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Original Research Article

Catalysing Circular and Sustainable Economy in African Countries

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ABSTRACT

Demographic and climate projections place resource management as a major concern for the African continent. Nevertheless, the capacity to meet this imminent challenge varies considerably across countries. The paper compares the circular and sustainable pathways of African countries and highlights the factors that facilitate or hinder the transition to a circular economy. The paper introduces two indices to assess the circularity of African economies: the static Circular Economy Sustainable Development Index and its dynamic counterpart, which measures the average annual growth of the indicators. It employs regression analysis to explore the factors influencing sustainable development trajectories. The findings delineate divergent sustainable trajectories within Africa, highlighting the pivotal role of the developmental level in catalysing the transition towards a circular economy. Resource rents emerge as a significant obstacle to this transformation. Additionally, enhancements in institutional quality and infrastructure exacerbate resource pressures, creating substantial barriers to the adoption of circular economy principles.

KEYWORDS

Africa, Circular Economy, Sustainable development, Composite indicators, Barriers.

INTRODUCTION

The concept of the circular economy (CE) has significantly gained attention in recent years, emerging as a viable alternative to the traditional linear model. The CE prioritises efficient resource allocation while decoupling economic growth from resource consumption [1]. It emphasises a balance between economic prosperity and environmental sustainability [2]. Additionally, the CE plays a vital role in reducing inequalities, promoting sustainable development [3] and driving job creation [4].

Several developed countries are leading the way in promoting CE. In the EU, national CE policies focused on reducing, reusing, and recycling have significantly contributed to climate neutrality, particularly in Germany and Ireland [5]. In Asia, countries such as Japan and South Korea have placed greater emphasis on public awareness and accountability for resource use [6]. Nevertheless, the full integration of CE into less developed countries has not yet occurred [7], which hinders the global transition to CE [8]. Consequently, there is a strong, urgent need to invest in diverse contexts and to gain a comprehensive understanding of the characteristics of the regional CE model [9]. The African continent presents a particularly intriguing case. Approximately 62% of Africa's GDP is closely linked to natural

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resources, underscoring the importance of transitioning to a CE model [10]. Conversely, the continent faces high poverty rates, unplanned urban development, and vulnerability to climate change [11]. Such factors intensify the pressure on the availability of food, water, energy, and land [12].

This situation prompts the question of whether this fragility is a hindrance to the transition to a CE or a catalyst that encourages countries to embrace change. To what extent does resource availability influence the circular trajectory of African countries? Is weak development a barrier to the integration of circular practices? If so, how can it be overcome? To what extent does the level of development of African countries affect their ability to adopt a circular path?

This research aims to explore the CE model within the African context, an area that has received limited attention in previous research. To this end, the paper first proposes to assess the circular trajectories of African countries using two composite indices. A static index measures a country's efforts over a period, and a dynamic index shows the average annual rate of progress of African countries over time. This evaluation will lead to a typology of African countries based on their efforts to implement the CE. Second, the paper sheds light on the main factors influencing the circular trajectories of African countries. This approach will allow better targeting of capacity building in developing countries and enable actors to allocate resources more effectively to remove barriers to the adoption of CE principles.

The complexity of assessing the multidimensionality of circular economy

The literature review reveals a fragmented consensus on the definition of the CE, despite research dating back to the 1960s [13]. While many scholars concur that CE encompasses the reduction, reuse, and recycling of raw materials (the 3Rs), others argue that CE transcends environmental considerations to incorporate socio-economic strategies, thereby contributing to global well-being [14]. The challenge of defining CE's scope, akin to an "umbrella concept" [15], complicates the selection of indicators for measuring circularity [16]. To address the gaps in CE monitoring, some studies [17] suggest developing a composite index, though selecting inclusive criteria remains a challenge, necessitating a methodical approach. Studies indicate that the context and geographical implementation area can influence the sustainability and circularity pathways [18]. Indeed, the CE can stray from long-term environmental sustainability when product transformation processes shift one type of pollution to another [19]. A holistic approach ensures interdependence and prevents the focus from being limited to a single Sustainable Development Goal (SDG) [20]. The multidimensional nature of the CE raises questions about prioritising challenges in each context and how different dimensions interact. Addressing CE's main challenge, resource conservation in production and consumption, highlights the critical role of food and energy resources, particularly for African countries [21]. Food and energy are closely linked [22], with rising energy prices affecting the costs of food production, storage, transport, and distribution. Nexus thinking positions the CE as part of an integrated and interdependent sustainability strategy.

Barriers and drivers to circular economy trajectories for African countries

The literature review underscores the pivotal role of governments in fostering the institutional framework and implementation of a transformative change process conducive to the transition to a CE [23]. Furthermore, it identifies numerous barriers and drivers influencing the transition to a CE, with specific implications for the African context [24]. Technical barriers are predominant, as countries require not only access to circular technical solutions but also the capability to implement these solutions swiftly. Information and communication technologies play a crucial role in enhancing these technical capabilities [25]. Technical skills present a significant challenge in Africa, often misaligned with the continent's unique needs and conditions. For example, construction techniques in sub-Saharan Africa mimic those of developed countries, frequently ignoring the local climate and leading to increased energy consumption due to the lack of an adaptive bioclimatic design approach [26]. The excessive dependence on unsustainable techniques, such as the use of off-grid solar technology, results in substantial waste and short product lifespans in the region [27]. Additionally, the scarcity of repair skills and the prevalence of a large informal market undermine countries' technical capabilities [28]. Economic barriers also play a role, with market uncertainties and high costs deterring investment.

Furthermore, socio-economic inertia serves to exacerbate the reliance on unsustainable solutions and to restrict funding for innovation, especially among small and medium-sized enterprises (SMEs) [29]. A number of studies have highlighted that African countries often overexploit resources without satisfying their needs, a situation that is further compounded by low levels of production investment, inadequate infrastructure, suboptimal resource management, and a lack of human resource capacity [22]. Nevertheless, the vulnerability caused by resource depletion or price volatility can also drive the shift towards CE [23].

