) on economic development in the 1950s) described an inverted "U" relationship between a country's level of development and income inequality (John A. List, 1999). However, it wasn't until 1993 that the term "Environmental Kuznets Curve" (EKC) emerged (Paul Ekins, 1997). Economic growth is accompanied by an improvement in environmental conditions, particularly a reduction in pollution, starting from the significant turning point, as illustrated in Figure 7.

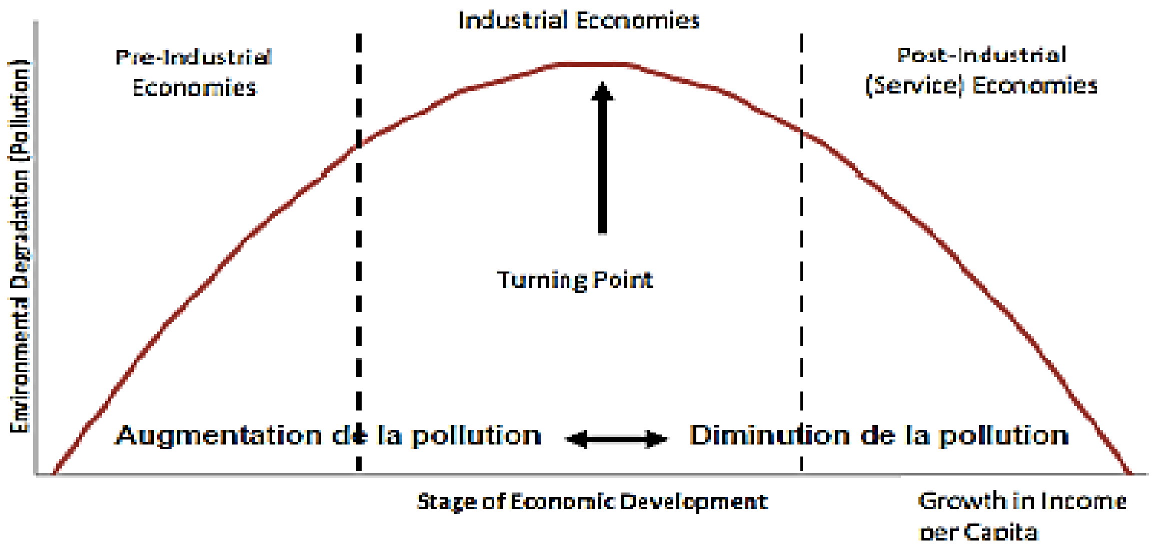


Figure 7. Environmental Kuznets Curve.

First, there is a phase of environmental degradation due to a pre-industrial economy, followed by a phase of a post-industrial economy, and finally a phase where the hostile effects of growth on the environment are controlled. Since the foundational article by Grossman and Krueger (1991), opinions have been divided (Herschel I. Grossman, 1995). The literature has been enriched by numerous studies on the subject, which have later been synthesized in excellent literature reviews (Jörg Müller, 2010). Regarding other interesting variables introduced in this literature, Bimonte (2002) used the number of newspapers sold per 1,000 inhabitants as a proxy for access to information (Bruce Bimber, 2001). Furthermore, it appears that the intensity of natural resource use and income describe an inverted "U" relationship, which is also referred to as the "intensity-of-use hypothesis" (Mădălina Andreea Hodor, 2021).

3. Theoretical Review of Income Inequality

The true Kuznets curve, which describes an inverted "U"-shaped functional relationship, highlights the link between economic growth and income inequality in the 1950s (Timothy Patrick Moran (2005); David Dollar (2015)). In a graph where the vertical axis represents inequality—often measured by the Gini coefficient—and the horizontal axis represents time or per capita income, this relationship is illustrated in Figure 8.

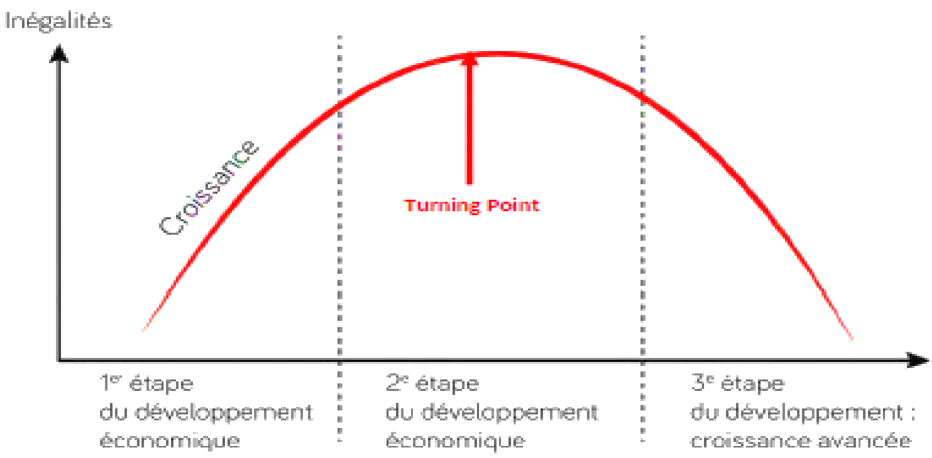


Figure 8. Social Kuznets Curve, Wikipedia.

First, a progressive increase in inequality occurs during the initial phase of economic growth, followed by a transition toward a more equitable situation as growth becomes advanced and sustainable (Timothy Patrick Moran, 2005). Kuznets (1955) proposed two explanations for this historical phenomenon: H1: Workers shifted from agriculture to industry. H2: Rural workers migrated to urban areas (J. Vernon Henderson, 2005). In both cases, inequality decreases once 50% of the workforce is employed in higher-income sectors. Kuznets' data primarily focused on middle-income Latin American countries, where inequality had long been prevalent (Leonardo Gasparini, 2011). Ultimately, the iconic inverted "U" shape of his curve appears to be less related to the progression of economic development within each country than to historical differences between them. Piketty, however, emphasizes the inconsistency of Kuznets' hypothesis in the context of 21st-century societies (Thomas Piketty, 2014).

II. Empirical Reviews on Economic Growth and Sustainable Development

1. Empirical Review of Economic Growth

The Solow-Swan model (1956) highlights the relationship between high demographic growth and poverty (N. Gregory Mankiw, 1992). Specifically, an increase in population growth, all else being equal, leads to a decline in capital per capita, ultimately resulting in national impoverishment an idea that aligns with Malthusian theory (Derek Headey, 2009). Conversely, an increase in the savings rate (s), all else being equal, leads to higher capital per capita, an increase in per capita wealth, and consequently, a period of accelerated economic growth before reaching a new equilibrium (Pradeep Agrawal, 2001). It is important to note that the savings rate (s) does not influence the long-term growth rate but only the speed of convergence to the steady-state equilibrium. In a two-factor production function framework, the commonly used functional form is as follows:

:

$$Y = c.K^{\alpha}.L^{\beta} \qquad (1)$$

Where β = 1- α

- ☑ Y : It corresponds to the level of production parameter
- ☑ K : capital parameter
- ☑ L : work parameter
- ☑ C : α et β are the constants determined by technology

In the case where all production factors double within a firm, how will output (Y) respond? A straightforward assumption is that production would also double. This leads to the concept of returns to scale, which can be expressed as follows (Gregory M. Gelles, 1996):

IF $F(K,L) = Y$, then $F(\pi K, \pi L) = \pi Y$ (2)

The returns to scale in this equation are therefore constant. However, increasing and decreasing returns to scale can also occur. The first case refers to a production process where optimizing the utilization of production factors would be beneficial. An example of the second case is mining. When considering an increase in a production factor, what effect could this have on output? While an increase in production is not ruled out, it is likely to occur at a decreasing rate, leading to the concept of marginal returns of factors. This can be expressed through a mathematical equation. Assuming that capital input does not increase, the returns to scale in this equation remain constant. Nonetheless, both increasing and decreasing returns to scale can be observed. In the case of increasing returns to scale, optimizing the efficiency of production factors may be necessary. Conversely, a typical example of decreasing returns to scale is found in mining, where resource extraction becomes less efficient over time. If a production factor increases, what would be the impact on total output? While an increase in production is possible, it is likely to occur at a diminishing rate, reinforcing the notion of marginal returns of factors. This relationship can be mathematically formulated, assuming that capital remains constant.

Cobb-Douglas Function : F(K,L) = $K^{\alpha}.L^{1-\alpha}$ (3)

We obtain: $$Rmf_K = \frac{\nabla Y}{\nabla K} = \alpha K^{\alpha-1} L^{1-\alpha} \quad (4)$$

Further : $$Rmf^2{}_K = \frac{\nabla^2 Y}{\nabla^2 K} = \alpha(\alpha-1)K^{\alpha-2}L^{1-\alpha} \quad (5)$$

With : $$\alpha < 1 \leftrightarrow \alpha - 1 < 0 \rightarrow Rmf^2{}_K < 0$$

In the framework of the pure and perfect competition model, the coefficients α and β represent the distribution of income between labor and capital. Thus, in Solow's steady-state model, Total Factor Productivity (TFP) is a function of labor (L) rather than capital (K).

The Solow model assumes the exogeneity of the savings rate, the population growth rate, and technological progress. The growth rates of L and A are identical to the constants n and g, respectively. Additionally, the depreciation of physical capital is exogenous and is given by the equation governing the variation in the stock of physical capital:

$$k = s.f(k, L.A) - \delta k \quad (6)$$

To calculate the growth rate, one should first divide by L and then by k:

$$\tau_k = \frac{s.f(k,A)}{k} - (n+g) \quad (7)$$

The curve of the average product of capital intersects the depreciation line at point k. The steady-state growth rate remains constant.

1.1. Convergence Theory

The neoclassical Solow model indicates a transition dynamics toward a steady-state, specifically the convergence of an economy to its steady state or toward another economy. This leads to the expressions: $k = K/AL$ and $y = Y/AL$, and by deriving the equation for k:

First, y = F(k, A) = K. F(1, A / k) is equivalent to y = F(k,1) = f(k) (8)

Then : $$\nabla k = s.\frac{f(k)}{k} - (n + g + \delta) \quad (9)$$

At the steady state, the growth rate per effective worker k and the steady-state value satisfy the following condition: : $s.f(k^*) = (n + g + \delta).k^*$, where $k^*$is obtained by the intersection of two entities (the curve $s.f(k)/k$ and the effective depreciation line $n + g + \delta$).

IF k = K/LA $< k^*$, then the growth rate of k is positive and increases towards k^* and vice versa. When the transition starts with initially low capital per worker k^*(capital per worker at steady state) is stable. There is a strong understanding of the importance of determining the speed of convergence, which is limited to the case of the Cobb-Douglas function. Taking the logarithm of equation (10) near the steady state, we get:

$$\nabla k = \frac{\nabla \ln(k)}{\nabla t} = -\beta . \ln(\frac{k}{k^*}) \quad (10)$$

The coefficient β thus determines the speed of convergence of k towards k^* and its formulation is as follows:

$$\beta = (1 - \alpha)\ (n + g + \delta) \quad (11)$$

One remarkable aspect of the speed of convergence is that the savings rate does not influence the speed. It is well known that the higher the savings rate, the greater the investment, which consequently accelerates this speed.

However, from another perspective, a high savings rate leads to an increase in capital at the steady state, which slows down the speed of convergence. The convergence coefficient is also independent of technology A. The steady state of an economy is reached when:

$$\Delta k_t = sf(k_t) - \delta k_t = 0 \tag{12}$$

where s et δ represent the savings rate and the depreciation rate.

Islam (1995) further extended the case of panel data for the conditional convergence equation of the Solow model, given by the following formula :

$$\ln(y_{i,t}) = \beta_0 + (\beta + 1)\ln(y_{i,t-1}) + \theta\ln(x_{i,t}) + \varepsilon_{i,t} \tag{13}$$

where $x_{i,t}$ is a vector of explanatory variables., β determines the speed of convergence using the following formula:

$$\vartheta = \frac{-\ln(1+\beta T)}{T} \text{ with a half-life of } DV = \frac{-\ln(2)}{\ln(1+\beta)} \tag{14}$$

Absolute beta-convergence implies that countries converge to the same equilibrium level. Typically, it is assumed that countries have the same initial conditions. Conditional convergence, on the other hand, indicates a long-term steady state that is specific to each country. The development of spatial econometrics has highlighted the influence of spatial effects in determining the conditional convergence of economies (Giuseppe Arbia, 2003).

1.2. Green Solow Model (GSM)

It is possible to derive the relationship between economic growth and CO2 emissions from the Environmental Kuznets Curve using the Solow model (1956), theoretically developed by Brock and Taylor (2004). This equation provides a convergence of CO2 emissions between countries within the same region. Thus, we consider an economy with a growth rate of $n + g + \delta$.

The production technique, whose growth rate negatively impacts the degradation of environmental quality through CO_2 emissions, is given by the following growth rate:

$$\gamma_e = \gamma_c - \gamma_p \tag{15}$$

Where γ_e, the growth rate of emissions of CO_2, γ_c growth rate and γ_p, growth rate of the production technique. Similarly, for the convergence of pollutants, its equation takes the following form:

$$\ln\left(\frac{e_t}{e_{t-1}}\right) = \beta_0 + \beta \ln(e_{t-1}) \tag{16}$$

We can rewrite the previous equation by introducing a vector of control variables :

$$\ln(e_{i,t}) = \beta_0 + (1+\beta)\ln\left(e_{i,t-1}\right) + \theta \ln\left(x_{i,t}\right) + \varepsilon_{i,t} \tag{17}$$

Where $x_{i,t}$ is a vector of explanatory variables, and β determines the rate of convergence of the pollutant according to the following formula:

$$\vartheta = \frac{-\ln(1+\beta T)}{T} \text{ with a half-life of } DV = \frac{-\ln(2)}{\ln(1+\beta)} \tag{18}$$

From this equation, Brock and Taylor demonstrate the theory of the Environmental Kuznets Curve based on the Solow model. Absolute convergence coincides with θ being zero; otherwise, we speak of conditional convergence.

1.3. Presentation of the Economic Growth Model

In the context of this thesis, our empirical analysis of economic growth is based on four macro-econometric models, ranging from exogenous growth to endogenous growth, by examining the interrelations between production, human capital, and physical capital. Their modeling is outlined as follows:

- **Basic Solow Model :**

$$\ln(GDP_{i,t}) = \ln(SE_{i,t}) + \ln(PGR_{i,t}) + \varepsilon_{i,t} \tag{19}$$

Where the variable GDP represents Gross Domestic Product per capita. The variables SE and PGR represent the savings rate and the average population growth rate, respectively.

- **Augmented Solow Model: :**

$$\ln(GDP_{i,t}) = \ln(SE_{i,t}) + \ln(PGR_{i,t}) + \ln(PRS_{i,t}) + \varepsilon_{it} \tag{20}$$

Where the variable GDP represents Gross Domestic Product per capita. The variables SE, PGR, and PRS represent the savings rate, the average population growth rate, and the number of primary school students, respectively.

- **Test de convergence conditionnelle du modèle de Solow :**

$$\log(\mathrm{GDP}_{i,t}) = \log(\mathrm{GDP}_{i,t-1}) + \log(\mathrm{SE}_{i,t}) + \log(\mathrm{PGR}_{i,t}) + \log(\mathrm{TRADE}_{i,t}) + \log(\mathrm{IND}_{i,t}) + \log(\mathrm{AGR}_{i,t}) + \log(\mathrm{SER}_{i,t}) + \log(\mathrm{NCI}_{i,t}) + \varepsilon_{i,t} \tag{21}$$

Where the variable GDP represents Gross Domestic Product per capita. The variables GDPt-1, SE, PGR, TRADE, IND, AGR, SER, and NCI represent the previous GDP, the savings rate, the population growth rate, the trade openness rate, the share of GDP from the industrial sector, the share of GDP from the agricultural sector, the share of GDP from the services sector, and net capital inflows, respectively.

Test of Conditional Convergence of the Augmented Solow Model :

$$\log(\mathrm{GDP}_{i,t}) = \log(\mathrm{GDP}_{i,t-1}) + \log(\mathrm{SE}_{i,t}) + \log(\mathrm{PCG}_{i,t}) + \log(\mathrm{OP}_{i,t}) + \log(IS_{i,t}) + \log(AS_{i,t}) + \log(SS_{i,t}) + \log(FDI_{i,t}) + \log(EBR_{i,t}) + \varepsilon_{i,t} \quad (22)$$

Where the variable GDP represents the Gross Domestic Product per capita. The variables GDPt-1, SE, PCG, OP, IS, AS, SS, FDI, and EPR represent the previous GDP per capita, the savings rate, the population growth rate, the trade openness rate, the share of GDP from the industrial sector, the share of GDP from the agricultural sector, the share of GDP from the services sector, net capital inflows, and the number of primary school students, respectively.

2. Empirical Review of the Relationship Between Economic Growth and CO_2 Emissions

In the literature, several approaches have been proposed to formulate the environmental variable based on different pollutants or greenhouse gases present in the atmosphere, such as sulfur dioxide (SO2), carbon dioxide (CO2), and carbon monoxide (CO), leading to an inverted "U" shaped relationship. However, in particular, carbon dioxide (CO2) remains one of the main contributors to air pollution. According to a study by Meunié (2004), "this curve is only detected for certain pollutants with localized effects. Furthermore, numerous methodological criticisms undermine its relevance. This relationship is true only for some localized pollutants (such as sulfur dioxide or nitrogen dioxide)." Several other studies have highlighted the influence of the period considered and the country sample selected in the modeling. Selden & Song (1994) tested the hypothesized relationship between growth and the environment for four pollutant emission variables, namely SO2, NOx, SPM, and CO.

