ANALYSIS OF THE ENVIRONMENTAL EFFICIENCY OF AFRICAN COUNTRIES THROUGH THEIR ECOLOGICAL FOOTPRINT AND BIOCAPACITY

Abstract

Population inequality and climate change are two of the factors that are most disruptive to the ecological balance; accordingly, there have been countless studies in recent years focusing on analysing the Ecological Footprint (EF) and Biocapacity (BC). The markedly disparate characteristics of African countries have motivated the choice of this geographic area as the focus of the research. First, this study uses Data Envelopment Analysis to calculate the efficiency of 45 African countries, taking their EF and country size as determinants of the level of production. Second, the effect of time on EF and BC is analysed using Ordinary Least Squares estimation, in order to determine possible trends in both variables and to draw conclusions that support the adoption of the most appropriate environmental policies. The results reveal similar efficiency levels between one group of countries with ecological deficits and another with ecological surpluses. Also, the countries that have a deficit in terms of BC, but whose resource consumption is appropriate to their production volume, need to introduce technological advances that foster sustainable economic development, helping them to adapt to their existing BC. In addition, by incorporating innovative technologies, these countries should be able to transform their existing overpopulation problem into a potential labour force that fosters their sustainable growth.

Keywords: Ecological Footprint; Biocapacity; Africa; Efficiency

1. Introduction

The relationship between resources and economic growth has always been a focus of study for economists. Natural resources, considered as natural capital, have been and continue to be degraded as a result of human impact, faster than the resource regeneration rate and growth of alternatives (Fu et al., 2015). Also, the importance of carbon emission reduction and environmental pollution reduction has been a topic of great interest in research papers in the literature (Zeng, et al, 2017; Sun, et al, 2018; Li et al 2018; Zeng et al, 2018).

In response to changing global demographic trends, as well as increases in the demand for resources, production of waste and consumption, several tools have been developed to measure the pressure exerted by humans in maintaining current growth trends (Niccolucci et al., 2012). The Ecological Footprint (EF) was designed as a tool for revealing the relationship between the lifestyles and consumption patterns of a population and the natural capital consumed (Rees, 1992). The Global Footprint Network (2018) describes the EF as “a measure of how much area of biologically productive land and water an individual, population, or activity requires to produce all the resources it consumes and to absorb the waste it generates, using prevailing technology and resource management practices”. The EF is a comprehensive index that measures our use of natural resources, analysing six main categories of ecologically-productive area; namely, arable land, grazing land, forest land, fishing area, built-up land and energy land (Fu et al., 2015). Aydin et al. (2019) conclude that the EF is an important indicator that shows the biologically-productive areas around the world, the size of the land and water areas required for waste disposal, and how much biologically productive area countries use. Also, Rudolph and Figge (2017) employ the EF as proxy for human ecological demands. They argue that the EF is globally comparable, scientifically rigorous and widely accepted across the social sciences.

The EF is a key aggregate environmental indicator as it helps countries, local leaders and individuals to, respectively, understand and enhance well-being, get the best from public investment projects and comprehend their influence on the planet. It provides the basis for settings goals, identifying options for action, and tracking progress toward stated goals (Ulucak and Apergis, 2018). In general, core, wealthy nations such as the United States tend to have a large EF, while developing nations, including those in Africa, tend to have lesser environmental imprints (Marquart-Pyatt, 2015).

The most widely-used application for EF accounting is the National Footprint Accounts (NFAs). NFAs provide annual accounts of Biocapacity (BC) and the EF for the world as a whole as well as for individual countries, with BC being understood as the planet's ability to supply useful natural resources and absorb human-generated waste. Since 2003, the Global Footprint Network has served as the steward of the NFAs, and the underlying methodology for calculating the EF of countries. Moreover, it has continuously implemented advances in science and accounting methodology into each iteration or edition of the NFA. To ensure consistent results, each edition provides updated results for the entire available timeline from 1961 to the current NFA data year (Global Footprint Network, 2018).

For a theoretical background of the EF method, several papers can be consulted, such as the pioneering analyses by Rees (1992) and Rees and Wackernagel (1994). The concept of the EF has been adopted in a growing number of studies applied to geographical regions and countries, as well as specific productive activities. There are a few studies that analyse the stationarity (or convergence) of ecological indicators using the Fourier unit root test (Ulucak and Lin, 2017; Solarin and Bello, 2018; Ozcan et al., 2019; Yilanci et al., 2019). Other authors have focused on the global distribution of the EF using methods to measure the distribution of income (White, 2007) and on the variation in some national Footprints (Galli et al., 2012), as well as its relation to other indices such as GDP (Jorgenson and Burns, 2007) and the Human Development Index or HDI (WWF, 2010).

To sum up, the purpose of this paper is to analyse the environmental efficiency of African countries through their EF. To do so, the analysis consists of four main steps. First, the EF and BC for 45 African nations in 2014 (the latest data set available) are examined and grouped into creditor or deficit countries. Efficiency levels are then obtained by applying Data Envelopment Analysis (DEA) to each set in order to identify the differences that separate them. Third, two regressions are estimated for the set of efficient countries in order to determine how EF and BC change over time. Finally, the results of these models are used to estimate when the African nations will reach a balance between EF and BC.