In order to identify the factors influencing the transition trajectories towards a circular and sustainable economy in African countries, the remainder of the paper is structured as follows: Section 2 outlines the method for assessing the impact of barriers and drivers on the CE trajectory in African countries, addressing the challenges of data collection. Section 3 presents a typology of African countries based on their CE efforts, models the factors influencing CE in Africa, and offers recommendations to enhance circularity. Section 4 concludes with the main findings of the research.

METHOD

The research method (**Figure 1**) is divided into two stages to analyse the factors influencing the CE trajectories in African countries. The first stage proposes a measure of circular trajectories in the African context using a multidimensional approach that facilitates comparisons between countries by combining information into a single value. It responds to the openness of the CE concept, taking into account the interaction between resources such as food, water, land and energy and the trade-off with resource efficiency. The use of both static and dynamic composite indices makes it possible to analyse better the trajectories of African countries and measure their capacity to implement CE models. In a static approach, the Circular Economy Sustainable Development Index (*CESDI*) compares the 54 African countries at a given time[†] and identifies those countries where resource conservation is more critical. Thus, a high CESDI index value, close to 1, indicates the country's ability, compared to other African Countries, to preserve its food and energy resources and distribute them more effectively.

From a dynamic perspective, the circularity of the economy is measured by the average annual growth (aag) of the indicators. The *CESDIaag* captures the improvements made by countries to ensure resource conservation. The higher the *CESDIaag* index value, the stronger the dynamic of CE and natural resource preservation. This approach overcomes the problem of the non-availability of information for specific indicators in the same year, making it possible to compare average annual progress over a given period. In terms of decision-making, the two indices jointly define the priority areas that deserve support to move towards sustainable and circular development.

The second stage highlights the socio-economic, technical and institutional barriers and drivers that influence circularity trajectories in Africa. A multiple regression model is used to identify the factors that explain the *CESDI* and *CESDIaag* indices.

[†] Given that the data used come from different data sources and contain different time periods, *CESDI* is built using different analysis periods in order to cope with the limited availability of data.

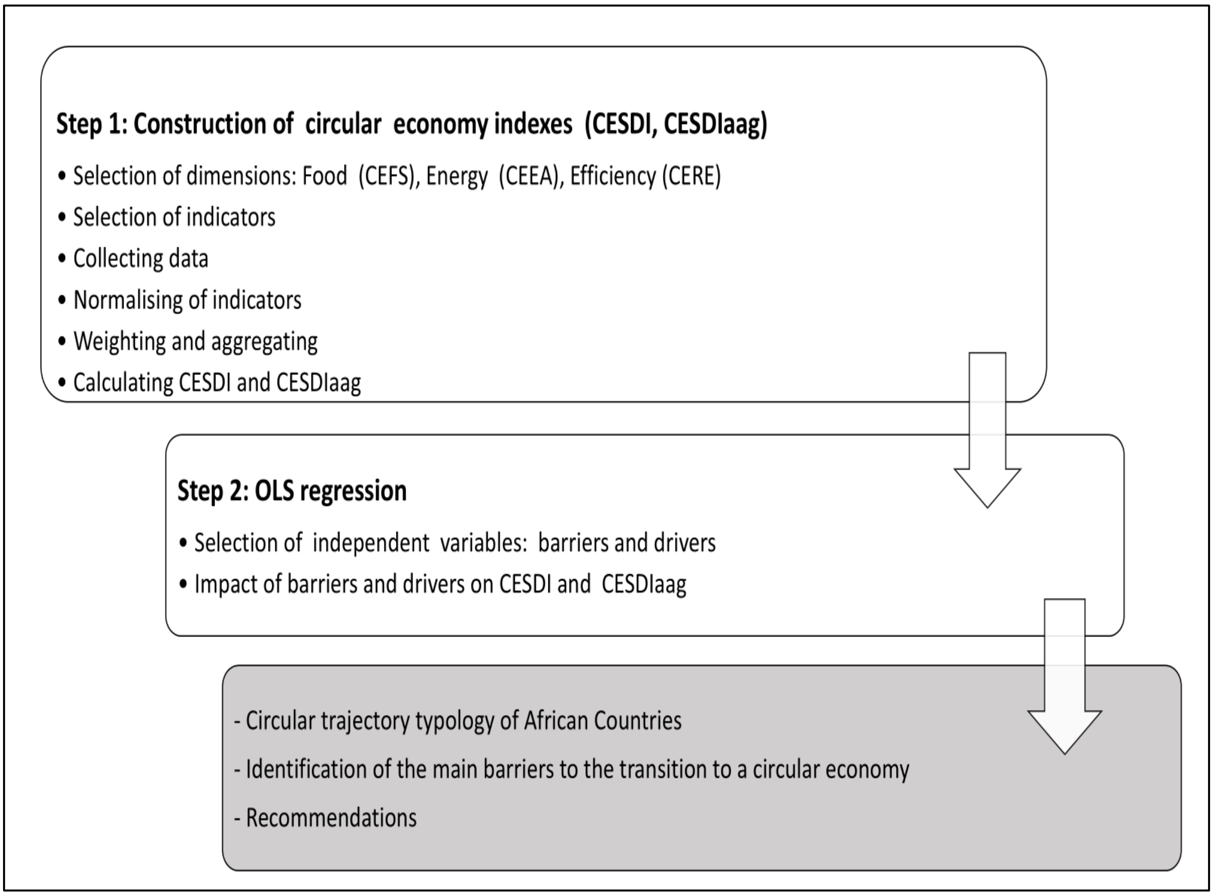

Figure 1. Research purpose steps

Construction of circular economy indexes

Methods for constructing a composite index [30] propose a multi-step approach: defining the object of study with reference to a theoretical context, selecting suitable simple indicators, standardising each indicator and choosing the aggregation method. While there is consensus on the above steps, it is crucial to recognise that the substitutability or non-substitutability of the indicators selected, the aggregation method (complex or simple), the relative or absolute comparison between countries and the indicator weighting method all have a significant impact on the construction of the *CESDI* and *CESDIaag* indices.

Selection of indicators and collecting data. According to the recommendations [31] issued by the OECD, the method of indicator selection refers to the theoretical framework and takes into account their relevance, accessibility, and availability. The selection must ensure a trade-off between the inclusion of redundant variables and the risk of losing information. For this research, the choice of variables relates to a literature review [3], which highlights the CE principles that include the reduction, reuse and recycling of materials and enable the conservation and efficient use of food and energy resources.