This article demonstrated the existence of the EKC hypothesis for all environmental variables in industrialized countries. However, the turning points are significantly different for each type of pollutant. Indeed, the income level at which the positive relationship between growth and the environment breaks down was established at $8,700 for SO2, $11,200 for NOx, $10,300 for SPM, and $5,600 for carbon monoxide (CO).

2.1. Presentation of the Model

The environmental Kuznets curve (EKC) model proposed by Grossman and Krueger (1991) for empirical testing is as follows:

$$e_{i,t} = \alpha_i + \beta_{1,i} \log(Y_{i,t}) + \beta_{2,i}\log(Y_{i,t})^2 + \beta_{3,i}\log(Y_{i,t})^3 + \varepsilon_{i,t} \qquad (23)$$

Where $e_{i,t}$ is an indicator of pollution (in our case, CO2 emissions per capita), Y is wealth per capita (measured by GDP per capita), $\varepsilon_{i,t}$ The error term and α_i the intercept. The shape of the curve is determined by the parameters. $\beta_{k,i} \; \forall \; k \in [1,..,3] \; et \; \forall \; i \in [1,..,n]$. For the relationship between CO2 emissions per capita and income per capita to take the form of an inverted "U," it is necessary that $\beta_{1,i} > 0$, a$\beta_{2,i} < 0$ et $\beta_{3,i} = 0$. NWe can thus determine the turning point (Tp), the income level at which carbon dioxide emissions reach their maximum, using the formula:

$$T_p = -\frac{\beta_{2,i}}{2\beta_{1,i}} \qquad (24)$$

Where $\beta_{1,i}$ coefficient de revenu par tête, $\beta_{2,i}$ coefficient du revenu par tête au carré. $\beta_{1,i}$.

Other forms of relationships that may be identified between growth and the environment include:

☑ A positive linear relationship, in this case : $\beta_{1,i} > 0$, a$\beta_{2,i}$= 0 and $\beta_{3,i} = 0$

☑ A negative linear relationship, in this case:: $\beta_{1,i} < 0$, a$\beta_{2,i}$= 0 and $\beta_{3,i} = 0$

☑ No relationship, in this case: $\beta_{1,i} = 0$, a$\beta_{2,i}$= 0 and $\beta_{3,i} = 0$

☑ A "U-shaped" relationship, in this case: $\beta_{1,i} < 0$, a$\beta_{2,i} > 0$ and $\beta_{3,i} = 0$

☑ An "N-shaped" relationship, in this case: $\beta_{1,i} > 0$, a$\beta_{2,i} < 0$ and $\beta_{3,i} > 0$

☑ An inverted "N-shaped" relationship, in this case: $\beta_{1,i} < 0$, a$\beta_{2,i} > 0$ and $\beta_{3,i} < 0$

We have already extensively discussed in the introduction the possibility of adding several additional variables to the right-hand side of equation (23). However, we will limit ourselves to one that seems indispensable today: energy consumption per capita in Africa. On the other hand, it is also possible to calculate the turning point when the Kuznets relationship is no longer identified between CO2 emissions and wealth, or between income inequality and wealth. This pertains to several other forms of relationships, including a monotonic positive or negative relationship, an "N" relationship, an inverted "N" relationship, a "U" relationship, etc. Later, with the support of the works of Apergis & Payne (2010) and Acaravci & Ozturk (2010) regarding relevant control variables in equation (1), which should be inserted, we can refine the model. While these variables may influence pollution, Jobert and Karanfil (2010) identified energy consumption per capita as a key factor. Another category of research has focused on the introduction of policy variables (Torras & Boyce, 1998), product structure (Panayotou, 1997), trade (Suri & Chapman, 1998), and energy variables (Jobert & Karanfil, 2010). However, many authors dispute the inverted "U" relationship between growth and the environment. Our empirical model for Africa is formulated as follows:

$$\ln(CO2_{i,t}) = a_3 + B_{31}.\ln(PIBH_{i,t}) + B_{32}.\ln(PIBH^2{}_{i,t}) + B_{33}.Ln(PIBH^3{}_{i,t}) + B_{34}.\ln(UEH_{i,t}) + B_{35}.\ln(TCOU_{i,t}) + B_{36}.\ln(DCMS_{i,t}) + B_{37}.\ln(EEN_{i,t}) + B_{38}.\ln(EAD_{i,t}) + \varepsilon_{3,t} \quad (25)$$

Where the variable CO2 represents per capita carbon dioxide emissions. The variables PIBH, PIBH2, and PIBH3 represent income per capita and its quadratic and cubic forms, respectively. The variables TCOU, DCMS, EEN, and EAD represent per capita energy consumption, household final consumption expenditure, the share of income allocated to damage from the depletion of natural resources, and the share of income allocated to damage from CO2 emissions, respectively. The country-specific effects in the panel data are represented by the term a3. The term µ3t represents the model's omission error. The coefficients B are to be estimated. The indices t and i represent the study periods and countries.

In the study of the relationship between growth and the environment, we will also propose the Green Solow model, which is presented as follows:

$$\ln(CO2_{i,t}) = a_4 + B_{41}.\ln(CO2_{i,t-1}) + B_{42}.\ln(TEP_{i,t}) + B_{43}.\ln(TCP_{i,t}) + B_{44}.\ln(TOU_{i,t}) + B_{45}.\ln(PSE_{i,t}) + B_{46}.\ln(PIN_{i,t}) + B_{47}.\ln(PAGi_{,t}) + B_{48}.\ln(ENC_{i,t}) + B_{49}.\ln(NBE_{i,t}) + \varepsilon_{4t} \quad (26)$$

Where the variable CO2 represents carbon dioxide per capita. The variables CO2t-1, TEP, TCP, TOU, PIN, PAG, PSE, EN, and NBE represent the previous per capita CO2, the savings rate, the population growth rate, the openness rate, the share of GDP from the industrial sector, the share of GDP from the agricultural sector, the share of GDP from the service sector, net capital inflows, and the number of primary school students, respectively.

3. Empirical Review on Income Inequality

Kuznets' initial publication in 1955 on the relationship between growth and inequality, known as the Social Kuznets Curve rather than the Environmental Kuznets Curve (EKC), was a historical and quantitative study focusing on income inequality and the growth of both wealthy and developing countries in the 19th century (in 1950). This study eventually led to the well-known hypothesis of the inverted "U" curve, which, although widely debated today, remains a contentious topic both within the intellectual community and in public opinion.

In this context, Kuznets made the following observation: "Due to their generality and consistency, it first demonstrates a constant relativity of income after the First World War, or even before." The Kuznets curve represents economic inequality in a country as a function of its development level, which is assumed to increase over time.

In the early stages of development, when investment in infrastructure capital and natural capital is the primary mechanism for growth, inequalities encourage growth by distributing resources in favor of those who save and invest the most. This economic phenomenon is referred to as the "Kuznets Curse." The Kuznets ratio measures the proportion of income earned by the top 20% of earners, divided by the proportion of income earned by the bottom 20% of earners in a society. A value of 1 would thus indicate perfect equality.

3.1. Model Presentation

In more advanced economies, human capital accumulation gradually replaces physical capital accumulation as the primary driver of economic growth. At this stage, income inequality hampers economic growth by limiting overall education levels, as not everyone can afford to finance their education. The Kuznets curve illustrates an inverted U-shaped functional relationship: the vertical axis represents income inequality, often measured by indicators such as the Gini coefficient or Theil index, while the horizontal axis represents time or per capita income. The empirical model to be tested for the relationship between economic growth and income inequality is formulated as follows (Bebonchu Atems, 2014):

$$Gini_{i,t} = \alpha_i + \beta_{1,i}\log(Y_{i,t}) + \beta_{2,i}\log(Y_{i,t})^2 + \beta_{3,i}\log(Y_{i,t})^3 + \varepsilon_{i,t} \qquad (27)$$

Where $e_{i,t}$ represents an indicator of income inequality (in our case, the per capita Gini coefficient), while Y denotes per capita wealth (measured by per capita Gross National Income, GNI), $\varepsilon_{i,t}$ represent the error term and α_i the intercept. The shape of the curve is determined by the parameters $\beta_{k,i}\ \forall\ k \in [1,..,3]\ and\ \forall\ i \in [1,..,n]$. For the relationship between CO2 emissions per capita and wealth per capita to take an inverted "U" shape, the following condition must be met: $\beta_{1,i} > 0$, a$\beta_{2,i} < 0$ and $\beta_{3,i} = 0$. Thus, we can determine the turning point the income level at which carbon dioxide emissions reach their maximum using the following formula:

$$\boxed{\text{PDR} = -\ \beta_{2,i} / 2\beta_{1,i} \qquad (28)}$$

Other possible forms of relationships between growth and the environment include:

☑ A positive linear relationship, in which case: $\beta_{1,i} > 0$, a$\beta_{2,i} = 0$ and $\beta_{3,i} = 0$

☑ A negative linear relationship, in which case: $\beta_{1,i} < 0$, a$\beta_{2,i} = 0$ and $\beta_{3,i} = 0$

☑ No relationship, in which case: $\beta_{1,i} = 0$, a$\beta_{2,i} = 0$ and $\beta_{3,i} = 0$

- ☑ A "U" shaped relationship, in which case : $\beta_{1,i} < 0$, a$\beta_{2,i} > 0$ and $\beta_{3,i} = 0$
- ☑ An "N" shaped relationship, in which case : $\beta_{1,i} > 0$, a$\beta_{2,i} < 0$ and $\beta_{3,i} > 0$
- ☑ An inverted "N" shaped relationship, in which case: $\beta_{1,i} < 0$, a$\beta_{2,i} > 0$ and $\beta_{3,i} < 0$

We have already extensively discussed in the introduction the possibility of adding numerous additional variables to the right-hand side of Equation (27). While Kuznets' argument is based on a process that marks the transition from a purely agricultural economy to an industrialized one, Oshima (1962, 1992, and 1995) suggests incorporating variations in economic and social policies into the model. Our empirical model in the African context is formulated as follows:

$$\ln(IGI_{i,t}) = a_5 + B_{51}.\ln(PIBH_{i,t}) + B_{52}.\ln(PIBH^2_{i,t}) + B_{53}.\ln(pibh^3_{i,t}) + B_{54}.\ln(TCP_{i,t}) + B_{55}.\ln(TOU_{I,t}) + B_{56}.Log(TAP_{i,t}) + B_{57}.\ln(TCH_{i,t}) + B_{58}.\ln(ISR_{i,t}) + \varepsilon_{5,t} \quad (29)$$

Where the variable IGI represents the income inequality index. The variables PIBH, $PIBH^2$, and $PIBH^3$ correspond to per capita income and its quadratic and cubic forms, respectively. The variables TCP, TOU, TAP, TCH, and ISR represent the population growth rate, trade openness rate, literacy rate, unemployment rate, and income tax, respectively. The country-specific effects in the panel data are captured by the term a_3, while μ_{3t} accounts for model specification errors. The coefficients B are to be estimated. The indices t and i denote the study periods and countries, respectively.

Chapter 2: Literature Review on Economic Growth and Sustainable Development

Conclusion :

Based on an exhaustive review of the literature on economic growth and sustainable development, theoretical and empirical studies converge around three key pillars of sustainable development: economic sustainability, ecological viability, and social equity. Within this framework, the empirical growth literature, particularly the Solow model (1956), serves as a basis for analyzing economic growth in Africa. This analysis explores the interactions between growth rates, physical capital, and human capital, ultimately examining the conditional convergence of economies toward a steady state in the African context.

However, it is equally relevant to extend this notion of conditional convergence to the environmental analysis of countries. In such a framework, this approach is referred to as the Green Solow Model (GSM). Regarding environmental degradation in relation to the ecological constraints imposed on economic growth, empirical literature highlights the Environmental Kuznets Curve (EKC). This model allows us to assess the existence of an inverted "U" relationship in Africa, suggesting that pollution levels tend to decline in the long run due to economic diversification. While several parametric and non-parametric studies challenge this hypothesis, the estimated relationship strongly depends on the chosen estimation method, the selection of control variables, and the study period—factors that influence the identification of this curve.

Similarly, the empirical literature on income inequality draws on Kuznets' analytical approach, which predicts a long-term decline in inequality after reaching a calculable turning point, provided that the functional form follows a negatively signed concave or parabolic curve, commonly referred to as an inverted "U" curve. However, this perspective has been categorically rejected by Thomas Piketty, who considers it a "dead and buried" theory.

Chapter 3 : Methodological Analysis of Economic Growth and Sustainable Development

Introduction

This chapter is dedicated to methodological analysis, where we conduct an in-depth statistical and econometric investigation into economic growth and sustainable development in the African context.
From a statistical perspective, the analysis is based on describing the information contained in a dataset, focusing on time-invariant data. The econometric approach, on the other hand, aims to explain the behavior of a given variable through a set of explanatory variables, employing various analytical methods. Building on the work presented in this study, we will apply a range of statistical and econometric analyses to provide insights based on the results obtained.

I. Statistical Analyses

1. Data of the Study

In the context of the statistical analysis methodology, the variables of interest are reconstructed using data from the World Bank platform. The aim is to observe several phenomena revolving around three key concepts, specifically the three pillars of economic growth and sustainable development.

These include GDP per capita, CO_2 emissions per capita, the income inequality index (Gini), etc. The study focuses on 54 African countries, excluding Western Sahara (not recognized by the UN), using data for the year 2016 for univariate and joint analysis, and for 2015 for multidimensional analysis.

2. Descriptions des variables

Variables d’études	Descriptions des variables
PIBh :	Gross Domestic Product per capita
PIBh2 :	Gross Domestic Product per capita squared
PIBh3 :	Gross Domestic Product per capita cubed
TEP :	Savings rate (%)
TCP :	Population growth rate
TOU :	Economic openness rate (%)
PSE :	Share of services sector (% GDP)
PIN :	Share of industrial sector (% GDP)
PAG :	Share of agricultural sector (% GDP)
ENC :	Net capital inflows
NBE :	Number of primary school students
NSG :	Average population growth rate (%)
CO_2 :	CO2 emissions per capita
UEH :	Energy consumption per capita
TCOU :	Coverage rate (%)
DCMS :	Final household consumption expenditure
EEN :	Share of income for natural resource depletion (% GNI)
EAD :	Share of income for CO2-related damage (% GNI)
IGI :	Gini coefficient
TAP :	Literacy rate (%)
TCH :	Unemployment rate (%)
ISR :	Income tax

3. Univariate Statistical Analysis

In univariate statistical analysis, we focus on extracting insights from a dataset. Typically, this begins by organizing, cleaning, and visualizing the data, as well as grouping similar data points. The goal is to summarize the information in a more manageable and communicable form. To achieve this, we rely on numerous tools and methods from descriptive statistics, including measures of central tendency (median, mean, quartiles, deciles, etc.), measures of dispersion (interquartile range, variance, standard deviation, etc.), and measures of kurtosis and skewness, among others.

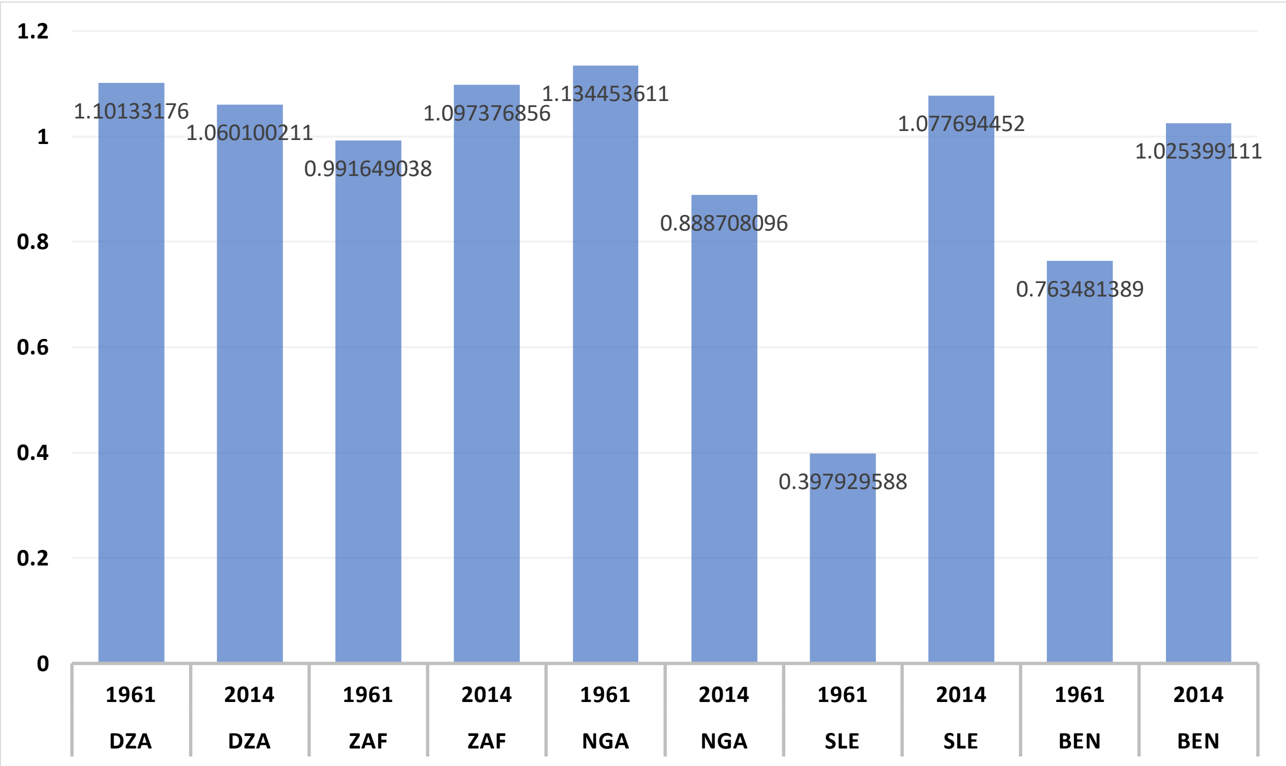


Figure 9 : Index of Decoupling and Recoupling. Source: Author, 2018.