The fundamental contributions of this paper to the field are twofold. First, unlike other studies in the existing literature, the results help identify the patterns established by the African countries considered eco-efficient. This will help guide the changes to be made by those countries who are willing to improve their situation. Second, there are no empirical studies to date that project the temporal evolution of EF and BC in African countries; this research produces forecasts of the situation in these countries over the coming years, thus providing the responsible institutions with key information for tackling future cases of ecological deficit. Focusing on a single continent makes it possible to identify the differences between countries, despite the fact that they are all considered emerging economies. The methodology applied, both DEA and linear regression, has been widely used in the literature, confirming its appropriateness for solving economic problems. However, the combination of these two methods in the context of this research represents a novel contribution, as does the composition of the sample used in the analysis. Although the proposed study focuses on the latest information available at the time of the research, the evolution of EF and BC over time offers us a glimpse of future scenarios.

To this end, the rest of the paper is organized as follows. Section 2 describes the relationship between the EF and BC of African economies. Section 3 explains the methodology, the empirical model and data used in the analysis. Section 4 presents the empirical results and section 5 concludes the study.

2. Relationship between ecological footprint and biocapacity in African countries

Humanity’s total EF has been increasing steadily at an average of 2.1% per year since 1961, nearly tripling from 7.0 billion global hectares (gha) in 1961 to 20.6 billion gha in 2014. The increase in EF has been outpacing that of BC, which has been growing at an average of 0.5% per year, from 9.6 billion gha in 1961 to 12.2 billion gha in 2014. Together, these results indicate that ecological overshoot began in the 1970s, and continues to grow at an average rate of 2% per year. In 2014, humanity’s EF was 69.6% greater than the Earth’s BC (Global Footprint Network, 2018).

The relationship between the EF and BC of a given geographic area can be used as a reference point to determine the minimum conditions for sustainability (Lin et al., 2018). This allows us to draw a new map of the world, in which nations are classified as either ecological creditors or ecological debtors according to the ratio EF/BC. A ratio over 1 indicates that the total EF exceeds the BC, indicating a debtor country, whereas a ratio below 1 means that the total EF is lower than the BC, and therefore the country is a creditor.

Ecological deficit is a state where the EF surpasses the BC because the country’s demand for resources is not met by a sufficient domestic supply, expressed by BC. Such countries are often dependent on other countries, which enjoy a surplus of natural resources with respect to local demand (Niccolucci et al., 2012). In contrast, creditor countries are abundant in natural resources and their demand is less than supply (EF<BC).

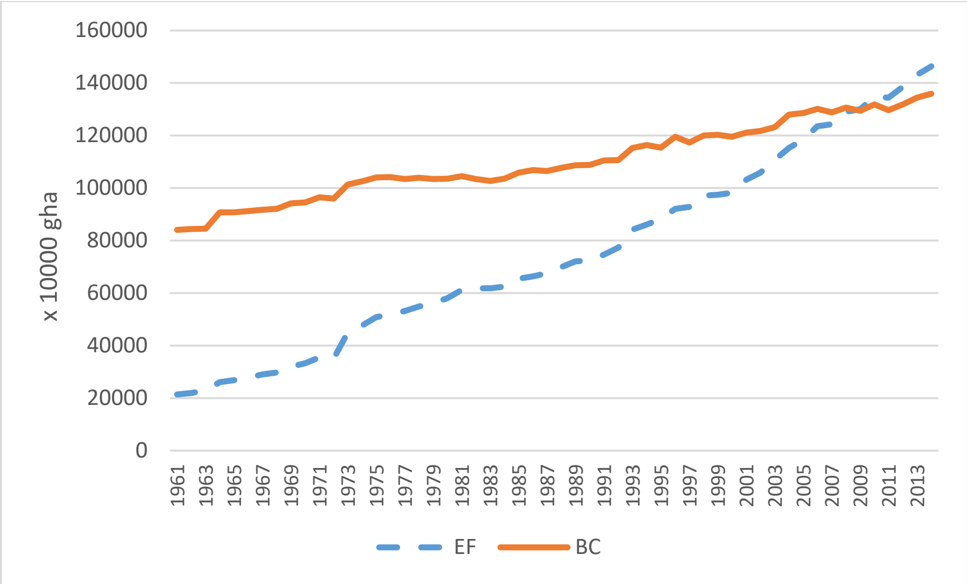
Africa is balancing on a knife edge, according to the latest data, with the human EF just about equal to the continent’s BC, measured in per capita terms. If the whole world used its land, water and energy resources the way the average African does, it would take 70% of the Earth’s current resources to sustain us all – meaning that there would be a surplus left over. But the “good” African average masks huge disparities among countries. North Africa and the continent’s island nations have a particularly large EF, as a result of relatively high per capita incomes – translating into more energy consumption and higher carbon emissions. Conversely, those countries have almost zero forest cover, which means that very little carbon is recycled through photosynthesis in plants and trees (Mungai, 2015).

Another indication of Africa's complicated development is the fact that 31% of grazing land and 19% of forests and forest areas are classified as degraded, so that arid land covers 60% of the continent's surface. Of the productive land, 10% is devoted to subsistence agriculture and more than 25% has a low potential for sustainable agriculture. Looking ahead, about 4 million hectares of forest area are being lost each year, and desertification-prone land occupies about 5% of the continent, where about 22 million people live (Cano and Díaz, 2010).