The indices cover three dimensions and a total of twelve variables using a holistic approach that recognises the interconnectedness of resources. First, the food-forest-water nexus is at the heart of sustainable food security. Second, the energy dilemma lies in determining the optimal trade-off between promoting renewable energy and ensuring equitable access to electricity and depends on environmental regulation measured by three indicators: the Nationally Determined Contributions (NDC)[‡] indicator measures mitigation and adaptation targets, the number of Multilateral Environmental Agreements (MEA) in

[‡] All African countries except Libya have ratified the 2015 Paris Agreement defining the NDC system

force measures countries' commitment to environmental issues and the number of National Environmental Policies (NEP) in force measures the level of current national efforts to regulate the environment. Finally, for resource efficiency, the Domestic Material Consumption (DMC) per GDP indicator, defined as the global amount of material (biomass, fossil fuels, metal ores and non-metallic minerals) used by the economy, measures the national intensity of resource use [32]. It includes domestic extraction related to the raw material, as well as the physical import of the material, and excludes the physical export.

Table 1. Variables measuring circular economic sustainable development indexes (*CESDI* and *CESDIaag*)

Dimension of *CESDI*/ *CESDIaag*	Variables	CE principles
Circular economy for food security (CEFS)	Agricultural land per capita	Reuse and regenerate land under demographic pressure
	Forest area per land area	Reduce deforestation externality
	Total renewable water resources	Reuse renewable water resources
	Total population with access to drinking water	Equitable access to drinking water
Circular economy for energy availability (CEEA)	CO_2 emission per capita	Reduce carbon emission
	Percentage of renewable energy consumption	Reduce fossil energy and reuse renewable energy
	Environmental regulation (composite indicator)	Reduce pollution and resource depletion
	Access to electricity	Equitable access to energy
Circular economy for efficient resource (CEER)	Domestic material consumption per GDP	Reduce material consumption
	Waste generation	Reduce waste generation
	Recycling rate	Recycle
	GDP per capita	Ability to create value and richness

Enriching the index with other indicators. Data availability and index simplicity have been taken into account. The construction of the index is challenged by the unavailability of data for specific dates. In many cases, several sources are utilised to complete the missing data, as shown in **Table 2**. All referenced sites rely on internationally recognised official sources or the public entities that produce them to ensure data reliability. For the waste generation indicator, the World Bank's 2016 estimate [33] and the latest available data from World Bank reports are used to calculate *CESDIaag*.

For certain countries, such as Equatorial Guinea, Eswatini and Somalia, data availability is limited. The average waste generation corresponding to each country's development level in 2010 was applied to address this: upper-middle income for Equatorial Guinea and lower-middle income for Eswatini and Somalia.

Table 2. Method for collecting data for *CESDI* and *CESDIaag* (* calculated by the author)

Indicator	Sources	*CESDI* Year	*CESDIaag* Annual growth rate between
I^1.0^: Agricultural land per capita	[34] Sudan [35], South Sudan [36], Eritrea [37]	2016	2010–2016
I^2.0^: Forest area/ Land area	[34] Sudan [36], South Sudan [38]	2016	2010–2016 South Sudan 2013–2016
I^3.0^:Total renewable water resources	[39]	2017	2012–2017
I^4.0^: Population with access to drinking water	[39]	2015	2012–2015
I^5.0^: Air pollution	[34]	2016	2010–2016 Seychelles 2012–2016
I^6.0^: Environmental regulation	Composite indicator *		
I^6.1^: NDC	[40]	2015	2010–2015
I^6.2^: NEP	[41]	2020	2010–2020
I^6.3^: MEA	[41]	2020	2010–2020
I^7.0^: Renewable energy consumption	[34]	2015	2010–2015 South Sudan 2012–2015
I^8.0^: Access to electricity	[34]	2018	2010–2018 Equatorial Guinea 2011–2018
I^9.0^: DMC per unit GDP	[42]	2015	2010–2015. South Sudan 2012–2015
I^10.0^: Waste generation	[43], [33]	2016 (estimated data)	Last available data–2016 (estimated data)
I^11.0^: GDP per capita	[34]	2016	2010–2016
I^12.0^: Recycling rate	[43], [33]	Last avail-able data	Last available data: after 2015, before 2015

Information on recycling is also scarce in African countries, where the strong presence of the informal recycling sector further complicates this situation. The lack of available data suggests the absence of a formal national system and recycling strategy. It also reflects a reluctance to integrate the informal sector and signals a potential worsening of the situation without appropriate measures. Due to the scarcity of information, the absence of official data in this study is interpreted as a lack of formal and inclusive recycling activities, recorded as zero.

The construction of the indices allows indicators to be interchangeable in their contribution to circularity. Strong performance in one area, such as reduced waste generation, can compensate for weaker performance in another, such as reduced material consumption or reduced deforestation, reflecting the specific priorities and circumstances of each country.

Method of normalising indicators

Normalisation is required before aggregation and allows for the comparison of indicators on different scales by transforming them into normalised values in the range 0–1. The normalisation method depends on the type of comparison (absolute or relative). A relative comparison was chosen to assess and benchmark the performance of different African countries effectively. The value of the normalised index that tends to 1 indicates a significant contribution to the country's circularity compared to other African countries. On the other hand, when the value reaches 0, the country's performance is weak compared to all African countries.

Table 3 summarises the normalisation approach by presenting selected indicators with different units, each reflecting a key dimension of the CE in Africa.