In this graph, we illustrate the decoupling index (decoupling; decreasing environmental pressure), which measures the sensitivity of CO_2 emissions to variations in per capita income. When its value is between 0 and 1, it is referred to as relative decoupling, and absolute decoupling when it is greater than or equal to 1. Additionally, if the index is below 0, it indicates a situation of recoupling (increasing environmental pressure). As an example, we present a few countries at different dates. All the countries selected for this analysis are in a situation of relative and absolute decoupling. This is a positive sign for environmental preservation in Africa.

Table 1 : Descriptive Statistics of the Variables.

	MIN	MAX	MEDIAN	MEAN	SD	CV	Dispersion
PIBH	285,7	1,51E+04	1003	2210	2857	1,2928	Homogène
PAG	2,44	61,42	24,41	24,82	14,05	0,5661	Homogène
PIN	2,611	53,97	21,64	24,36	11,33	0,4651	Hétérogène
PSE	32,66	70,61	50,85	50,21	9,474	0,1887	Hétérogène
NBE	3,64E+04	4,36E+06	1,85E+05	1,19E+06	2,12E+06	1,7758	Homogène
TEP	16,62	27,71	22,16	22,16	7,843	0,3539	Hétérogène
TOU	30,36	64,6	39,92	45,83	13,76	0,3002	Hétérogène
ENC	-262,6	-91,03	-128,4	-153,2	67,49	-0,4405	Hétérogène
NSG	0,5585	8,885	7,213	7,1	1,257	0,1770	Hétérogène
PIB2	8,16E+04	2,27E+08	1,01E+06	1,29E+07	3,60E+07	2,7966	Homogène
TCOU	49,35	100,6	70,7	70,59	19,85	0,2812	Hétérogène
PIB3	2,33E+07	3,43E+12	1,01E+09	1,22E+11	5,03E+11	4,1196	Homogène
DCM	1,02E+08	6,04E+10	2,31E+09	6,47E+09	1,20E+10	1,8523	Homogène
SCR	2267	5948	4108	4108	2603	0,6336	Homogène
ISR	8,43	575	22,43	39,78	86,84	2,1830	Homogène
TAP	15,3	92,9	60,2	57,02	21,58	0,3785	Hétérogène
TCH	1,1	89,8	6,95	11,76	13,34	1,1344	Homogène
IGI	31,45	62,15	42,95	43,55	7,76	0,1782	Hétérogène
TCP	0,06872	3,847	2,519	2,396	0,7541	0,3147	Hétérogène

Source: Author, 2018

The table above presents key descriptive statistics for the measured variables, including minimum, maximum, mean, median, standard deviation, and coefficient of variation values.

The data reveals significant variations across African nations. For instance, 2016 GDP per capita figures ranged from $285.7 to $15,100. The coefficient of variation exceeding 50% for GDP-related emissions indicates substantial cross-country heterogeneity. Similar variability is observed in coverage and literacy rates.
The Gini coefficient analysis shows persistent inequality across the continent, with values ranging from 31 to 62.15 in 2016 (where values approaching 100 indicate greater inequality).

Sectoral analysis demonstrates that services constitute the largest share of GDP (32.66%-70.61%), followed by agriculture (2.44%-61.42%) and industry (2.61%-53.97%). This confirms Africa's service-oriented economy with significant agricultural contributions. Notably, only the agricultural sector exhibits relative homogeneity, while other sectors show country-specific patterns.

Significant cross-country disparities exist in coverage and savings rates, unlike the more consistent literacy and population growth rates. Data limitations should be noted, particularly the absence of per capita CO_2 emissions in the 2016 World Bank dataset. These missing values also constrain more comprehensive bivariate and multivariate analyses.

4. **Joint Statistical Analysis**

When examining the linear relationship between two variables simultaneously, the focus shifts to bivariate descriptive statistics. This involves analyzing the correlation matrix, least squares regression line, chi-square test, analysis of variance (ANOVA), regression analysis, among other methods.

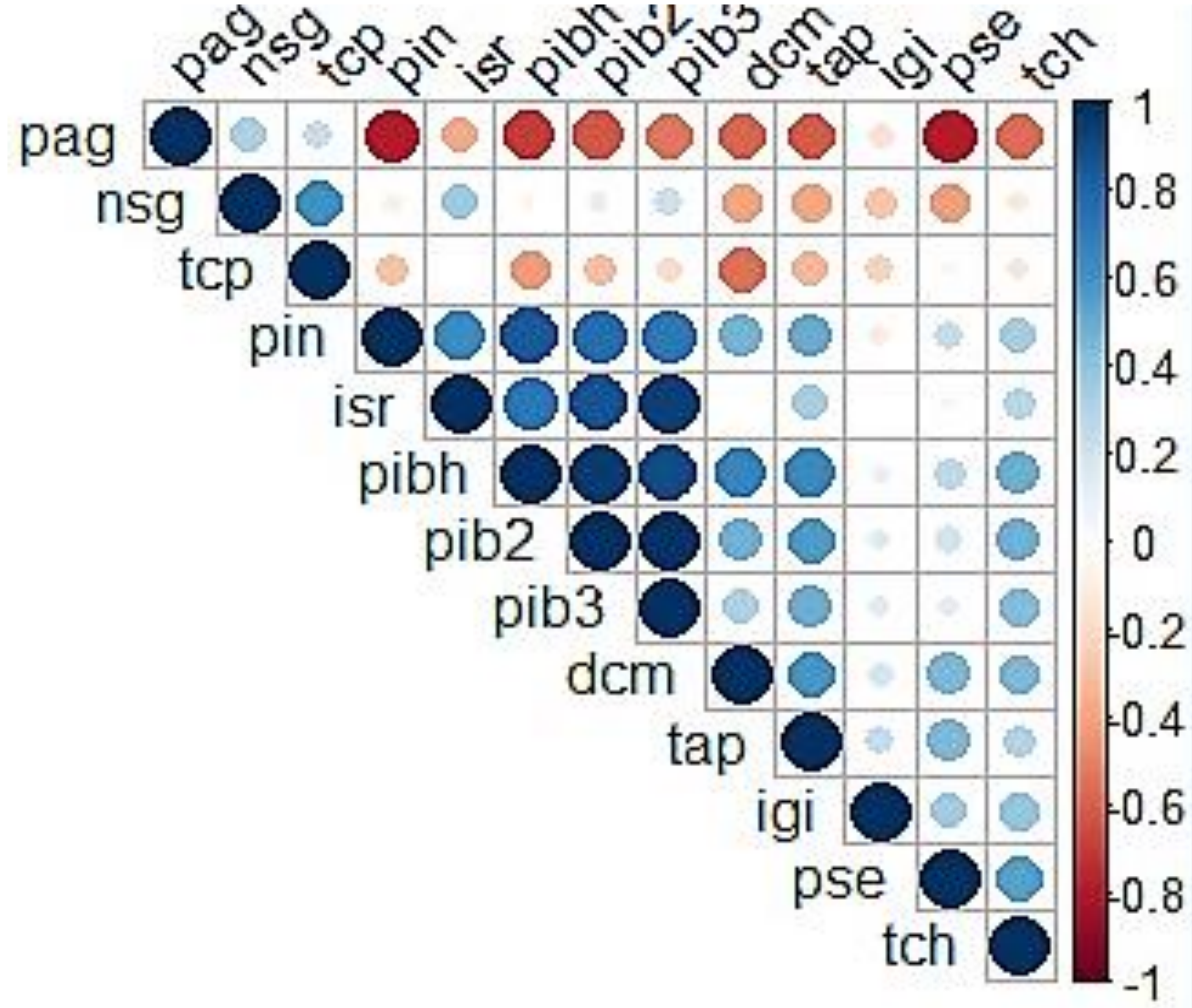


Figure 10: Heatmap of Correlation graph between quantitative variables.

The graph above studies the intensity of the bond between variables, although the term was first used by Galton (1888), it focuses on analyzing the linear bond between variables described by a coefficient between -1 and 1. In our case, we represent it graphically. Inside each quadrant we observe a circular diagram representing the intensity of the correlation between two variables. Indeed, the larger the diameter of the circle, the closer the correlation coefficient is to 1 in absolute value and therefore the variables are strongly linked, this is the case between GDP per capita and ISR (income tax) although strongly correlated, it is outside the diagonal. We can see the exact values of these coefficients using the correlation matrix. Nevertheless, we can test this link using Pearson's correlation test, or Kendal's non-parametric version.

5. Multidimensional Statistical Analysis

When we are interested in describing the relationships between several variables and individuals in a measurement table, we can highlight the multivariate descriptive statistics of measurable variables called Principal Component Analysis (PCA) seen as an exploratory multidimensional method for studying the correlation matrix in a dimension as large as physics.

5.1. Bartlett's Test of Sphericity and the KMO Index

Table 2: Bartlett test.

Bartlett test
Chisq : 1096.432
Df : 91
p.value : 3.82774e-172

Source: Author, 2018

Bartlett's statistic approximately follows the Chi-square distribution with 91 degrees of freedom under the null hypothesis. The critical probability (3.82774e-172) associated with this test allows us to reject the null hypothesis of the invertibility of the correlation matrix (or the identity matrix), since it is lower than the 5% risk threshold. It is therefore quite possible to begin a principal component analysis on the data. However, this test is biased, it is only recommended when the n/p ratio is approximately less than 5. Indeed, we will further ensure with the KMO (Kaiser-Meyer-Olkin) index.

Table 3: Results of the Kaiser-Meyer-Olkin KMO indices.

Kaiser-Meyer-Olkin indice	
Kaiser-Meyer-Olkin global	model= 0.5638448
Kaiser-Meyer-Olkin individual	pibh = 0.644351627054534
Kaiser-Meyer-Olkin individual	Pag = 0.542092830996089
Kaiser-Meyer-Olkin individual	pin = 0.427349524184568
Kaiser-Meyer-Olkin individual	pse = 0.467611377632605
Kaiser-Meyer-Olkin individual	nsg = 0.564694987170143
Kaiser-Meyer-Olkin individual	pib2 = 0.537583724110948
Kaiser-Meyer-Olkin individual	pib3 = 0.491582649678031
Kaiser-Meyer-Olkin individual	dcm = 0.506726308060334
Kaiser-Meyer-Olkin individual	eap = 0.63062070916509
Kaiser-Meyer-Olkin individual	isr = 0.492605829295805
Kaiser-Meyer-Olkin individual	tap = 0.811209777230741
Kaiser-Meyer-Olkin individual	tch = 0.887970779775386
Kaiser-Meyer-Olkin individual	igi = 0.593479684041235
Kaiser-Meyer-Olkin individual	tcp = 0.593917312483421

Source: Author, 2018

It results from this table, the KMO indices on all the variables and by variables. We can understand that the result is the same as the Bartlett test. Indeed, according to Kaiser's scale, the overall KMO of the matrix is in the "mediocre" range. Moreover, the 10 variables have a KMO that is in the same range and 2 variables in the 'Very good' range. This reassures us that each of the variables considered has a certain degree of correlation with the other variables, which is what the different correlation tests had affirmed. It is therefore legitimate to proceed with the principal component analysis (PCA) with all these variables.

5.2. Standardized Principal Component Analysis (PCA)

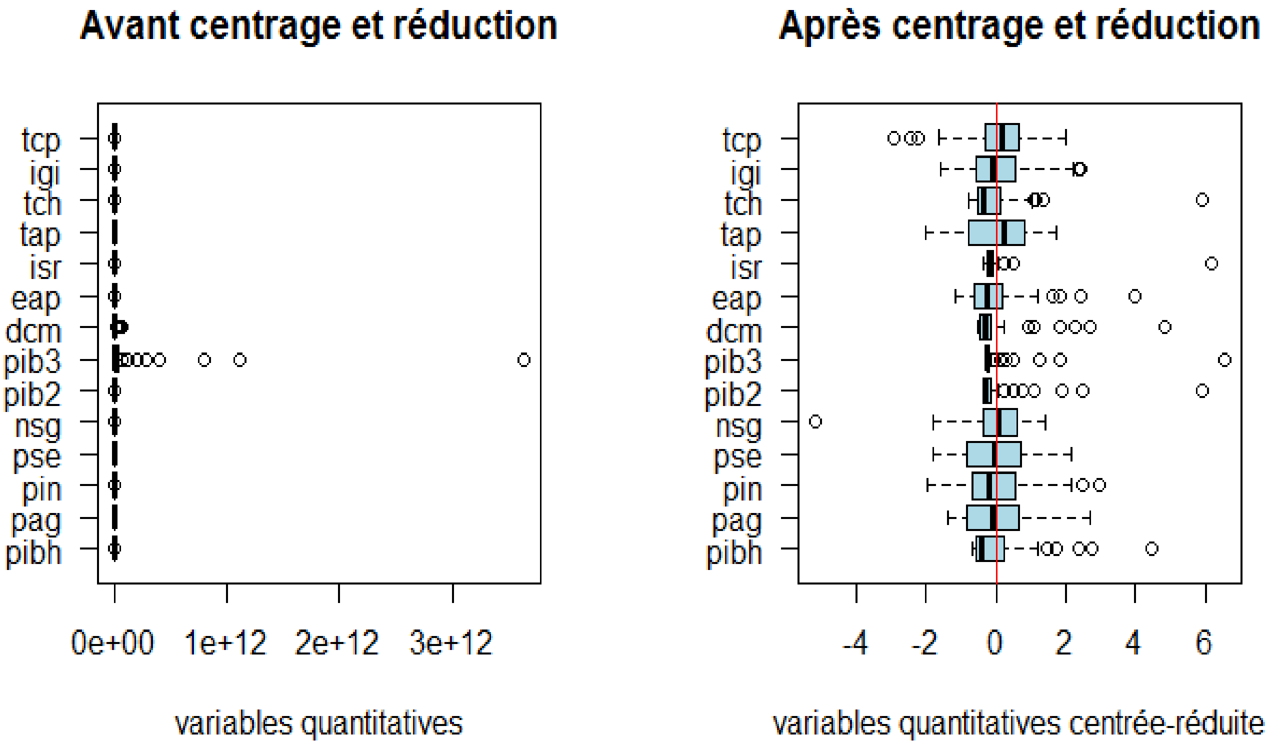


Figure 11 : Comparison between observed data and centered data.

Source: Author, 2018.

The representations above illustrate the interest of centering and reducing the data in order to take into account both the effects of the units and the sizes of the different data to carry out a multidimensional analysis. Although it is a geometric analysis, it is preferable to get rid of any disturbing element. Centering a variable involves subtracting its mean and reducing it consists of dividing by its standard deviation.

5.2.1. Choice of the number of axes to retain

Table 4 : Eigenvalues of the diagonalization of the correlation matrix.

	Eigenvalue	Variance.Percent	Cumulative.Variance.Percent
Dim.1	6,432	45,941	45,941
Dim.2	2,061	14,718	60,659
Dim.3	1,795	12,823	73,482
Dim.4	1,196	8,543	82,025
Dim.5	0,710	5,073	87,098
Dim.6	0,524	3,746	90,843

Source: Author, 2018

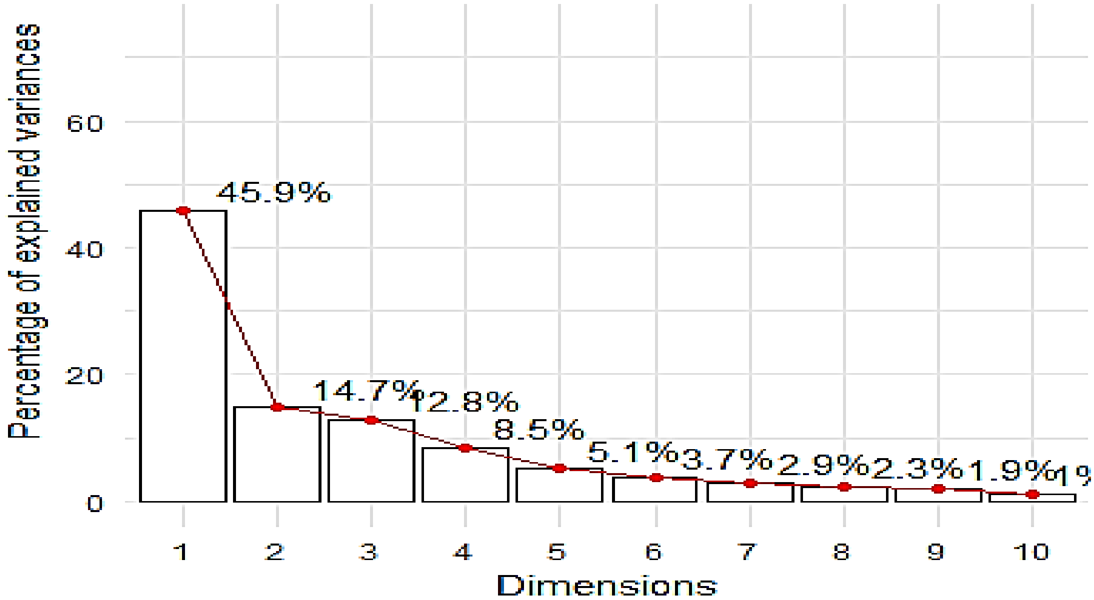


Figure 13: Scree-plot graph of eigenvalues. Source: Author, 2018.