The growth of the African continent requires an appropriate exploitation of its natural resources; its population must be able to and know how to benefit from them if it wishes to improve its quality of life. In terms of the continent's environmental wealth, sub-Saharan Africa is estimated to have 20% of the world's uranium reserves, 90% of its cobalt, 40% of its platinum, 65% of its manganese, between 6% and 8% of its oil reserves and 50% of its gold and diamonds, among other minerals. The Intergovernmental Platform on Biodiversity and Ecosystem Services warns of the "extreme vulnerability" of these countries to climate change. If the present situation continues, in 2100 they could face the loss of more than half of their birds and mammals, as well as a 20 to 30% decrease in the productivity of their lakes and a significant loss of plant species. It is currently estimated that at least half a million square kilometres of African soil are already degraded by overexploitation of natural resources, erosion, salinization or pollution. Against this backdrop, it is obvious that a worrying future lies ahead, and work must begin to reverse the damage caused by climate change and human action.

In terms of total global hectares of EF and BC, Graph 1 shows a changing trend. The ecological surplus enjoyed by Africa since 1961 becomes a deficit in 2009, revealing an upward trajectory of the EF. This turning point coincides with the population growth of the African continent, considered one of the main causes of the depletion of reserves. In addition, it is believed that this phenomenon has just begun; it is predicted that the population explosion is yet to come and could cause significant damage.

Graph 1. Evolution of EF and BC of total Africa

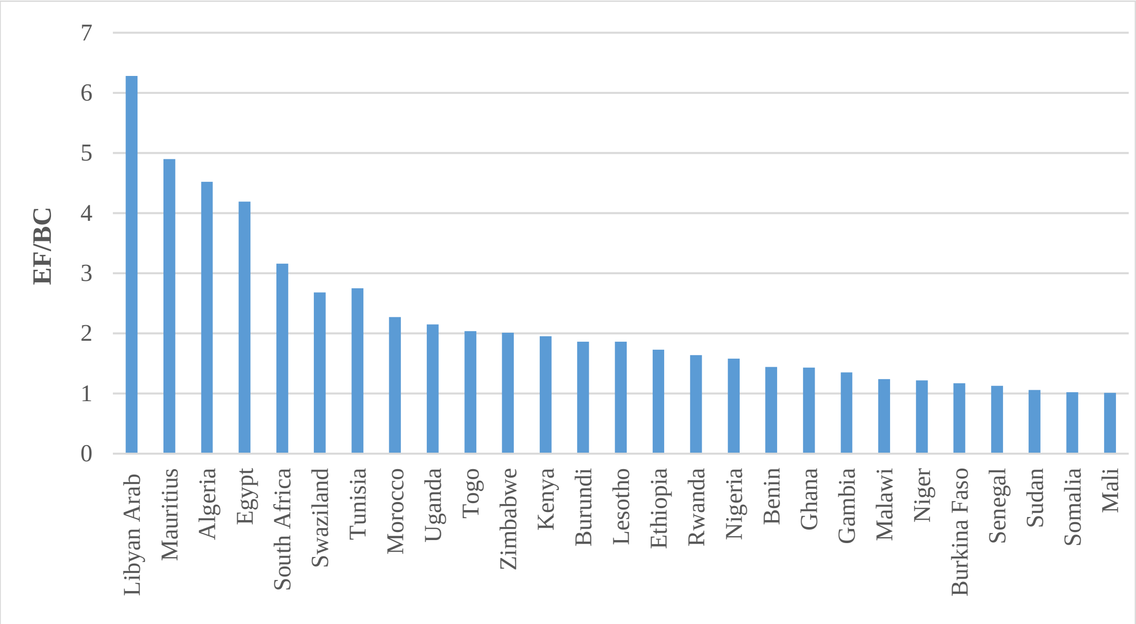


Source: Global Footprint Network

Individual analysis of the countries with available data on the EF/BC reveals that in 2014, 60% of them had an ecological deficit, with Libya being the most extreme case. Also, Mauritius exerts a far higher demand on nature than the island nation can actually support. Ecologically speaking, Mauritians' current consumption habits actually require the equivalent of 4.4 Mauritiuses to support them. The same goes for countries such as Algeria, Egypt and South Africa, where human pressures on the environment – largely carbon emissions and demand for cropland – exceed what those countries can support (Graph 2).

These countries score highly on development and environmental sustainability indices, showing a growing political environmental awareness (Niccolucci et al., 2012). Although they are emerging economies, they have an ecological deficit just as major world powers such as the USA, France or Germany do. This confirms that there is not necessarily a positive correlation between economic and social development and sustainability, as demonstrated in the literature (Bagliani et al., 2008).

Graph 2. Countries with ecological deficit in 2014



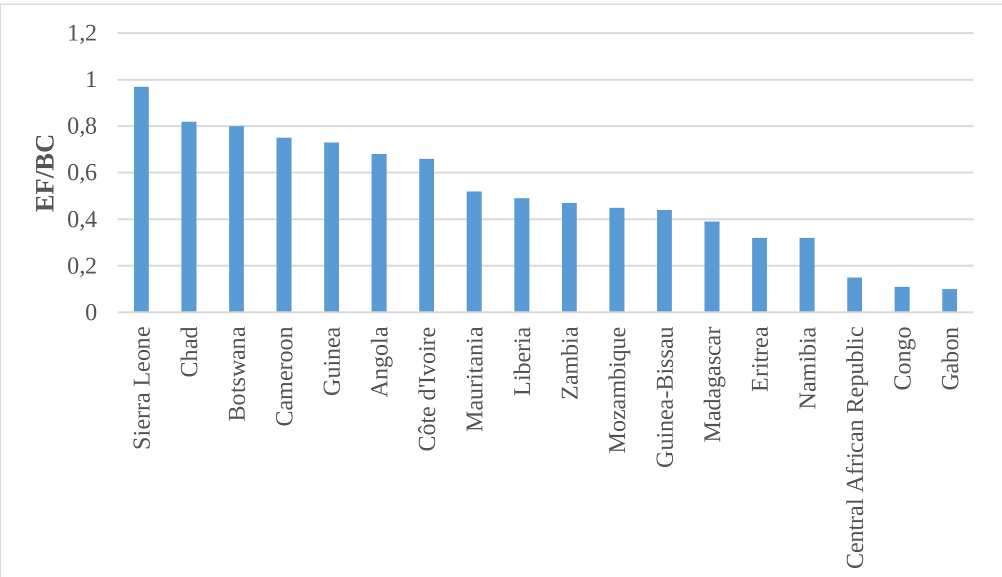
Source: Own Elaboration with Footprint network data