Table 3. Method of normalising indicators for *CESDI*

Indicator	Unit	Year	$maxX^{i.s}$	$minX^{i.s}$	Contribution
$y^{1.0}$: Agricultural land/ Total population	km^2/cap	2016	0.16 Namibia	0.00016 Seychelles	+
$y^{2.0}$: Forest area/ Land area	%	2016	90.04 Gabon	0.074 Egypt	+
$y^{3.0}$:Total renewable water resources	m^3/cap/ year	2017	158,145 Congo	13.75 [a] Seychelles	+
$y^{4.0}$: Population with access to drinking water	%	2015	100	47.9 Equatorial Guinea	+
$y^{5.0}$: Air pollution	t CO_2/cap/ year	2016	8.480 Uganda	0.0256 Central A.R.	-
$y^{6.0}$: Environmental regulation					+
$y^{6.1}$: NDC [b]	%	2015	89 Namibia	0 [c] South Africa	+
$y^{6.2}$: NEP		2020	76 South Africa	0	+
$y^{6.3}$: MEA		2020	449 Morocco	43 South Sudan	+
$y^{7.0}$: Renewable energy consumption	%	2015	100	0 Algeria	+
$y^{8.0}$: Access to electricity	% of population	2018	100	11.02 Burundi	+
$y^{9.0}$: GDP per capita	constant USD 2010	2016	13,606 Seychelles	90.72 Somalia	+
$y^{10.0}$: DMC per GDP	kg/ USD 2005	2015	15.76 Sierra Leone	0.16 Seychelles	-
$y^{11.0}$: Waste generation	kg/cap/ day	2016	1.57 Seychelles	0.11 Lesotho	-
$y^{12.0}$: Recycling rate	%	Last available data	28 South Africa	0	+

[a] Limited to the total capacity of dams per capita assumed constant since 1989 for Seychelles.
[b] For Tanzania, the NDC ranges from 10 to 20, with an average value of 15 considered.
[c] South Africa does not commit to a reduced level, but it offers a three-phase approach: peak, plateau and decline, and an emission level between 398–614 Mt CO_2 eq.

The data are collected for the same year to facilitate comparison. The contribution column specifies whether an indicator positively or negatively affects CE performance. The *maxX* and *minX* columns indicate the countries with the highest and lowest values for each indicator, respectively. These insights reveal regional disparities and diverse circular economy trajectories across Africa, facilitating cross-country comparisons and highlighting sustainability performance gaps.

The max-min method is applied for normalisation, utilising equations (1) and (2). For both equations, $y_j^{i.s}$ represents the normalised value of the indicator $I^{i.s}$ for the given country j, while $X_j^{i.s}$ denotes the raw value of the same indicator for country j.

The parameters are defined as follows: j varies from 1 to N where N = 54 represents the number of African countries, i ranges from 1 to 12 representing different indicators included in the construction of *CESDI* and *CESDIaag* indices, s takes the value 0 when the indicator is directly integrated into the calculation of *CESDI* and *CESDIaag* values and ranges from 1 to 3 for indicators used to construct the environmental regulation composite indicator $y^{6.0}$, $maxX^{i.s}$ and $minX^{i.s}$ are the maximum and minimum values of $X_j^{i.s}$ across all countries.

$$y_j^{i.s}(X_j) = \frac{X_j^{i.s} - minX^{i.s}}{maxX^{i.s} - minX^{i.s}} \tag{1}$$

Alternatively

$$y_j^{i.s}(X_j) = \frac{X_j^{i.s} - maxX^{i.s}}{min\,X^{i.s} - maxX^{i.s}} \tag{2}$$

Eq. (1) normalises data where the high value indicates more circularity and contribution to Africa's sustainable development challenges, such as agricultural land, total renewable water resources and other indicators mentioned in **Table 3**. Eq. (2), on the other hand, normalises data where a low value indicates more contribution to CE, such as waste generation, air pollution and domestic material consumption.

The following example illustrates the calculation method using eq. (1) for the normalised indicator of Agricultural land per capita in Gabon. In this case, i = 1, s = 0 and j = Gabon. The raw value of the indicator is $X_{Gabon}^{1.0}$ = 0.0317. From **Table 3**, the raw maximum value is $maxX^{1.0}$= 0.16 (observed in Namibia), and the raw minimum value is $minX^{1.0}$ = 0.00016 (observed in Seychelles).

The normalised indicator value is then calculated as follows:

$$y_{Gabon}^{1.0}(X_{Gabon}) = \frac{X_{Gabon}^{1.0} - minX^{1.0}}{maxX^{1.0} - minX^{1.0}} = 0.197$$

Another example illustrates how eq. (2) can be used to calculate the normalised indicator $y^{5.0}$ for air pollution in Gabon. In this case, i = 5, s= 0. The raw air pollution value for Gabon is $X_{Gabon}^{5.0}$ = 0.2474, recorded in the database **[34]**. From **Table 3**, the raw minimum value is $minX^{5.0}$= 0.0256, observed in the Central African Republic, while the raw maximum value, $maxX^{5.0}$= 8.480, is recorded in Uganda.

The normalised indicator value is then calculated as:

$$y_{Gabon}^{5.0}(X_{Gabon}) = \frac{X_{Gabon}^{5.0} - maxX^{5.0}}{minX^{5.0} - maxX^{5.0}} = 0.973$$

For *CESDIaag*, $X_j^{i.s}$ is replaced by $X_{j\ aag(Tf-Tk)}^{i.s}$ in equations (1) and (2) to normalise the average annual growth for the rate of indicator $I^{i.s}$ over a given period (T_f–T_k). $X_{j\ aag(Tf-Tk)}^{i.s}$ represents the average annual growth rate of the indicator $X_j^{i.s}$ over the period (T_f–T_k) as shown in eq.(3), $maxX_{aag}^{i.s}$ and $minX_{aag}^{i.s}$ are the maximum and minimum values of $X_{j\ aag(T_f-T_k)}^{i.s}$ across all countries. For each indicator, T_f is the most recent date and T_k is the initial date. So,

$$X_{j\ aag(T_f-T_k)}^{i.s} = \sqrt[(Tf-Tk)]{\frac{X_{j\ T_f}^{i.s}}{X_{j\ T_k}^{i.s}}} - 1 \tag{3}$$

Thus, in the case of Gabon, and referring to the indicator agricultural land per capita, T_f corresponds to the year 2016 and T_k to the year 2010, as specified in **Table 2**, so (T_f – T_k) = 6. On this basis, it can be deduced that:

$$X_{Gabon\ aag(6)}^{1.0} = \sqrt[6]{\frac{X_{Gabon\ 2016}^{1.0}}{X_{Gabon2010}^{1.0}}} - 1 = -0.034729$$

The normalised value is then deduced by applying eq. (1), given that indicator values are $maxX_{aag}^{1.0} = -0.00428$ and $minX_{aag}^{1.0} = -0.0839$, so $y_{aag\ (6)Gabon}^{1.0}\ (X_{Gabon}) = 0.617$.