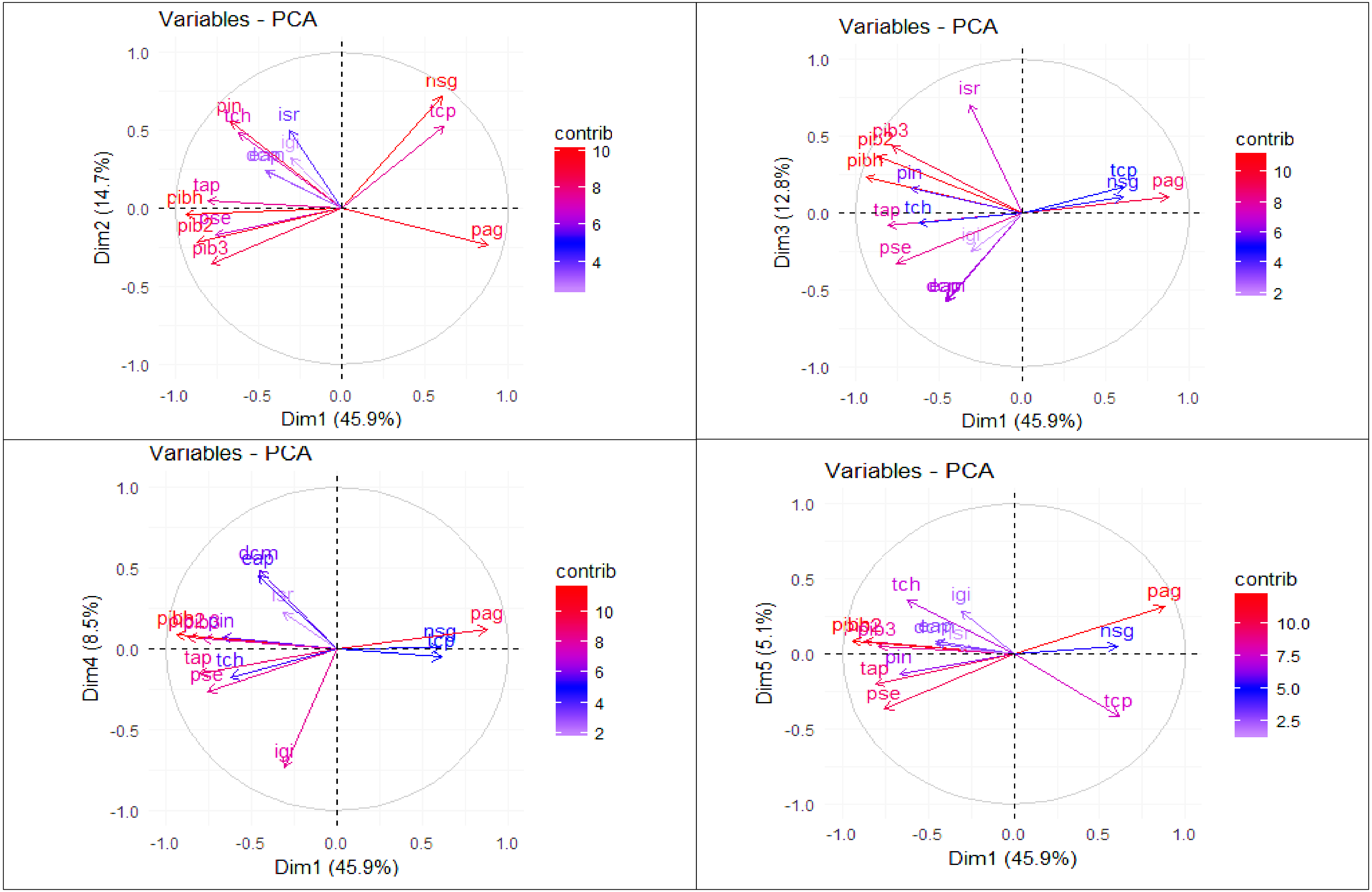
It emerges from the table of eigenvalues and that of the graph, the eigenvalues that will determine the new eigen spaces for the principal component analysis. In practice, the q unit vectors to be retained are those that provide nearly 80% of the total inertia

(Pareto's law), in general, which can give a sense of interpretation. Kaiser's criterion, on the other hand, considers the eigen values (called Eigen Value in English) greater than or equal to 1. The choice of selecting the axes for optimizing the total inertia is already given in the table. Kaiser's criterion allows to keep up to 4 main axes. As for the graphical analysis of scree, the drop is significant from the fourth axis which no longer retains only 82.88% of the total inertia. Finally, the Scree-test criterion also goes in the same direction, we only take into account the first two main axes. In conclusion, the first four principal components restore a total inertia of 82.03%. In reality, the more we retain enough principal axes, the more the points of the dual and direct cloud (variables and individuals) will group around their origin and therefore it would be regrettable to interpret poorly represented points in the "dimensional curse".

5.2.2. The graphs of the Standardized PCA

The figures of the Principal Component Analysis are on the one hand the circle of correlation of the variables (dual cloud) examining the proximity between the variables by their correlations. The latter studies the intensity of the linear link between a pair of variables. On the other hand, the projections of the individual points (direct graph) explaining, for its part, the similarity between individuals and the dissimilarity between groups of individuals thanks in particular to the calculation of Euclidean distance. Thus, we represent the variable and individual points in a two-dimensional space in which the number of these components is predetermined. Below, we present the results of the Standardized Principal Component Analysis (PCA).

Figure 14 : Cercle de corrélation des variables



Source : Auteur, 2018

Interpretation aids make it easy for us to identify the variables that contribute the most to the formation of axis 1 or the first principal component. By convention, these variables are gross domestic product (GDP), the share of the agricultural sector in GDP (AGS), and the literacy rate (LR). As with these findings, it is clearly convincing in the correlation circle graph of the factorial plane (1 and 2) that these mentioned variables are not only well represented on the 1-2 plane but also strongly correlated with dimension one. This otherwise justifies the selection of these variables for the first principal axis. At first glance, the description of axis 1 as the axis of economic growth, we will likewise give meaning to axis 2. By checking the corresponding bar diagrams of axis 2, it is easy for us to detect these variables, namely the share of the industrial sector in GDP (INS), the population growth rate (PGR), income tax (IT), and the unemployment rate (UR). An equivalent pseudonym for axis 2 would be that of the axis of African society. As a strong restitutor of information, the first factorial plane gives us a little more than 50% of information, or 60.60% of the total inertia. Regarding axis 3, it is similarly designated. With precision, income tax (IT), household consumption expenditure (HCE), and the share of income dedicated to CO2 damage (ICD). Although it is the second-best factorial plane, it provides nearly 58.70% of the total inertia contained in the correlation matrix. With accuracy, the third principal component governs investment or physical capital. The fourth principal axis, on the other hand, is attached to the coefficient of income inequality (IIC), final household consumption expenditure, and the share of income due to CO2 emission damage. It goes hand in hand to say that the fourth principal component reflects income inequality. It seems true that we had set aside expressing the squared cosine, which is also a tool considered essential and indispensable for interpretation. In truth, it is just like the correlation with the principal dimensions. The quality of the representation or the sum of the squared cosines of the variables on the plane evolves in the same interpretative perspective. These tools go in the same direction as the contribution.

Figure 15: Graphes directs

Source : Auteur, 2018

The diagrams display the statistical individuals that significantly contribute to the formation of Axis 1 or are well represented on this axis, as indicated by a squared cosine (cos^2) value close to 1. Specifically, these include the following countries: Burundi (BDI), Chad (TCD), Burkina Faso (BFA), Mali (MLI), Botswana (BWA), Ethiopia (ETH), and Seychelles (SLE).

This observation is further supported by the factorial plane (axes 1 and 2), where these countries are not only clearly visible but also well represented, particularly along Dimension 1. This strong representation justifies their selection with coherence and accuracy. Given that Axis 1 is interpreted as reflecting economic growth, it can be inferred that the countries mentioned above were characterized by relatively higher wealth per capita in 2015.

In contrast, the bar plot corresponding to Axis 2 does not highlight any country as being well represented. Although informative, the first factorial plane accounts for a little more than 50% of the total variance specifically, 60.60%. Similarly, Axis 3 explains approximately 58.70% of the total inertia derived from the correlation matrix and is interpreted as reflecting investment patterns. Axis 4 retains around 54.4% of the information.

However, it is important to note that the squared cosines of the individuals (countries) on the first four principal axes remain relatively low, which increases the risk of misinterpretation. Regarding the coordinates of the countries on the principal dimensions, their quality of representation measured by the sum of squared cosines follows a similar interpretive trend. As for supplementary individuals, none were added in this case study. All individuals included conform to the spatial scope and context of the analysis.

6. Hierarchical Cluster Analysis of Variables and Individuals

We use this approach to further explore the similarity or conversely, the dissimilarity among variables and among individuals through a hierarchical organization, whether ascending or descending. It offers an alternative and often more visually insightful way to interpret the results of a Principal Component Analysis (PCA). In this context, the dissimilarity between two elements (e.g., variables) is typically denoted as *dissim(x, y)*. Hierarchical clustering is a process that encompasses various clustering methods, relying on different algorithms such as Euclidean distance, Manhattan distance, Ward's method, average linkage, centroid linkage, and K-means, among others. This procedure is referred to as Hierarchical Ascendant Classification (HAC) because it begins with each individual as a separate cluster and then progressively merges them into larger clusters. The term *hierarchical* reflects the existence of an ordered structure in the clustering process, where groups are formed based on the shortest calculated distances between data points. Although the method assumes the existence of dissimilarities among individuals, Euclidean distance is commonly used as a dissimilarity measure, particularly in a Euclidean space. With a finite number of iterations, the algorithm ultimately produces a partition of the population. This partition can be visualized by cutting the resulting dendrogram at a specific height. To aid in determining the optimal number of clusters, one can analyze the jumps in inertia in the dendrogram or compute the ratio of within-cluster inertia to total inertia. These tools allow for a clearer interpretation of the hierarchical structure and assist in identifying meaningful groupings within the data.

6.1. Dendrograms of the Variables

The clustering diagram illustrates both the intra-group and inter-group dispersion of the variables based on their correlations, which reflect the underlying similarities and differences among them.

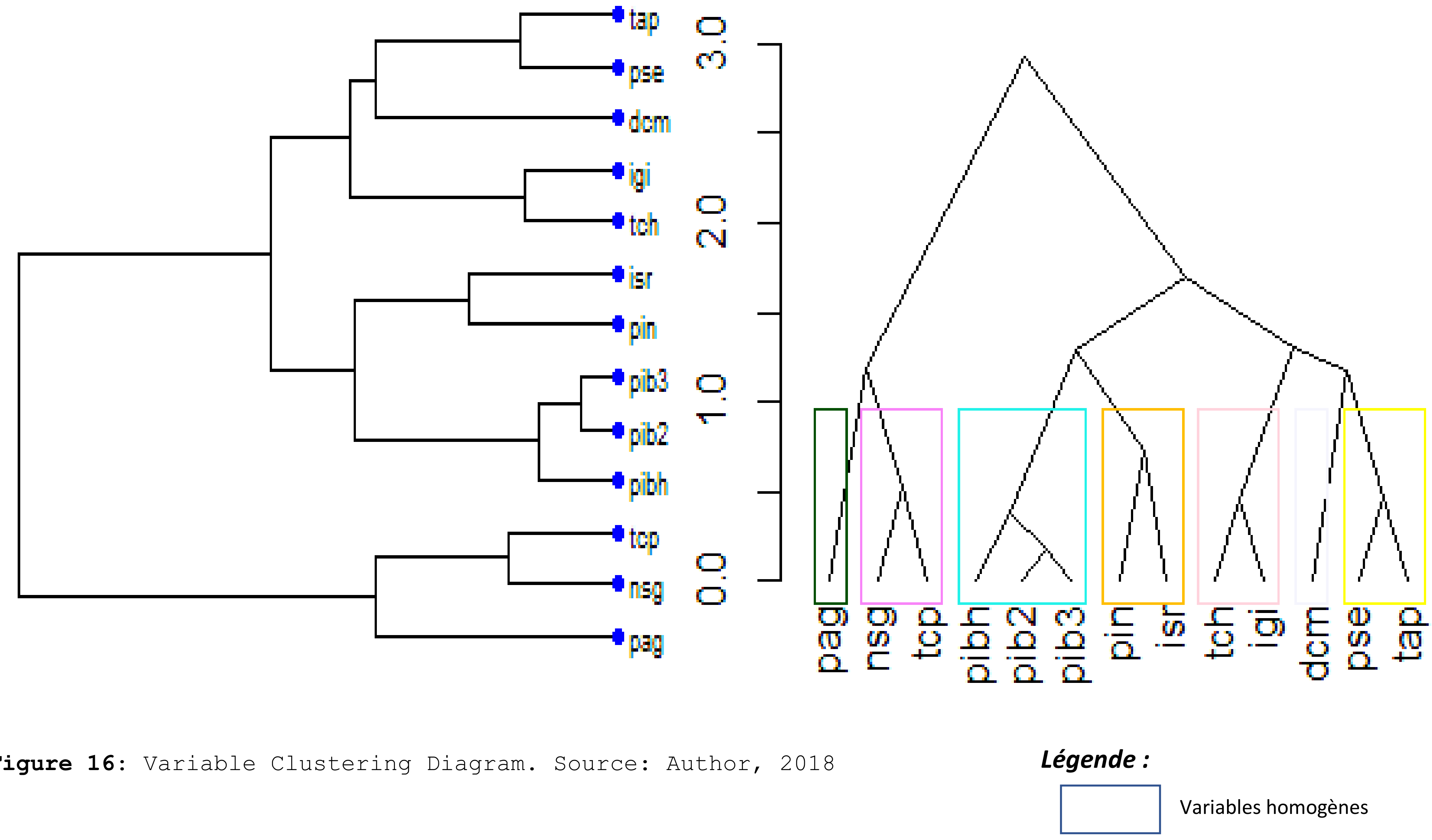


Figure 16: Variable Clustering Diagram. Source: Author, 2018

The hierarchical ascending classification of the variables is presented above. The objective of this segmentation or partitioning is to illustrate the similarities and dissimilarities among the variables based on dissimilarity measures and homogeneity criteria. These criteria are generally focused on minimizing within-group inertia, which serves as an indicator of class quality.

In this analysis, the partitioning algorithm used is based on Ward's method, although other clustering techniques such as K-means, K-modes, K-prototypes, Kohonen networks, mixed approaches, or relational methods may also be applied. Ward's technique groups variables in a way that maximizes the increase in between-cluster inertia, or equivalently, according to Huygens' theorem, minimizes the increase in within-cluster inertia.

From this perspective, seven distinct clusters of variables emerge:

- Class 1: Share of the agricultural sector in GDP (PAG)
- Class 2: Population growth rate (TCP)
- Class 3: Gross Domestic Product squared (PIB^2) and cubed (PIB^3)
- Class 4: Share of the industrial sector in GDP (PIN) and personal income tax (ISR)
- Class 5: Unemployment rate (TCH) and Gini index (IGI)
- Class 6: Household consumption expenditure (DCM)
- Class 7: Share of the service sector in GDP (PSE) and literacy rate (TAP)

This typology should also be compared with the one observed in the dual-space graphical representation (factorial plane) to better understand the data structure. Within each cluster, variance is minimized, resulting in groups that are internally homogeneous but may differ in terms of their association with economic growth and sustainable development.