Today, there are just 18 countries that currently hold an "ecological surplus" and they might become countries of refuge in the next few decades; before long, they might find themselves hosting environmental refugees. In these countries, the abundance of natural resources and their mineral wealth negatively affect their political stability, leading to inadequate economic development.

They all have an EF/BC ratio of less than one, with Congo and Gabon occupying the best positions, exploiting only 11% and 10% of their resources, respectively (Graph 3). Niccolucci et al. (2012) refers to this type of countries as “wedge”, characterized by high demographic growth rates and low-consumption lifestyles. They are or have been the richest reservoirs of raw materials in the world. Their reserves of resources mean they are well-positioned but they lack strong policy instruments to deal with their wealth.

Sierra Leone is the country with the highest surplus: it is a very poor country but has enormous mineral riches such as diamonds, iron, platinum, rutile and bauxite. However, its social conflicts, lack of infrastructure and an underdeveloped economy mean that its BC is well above its EF. The Chadian economy is similar but more centred on the agricultural sector. And thirdly, there is Botswana, which has very poor surface soil but the country has been one of the world´s largest producers of gem diamonds.

Graph 3. Countries with an ecological surplus in 2014



Source: Own Elaboration with Footprint network data

The countries are grouped together according to their deficit/surplus status; however, their way of managing their resources differs widely depending on their culture, politics and/or religion. The efficiency analysis applied to this homogeneous grouping (as far as their ecological needs are concerned), will make it possible to identify which of them could serve as a model for the necessary changes to be implemented, thus helping to prevent the predicted environmental degradation.

3. Methodology and data

In the previous literature, there are several studies that have addressed the environmental efficiency of selected countries, or economic or political communities. Mzoughi (2011) points to the fact that although the countries that joined the EU later have lower environmental efficiency, their productivity growth has been higher. In most related studies, authors have measured efficiency by means of DEA and various modifications of DEA (Dios and Martinez, 2011; Hernández-Sancho et al., 2011; Klumpp, 2017; Lacko and Hajduová, 2018). Recently, some new DEA models have been applied in regional sustainable development assessment, such as the non-radial directional distance function (Wang et al., 2013), the sequential generalized directional distance approach (Zhang et al., 2014) and the non-oriented directional distance function model (Chang, 2015).

DEA is a non-parametric technique that makes it possible to measure the relative efficiency of homogenous units. This method is one of the most widely used when a study involves multiple inputs and outputs. It allows the researcher to determine which countries perform best by comparing each one to all the possible linear combinations of the rest of the sample, which can later be used to define an empirical production frontier.

In this regard, the efficiency of each unit analysed is measured in terms of its distance from that frontier.

Following the pioneering work by Farrell (1957), the DEA model was developed by Charnes, Cooper and Rhodes (1978) in order to find the optimum set of weights that maximizes the relative efficiency (h_0) of the country under analysis. The relative efficiency is defined as the ratio between the weighted sum of outputs and the weighted sum of inputs, subject to the restriction that no other country can have an efficiency score higher than one using the same weightings. More specifically, the original linear programming problem with constant returns to scale is as follows:

$$Max_{u,y}\ h_0 = \frac{\sum_{r=1}^{s} u_r \cdot y_{r0}}{\sum_{i=1}^{m} v_i \cdot x_{i0}}$$

$$s.a. \frac{\sum_{r=1}^{s} u_r \cdot y_{rj}}{\sum_{i=1}^{m} v_i \cdot x_{ij}} \leq 1 \qquad (1)$$

$$u_r, v_i \geq 0$$

where:

x_{ij}: amounts of inputs i (i=1,2, …., m) used by the jth country

x_{i0}: amounts of inputs i used by the country analysed

y_{rj}: amounts of outputs r (r= 1,2, …, s) produced by the jth country

y_{r0}: amounts of outputs r produced by the country analysed

u_r: output weightings

v_i: input weightings

The applied model is an input-oriented model, so it is focused on minimizing a country’s consumption of resources while still obtaining a given level of income. Further, it is assumed that there are several DMUs and that inputs and output comply with the following requirements (Klumpp, 2017):

1. For each input and output, there are numerical, positive data available for all DMUs.

2. Selected values (inputs, outputs and the chosen DMUs) reflect decision-makers' interests regarding the relative efficiency evaluations
3. DMUs are homogenous in terms of the same types of inputs and outputs
4. Input and output indicator units and scales are congruent.