Weights and aggregation

The normalised data are aggregated. Thus, the *CESDI* is a composite of three dimensions having the same ponderation as mentioned in eq. (4).

$$CESDI_j = \frac{1}{3} \times \left(CEFS_j + CEEA_j + CEER_j\right) \tag{4}$$

Each dimension is composed of four equally weighted indicators, as explained in eq. (5).

$$CEFS_j = \frac{1}{4}\sum_{i=1}^{4} y_j^{i.0},\ CEEA_j = \frac{1}{4}\sum_{i=5}^{8} y_j^{i.0},\ CEER_j = \frac{1}{4}\sum_{i=9}^{12} y_j^{i.0} \tag{5}$$

Thus, the composite *CESDI* index is the sum of 12 indicators, as specified in eq. (6). All integrated indicators are simple, except for that related to environmental regulation, which is itself a composite indicator consisting of three indicators, as mentioned in eq. (7). So,

$$CESDI_j = \propto_i \sum_{i=1}^{12} y_j^{i.0} \tag{6}$$

$$y_j^{6.0} = \frac{1}{3} \times \left(y_j^{6.1} + y_j^{6.2} + y_j^{6.3}\right) \tag{7}$$

Where $\propto_i$ is the weight given to the *i*-th indicator. The value of $\propto_i$ indicates the degree of importance of each variable in the construction of the index. The choice of the weight given to each dimension is an arbitrary decision [30]. In this research, the same weight (equal to $\frac{1}{3} \times \frac{1}{4}$) is assigned to the indicators to emphasise the equal importance of each dimension and each indicator, while the variables are combined using an additive function.

The classification of countries based on the method of nested averages will make it possible to establish a typology of African countries in terms of their static and dynamic circular economy performances.

Ordinary Least Square regression

In order to measure the impact of barriers and drivers on the CE trajectory of African countries, the following models represented by equations (8) and (9) are considered:

$$\text{Model 1: } CESDI_j = \beta_1^{(1)} Z_{1j} + \beta_2^{(1)} Z_{2j} + \cdots \beta_k^{(1)} Z_{kj} + \varepsilon_{kj}^{(1)} \quad (8)$$

$$\text{Model 2: } CESDIaag_j = \beta_1^{(2)} Z_{1j} + \beta_2^{(2)} Z_{2j} + \cdots \beta_k^{(2)} Z_{kj} + \varepsilon_{kj}^{(2)} \quad (9)$$

Where *CESDI* and *CESDIaag* are the dependent variables, $\beta_k^{(1)}$ and $\beta_k^{(2)}$ are the coefficients of the regressions and Z_{kj} are the different independent variables for the countries identified by subscript *j*, *ε* is the error term.

In this study, Stata software was used to perform Ordinary Least Squares (OLS) regression analysis to estimate the association between the independent variables (*CESDI*, *CESDIaag*) and different barriers and drivers affecting the CE. OLS regression, a linear modelling technique, was chosen for its ability to model relationships involving multiple dependent and independent variables [44]. The factors influencing CE (underlined names in **Table 4**) are indicative of the barriers and drivers discussed in the literature presented in the first section. Some factors were omitted from the models due to multicollinearity concerns or other considerations.

The OLS method is a statistical technique that seeks to minimise the sum of the squared differences (residuals) between observed values and those predicted by the model. The estimated coefficients $\hat{\beta}_k$ quantify the individual contribution of each independent variable, indicating the marginal effect of each explanatory variable on the dependent variable. Under the standard assumptions of linearity, homoscedasticity, and error independence, OLS produces unbiased and efficient estimators with the lowest possible variance. Hypothesis testing to assess the statistical significance of an explanatory variable is performed on its corresponding *β* coefficient. The null hypothesis (H_0: $\beta_k = 0$) states that the variable has no effect on the dependent variable. The standard error (SE) quantifies the uncertainty surrounding the estimation of the coefficient $\hat{\beta}_k$. It is directly involved in the calculation of the Student's *t*-test statistic, presented in eq. (10), which is used to evaluate the validity of the null hypothesis. If this hypothesis is rejected, it suggests that the variable significantly contributes to predicting or explaining the target variable.

$$t = \frac{\hat{\beta}_k}{SE\,(\hat{\beta}_k)} \quad (10)$$

Table 4. Factors impacting circular economy trajectories in African countries

Factors	Variables	Description	Source	Year
Technical	Technical cooperation grants (BoP, current USD) Technic	Captures the amount of subsidies intended to strengthen technical skills transfer	[34]	2017
Socio-economic	Population living in slums (% of urban population) Slums	Measures the infrastructure barriers	[34], [45], [46]	2018 2014 Mauritius, Libya, Eritrea, Somalia, South Sudan, Seychelles and Djibouti
	Total natural resources rents (% of GDP) Rent	Measures a country's production structure and the share of rent in the value created.	[34]	2018 2015 South Sudan, 2011 Eritrea
	Human development index HDI	Measures the country's level of socio-economic development.	[47]	2018 2012 Somalia
	Foreign direct investment, net inflows (% of GDP) FDI	Captures the transfer of technology and know-how between countries.	[34]	2019 2015 South Sudan 2011 Eritrea
Institut-ional	Government effectiveness Government	Estimates the perceptions of the quality of public services.	[34]	2019

RESULTS AND DISCUSSION

The results provide valuable insights into the potential for a CE within the African context characterised by economic, climatic, and institutional vulnerabilities. Firstly, the findings highlight the efforts of African countries in key areas such as food, energy, and resource efficiency. This allows for the identification of circular trajectories for 54 African countries, relying on the *CESDI* and *CESDIaag* indices. The second part presents an analysis of the technical, socio-economic, and institutional factors that influence the circular trajectories of African countries.

Circular economy trajectories of African countries

Figure 2 provides an analysis of the static and dynamic circular performances of African countries in terms of food (CEFS, CEFSaag), energy (CEEA, CEEAaag) and resource efficiency (CEER, CEERaag).