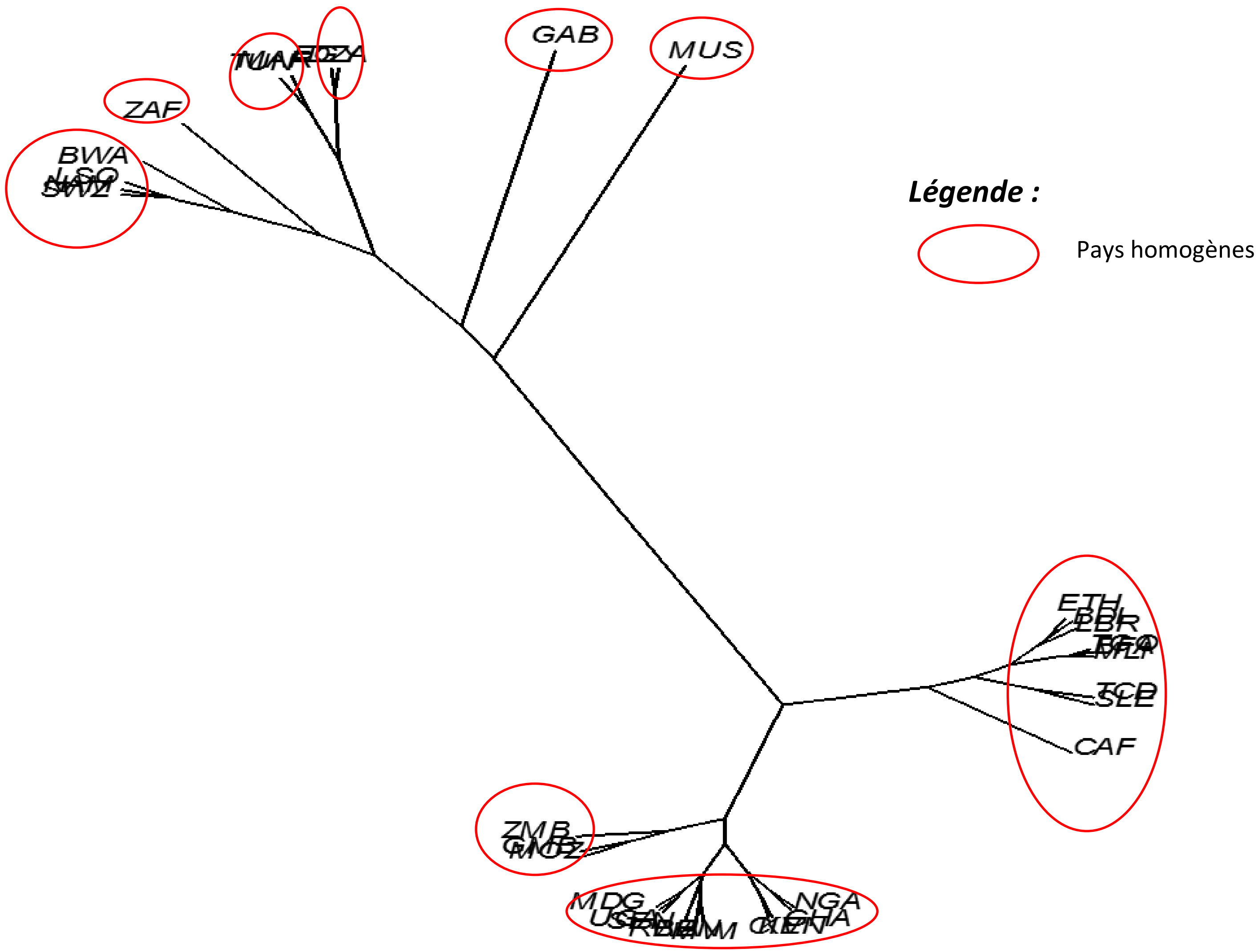


Figure 17: Hierarchical Ascending Classification. Source: Author, 2018.

This time, we present a more insightful clustering compared to the previous one: the hierarchical ascending classification of African countries. Indeed, there are 54 countries on the African continent recognized by the United Nations. However, Western Sahara is not recognized by the UN. This segmentation, or partitioning, of the entire set of observations is performed to highlight their similarities and dissimilarities using dissimilarity measures and a homogeneity criterion, which generally refers to minimizing within-cluster inertia—thus measuring the quality of each cluster.

The partitioning algorithm applied in this context is based on Ward's method, although other clustering techniques such as K-means, K-modes, K-prototypes, Kohonen networks, mixed methods, and relational approaches can also be employed. Ward's method groups classes so that the increase in between-cluster inertia is maximized, or equivalently, according to Huygens' theorem, so that the increase in within-cluster inertia is minimized.

From this analysis, nine distinct clusters emerge among the 33 selected countries, as highlighted below:

- **Cluster 1 :**

Gambie (GMB), Mozambique (MOZ) et le Zombie (ZMB)

- **Cluster 2 :**

Benin (BEN) Cote d'ivoire (CIV), Ghana (GHA), Kenya (KEN), Madagascar (MDG), Malawi (MWI), Nigeria (NGA), Uganda (UGA), Rwanda (RWA) et le Sénégal (SEN).

- **Cluster 3 :**

Centre Afrique (CAF)

- **Cluster 4 :**

Burkina Faso (BFA), Burundi (BDI), Ethiopie (ETH), Liberia (LBR), Mali (MLI), Seychelles (SLE), Tchad (TCD) et le Togo (TGO).

- **Cluster 5 :**

Maurice (MUS)

- **Cluster 6 :**

Gabon (GAB)

- **Cluster 7 :**

Algérie (DZA), Egypte (EGY), Maroc (MAR) et la Tunisie (TUN)

- **Cluster 8 :**

Afrique du Sud (ZAF)

- **Cluster 9 :**

Botswana (BWA), Lesotho (LSO), Namibie (NAM) et la Swaziland (SWZ)

It is also important to compare this typology or segmentation with those observed in the graphical representations of the individuals in order to better understand this partitioning. Within each cluster, variance is minimized, resulting in groups that are homogeneous internally.

From an economic perspective, nine profiles of similar countries in Africa have been identified based on factors such as economic growth, income inequality, household consumption, population growth rate, and others. This analysis excludes 21 countries due to unavailable data for the year 2015. Each of these groups is homogeneous internally and heterogeneous between clusters, reflecting minimized within-cluster inertia.

In this context, some countries appear isolated, such as Gabon, Mauritius, and the Central African Republic. West African countries, particularly members of the West African Monetary Union, are also divided: Burkina Faso, Mali, and Togo form one group, while Benin and Senegal form another.

The strength of this analysis lies in its ability to study diverse countries through a variety of indicators. Finally, the last step of this statistical analysis will be to test the classification of these countries according to economic growth and sustainable development.

6.2. Unilateral and Bilateral Comparison Tests

Table 5 : Bilateral and unilateral (right-tailed and left-tailed) tests for comparing the mean GDP per capita.

Groupes des pays	Test Bilatéral (P-value)	Test unilatéral à droite (P-value)	Test unilatéral à gauche (P-value)
G1-G2	0.437	0.7815	0.2185
G1-G4	0.5593	0.2796	0.7204
G1-G7	0.000881	0.9996	0.0004405
G1-G9	0.07267	0.9637	0.03633
G2-G4	0.05354	0.02677	0.9732
G2-G7	0.0001815	0.9999	9.074e-05
G2-G9	0.09251	0.9537	0.04625
G4-G7	0.00123	0.9994	0.0006148
G4-G9	0.06604	0.967	0.03302
G7-G9	0.8275	0.5862	0.4138

Source: Author, 2018

The table below illustrates the critical p-values from the Student's t-test comparing the mean GDP per capita (GDP/H) between the country groups 1, 2, 4, 7, and 9. The other groups consist of only a single isolated country.

Both bilateral (two-tailed) and unilateral (left-tailed and right-tailed) Student's t-tests support retaining the null hypothesis of no significant difference in mean GDP per capita between groups 1 and 2, 1 and 4, and 7 and 9, as their p-values exceed all conventional significance levels (1%, 5%, and 10%).

Conversely, these tests indicate a significant difference in mean GDP per capita between groups 1 and 7, 1 and 9, 2 and 7, 2 and 9, 4 and 7, and 4 and 9, thus confirming the relevance of the hierarchical ascending classification of the statistical units.

II. Econometric Analyses

1. Simultaneous Equations Model with Panel Data

Simple models limited to a single linear equation (such as error correction models, distributed lag models, autoregressive models, etc.) are often preferred due to their ease of implementation. Typically, such a model features, on the left-hand side of an equation, an endogenous variable (dependent or explained variable, denoted by Y), which is assumed to result from a set of exogenous variables (independent or explanatory variables) plus a random error term on the right-hand side.

Indeed, economic phenomena, although complex, are described by sets of variables and equations. However, their modeling generally requires more than one equation, linking macroeconomic variables together; this leads to what are called simultaneous equations models. Similar to the simple model, simultaneous equations models distinguish between endogenous variables, which are determined or explained by the model, and exogenous variables, which are observed and known a priori.

Econometric modeling is generally structured into five phases:

- Specification of endogenous and exogenous variables in the model
- Estimation of the model equations using appropriate techniques
- Evaluation of the model through various validation tests
- Solution of the model for simulation or forecasting purposes
- Formulation of recommendations

Unlike the classical model, in simultaneous equations models the variables are not only interdependent, but the error terms are correlated with the explanatory variables. Consequently, the ordinary least squares (OLS) estimator is biased and inconsistent.

Alternative estimation methods have been developed to overcome the inefficiency of classical methods and to provide consistent and convergent estimators.

Whereas the classical simultaneous equations model typically applies to cross-sectional data without considering the temporal dimension, our approach involves a simultaneous equations model using panel data. This requires accounting for both the longitudinal (time series) and cross-sectional dimensions of the data set.

1.1. Forms of Simultaneous Equations

1.1.1. The Structural Form Equation

Models whose equations reflect the underlying economic principles are referred to as being in structural form. Indeed, the coefficients we aim to estimate generally have significant economic meaning, as exemplified by the Hansen and Benzel model, which studies the evolution of consumption, investment, and income. The complex relationships between variables render the Ordinary Least Squares (OLS) estimators, considered BLUE by the Gauss-Markov theorem, vulnerable and sometimes obsolete. Even when the error term ε satisfies OLS assumptions (under natural conditions, it can be shown that the true value of the coefficient b is overestimated). Consequently, OLS estimates of structural form coefficients are generally biased, although they remain widely used.

1.1.2. The Reduced Form Equation

A simultaneous equations model is described by a set of relationships obtained by expressing each endogenous variable as a function of only the exogenous variables and lagged endogenous variables if applicable: this is called the reduced form model. It is derived by eliminating the “explanatory” endogenous variables from the structural equations. However, it is important to note that under suitable assumptions on the disturbances, estimation of the reduced form equations by ordinary least squares (OLS) provides unbiased estimates of their coefficients. From these estimates, one can attempt to recover the coefficients of the structural form through the relationships linking them to the reduced form coefficients. The difficulty lies in the fact that the transformation from the estimated reduced form coefficients to the structural form coefficients is nonlinear, causing the latter to no longer be unbiased, though they converge to an asymptotically unbiased estimator under certain assumptions.

1.2. Identification of the model's equations

In practice, identification serves to specify the most appropriate estimation method for a given equation in the system. More precisely, it is a criterion used to define a structural equation as identified, over-identified, or under-identified. The most restrictive case occurs when the structural coefficients can no longer be deduced from the reduced form equation; this is called under-identification. When the calculation is possible in only one direction, the equation is said to be just-identified. Econometric equations are most often over-identified. A model containing under-identified equations is insufficiently specified; its structural form is too vague and therefore cannot be properly estimated. A necessary condition for an equation to be identified is that the number of variables excluded from it equals the number of endogenous variables in the model minus one.

1.3. Model Estimation

In the context of estimating a simultaneous equations model, estimation methods are applied immediately after assessing the identifiability of each equation in the model. However, there exists a wide variety of methods for estimating simultaneous equations models. For example, the Ordinary Least Squares (OLS) method is mentioned despite its weaknesses; there are cases where it leads to correct estimates, such as recursive models, in which an endogenous variable appears as an explanatory variable only if it is explained by a preceding equation.

The Indirect Least Squares (ILS) method is reserved for the less common case of exactly identified equations. Instrumental Variables (IV) and Two-Stage Least Squares (2SLS) methods are used when an endogenous variable is explained by various endogenous and exogenous variables. The instrumental variables method operates in two stages: first, the endogenous regressors are replaced by their predicted values obtained from OLS regressions on a chosen set of exogenous, predetermined, or external variables called instruments. The goal is to obtain consistent estimates through a suitable choice of instrumental variables. Then, the regression is performed using OLS with these predicted values and the exogenous variables initially included in the equation.

When all exogenous and predetermined variables are used as instruments (usually for small models), the method is sometimes called Two-Stage Least Squares (2SLS). These methods apply to identified or over-identified equations. It is shown that 2SLS is equivalent to ILS in the case of exactly identified equations.

Under fairly general assumptions, 2SLS estimates are consistent, but this property often fails when lagged endogenous variables and autocorrelated errors are present.

Three-Stage Least Squares (3SLS) and the Seemingly Unrelated Regression (SUR) methods are more mathematically complex. The previous three methods estimate the model "equation by equation," whereas these latter methods estimate all the equations jointly, for example, to account for the likely correlation between error terms across different equations.

The 3SLS method starts by estimating each equation with 2SLS (or IV), then uses the residuals from this first step to estimate the covariance structure of the errors across equations, and finally applies Generalized Least Squares (GLS) to estimate the entire model considering this information.

For apparently independent equations (where the endogenous variable of one equation is not an explanatory variable of another), the SUR method leverages the likely correlation between the errors of different equations. It is implemented in three steps: first, OLS estimation of each equation; second, estimation of the variance-covariance matrix of the residuals; and third, parameter estimation using the SUR method.

2. Endogeneity Problem

Endogeneity of a parameter or variable refers to the correlation between that parameter or variable and the error term. This violates the fifth assumption of the Ordinary Least Squares (OLS) method. Endogeneity can arise from measurement error, autoregressive processes, or the omission of a relevant variable. Consequently, the estimation of the coefficient of interest may lead to misleading, illusory, or even fallacious conclusions. In econometrics, endogeneity problems stem mainly from three sources:

📖 **Source 1 : Simultaneity**

A central problem causing biased coefficient estimates. For instance, if xxx causes y, it must also be true that x is not simultaneously influenced by y. One solution is to instrument the variable x with another variable www that is not affected by y.

📖 **Source 2 : Unobserved heterogeneity**

The relationship between x and y may be confounded by an unobserved third factor z, which affects y. If possible, the model should include a control variable to account for this factor z.

📖 **Source 3 : Measurement error in variables**

Some variables may be measured imprecisely, leading to bias in the estimation of the coefficient of interest and thus to invalid conclusions.

3. Study Data

Within the framework of the econometric analysis methodology, the development of the simultaneous equations model on one hand, and the design of the spatial model on the other, are based on variables reconstructed from the World Bank platform. Although the analysis concerns multiple phenomena centered around economic growth and sustainable development, we provide a detailed description of these variables in the table below. The context of our study focuses on 54 African countries, excluding Western Sahara (not recognized by the UN), over the period from 1960 to 2016. Due to missing data in several variables, the year 2017 was not included.

4. Expected Signs of the Coefficients

In line with the literature review, the impact or elasticity of an exogenous variable on the endogenous variable is reflected by the estimated coefficients. The table below summarizes the expected signs for each variable in the simultaneous equations model:

Table 6: Expected Signs of the Model Coefficients.

Study variables	Descriptions / Labels of Variables	Expected Signs
PIBh	Gross Domestic Product per capita	+
PIBhp	Lagged Gross Domestic Product per capita	+
PIBh2	Squared Gross Domestic Product per capita	-
PIBh3	Cubed Gross Domestic Product per capita	
TEP	Savings rate (%)	+
TCP	Population growth rate	-
TOU	Economic openness rate (%)	+/-
PSE	Share of services sector (%PIB)	+/-
PIN	Share of industry sector (%PIB)	+/-
PAG	Share of agriculture sector (%PIB)	+/-
ENC	Net capital inflows	+/-
NBE	Number of primary school students	+
NSG	Average population growth rate (%)	-
CO2	CO2 emissions per capita	+
CO2p	lagged CO2 emissions per capita	
UEH	Energy consumption per capita	+
TCOU	Coverage rate (%)	+/-
DCMS	Final household consumption expenditure	+/-

EEN	Share of income for natural resource depletion (%RNB)	+
EAD	Share of income for CO2 damage (%RNB)	+
IGI	Gini coefficient	
TAP	Literacy rate (%)	-
TCH	Unemployment rate (%)	+
ISR	Income tax	+/-

ource: Author, 2018.