Bearing in mind that the measure of efficiency takes values between 0 and 1, it is interpreted as follows:

- If h_0=1, the DMU is efficient in relation to the others and, therefore, will be located on the production frontier.
- If h_0<1, another DMU is more efficient than the one under analysis.

The model by Charnes et al. (1978) is not linear, but can be linearized by modifying the constraints of the original model. Taking into account that there are more constraints than variables, the problem is solved by means of its corresponding dual model. This article follows the proposal by Banker, Charnes and Cooper (1984), who considered a linear programming model with variable returns to scale and a convexity constraint. This is a modification of problem (1), posing the dual problem and adding a convexity constraint, N1´λ=1. The new specification is:

$$
\begin{gathered}
Min\ \theta, \lambda \cdot \theta \\
s.a. -y_i + Y\lambda \geq 0 \\
\theta x_i - X\lambda \geq 0 \\
N1'\lambda = 1 \\
\lambda \geq 0
\end{gathered}
\qquad (2)
$$

where N1 is a vector whose components are all unity and whose size is Nx1.

The approach with variable returns to scale leads to the efficient frontier forming a convex zone where all points are located more limited than with constant returns to scale, thus obtaining equal or greater efficiency results. The DEAP 1.2 software designed by Coelli

(1996) has been used to calculate the efficiency levels of each of the African countries analysed.

However, DEA is not free from limitations. This technique has been criticized for failing to consider random errors in the data (database or random errors): any deviation from the optimum level is considered inefficiency. Furthermore, results can be affected by the presence of unusual observations (outliers), which on many occasions are due to database errors (Giner and Muñoz, 2008).

When applying DEA, the researcher must determine the variables that constitute the inputs and outputs of the model. In the field of environmental sustainability, Fu et al. (2015) use gross domestic product (GDP) as the output, which indicates the total output of a country, and EF as the indicator to describe all types of natural resource input. Peris (2017), in addition to the variables mentioned by Fu et al. (2015), introduces others with a social dimension that facilitate the characterization of the sample. Following this approach, the efficiency analysis proposed in this study includes the following variables:

- Output: GDP[1]
- Inputs: EF and population

GDP (constant 2010 prices in US Dollars), the model's only output, is an indicator of the country's total production, thus reflecting its level of economic development. It has been obtained from statistics published by the United Nations. In terms of inputs, the EF is a biophysical sustainability indicator that captures the set of impacts exerted by each nation on its environment. It is obtained from the Global Footprint Network and is expressed in global hectares (gha). The size of the country has been defined in terms of its population and, like GDP, this figure has been extracted from the United Nations database. The

[1] Lacko and Hajduova (2018) use GDP per capita as their sole output. In the present study, total GDP is used since the population is a model input that adjusts the size of the economy.

incorporation of these inputs and outputs represents a methodological innovation of this research, whereby efficiency is measured through a production function in which GDP is determined by the EF and the size of the country. In addition, the sample is made up of 45 countries on the African continent for which the EF is known. The diversity of these African nations is also a novel contribution; this paper thus sets itself apart from other studies in the related literature, which analyse the continent as a whole, a specific region or focus on the most prominent countries. (Oppon, et al, 2018; Nhemachena et al, 2018). Table 1, below, lists the basic descriptive characteristics of the inputs and output used in the DEA models.

Table 1. Descriptive statistics of variables (2014)

	GDP	EF	POPULATION
	AFRICAN COUNTRIES/DEFICIT		
MEAN	66,460,327,361.3	46,504,610.3	30,162,179.7
STD. DEV.	119,264,699,493.7	56,950,944.1	38,246,163.2
MAX.	452,284,447,648.3	197,940,185.8	177,475,986.0
MIN.	1,019,600,869.4	1,859,988.3	1,268,567.0
OBS.	27	27	27
	AFRICAN COUNTRIES/SURPLUS		
MEAN	17,366,693,863.1	24,782,714.6	11,041,225.8
STD. DEV.	23,347,842,454.5	45,255,789.6	9,210,711.2
MAX.	102,821,375,646.7	200,864,972.7	27,216,276.0
MIN.	933,283,632.3	2,303,874.1	1,687,673.0
OBS.	18	18	18

Note: Std. Dev is the abbreviation of standard deviation. Max. is the Maximum value. Min. is the minimum value. Obs means the number of observations.

Source: Own Elaboration

According to the descriptive statistics, it can be observed that the group of countries characterized as having an ecological deficit present higher values on average; that is to say, they have greater production, are more populated and use more resources than the creditor nations. However, among the latter, Angola's GDP is higher than the average of those with deficits.

4. Efficiency analysis results and discussion

The efficiency results represent an indicator of the management carried out by each of the observations, in this case use of natural resources, at a given point in time. The level of efficiency obtained is a relative value, dependent on the other units in the sample with which a unit is compared. In this case, the aim is to measure the efficiency of 45 African countries, grouped according to their ecological deficit or surplus, in order to identify homogeneous groups in terms of their available or attainable natural resources. For DEA to be used correctly, it must be applied to homogeneous groups to prevent possible extreme values from distorting the results. Table 1A shows the levels of efficiency achieved in 2014 by each of the countries that make up the groups analysed. Table 2 shows average and minimum values for the results obtained in each sample of economies.