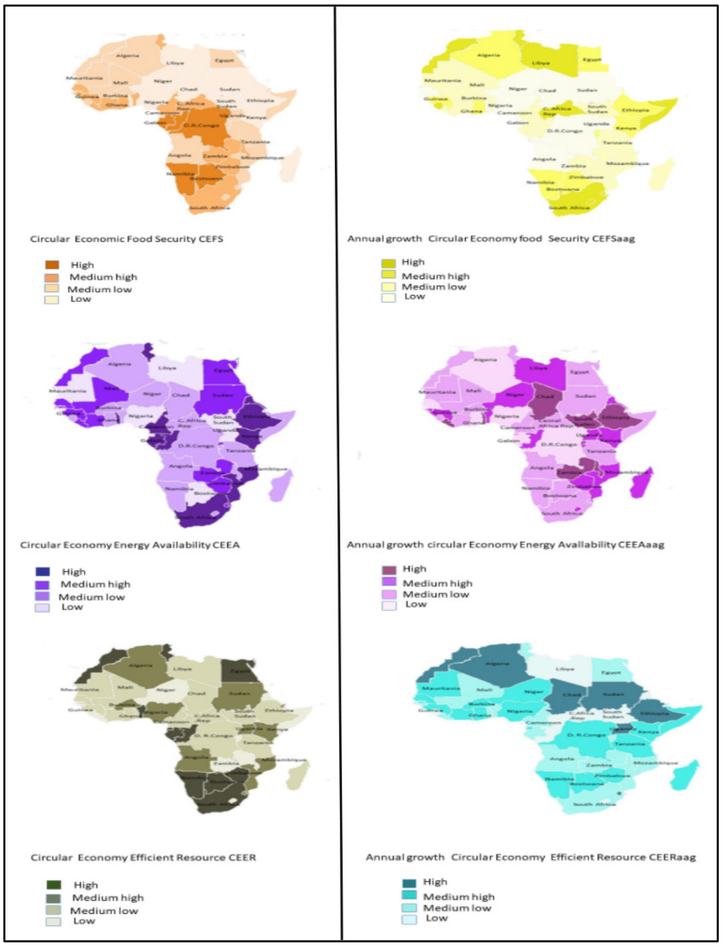

Figure 2. Performance levels of African countries related to CEFS, CEFSaag, CEEA, CEEAaag, CEER and CEERaag

Regarding food, the CEFS map shows that neighbouring countries, both low- and high-CEFS ones, face similar water, land and deforestation nexus for countries. This finding is confirmed by the CEFSaag map, which delineates the dynamic perspective and reveals a clustering of low dynamic countries in the central and western regions facing significant challenges, in particular, political conflicts that impede the rapid implementation of essential economic and political reforms in the agricultural sector [48]. For energy, the CEEA map shows that the main producers of fossil energy (oil and gas) in Africa, such as Nigeria, Algeria, Libya and Egypt [49], are not well classified according to CEEA. The abundance of fossil natural resources prevents the consideration of long-term strategies, such as the transition to renewable energy and the reduction of pollution. Renewable energy is not considered as part of a sustainable and equitable energy access strategy for African countries, as also mentioned by other studies [50]. The CEEAaag map shows that Malawi, Liberia, Rwanda, Ethiopia and Seychelles have made the most efforts to strengthen energy availability. At the same time, Algeria, Chad, Djibouti and Senegal are the least developed countries on this axis.

In terms of resource efficiency, the CEER map highlights the ability of African countries to decouple growth from resource use. It indicates that South Africa, the Republic of the Congo, Equatorial Guinea, and Mauritius are the best performers in the static approach (CEER). Using the dynamic approach, Uganda, Comoros, Ethiopia, Sudan, Mauritius, and Eswatini (Swaziland) have made the most progress.

Appendix **Tables A1** and **A2** show the results of applying the *CESDI* and *CESDIaag* indices to 54 African countries and compare their performance in static and dynamic approaches. This ranking serves as the basis for defining a typology of African countries in terms of their circular and sustainable performances, as illustrated in **Figure 3**.

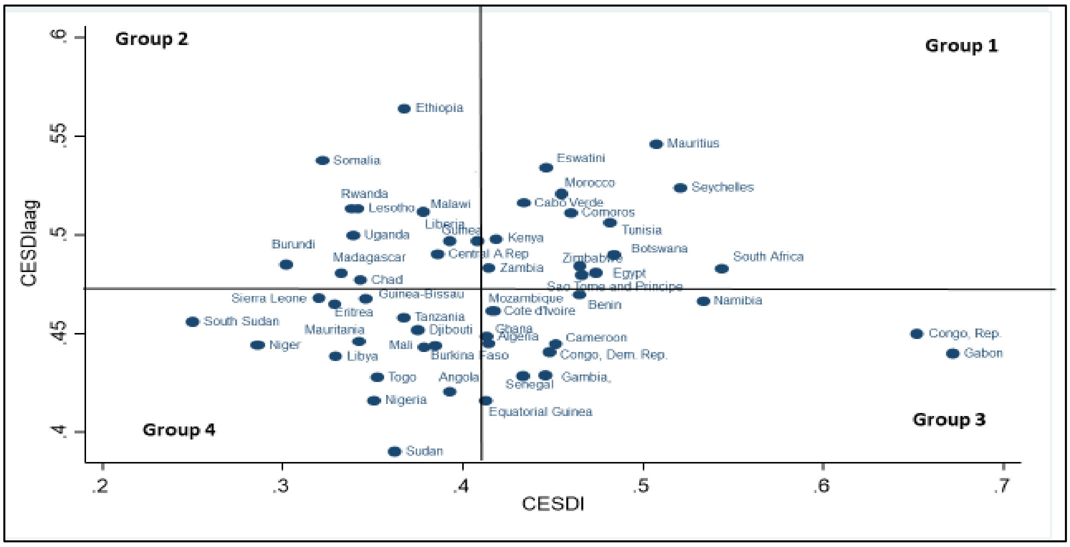

Figure 3. Typology of African countries according to *CESDI* and *CESDIaag* performances

Each country is placed on the graph according to its performance on the *CESDI* (horizontal axis) and the *CESDIaag* (vertical axis). Thus, the first group, "constantly moving forward", is made up of countries whose *CESDI* and *CESDIaag* performances are above average. These countries are in an interesting CE dynamic. This group includes five island countries: Cape Verde, São Tomé and Principe, Comoros, Mauritius and the Seychelles. Despite their vulnerability to climate change, they have risen to the challenge of implementing optimal resource management. Group 2 "be awake" is made up of countries that have a low *CESDI* but a high *CESDIaag*. Some disadvantaged and low-development countries, particularly those in the eastern region, are making good progress that will allow them to catch up and move to CE in the future. These include countries such as Ethiopia, Somalia, Rwanda, Lesotho and Burundi.