5. Presentation of the Economic Growth and Sustainable Development Model in Africa

We consider the simultaneous equations model in the following structural form :

- **Economic growth equation:**

$$\ln(PIBH_{i,t}) = a_1 + B_{11}.\ln(TEP_{i,t}) + B_{12}.\ln(NSG_t) + B_{13}.\ln(NBE_{i,t}) + \mu_{1t} \quad \textbf{(1)}$$

- **Conditional growth convergence equation::**

$$\ln(PIBH_{i,t}) = a_1 + B_{21}.\ln(PIBH_{t-1}) + B_{22}.\ln(TEP_t) + B_{23}.Ln(TCP_{i,t}) + B_{24}.\ln(TOU_t) + B_{25}.\ln(PSE_{i,t}) + B_{26}.\ln(PIN_{i,t}) + B_{27}.\ln(PAG_{i,t}) + B_{28}.\ln(ENC_t) + B_{29}.\ln(NBE_{i,t}) + \mu_{2t} \quad \textbf{(2)}$$

- **CO2 emissions equation :**

$$\ln(CO2_{i,t}) = a_3 + B_{31}\ln(PIBH_{i,t}) + B_{32}.\ln(PIBH^2_{i,t}) + B_{33}.\ln(PIBH^3_{i,t}) + B_{34}.\ln(UEH_{i,t}) + B_{35}.\ln(TCOU_{i,t}) + B_{36}.\ln(DCMS_{i,it}) + B_{37}.\ln(EEN_{i,t}) + B_{38}.\ln(EAD_{i,t}) + \mu_{3t} \quad \textbf{(3)}$$

- **Green Solow model :**

$$\ln(CO2_{i,t}) = a_4 + B_{41}.\ln(CO2_{i,t-1}) + B_{42}.\ln(TEP_{i,t}) + B_{43}.\ln(TCP_{i,t}) + B_{44}.\ln(TOU_{i,t}) + B_{45}.\ln(PSEi_{,t}) + B_{46}.\ln(PINi_{,t}) + B_{47}.\ln(PAGi_{,t}) + B_{48}.\ln(ENC_{i,t}) + B_{49}.\ln(NBE_{i,t}) + \mu_{4t}$$

(4)

⌗ **Income inequality equation:**

$$\ln(IGI_{i,t}) = a_5 + B_{51}.\ln(PIBH_{i,t}) + B_{52}.\ln(PIBH^2_{i,t}) + B_{53}.\ln(PIBH^3_{ti,}) + B_{54}.\ln(TCP_{i,t}) + B_{55}.\ln(TOU_{i,t}) + B_{56}.\ln(TAP_{i,t}) + B_{57}.\ln(TCH_{i,t}) + B_{58}.\ln(ISR_{i,t}) + \mu_{3t} \quad \textbf{(5)}$$

Avec :

ln : Logarithm of the variable

μ_{nt} : Error term of the equation

In practice, the goal is to estimate the model from its structural form. The consistency of this system lies in the interdependence of the variables in each equation. However, the reduction of the model consists in substituting the explanatory endogenous variables by their respective values. Mathematically, this involves a reduction exercise by substitution or combination, which can indeed be solved using matrix methods. Given the number of variables, the calculations may become very large.

6. Identification of the equations of the economic growth and sustainable development model

Identifying the simultaneous equations model consists of specifying the most appropriate estimation method for each econometric equation in order to obtain reliable estimators that can be economically interpreted and serve as better decision-making tools. To do this, we distinguish the endogenous and exogenous variables of the model, as well as any possible restrictions. Thus, we consider :

- Y : The number of endogenous variables in the model
- y : The number of endogenous variables in the equation
- X : The number of exogenous variables in the model
- x : The number of exogenous variables in the equation
- k : The number of restrictions in the equation

The model specification conditions are presented as follows:

- ☑ Si (Y-y) + (X-x) +k < (Y-1) => Then the equation is over-identified, so we can use Two-Stage Least Squares (TSLS) estimators.

- ☑ Si (Y-y) + (X-x) +k = (Y-1) => If the equation is exactly identified, we can choose between Two-Stage Least Squares (TSLS) or Indirect Least Squares (ILS) methods.

- ☑ Si (Y-y) + (X-x) +k > (Y-1) => If the equation is under-identified, then no estimation method is appropriate in this case.

Let's begin by identifying the first equation of the model:

In total, we have listed three endogenous variables and twenty exogenous variables in the model. Thus, we have Y= 3 et X=21, Therefore, for each equation, the identification proceeds as follows:

» **Economic Growth Equation:**

$$\ln(PIBH_{i,t}) = a_1 + B_{11}.\ln(TEP_{i,t}) + B_{12}.\ln(NSG_{i,t}) + B_{13}.\ln(NBE_{i,t}) + \mu_{1t}$$

- y = 1, x = 4 et k=0, alors (3-1) + (21-4) +0 > (3-1)

The inequality condition for identification indicates that the estimators of equation (1) are provided by the two-stage least squares method (2SLS); indeed, we are in the case of over-identification.

» **Conditional convergence test equation for economic growth:**

$$\ln(PIBHt) = a_1 + B_{21}.\ln(PIBH_{t-1}) + B_{22}.\ln(TEP_t) + B_{23}.\ln(TCP_t) + B_{24}\ln(TOU_t) + B_{25}\ln(PSE_t) + B_{26}.Log(PIN_t) + B_{27}.\ln(PAG_t) + B_{28}.\ln(ENC_t) + B_{29.}\ln(NBE_t) + \mu_{2t}$$

- y = 1, x = 10 et k=0, alors (3-1) + (21-10) + 0 > (3-1)

The inequality in the identification relation indicates that the estimators of equation (2) are those provided by two-stage least squares, due to its over-identification.

» **CO_2 Emissions Equations :**

$$\ln(CO2_{i,t}) = a_3 + B_{31}\ln(PIBH_{i,t}) + B_{32}.\ln(PIBH^2_{i,t}) + B_{33}.\ln(PIBH^3_{i,t}) + B_{34}\ln(UEH_{i,t}) + B_{35}\ln(TCOU_{i,t}) + B_{36}.\ln(DCMS_{i,t}) + B_{37}\ln(EEN_{i,t}) + B_{38}.\ln(EAD_{i,t}) + \mu_{3t}$$

- y = 2, x = 8 et k=0, alors (3-2) + (21- 8) + 0 > (3-1)

The inequality in the identification condition confirms that the estimators of equation (3) are those obtained through the two-stage least squares method, due to over-identification.

» **Equations for testing conditional convergence of CO_2 emissions:**

$$\ln(CO2_{i,t}) = a_4 + B_{41}.\ln(CO2_{i,t-1}) + B_{42}.\ln(TEP_{i,t}) + B_{43}.\ln(TCP_{i,t}) + B_{44}.\ln(TOU_{i,t}) + B_{45}.\ln(PSE_{i,t}) + B_{46}.\ln(PIN_{i,t}) + B_{47}.\ln(PAG_{i,t}) + B_{48}.\ln(ENC_t) + B_{49}.\ln(NBE_{i,t}) + \mu_{4t}$$

- y = 1, x = 10 et k=0, alors (3-1) + (21-10) +0 > (3-1)

The inequality in the identification condition confirms that the estimators of equation (4) are those provided by the two-stage least squares method, due to its over-identification.

» **Income Inequality Equation :**

$$\ln(IGI_{i,t}) = a_5 + B_{51}.\ln(PIBH_{i,t}) + B_{52}.Log(PIBH^2_{i,t}) + B_{53}.\ln(PIBH^3_t) + B_{54}.\ln(TCP_{i,t}) + B_{55}.\ln(TOU_{i,t}) + B_{56}.\ln(TAP_{i,t}) + B_{57}.\ln(TCH_{i,t}) + B_{58}.\ln(ISR_{i,t}) + \mu_{3t}$$

- y = 2, x = 8 et k=0, alors (3-2) + (21-8) +0 > (3-1)

The inequality in the identification condition confirms that equation (5) is over-identified and that, consequently, the most appropriate method is two-stage least squares.

7. Analysis of the Estimation Results of the Simultaneous Equations Model

Before interpreting the results of our estimations, it is necessary to establish a number of hypotheses based on the literature review concerning economic growth and sustainable development in Africa. We will thus analyze five equations within a model. These include the economic growth equation and the convergence test for economic analysis in Africa; the Environmental Kuznets Curve equation to study the relationship between growth and the environment in Africa; and the Social Kuznets Curve equation to examine the relationship between growth and income inequality in Africa.

The hypotheses guiding our investigation into economic growth and sustainable development in Africa are as follows:

- H1: The relationship between physical capital and human capital in Africa is positively associated with economic growth.
- H2: There is no conditional convergence among economies, nor in CO_2 emissions in Africa.
- H3: The Environmental Kuznets Curve relationship may not exist between economic growth and CO_2 emissions in Africa.
- H4: The Social Kuznets Curve relationship may also not exist between economic growth and income inequality in Africa.
-

In the following section, we will examine the results of the simultaneous equations model estimated using the OLS, TSLS, 3SLS, I3SLS, and SUR methods, as described below:

Table 7 : Summary of Two-Stage Least Squares (TSLS) Indicators for the Simultaneous Equations Model.

System Results Method: TSLS						
system	N	DF	SSR	detRCov	OLS-R2	McElroy-R2
	2495	2453	783.651	8,00E-06	0.735576	0.971438

	N	DF	SSR	MSE	RMSE	R2	Adj R2
CroissanceEconomique	499	495	318.91404	0.644271	0.802665	0.266061	0.261613
ConvergenceCroissance	499	489	8.89393	0.018188	0.134863	0.979532	0.979155
EmissionCO2	499	490	46.53667	0.094973	0.308177	0.933171	0.932080
ConvergenceCO2	499	489	5.43384	0.011112	0.105414	0.992197	0.992053
InegalitéRevenue	499	490	403.87264	0.824230	0.907871	0.424568	0.415173

The covariance matrix of the residuals					
	CroissanceEconomique	ConvergenceCroissance	EmissionCO2	ConvergenceCO2	InegalitéRevenue
CroissanceEconomique	0.63910629	0.01715486	-0.02156460	-0.00386413	0.08784746
ConvergenceCroissance	0.01715486	0.01782351	0.00110740	0.00167683	-0.00741901
EmissionCO2	-0.02156460	0.00110740	0.09325987	0.00522796	-0.09070614
ConvergenceCO2	-0.00386413	0.00167683	0.00522796	0.01088946	0.00161842
InegalitéRevenue	0.08784746	-0.00741901	-0.09070614	0.00161842	0.80936400

Table 7 continued

The correlations of the residuals					
	CroissanceEconomique	ConvergenceCroissance	EmissionCO2	ConvergenceCO2	InegalitéRevenue
CroissanceEconomique	1.0000000	0.1607326	-0.0883298	-0.0463193	0.1221436
ConvergenceCroissance	0.1607326	1.0000000	0.0271619	0.1203619	-0.0617700
EmissionCO2	-0.0883298	0.0271619	1.0000000	0.1640519	-0.3301546
ConvergenceCO2	-0.0463193	0.1203619	0.1640519	1.0000000	0.0172391
InegalitéRevenue	0.1221436	-0.0617700	-0.3301546	0.0172391	1.0000000

Source: Author, 2018

The table above presents various indicators relating both to the predictive and explanatory quality of the simultaneous equations model estimated using the two-stage least squares (TSLS) method. Specifically, the statistics describe the overall system as well as each individual equation. The value 2495 corresponds to the number of observations, which implies a degree of freedom of 2453, given that it is the difference between the number of observations and the number of variables. The model demonstrates a fairly good explanatory power, with approximately 73.59% of the variability in CO_2 emissions, human capital (PIBH), and income inequality (IGI) explained and predetermined by the system. Next, in the second part, the explanatory indicators (R^2 and Adjusted R^2) and predictive indicators (SSR, MSE, and RMSE) are presented by equation. There are five equations in total: the economic growth equation, the convergence test equation for economies, the CO_2 emissions equation, the Green Solow model equation, and the income inequality equation. Finally, the residual covariance matrix and the correlation matrix between the model's equations are provided.

Table 8: Estimation Results of the Simultaneous Equations Model.

	OLS estimates for 'CroissanceEconomique' (equation 1)		2SLS estimates for 'CroissanceEconomique' (equation 1)		3SLS estimates for 'CroissanceEconomique' (equation 1)		I3SLS estimates for 'CroissanceEconomique' (equation 1)		SUR estimates for 'CroissanceEconomique' (equation 1)	
	Estimate	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**
Itcpt	0,1490	0,0004	0,1490	0,0004	0,1439	0,0005	0,3595	0,0000	0,1428	0,0006
tep	0,3289	0,0000	0,3289	0,0000	0,3305	0,0000	0,0010	0,8622	0,3309	0,0000
nsg	-0,2208	0,0000	-0,2208	0,0000	-0,2308	0,0000	0,0000	0,7713	-0,2316	0,0000
nbe	-0,0282	0,2469	-0,0282	0,2450	-0,0291	0,2274	-0,0276	0,0000	-0,0278	0,2501
	OLS estimates for 'ConvergenceCroissance' (equation 2)		**2SLS estimates for 'ConvergenceCroissance' (equation 2)**		**3SLS estimates for 'ConvergenceCroissance' (equation 2)**		**I3SLS estimates for 'ConvergenceCroissance' (equation 2)**		**SUR estimates for 'ConvergenceCroissance' (equation 2)**	
	Estimate	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**
Itcpt	0,0233	0,0043	0,0233	0,0039	0,0276	0,0006	0,3595	0,0000	0,0276	0,0007
pibhp	1,0214	0,0000	1,0214	0,0000	0,9936	0,0000	0,0000	0,0000	0,9934	0,0000
tep	0,0051	0,5849	0,0051	0,5811	0,0148	0,1093	0,0010	0,8622	0,0148	0,1136
tcp	-0,0429	0,0004	-0,0429	0,0003	-0,0487	0,0000	0,0000	0,0015	-0,0485	0,0000
tou	0,0113	0,2830	0,0113	0,2781	0,0158	0,1247	0,0000	0,1274	0,0150	0,1496
pse	-0,0514	0,3073	-0,0514	0,3024	-0,0471	0,3359	0,0000	0,3313	-0,0471	0,3409
pin	-0,0474	0,3571	-0,0474	0,3522	-0,0478	0,3399	0,0000	0,3463	-0,0476	0,3466
pag	-0,0690	0,2964	-0,0690	0,2916	-0,0663	0,3027	0,0000	0,3081	-0,0667	0,3045
enc	0,0529	0,0000	0,0529	0,0000	0,0523	0,0000	0,0000	0,0000	0,0523	0,0000
nbe	0,0020	0,6694	0,0020	0,6662	0,0016	0,7310	-0,0276	0,0000	0,0012	0,7930

Table 8 continued

	OLS estimates for 'Emissionco2' (equation 3)		2SLS estimates for 'Emissionco2' (equation 3)		3SLS estimates for 'Emissionco2' (equation 3)		I3SLS estimates for 'Emissionco2' (equation 3)		SUR estimates for 'Emissionco2' (equation 3)	
	Estimate	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**
ltcpt	0,2854	0,0000	0,2830	0,0000	0,2800	0,0000	-0,5895	0,0000	0,2832	0,0000
pibh	0,7002	0,0000	0,8865	0,0000	0,8621	0,0000	3,3873	0,0000	0,6562	0,0000
pibh2	-2,0716	0,0000	-2,6659	0,0000	-2,6539	0,0000	-3,0074	0,0000	-2,0050	0,0000
pibh3	2,2262	0,0000	2,8823	0,0000	2,9583	0,0000	3,4564	0,0000	2,2421	0,0000
ueh	1,0389	0,0000	1,0268	0,0000	1,0530	0,0000	1,0322	0,0000	1,0683	0,0000
tcou	-0,0680	0,0019	-0,0787	0,0003	-0,0584	0,0044	-0,0116	0,5701	-0,0458	0,0236
dcm	-0,0610	0,0130	-0,0719	0,0036	-0,0791	0,0007	-0,0546	0,0120	-0,0663	0,0038
een	-0,0561	0,0198	-0,0395	0,1046	-0,0800	0,0005	-0,0446	0,0434	-0,1007	0,0000
ead	0,1325	0,0000	0,1438	0,0000	0,1468	0,0000	0,1610	0,0000	0,1327	0,0000
	OLS estimates for 'ConvergenceCO2' (equation 4)		**2SLS estimates for 'ConvergenceCO2' (equation 4)**		**3SLS estimates for 'ConvergenceCO2' (equation 4)**		**I3SLS estimates for 'ConvergenceCO2' (equation 4)**		**SUR estimates for 'ConvergenceCO2' (equation 4)**	
	Estimate	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**
(Intercept)	0,0064	0,3134	0,0064	0,3085	0,0032	0,6073	0,0060	0,3382	0,0040	0,5263
co2p	0,9900	0,0000	0,9900	0,0000	0,9864	0,0000	0,9844	0,0000	0,9871	0,0000
tep	0,0021	0,7800	0,0021	0,7778	0,0013	0,8591	0,0020	0,7880	0,0013	0,8577
tcp	-0,0102	0,2447	-0,0102	0,2399	-0,0139	0,1040	-0,0136	0,1085	-0,0135	0,1164
tou	-0,0040	0,6361	-0,0040	0,6327	0,0036	0,6649	0,0035	0,6686	0,0037	0,6646
pse	0,0004	0,9914	0,0004	0,9913	-0,0034	0,9292	-0,0049	0,8961	-0,0018	0,9620
pin	0,0051	0,8979	0,0051	0,8969	0,0003	0,9946	0,0018	0,9620	0,0013	0,9741

Table 8 continued

pag	-0,0118	0,8182	-0,0118	0,8164	-0,0194	0,6984	-0,0182	0,7138	-0,0160	0,7522
enc	0,0139	0,0555	0,0139	0,0531	0,0148	0,0364	0,0152	0,0303	0,0157	0,0287
nbe	-0,0014	0,7052	-0,0014	0,7024	0,0035	0,3204	0,0003	0,9368	0,0033	0,3531
	OLS estimates for 'InegalitéRevenue' (equation 5)		**2SLS estimates for 'InegalitéRevenue' (equation 5)**		**3SLS estimates for 'InegalitéRevenue' (equation 5)**		**I3SLS estimates for 'InegalitéRevenue' (equation 5)**		**SUR estimates for 'InegalitéRevenue' (equation 5)**	
	Estimate	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**	**Estimate**	**Pr(>|t|)**
ltcpt	-0,1288	0,0200	-0,1365	0,0136	-0,1178	0,0311	-1,2272	0,0000	-0,1122	0,0400
pibh	-0,7533	0,0168	-0,4846	0,2122	-0,7202	0,0550	2,4568	0,0000	-0,8943	0,0033
pibh2	5,2383	0,0000	4,4071	0,0004	4,8419	0,0001	4,9946	0,0000	5,3049	0,0000
pibh3	-8,0318	0,0000	-7,0945	0,0000	-7,5253	0,0000	-7,6399	0,0000	-8,0409	0,0000
tcp	0,6705	0,0000	0,7046	0,0000	0,6821	0,0000	0,6914	0,0000	0,6366	0,0000
tou	0,2243	0,0011	0,2238	0,0010	0,1285	0,0477	-0,0143	0,8252	0,1285	0,0482
tap	0,0602	0,3336	0,0569	0,3567	0,0910	0,1160	0,0920	0,1033	0,0972	0,0936
tch	1,2170	0,0000	1,1715	0,0000	1,1944	0,0000	1,1909	0,0000	1,2472	0,0000
isr	-0,1683	0,1009	-0,1756	0,0850	-0,2506	0,0088	-0,2905	0,0019	-0,2474	0,0096

Source : Author, 2018.