Table 2. Efficiency results in African countries (2014)

	AFRICA/DEFICIT	AFRICA/SURPLUS
NO. EFFICIENT COUNTRIES	5 (18.5%)	3 (16.6%)
NO. INEFFICIENT COUNTRIES	22	15
AVERAGE EFFICIENCY	0.520	0.540
MINIMUM EFFICIENCY	0.102	0.168

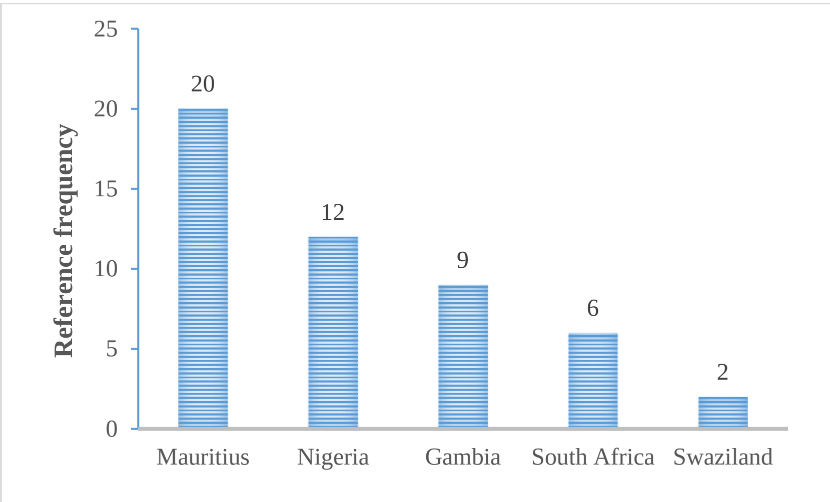
Source: Own Elaboration

As can be seen in Table 2, the analysis carried out indicates that all African countries register similar environmental efficiency performance, regardless of their ecological situation. The average efficiency in both groups is around 0.5, i.e. there are no major differences in the ratio of natural resources consumed to GDP. However, there is a larger proportion of fully efficient countries among the deficit countries (18.5%). All of them obtain the maximum output with the inputs used; however, they present a notable depletion of natural resources due to their low BC relative to their high input needs. This group comprises Gambia, South Africa, Swaziland, Mauritius and Nigeria; in each of these countries, although they have been classified as having maximum efficiency, their EF exceeds their BC.

In the other group, Angola, Gabon and Guinea-Bissau are also fully efficient; however, they have surplus natural resources that allow them to obtain a certain level of production without their input needs exceeding the BC.

With regard to efficient observations, it is possible to determine which of them performs better than the rest. It is a question of identifying the country whose form of production could serve as a "model" for the rest of the members of the group. The results of the deficit countries are presented below (Graph 4).

Graph 4. Frequency of efficient deficit countries taken as reference by inefficient countries

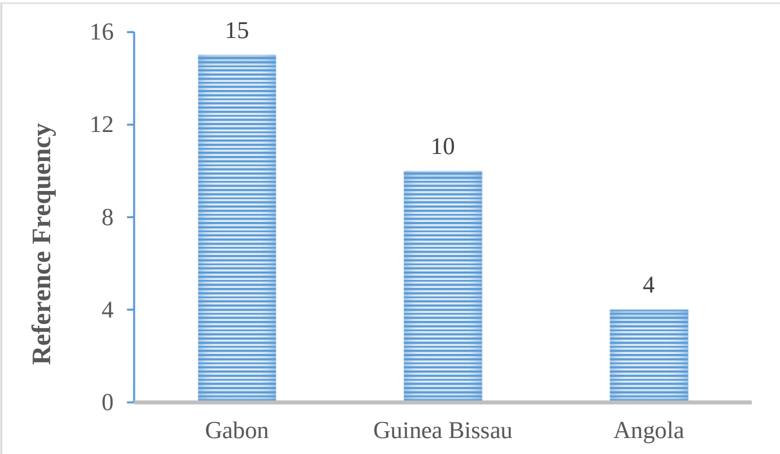


Source: Own Elaboration

According to Graph 4, Mauritius has most often been used as a benchmark by the 20 inefficient countries, followed by Nigeria, Gambia, South Africa and Swaziland. It is a country with stable economic growth of around 5% per year. It lacks exploitable natural resources; hence, its efforts have focused on achieving high levels of social cohesion and well-being, working to avoid the inequality characteristic of its closest neighbours. In just 50 years, Mauritius' GDP per capita has risen from $400 to over $6,700, turning a sugar monoculture into a diversified economy ranging from tourism to textiles.

Similarly, Graph 5 shows how many times fully efficient and surplus countries have been used as a benchmark by inefficient countries in this group. In this case, Gabon stands out, followed by Guinea Bissau and Angola. Gabon is characterized by having one of the most varied biodiversities of the planet, in addition to substantial mining wealth. However, its heavy dependence on foreign capital jeopardizes its achievement of autonomous and sustainable growth.

Graph 5. Frequency of countries with efficient surpluses taken as reference by inefficient ones



Source: Own Elaboration

Regarding the set of inefficient countries, a detailed study of each of them is required in order to determine how they should modify input consumption to improve their efficiency levels. Table 3 shows the percentage by which their population and EF would have to decrease in order to achieve this objective. It is generally observed that, regardless of whether they have a deficit or a surplus, it would be necessary to significantly reduce the population in all these countries (by 66.9% and 67.3%, respectively) as well as the EF (by more than 55%).

This would entail very drastic changes in African society that would be difficult to achieve. As such, it is necessary to introduce improvements and technological advances that allow for an increase in the volume of production and ensure the entire population can be accommodated in the production chains, while at the same time trying to achieve a more sustainable use of environmental resources.