On the other hand, group 3 "stay stagnant" is made up of countries with high *CESDI* and low *CESDIaag* values. The countries in this group have interesting circular performances compared to other African countries. Still, they are not in a circular dynamic that could allow for the prediction of future progress. Many of these countries are in West Africa. Some of them have benefited from an abundance of natural resources, especially fossil resources. The last group, "unable", represents the countries that are in the most critical situation with a low *CESDI* and a low *CESDIaag*. It includes countries such as South Sudan, Niger, Libya and Togo.

Barriers and drivers to a circular economy for African countries

The results of the regressions in **Table 4** provide further explanation of the typology of African countries. The R-squared indicates that more than 97% of *CESDI* and *CESDIaag* are explained by the independent variables, which confirms the goodness of fit of the models. Additionally, the significance levels reflect the statistical confidence in the observed relationships: *** denotes a highly significant result with a probability of randomness below 1%, ** indicates statistical significance with a probability below 5%, and * represents moderate significance with a probability of randomness up to 10%.

Model 1 results demonstrate a positive relation between *CESDI* and variable HDI. This relationship is significant at a 99% level and indicates that human development has an impact on the ability of African countries to adopt circular and sustainable approaches. The higher a country's level of development, the more likely it is to adopt the principles of a CE. Conversely, low development represents a significant barrier to the transition to a CE. This result is in line with Beckerman's work [51] on the Kuznets Environmental Curve, which demonstrates that development is the key to better environmental quality. The positive and significant relationship between *CESDIaag* and HDI in Model 2 confirms the importance of human development as the driving force behind a circular trajectory.

The estimation results show a significant and negative relationship between resource rents (variable Rent) and *CESDIaag*, indicating that the more the economy of an African country is based on resource rents, the weaker the dynamics of the transition towards a circular economy.

Table 4. The results of OLS regression; *** = p < 0.01, ** = p < 0.05, * = p < 0.10

	Model 1: *CESDI*		Model 2: *CESDIaag*	
	β	t	β	t
Technic	−1.37 e−10	−1.12	6.04 e−11	0.52
Slums	0.001	1.65	0.002	4.01***
Rent	0.001	1.03	−0.002	−1.94*
HDI	0.666	17.51***	0.643	17.81***
FDI	0.001	0.69	0.002	1.12
Government	0.008	0.33	−0.335	−1.73*
R squared	0.9769		0.982	
Prob > F	0.0000		0.0000	

The government effectiveness variable (Government) is significant and negative in Model 2. Circular dynamics are highest in countries where the perception of the quality of public services is lowest. This result may appear counterintuitive, but it underscores the intricate nexus between the quality of institutions and the pressure on resources in the African context. Indeed, some studies have demonstrated that low institutional quality is indicative of a high level of corruption, which reduces the attractiveness of resource-intensive projects, thereby contributing to enhanced environmental preservation [52]. Consequently, the quality of institutions does not appear to be a driver behind the transition to the CE in Africa.

This finding is corroborated in countries that also exhibit unsustainable infrastructure, as measured by the proportion of urban population living in slums (variable Slums). The positive and significant relationship between *CESDIaag* and the percentage of the population living in slums shows that it is in countries with the highest rate of slums that progress in resource conservation is most significant. Thus, the quality of the infrastructure is conducive to resource-intensive projects. The results of the estimated models show that the transfer of technical skills (variable Technic) and direct foreign investment (variable FDI) do not have a significant impact on the transition to CE in the African context. In this context, at present, the transfer of techniques does not contribute to resource circularity.

CONCLUSIONS

The paper shows divergent trajectories towards circular and sustainable development. The OLS method was used to identify factors that either hinder or drive circular transitions in African countries. Countries with a high level of human development can make the transition to CE. However, this transition is slowed by economic barriers, primarily when economic activity is based on resource rents. This situation leads to inertia towards change, low acceptance of new, clean technologies and a resource curse. Moreover, the reinforcement of institutional and infrastructural quality does not facilitate the transition to a CE; rather, it exerts additional pressure on African countries' resources.

Given this situation, public policies must promote the diversification of African economies in order to move away from the resource rent economy. It is also important to give priority to local African techniques rather than transferring techniques that are not adapted to the African context. There is an urgent need to integrate international cooperation and capacity-building efforts into sustainable development objectives and to ensure that improving the quality of institutions and infrastructure does not lead to additional pressure on African countries' resources.

NOMENCLATURE

Abbreviations

CE	Circular Economy
CEEA	Circular Economy for Energy Availability
CEER	Circular Economy for Efficient Resource
CEFS	Circular Economy for Food Security
CESDI	Circular Economy Sustainable Development Index
DMC	Domestic Material Consumption
GDP	Gross Domestic Product
GHG	Greenhouse Gas
MEA	Multilateral Environmental Agreement
NDC	Nationally Determined Contribution
NEP	National Environmental Policies
OECD	Organisation for Economic Cooperation and Development
OLS	Ordinary Least Squares
SDG	Sustainable Development Goal
SME	Small and Medium-sized Enterprise