Tables (7 and 8) present the estimation results of the simultaneous equations model using two-stage least squares (TSLS), three-stage least squares (3SLS) with and without iterations, and seemingly unrelated regression (SUR) estimators. We have emphasized the importance of the TSLS method when the model's equations are over-identified. However, the information presented goes beyond this point, exposing, among other things, the variety of possible estimations in simultaneous models for comparative purposes, without being exhaustive.

One of the primary motivations of our research is to reach a relevant conclusion by applying different estimators and to understand not only their divergences but also their convergences in order to test the hypotheses formulated in these models.

Thus, the two-stage least squares method (TSLS) illustrated in equation (1) captures the interrelations between economic growth, human capital, and physical capital in an African economy. Equation (2) analyzes the potential existence of absolute or conditional growth convergence among African countries, with the aim of promoting a future federal and continental state for this resource-rich old continent. Equation (3) focuses on the study of carbon dioxide (CO_2) emissions in Africa. Equation (4) examines the possibility of convergence in greenhouse gas emissions in Africa, also known as the Green Solow Model. Finally, the last equation sheds light on income inequality among African countries.

Undoubtedly, these equations highlight the major pillars of economic growth and sustainable development within the African context. It should be noted that this growth is envisioned alongside environmental quality improvement and inequality reduction in Africa. This requires, beforehand, a detailed and specific study of each of these equations over the period from 1960 to 2016.

The two-stage least squares method, given its performance, effectively addresses the endogeneity problem that many models suffer from. Importantly, this aligns with the stochastic assumptions of ordinary least squares estimation.

This refers to a violation of the underlying assumptions upon which the reliability and efficiency of the estimators depend. To address this fundamental issue, the Two-Stage Least Squares (TSLS) method emerged as an effective solution. Nevertheless, for comparison purposes, we also considered other methods whose effectiveness appears as strong as that of TSLS. These include: Three-Stage Least Squares (3SLS), Weighted Two-Stage Least Squares (WTSLS), Weighted Least Squares (WLS), Iterated and Weighted 3SLS, Seemingly Unrelated Regressions (SUR), Instrumental Variables (IV), THEIL-OLS, POOLED-SUR, THEIL-POOLED, THEIL-SUR, POOLED-OLS, Limited Information Maximum Likelihood (LIML), Full Information Maximum Likelihood (FIML), Maximum Likelihood with Missing Values (MLMV), Least Generalized Residual Variance (LGRV), Indirect Least Squares (ILS), K-Class Estimator, Maximum Likelihood (ML), and Least Variance Ratio (LVR).

Most of these methods were explored to compare estimators, particularly to identify those that yield similar results and those that diverge significantly.

Returning to the main objective of this study, it is to verify the key aspects outlined above. Specifically, both the savings rate and physical capital exert a significant and positive effect on economic growth—an outcome well-documented in the literature. Furthermore, our findings suggest that a positive increase in the savings rate results in a 32.89% rise in economic growth, ceteris paribus. However, human capital does not appear to be statistically significant in our results—a negative sign already noted in several previous studies.

Moreover, Mankiw, Romer, and Weil argue that including human capital in the model helps to correct the coefficient of physical capital investment.

Another equation relevant to economic growth is the one predicting conditional or absolute convergence of economies. The estimated convergence coefficient indicates a divergence among African economies when using OLS and TSLS estimators. In contrast, the 3SLS and SUR methods suggest the presence of conditional convergence.

These results are consistent with those found in several studies, including Barro (1991). The convergence speed is more evident when using the 3SLS method, whereas the TSLS method tends to show divergence among African economies.

Moreover, the coefficient for population growth rate indicates a negative impact on economic growth. An increase of one unit in the fertility or birth rate leads to a 4.3% decrease in economic growth. The probability of rejecting this variable is below the 1% significance level, confirming its statistical relevance.

Net capital inflows also demonstrate their role as a driver of growth. A positive and significant one-unit increase in net capital inflows results in a 5.3% rise in economic growth. Still within the framework of human capital, although the sign of the coefficient is positive, the probability of rejecting this variable exceeds conventional thresholds (1%, 5%, and 10%), making it statistically insignificant.

The augmented Solow model and endogenous growth theory appear to support these conclusions in the African context. Physical capital remains a fundamental driver of growth, unlike human capital, whose precise contribution requires further investigation using more robust proxies. However, data limitations remain a challenge in this regard.

Furthermore, the issue of carbon dioxide emissions in Africa is addressed through equations (3) and (4). Beyond Solow's principle, we turn to Kuznets, the renowned American economist and statistician, best known for the controversial inverted-U curve that bears his name. Applied to the African context, this principle yields findings similar to those reported in other studies.

We observe the absence of the traditional inverted-U shape and instead identify an inverted-N shape, as the coefficient of GDP per capita cubed is significantly positive. This result is also supported in several economic studies, including List & Gallet (1999), which notably validate this alternative form of the Kuznets curve.

Among the explanatory variables, per capita energy consumption has a significantly positive effect on CO_2 emissions. A one-unit increase in energy use per capita would lead to a 10.26% rise in CO_2 emissions per capita. Ceteris paribus, trade openness and final household consumption exert a negative influence on CO_2 emissions.

As surprising as it may seem, how can we explain this? It is entirely plausible to be convinced of the potential benefits of globalization on CO_2 emissions in Africa. It is possible that globalization contributes to a reduction in CO_2 emissions. Likewise, household final consumption expenditure appears to follow the same trend. Such spending may reflect an increasing awareness of the environmental degradation crisis and, in turn, a shift toward environmental protection and ecosystem preservation.

It is also realistically observed that the share of income allocated to mitigating environmental damage tends to rise as CO_2 emissions increase. Specifically, a one-unit increase in this expenditure share results in a 14.47% rise in emissions. This suggests a potential endogeneity issue. In reality, it is not environmental protection that causes higher emissions; rather, it is the increase in emissions that drives greater environmental protection efforts.

Regarding the convergence of CO_2 emissions in Africa, our findings confirm that per capita emissions are indeed converging across countries. However, this convergence is not absolute but conditional, with an estimated speed of convergence of 1.4%, corresponding to a half-life of approximately 68.97 years.

Unquestionably, the original Kuznets hypothesis lies in the relationship between income inequality and economic growth. When adapted to environmental studies, it becomes known as the Environmental Kuznets Curve (EKC). The signs of the coefficients in our model suggest a different relationship than that originally proposed by Kuznets — specifically, an inverted-N shape rather than an inverted-U.

Branko Milanovic (1994) suggested incorporating public policy variables and regional heterogeneity indicators in order to test for the presence of an inverted-U relationship.

Our findings indicate that population growth rate positively affects income inequality. A one-unit increase in the population growth rate leads to a 7% increase in income inequality. Similarly, trade openness results in a 2.24% increase in income inequality.

However, the unemployment rate emerges as the main driver of income inequality. An increase in this rate leads to an 11.72% rise in inequality across Africa. The income tax coefficient, although statistically significant, exerts a downward pressure on income inequality. Specifically, a one-unit positive increase in income tax results in a 17.60% reduction in inequality, ceteris paribus.

Regarding the overall model quality, the summary tables of the indicators reveal that direct comparison is somewhat challenging, as the estimation methods produce relatively similar results—particularly for equation (1), where the Ordinary Least Squares (OLS) and Two-Stage Least Squares (TSLS) estimators yield nearly identical coefficient values and signs.

The same observation holds true for the Three-Stage Least Squares (3SLS) estimators. However, the iterated version of 3SLS presents a notably different perspective. To preserve the most efficient, consistent, and convergent estimators—particularly between TSLS and 3SLS—it is advisable to conduct the Hausman endogeneity test. While this test is traditionally applied in panel data analysis to compare fixed-effects (Within) and random-effects (GLS) estimators, it remains useful here to evaluate endogeneity concerns in the context of simultaneous equations.

The table above provides further illustration of this point.

Table 9: Hausman Endogeneity Test.

Hausman specification test for consistency of the 3SLS estimation
data: datar
Hausman = -431.72, df = 42, p-value = 1

Source: Author, 2018.

The value of the Hausman test statistic (-431.72) follows a Chi-squared distribution with 42 degrees of freedom under the null hypothesis. Conventionally, the critical probability (p-value) associated with this test leads us not to reject the null hypothesis at all standard significance levels (1%, 5%, and 10%).

In other words, this result confirms that the Two-Stage Least Squares (TSLS) estimators are more efficient than the Three-Stage Least Squares (3SLS) estimators in this context.

While we have previously discussed conditional convergence in terms of economic growth and sustainable development, what about income inequality? Given the results from standard models on economic growth and sustainable development in Africa over the period 1960 to 2016, what might happen if the econometric analysis were taken a step further—towards spatial modeling?

We now turn to an examination of the spatial effects in our econometric analysis, presented in the following section:

Table 10 : Spatial Durbin Model (SDM) with Different Levels of Effects.

SDM_Effect:	Random	Spatial Fixed	Time Fixed	Spatial & Time Fixed	Direct	Indirect	Total
PIBH	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
TEP	0,1040	0,1307	0,0807	0,0945	0,1044	0,0279	0,1323
NSG	-0,1740	1,0448(**)	-0,2045(*)	0,699(**)	0,9957(.)	-1,0226	-0,0270
NBE	0,0217	-0,1002	-0,1533	-0,2056(*)	0,0502(.)	0,2601(***)	0,3103(***)
_CONS	-0,0273	---	---	---	---	---	---
rhoSpatial	0,31547	0,3552(***)	0,0618	0,1777	0.3185(***)	0.3185(***)	0.3185(***)
sigma2_e	0,474162	0,4683(**)	0,7567(***)	0 .3592(**)	0.4651(*)	0.4651(*)	0.4651(*)
R-sq within	0,0354	0.0147	0.0093	0.0204	0.0362	0.0363	0.0364
R-sq between	0,0922	0.0180	0.1823	0.0044	0.0571	0.0572	0.0573
R-sq overall	0,0619	0.0072	0.0628	0.0056	0.0227	0.0228	0.0229
AIC[1]	**6742,748**	**6393.501**	**7955.609**	**5604.758**	**6467.102**	**6467.102**	**6467.102**
BIC[2]	**6803,069**	**6441.616**	**8003.865**	**5653.014**	**6515.358**	**6515.358**	**6515.358**

Source : Author, 2018

[1] Akaike's information criterion
[2] Bayesian information criterion
Significatif codes : 0.000(***) 0.01 (**) 0.05 (*)

Table 10 presents the estimations of various specifications of the Spatial Durbin Model (SDM) for panel data, including models with random effects, spatial fixed effects, time fixed effects, both spatial and time fixed effects, as well as the decomposition into direct, indirect, and total effects.

A crucial step in spatial econometric modeling is the construction of the spatial weights matrix for the set of African countries. In this study, we employ a standardized contiguity matrix, where two countries sharing a common border are considered neighbors and assigned a value of 1 at the intersection of their respective row and column in the matrix.

However, the literature also discusses distance-based spatial matrices. In the context of optimal zone studies, such as those based on Newtonian gravity models, interactions between countries are often considered based on economic or geographic distance. In our case, interactions are assumed to occur only through land borders.

Interestingly, the spatial effects appear to have a positive influence on the convergence process. The coefficient of human capital remains negative, in line with findings in the existing literature. Meanwhile, the savings rate is not statistically significant across the various SDM specifications.

In spatial econometrics, the impact of an explanatory variable on the dependent variable is a combination of direct and indirect (spillover) effects. As emphasized by LeSage (2008), the impact of a change in an explanatory variable may differ from one country to another; hence, it is essential to compute average effects.

Following Pace and LeSage (2006):

- The average direct effects measure the average impact of a change in an exogenous variable X in country *i* on its own endogenous variable.
- The average indirect effects (spillover effects) measure the average impact of a change in X in neighboring countries on the endogenous variable of country *i*.
- The average total effects represent the sum of direct and indirect effects.

To compare model fit and determine the best spatial specification, we use the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC).

Finally, we extend our analysis by applying the Hausman test in the context of spatial panel models, which is detailed in the next section.

Ho: difference in coef. not systematic chi2(7) = 20.23   Prob>=chi2 = 0.0051

Furthermore, the Hausman test applied to the spatial model rejects the null hypothesis of the random effects model at all conventional significance levels (1%, 5%, and 10%). This result indicates that the fixed effects specification is more appropriate for our analysis.

Indeed, fixed effects allow us to account for country-specific unobserved heterogeneity, capturing structural characteristics that vary across countries but remain constant over time.

Table 11 : Results of the Dynamic Spatial Models of Augmented Solow Convergence.

SPATIAL LAG MODEL - MAXIMUM LIKELIHOOD ESTIMATION				
Variable	Coefficient	Std.Error	z-value	Probability
$PIBH_{t-1}$	0.994021	0.00423097	234.939	0.00000
CONSTANT	-0.228739	0.025729	-8.89033	0.00000
TEP	0.146241	0.0334097	4.3772	0.00001
TCP	-0.291423	0.0355937	-8.1875	0.00000
TOU	0.0587641	0.0297768	1.97348	0.04844
PSE	0.808924	0.104137	7.7679	0.00000
PIN	0.919016	0.114266	8.0428	0.00000
PAG	0.593933	0.145699	4.07644	0.00005
ENC	-0.304159	0.0299262	-10.1636	0.00000
R-squared				0.625846
Sq. Correlation				-
Sigma-square				0.372245
S.E of regression				0.610118
Schwarz criterion				1292.6
Akaike info criterion				1252.05
Lag coeff. (Rho)				0.994021
Mean dependent var				0.222906
S.D. dependent var				0.997445

SPATIAL LAG MODEL - MAXIMUM LIKELIHOOD ESTIMATION				
Variable	Coefficient	Std.Error	z-value	Probability
$PIBH_{t-1}$	0.994021	0.00423097	234.939	0.00000
CONSTANT	-0.227094	0.026843	-8.46007	0.00000
TEP	0.147192	0.0337004	4.36767	0.00001
TCP	-0.290937	0.0356642	-8.15767	0.00000
TOU	0.0569627	0.0309333	1.84147	0.06555
PSE	0.809579	0.104178	7.77113	0.00000
PIN	0.921555	0.114871	8.02252	0.00000
PAG	0.596098	0.146042	4.0817	0.00004
ENC	-0.305095	0.0302406	-10.0889	0.00000
NBE	-0.00416199	0.0193674	-0.214897	0.82985
R-squared				0.625872
Sq. Correlation				-
Sigma-square				0.372219
S.E of regression				0.610097
Schwarz criterion				1372.13
Akaike info criterion				1327.07
Lag coeff. (Rho)				0.994021
Mean dependent var				0.222906
S.D. dependent var				0.997445

Source : Author, 2018

The adjacent table presents the estimation results of the spatial Solow growth model. The literature offers a variety of dynamic approaches that incorporate a lagged endogenous variable. In this context, we highlight several examples of such models, focusing in particular on the Spatial Durbin Model (SDM) and the dynamic Spatial Autoregressive Model (SAR), estimated here using the maximum likelihood method as employed by Elhorst (2011), LeSage (2008), and Baumont & Le Gallo (2000).

The maximum likelihood estimators in the dynamic panel spatial framework prove to be highly competitive and confirm, when accounting for spatial effects, the existence of conditional convergence among African economies. Furthermore, most control variables are statistically significant, with the notable exception of human capital.

Although the savings rate is significant, it exerts a positive effect on per capita growth. Specifically, a one-unit increase in the savings rate corresponds to a 14.72% increase in growth, ceteris paribus. Conversely, the population growth rate negatively affects economic growth; a 100% increase in demographic growth leads to a 29% decline in economic growth.

Additionally, the openness rate positively influences per capita GDP, with a one-unit rise resulting in a 5.7% increase in economic growth. Contrary to traditional findings where sectoral shares often show negative signs, here the coefficients are positive. An increase of one unit in the industrial sector share is associated with more than a 92% increase in economic growth. Similarly, the service sector contributes to over an 80% rise in per capita GDP with a unit increase, while agriculture, although having the smallest effect among the three, still yields over a 59% growth increase for a unit rise in its share.

Finally, human capital exhibits a negative sign, consistent with previous studies such as Mankiw, Romer, and Weil (1992) under standard growth regimes.

Table 12 : Estimation of Dynamic Spatial Models of the Green Solow Model.