These results extend the work of Charfeddine and Mrabet (2017), who show that energy use has a detrimental impact on the EF in the Middle East and North African (MENA) region, while real GDP per capita has an inverted U-shaped relationship with EF for oil exporters, and a U-shaped relationship otherwise. This shows why the innovation to be implemented by African countries should be carried out in an environment that prioritizes responsible energy use. In addition, the results support the theory that life expectancy and the fertility rate have a long-term beneficial effect on the environment. Given the different economic and social profiles of the countries analysed, these authors recommend the implementation of specific policies tailored to the individual characteristics of each country; failure to do so could result in significant implementation errors.

Table 3. Modification of inputs to make African countries efficient

Africa/deficit	Variation population	Variation EF	Africa/surplus	Variation population	Variation EF
Burundi	-98.3%	-66.4%	**Mozambique**	-93.7%	-82.3%
Burkina Faso	-92.7%	-81.1%	**Madagascar**	-92.7%	-83.2%
Niger	-92.0%	-89.8%	**Chad**	-87.3%	-82.6%
Malawi	-91.1%	-73.7%	**Guinea**	-85.8%	-81.0%
Ethiopia	-87.2%	-84.2%	**Cameroon**	-74.7%	-63.6%
Rwanda	-86.6%	-60.5%	**Côte d'Ivoire**	-74.7%	-64.1%
Benin	-86.3%	-74.2%	**Zambia**	-74.0%	-45.9%
Mali	-85.1%	-77.8%	**Sierra Leone**	-71.9%	-64.4%
Zimbabwe	-84.3%	-65.8%	**Eritrea**	-65.0%	-0.2%
Uganda	-83.8%	-78.2%	**Central African Rep**	-62.6%	-56.2%
Somalia	-83.2%	-83.2%	**Congo**	-62.5%	-97.7%
Senegal	-82.5%	-64.1%	**Liberia**	-59.2%	-53.9%
Togo	-75.8%	-66.0%	**Mauritania**	-56.7%	-56.7%
Ghana	-63.4%	-63.4%	**Namibia**	-29.1%	-14.9%
Kenya	-63.4%	-54.7%	**Botswana**	-20.3%	-16.5%
Sudan	-50.8%	-49.3%			
Libyan	-50.2%	-60.4%			
Egypt	-42.1%	-42.1%			
Lesotho	-22.5%	-22.5%			
Morocco	-18.5%	-18.5%			
Tunisia	-16.4%	-16.4%			
Algeria	-15.1%	-15.1%			
Mean	**-66.9%**	**-59.4%**	**Mean**	**-67.3%**	**-57.5%**

Source: Own Elaboration

Next, following the research aims outlined above, two regressions have been estimated using Ordinary least squares for all the countries classified as efficient in 2014, in order to assess the effect of time on the EF and BC (Models 1 and 2). Table 4 shows the results for the two groups analysed.

$$\text{Model 1: } EF_{it} = \beta_0 + \beta_1 Time \quad (1)$$

where EF_{it} is Ecological Footprint of country "i" in year "t".

$$\text{Model 2: } BC_{it} = \beta_0 + \beta_1 Time \quad (2)$$

where BC_{it} is biocapacity of country "i" in year "t".

Table 4. Time evolution of FE and BC in efficient countries

	Ecological Deficit	
	Model 1	Model 2
Gambia **(1961-2014)**	*EF= -61,488,761.9+31,478.5time* $R^2=0.92$	*BC= 2,374,016.8 – 450.3time* $R^2=0.01$
South Africa **(1974-2014)**	*EF =-4,442,023,568+2,297.4time* $R^2=0,93$	*BC =-101,839,349.9+78,700.4time* $R^2=0.17$
Swaziland **(1989-2014)**	*EF =-103,874,637.6+52,994time* $R^2=0.57$	*BC =-570,822.38+829.8time* $R^2=0.04$
Mauritius **(1961-2014)**	*EF =-149,434,140.9+76,313.2time* $R^2=0.98$	*BC =2,099,360.2-577.6time* $R^2=0.08$
Nigeria **(1961-2014)**	*EF =-6,369,463,976+3,259.5time* $R^2=0.95$	*BC =-3,067,075,054+1,583.1time* $R^2=0.86$
	Ecological Surplus	
Angola **(1961-2014)**	*EF =-680,438,615+348,121time* $R^2=0.61$	*BC =-5,318,961.6+29,076.8time* $R^2=0.09$
Gabon **(2004-2014)**	*EF =-193,850,058+98,291time* $R^2=0.39$	*BC =-76,596,226.8+59,416.5time* $R^2=0.51$
Guinea-Bissau **(1968-2014)**	*EF = -71,391,947.5+36,725.5time* $R^2=0.97$	*BC = -20,598,925.9+12,746.2time* $R^2=0.88$

Note: The periods analysed depend on the availability of statistical information.
Source: Own Elaboration

Generally, and independently of the EF, time has proved to be a significant determinant of the EF and BC, with greater explanatory power in Model 1 (in 5 countries the regression fit exceeds 91%). In addition, the positive sign of the coefficient indicates that time positively affects the consumption of natural resources, i.e. each year, efficient nations increase their use of inputs to reach their production levels.