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APPENDIX

Table A1. Ranking of the African countries according to the *CESDI*

Rank	Country	CEFS	CEEA	CEER	*CESDI*
1	Gabon	0.636	0.795	0.584	0.671
2	Congo Republic	0.601	0.671	0.684	0.652
3	South Africa	0.266	0.655	0.710	0.543
4	Namibia	0.505	0.553	0.541	0.533
5	Seychelles	0.475	0.586	0.500	0.520
6	Mauritius	0.306	0.620	0.595	0.507
7	Botswana	0.474	0.425	0.552	0.484
8	Tunisia	0.271	0.644	0.528	0.481
9	Sao Tome and Principe	0.411	0.578	0.431	0.473
10	Egypt	0.248	0.596	0.553	0.466
11	Zimbabwe	0.257	0.574	0.563	0.465
12	Benin	0.257	0.548	0.587	0.464
13	Comoros	0.262	0.670	0.447	0.460
14	Morocco	0.229	0.613	0.521	0.454
15	Cameroon	0.267	0.670	0.417	0.451
16	Congo (RDC)	0.452	0.533	0.359	0.448
17	Eswatini	0.243	0.613	0.482	0.446
18	Gambia	0.347	0.615	0.374	0.445
19	Cabo Verde	0.275	0.598	0.427	0.433
20	Senegal	0.278	0.612	0.409	0.433
21	Kenya	0.104	0.673	0.478	0.418
22	Mozambique	0.187	0.637	0.427	0.417
23	Cote d'Ivoire	0.272	0.554	0.422	0.416
24	Ghana	0.321	0.549	0.373	0.414
25	Zambia	0.297	0.612	0.334	0.414
26	Algeria	0.189	0.545	0.505	0.413
27	Equatorial Guinea	0.190	0.408	0.639	0.412
28	Guinea	0.257	0.600	0.366	0.408
29	Liberia	0.339	0.556	0.283	0.393
30	Angola	0.173	0.530	0.474	0.392
31	Central African Republic	0.262	0.521	0.374	0.386
32	Burkina Faso	0.229	0.483	0.441	0.384
33	Mali	0.195	0.570	0.371	0.379
34	Malawi	0.301	0.518	0.314	0.378
35	Djibouti	0.231	0.453	0.441	0.375
36	Ethiopia	0.087	0.661	0.355	0.368
37	Tanzania	0.194	0.546	0.361	0.367
38	Sudan	0.086	0.556	0.444	0.362
39	Togo	0.092	0.626	0.339	0.352
40	Nigeria	0.127	0.479	0.445	0.350
41	Guinea-Bissau	0.385	0.336	0.317	0.346
42	Chad	0.081	0.545	0.403	0.343
43	Mauritania	0.197	0.408	0.422	0.342
44	Lesotho	0.186	0.500	0.338	0.341
45	Uganda	0.183	0.366	0.467	0.339
46	Rwanda	0.194	0.558	0.263	0.338
47	Madagascar	0.122	0.527	0.348	0.333
48	Libya	0.147	0.460	0.382	0.329
49	Eritrea	0.125	0.649	0.212	0.329
50	Somalia	0.173	0.553	0.239	0.322
51	Sierra Leone	0.231	0.507	0.223	0.320
52	Burundi	0.169	0.530	0.205	0.301
53	Niger	0.087	0.495	0.275	0.286
54	South Sudan	0.129	0.208	0.413	0.250

Table A2. Ranking of the African countries according to the *CESDIaag*

RANK	Country	CEFSaag	CEEAaag	CEERaag	*CESDIaag*
1	Ethiopia	0.515	0.619	0.559	0.564
2	Mauritius	0.672	0.449	0.518	0.546
3	Somalia	0.668	0.503	0.442	0.538
4	Eswatini	0.595	0.493	0.514	0.534
5	Seychelles	0.470	0.615	0.487	0.524
6	Morocco	0.594	0.476	0.491	0.521
7	Cabo Verde	0.636	0.529	0.384	0.516
8	Rwanda	0.525	0.636	0.380	0.514
9	Lesotho	0.671	0.549	0.320	0.513
10	Malawi	0.460	0.680	0.395	0.512
11	Comoros	0.469	0.502	0.563	0.511
12	Tunisia	0.639	0.489	0.391	0.506
13	Uganda	0.289	0.539	0.672	0.500
14	Kenya	0.505	0.556	0.433	0.498
15	Liberia	0.477	0.650	0.366	0.497
16	Guinea	0.493	0.534	0.465	0.497
17	Central African Republic	0.651	0.500	0.320	0.490
18	Botswana	0.534	0.510	0.425	0.490
19	Burundi	0.521	0.563	0.371	0.485
20	Zimbabwe	0.465	0.536	0.452	0.484
21	Zambia	0.442	0.589	0.418	0.483
22	South Africa	0.585	0.470	0.393	0.483
23	Sao Tome and Principe	0.517	0.519	0.407	0.481
24	Madagascar	0.475	0.522	0.445	0.481
25	Egypt	0.545	0.508	0.387	0.480
26	Chad	0.362	0.589	0.481	0.477
27	Benin	0.479	0.537	0.394	0.470
28	Sierra Leone	0.576	0.493	0.336	0.468
29	Guinea-Bissau	0.483	0.529	0.392	0.468
30	Namibia	0.501	0.472	0.427	0.467
31	Eritrea	0.544	0.561	0.290	0.465
32	Mozambique	0.440	0.563	0.382	0.462
33	Cote d'Ivoire	0.483	0.473	0.429	0.461
34	Tanzania	0.441	0.514	0.420	0.458
35	South Sudan	0.459	0.579	0.331	0.456
36	Djibouti	0.560	0.396	0.400	0.452
37	Congo Republic	0.482	0.530	0.339	0.450
38	Algeria	0.538	0.302	0.506	0.449
39	Mauritania	0.416	0.489	0.434	0.446
40	Ghana	0.521	0.379	0.436	0.445
41	Cameroon	0.448	0.477	0.410	0.445
42	Niger	0.360	0.551	0.422	0.444
43	Burkina Faso	0.417	0.470	0.445	0.444
44	Mali	0.428	0.496	0.406	0.443
45	Congo Democratic Republic	0.410	0.468	0.444	0.441
46	Gabon	0.452	0.467	0.401	0.440
47	Libya	0.657	0.566	0.094	0.439
48	Gambia	0.429	0.485	0.373	0.429
49	Senegal	0.411	0.432	0.444	0.429
50	Togo	0.305	0.571	0.408	0.428
51	Angola	0.401	0.485	0.376	0.421
52	Nigeria	0.365	0.464	0.419	0.416
53	Equatorial Guinea	0.304	0.477	0.467	0.416
54	Sudan	0.171	0.474	0.527	0.391

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