Spatial Lag Green Solow Model - Maximum Likelihood Estimation					**Spatial Lag Green Solow Aug. Model - Maximum Likelihood Estimation**				
Variable	Coefficient	Std.Error	z-value	Probability	Variable	Coefficient	Std.Error	z-value	Probability
CO_{2t-1}	0.994021	0.00423097	234.939	0.00000	CO_{2t-1}	0.994021	0.00423097	234.939	0.00000
CONSTANT	-0.222907	0.0334959	-6.65476	0.00000	CONSTANT	-0.264955	0.0344818	-7.68391	0.00000
TEP	0.0859553	0.04352	1.97508	0.04826	TEP	0.0616495	0.043313	1.42335	0.15464
TCP	-0.292954	0.0463649	-6.31845	0.00000	TCP	-0.305376	0.045837	-6.66221	0.00000
TOU	-0.13102	0.0387878	-3.37786	0.00073	TOU	-0.0849809	0.0397567	-2.13753	0.03256
PSE	0.578147	0.13565	4.26204	0.00002	PSE	0.561407	0.133893	4.19294	0.00003
PIN	0.74764	0.148844	5.02297	0.00000	PIN	0.682752	0.147636	4.62455	0.00000
PAG	0.284755	0.18979	1.50037	0.13352	PAG	0.229434	0.187698	1.22236	0.22157
ENC	-0.163332	0.0389824	-4.1899	0.00003	ENC	-0.139409	0.0388663	-3.58688	0.00033
NBE					NBE	0.106368	0.0248918	4.27323	0.00002
R-squared				0.402314	R-squared				0.402314
Sq. Correlation				-	Sq. Correlation				-
Sigma-square				0.631627	Sigma-square				0.614845
S.E of regression				0.79475	S.E of regression				0.784121
Schwarz criterion				1646.34	Schwarz criterion				1634.83
Akaike info criterion				1605.79	Akaike info criterion				1589.77
Lag coeff. (Rho)				0.994021	Lag coeff. (Rho)				0.994021
Mean dependent var				0.114855	Mean dependent var				0.114855
S.D. dependent var				1.028	S.D. dependent var				1.028

Source : Author, 2018

This table presents the estimation results of the dynamic spatial panel model. Specifically, it aims to highlight the CO_2-GDP relationship in a panel framework while accounting for spatial effects, particularly the borders between African countries. Although our primary focus has been to test the Kuznets Curve hypothesis in Africa, the relationship between economic growth and carbon dioxide emissions is generally characterized by a concave curve. This suggests that emissions initially increase during economic growth, followed by a decline as growth continues. In this study, we seek to verify, building on previous work, the possible existence of conditional convergence in CO_2 emissions, incorporating spatial effects.

To this end, the Green Solow Model (GSM) and its spatial extension (GSMA) address this objective. Notably, the model that includes human capital proves particularly insightful, as it indicates evidence of conditional convergence of CO_2 emissions in Africa. This finding aligns well with the results from the Solow model analysis. The additional inclusion of human capital is both coherent and significant, with a one-unit increase leading to a 10.63% rise in GDP per capita in Africa. Moreover, human capital substantially improves model performance, reflected by a slight reduction in residual errors and improved coefficient estimates with expected signs, such as physical capital (proxied by the savings rate) and human capital.

The savings rate, coverage rate, and the shares of the industrial, service, and agricultural sectors in GDP all exert positive effects on GDP per capita. Conversely, the population growth rate and net capital inflows negatively impact GDP per capita. It is worth noting, however, that the inclusion of human capital did not improve model performance or estimator efficiency in the augmented Solow model. These results are consistent with the findings of Lucas (1988) and Becker, Murphy, and Tamura (1990) within a standard growth framework.

Conclusion :

The statistical analysis results align with the econometric approach. The simultaneous equations model using panel data, although complex to implement, incorporates various economic concepts such as the economic growth equation, the conditional convergence equation of economic growth, the Environmental Kuznets Curve, the Green Solow Model, and the Social Kuznets Curve. This model of economic growth and sustainable development in Africa examines the three dimensions of sustainable development within a single system.

The analyses allowed for the estimation of several estimators including two-stage least squares (TSLS) for the simultaneous equations model, three-stage least squares (3SLS), and iterative three-stage least squares (I3SLS) among others. Our results confirm the conclusions of Mankiw, Romer and Weil from 1992 which state that countries with higher levels of human and physical capital are more likely to experience strong economic growth in the future. Conditional convergence is observed both for economic growth and carbon dioxide emissions in Africa.

Regarding the Kuznets model, our findings are similar to those of List and Gallet in 1999 who identified an inverted N-shaped relationship for sulfur dioxide emissions across 48 US states between 1929 and 1994 using a seemingly unrelated regression model. The literature also reports the existence of the Environmental Kuznets Curve in studies by Galeotti and colleagues in 2009 and by Dijkgraaf and Vollebergh in 2005. The study period, number of countries considered, choice of variables, and estimation methods can influence whether the inverted U-shaped curve is observed.

Moreover, diagnostics of the Social Kuznets model also reveal the presence of an N-shaped relationship in Africa from 1960 to 2016. Milanovic in 1994 suggested including public policy variables and regional heterogeneity to further test the Kuznets hypothesis concerning long-term income inequality. In both carbon dioxide emissions and income inequality, two turning points, a minimum and a maximum, are detected within the African context.

General Conclusion:

In conclusion, the study on economic growth and sustainable development in Africa proves to be highly insightful. We conducted two main methodological analyses: statistical and econometric. Regarding the statistical analyses of economic growth and sustainable development variables, we highlighted descriptive statistics for each quantitative variable, including dispersion measures, positional indicators, skewness, and kurtosis. Additionally, to explore the linear relationship between pairs of variables, we employed Pearson's correlation coefficient alongside its graphical representation through correlograms.

For the multidimensional analysis, we applied Bartlett's test and the Kaiser-Meyer-Olkin measure to assess the suitability of this approach. Multivariate analysis involved representing M variables and N observations within an N-dimensional space, aiming to capture the complex relationships among variables. One of the final steps in the statistical work was hierarchical ascending classification of both variables and individuals, which allowed us to identify groups of countries that are homogeneous or heterogeneous with respect to economic growth and sustainable development.

Regarding the econometric approach, we analyzed economic growth and sustainable development within a simultaneous equations panel data framework. We further extended this analysis to a spatial setting by constructing a weight matrix for the African continent. Within this framework, five equations were examined across a panel of 54 countries: the economic growth equation, the conditional convergence equation from 1905, the Environmental Kuznets Curve equation from 1992, the Green Solow model equations developed by Brock and Taylor in 2004 and 2010 as well as by Islam in 1995, and finally the Social Kuznets equation from 1955.

All these equations were integrated into a simultaneous equations model with the ultimate goal of testing the interactions among economic growth, CO2 emissions, and income inequality in the African context.

Recommandations :

Studies on the three pillars of sustainable development have unanimously highlighted critical observations essential for shaping future decisive projects aimed at promoting sustainable development in Africa.

From the perspective of economic growth, the savings rate plays a significant role and further propels the African economy. Indeed, it remains one of the main drivers of growth in Africa. Conversely, demographic growth negatively impacts economic growth. Nonetheless, this underscores the urgent need for substantial investment in education, particularly in promoting high-quality training across all educational levels. Such investment would lay a solid foundation for significant technological progress in Africa. This progress is likely to continuously stimulate economic activities while simultaneously delaying the convergence of the economy toward a steady-state. Additionally, net capital inflows also contribute positively to economic growth in Africa.

Regarding CO_2 emissions, the idea of quickly catching up in terms of environmental degradation appears unrealistic for Africa. Fossil fuel consumption per capita is a critical factor driving environmental degradation in Africa, more so than economic activities themselves. However, trade has helped mitigate CO_2 emissions. Therefore, it is crucial to strengthen trade relations further to reduce greenhouse gas emissions. Moreover, enhancing trade and diversifying energy dependence are essential strategies to better address climate change challenges. The share of income allocated to resource depletion contributes to improving and preserving environmental quality and helps reduce greenhouse gas pollution (CO_2).

Concerning income inequality in Africa, trade openness is, in fact, one of the factors exacerbating inequalities, despite its necessary role in combating pollution. Moreover, it contributes to increasing income inequality on the continent. The unemployment rate also remains a primary factor explaining income disparities. To address this social imbalance, it is necessary to implement fiscal adjustments through income taxation, which serves as a corrective mechanism for income inequality and promotes a fairer distribution of wealth across Africa.

As emphasized by Mr. Cheikh Anta Diop in his commitment to a prosperous Africa both economically and culturally, African countries must revisit their investments in education and work toward creating a population that is as well-educated as those in industrialized countries.

Finally, all of this will only be possible through the African Union's commitment to science promotion by establishing a continental university institution — an "African Harvard" that is multidisciplinary, rigorous, and highly qualified to train future leading African intellectuals and world-class laureates, including Nobel Prize winners. This calls for a strong commitment from public decision-makers, as Africa faces significant educational deficits.

Indeed, it is through quality education that the technical progress necessary for the economy can be achieved. It is also through quality education that energy dependence can be diversified. Strengthening Africa's human capital is a decisive step toward its economic flourishing in the short and medium term.

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Tables of Contents

Appendix :

Table 12: Country-wise Estimation of Equation 1: Economic Growth.

	Coefficients			
	(Intercept)	tep	nsg	nbe
AGO	0.24301048	0.006643362	NA	1.5233048
BEN	-0.15583264	-0.038525895	NA	0.5477773
BWA	24.56057634	-0.073734695	NA	44.8914384
CIV	0.15045194	NA	NA	NA
COD	-0.40457403	NA	NA	NA
CPV	0.97001393	NA	NA	NA
DZA	-0.26092256	0.450156183	NA	0.9229280
EGY	-0.70199915	-0.267806973	NA	0.4552704
ETH	0.12315132	-0.418852748	NA	NA
GAB	-15.53530375	-5.093596934	NA	-46.6310557
GHA	-0.39851328	-0.201345962	NA	0.7345414
GMB	5.24069006	-0.012026284	NA	10.1547751
GNB	5.50535542	0.158889663	NA	10.6798604
KEN	-0.50808139	-0.064122532	NA	0.2140208
LBY	-20.19187923	0.923942395	NA	-57.0068062
LSO	-0.09477045	NA	NA	NA
MAR	-0.24901601	-0.026607207	NA	1.2073597
MOZ	-0.45376911	0.044827832	NA	0.1654409
MUS	-217.58986717	0.193776946	NA	-380.6760080
NAM	26.30131738	-0.355895621	NA	51.5024542

Table 12 (continued)

NGA	-1.27731431	0.181604630	NA	0.2020273
SEN	-0.01329459	-0.202241478	NA	0.9788068
SWZ	19.48828892	-0.189888844	NA	34.4150353
SYC	1.80323418	13.926166886	NA	NA
TGO	-0.22871195	0.008637184	NA	0.3781610
TUN	0.97740519	-1.940838352	NA	-2.3274020
ZAF	3.78349001	-2.617888159	NA	-0.9520191
ZMB	-0.26515307	-0.152468556	NA	1.8151407

Sources : Author, 2018

Table 13: Country-wise Estimation of Equation 3: Environmental Kuznets Curve.

	Coefficients:								
	(Intercept)	pibh	pibh2	pibh3	ueh	tcou	dcms	een	ead
AGO	-213,3512	-7,2300	196,1335	-2168,8700	-1,7896	0,0184	0,6068	0,0235	NA
BEN	-29,2476	-0,5861	21,7244	-291,5657	-0,0821	0,0104	-0,3127	0,0476	2,3681
BWA	0,3537	0,8551	-1,9608	2,1067	0,5136	-0,0242	-1,2537	-0,3624	4,1945
CIV	-0,2200	NA	NA	NA	NA	NA	NA	NA	NA
COD	-0,4643	NA	NA	NA	NA	NA	NA	NA	NA
CPV	0,0765	NA	NA	NA	NA	NA	NA	NA	NA
DZA	1,1621	5,8002	-23,3198	38,9283	-1,3056	-0,0530	-0,1473	-0,2987	0,7464
EGY	-0,7339	0,3829	-0,1982	-8,7038	0,2187	-0,0213	0,0132	-0,0008	0,1105
ETH	-0,4101	0,0662	NA	NA	NA	NA	NA	NA	NA
GAB	20,4537	-22,6770	33,6390	NA	NA	NA	NA	NA	NA
GHA	2,2590	0,0668	-2,9909	25,4383	0,1555	0,0172	-0,0575	-0,0340	0,9840
GMB	1,5784	-0,5178	7,1427	NA	0,7679	NA	NA	NA	NA
GNB	-0,5387	0,2322	-1,1343	NA	NA	NA	NA	NA	NA
KEN	-4,8662	0,1805	9,0476	-55,2810	-0,0296	-0,0320	-0,4267	-0,0796	0,2045
LBY	4,6598	0,5084	-0,7866	0,5887	-0,2412	NA	NA	NA	NA
LSO	0,0801	NA	NA	NA	NA	NA	NA	NA	NA
MAR	0,3257	0,1438	0,0715	-2,1986	0,7279	-0,0050	-0,0364	0,1324	0,1689
MOZ	547,0172	14,7176	-426,2368	5461,8470	2,7361	-0,0128	0,0551	-0,0627	-1,0944
MUS	1,0082	0,0851	-0,1040	0,0109	1,0761	0,0116	-0,3276	NA	3,5753
NAM	1,1987	1,1076	-3,8229	7,2586	0,4574	-0,1385	-2,4336	0,4142	5,7839
NGA	-0,2592	0,4879	-0,2018	-2,9434	-0,9413	-0,0064	-0,0958	-0,0731	0,0722

Table 13 (continued)

SEN	40,3957	3,4461	-68,7135	456,7552	0,2921	-0,0471	1,1332	0,1761	-0,1977
SWZ	-23,9351	-32,7528	204,0329	-531,5529	6,8861	NA	NA	NA	NA
SYC	50,7941	-8,8144	NA	NA	NA	NA	NA	NA	NA
TGO	-134,2385	-2,0296	80,6305	-1305,4600	0,3620	-0,0036	1,3917	0,0065	-1,3048
TUN	0,8447	0,6120	-3,2803	6,7332	0,4331	0,0139	-0,4567	0,1383	1,3299
ZAF	0,3779	0,4181	-0,4344	0,4350	1,3233	0,0063	-0,0739	-0,0280	-0,0177
ZMB	-155,3588	-80,4511	647,5934	-2290,4920	NA	NA	NA	NA	NA

Source : Author, 2018

Table 14: Country-wise Estimation of Equation 5: Social Kuznets Curve.

	Coefficients :								
	(Intercept)	pibh	pibh2	pibh3	tcp	tou	tap	tch	isr
AGO	-0,138	0,000	0,000	0,000	0,000	0,000	NA	0,000	NA
BEN	-46,439	-3,798	69,238	-465,099	0,129	0,031	-0,068	-5,373	-2,902
BWA	2,119	0,761	-2,477	3,103	-0,077	0,079	-0,143	0,077	0,064
CIV	-0,423	NA	NA	NA	NA	NA	NA	NA	NA
COD	-0,211	NA	NA	NA	NA	NA	NA	NA	NA
CPV	0,459	NA	NA	NA	NA	NA	NA	NA	NA
DZA	-1,555	-1,129	5,271	-10,327	0,010	-0,301	0,236	-0,144	-0,137
EGY	-1,195	0,033	-1,200	5,194	0,022	-0,020	0,003	-0,352	0,362
ETH	-1,611	0,000	NA	NA	NA	NA	NA	NA	NA
GAB	-0,204	0,000	0,000	NA	NA	NA	NA	NA	NA
GHA	13,851	2,403	-33,117	176,281	0,011	0,136	0,115	-0,253	NA
GMB	0,552	0,000	0,000	NA	0,000	NA	NA	NA	NA
GNB	-0,018	0,000	0,000	NA	NA	NA	NA	NA	NA
KEN	15,059	-2,324	3,906	132,775	-0,255	-0,169	-0,191	0,884	1327,195
LBY	-1,179	0,000	0,000	0,000	0,000	NA	NA	NA	NA
LSO	1,508	NA	NA	NA	NA	NA	NA	NA	NA
MAR	-0,975	0,033	0,488	-4,121	-0,030	0,055	-0,006	-0,022	-0,273
MOZ	0,247	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
MUS	-1,058	-0,002	0,005	-0,003	0,001	0,001	-0,001	0,000	-0,006
NAM	3,044	2,147	-8,877	14,541	-0,129	0,097	-0,251	-0,543	0,108

Table 14 (continued)

NGA	1,153	-0,045	-0,262	3,672	-2,105	-0,048	0,278	1,791	0,845
SEN	52,499	7,068	-108,485	618,939	0,157	-0,240	0,038	1,340	2,291
SWZ	1,242	0,000	0,000	0,000	0,000	NA	NA	NA	NA
SYC	0,406	0,000	NA	NA	NA	NA	NA	NA	NA
TGO	-122,871	-3,653	107,073	-1246,580	0,007	-0,004	0,976	0,649	-0,413
TUN	-0,323	0,519	-2,877	6,424	-0,006	-0,084	0,005	0,226	-0,496
ZAF	1,753	-0,041	0,310	-0,390	0,011	0,016	0,395	-0,230	0,949
ZMB	-288,426	-169,441	1301,234	-4416,210	NA	NA	NA	NA	NA

Source : Author, 2018