However, very different results are obtained in Model 2, where time has not had such a relevant impact on BC. In countries such as Angola, Swaziland, South Africa, Mauritius and Gambia, it is just over 10%, with an inverse relationship observed in the last two countries. Only in Nigeria and Guinea-Bissau does the explanatory power of the point in time exceed 85%, showing that time positively affects the BC; i.e. these two African economies will be able to expand their supply of resources year-on-year.

There is a “transition point” in the trajectory from ecological surplus to ecological deficit, and it may be considered the moment in which there was a change from self-contained lifestyles and slow economies to accelerated consumerism (Niccolucci et al., 2012). Thus, the last research objective will be achieved by equalizing the two models to estimate the exact moment in time when EF and BC are in equilibrium.

The results in Table 5 show a clear differentiation between the two groups analysed. Deficit countries reached equilibrium at some time in the past, before 2000, while nations characterized by surpluses will manage to match their BC to the EF further in the future. This disparity may be due to the fact that the latter countries are characterized not only by their ability to increase their BC over time, but also by an economic backwardness that is even more pronounced than in deficit countries, with the consequent scarce demand for natural resources.

Table 5. Prediction of the moment where EF = BC

Africa/deficit	Year of equilibrium
South Africa	1956
Nigeria	1970
Mauritius	1970
Swaziland	1980
Gambia	2000
Africa/surplus	**Year of equilibrium**
Angola	2166
Gabon	3016
Guinea Bissau	2118

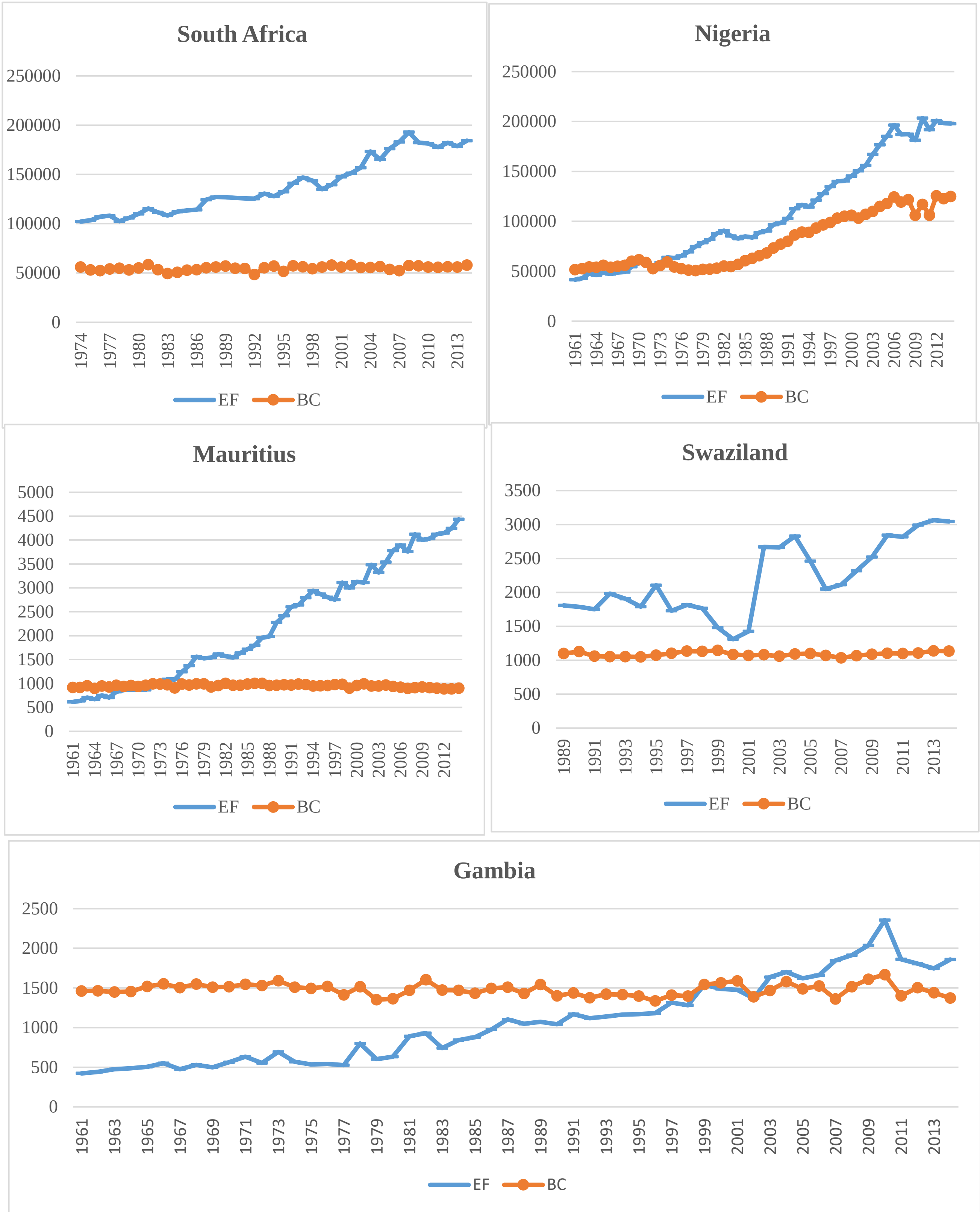
Source: Own Elaboration

The following graphs show the temporal trends of the EF and BC of the efficient ecologically deficit nations (Graph 6). In all these countries, it can be observed that, once equilibrium has been reached, the EF grows exponentially. These are countries that have not appropriately managed their natural resource needs; indeed, their economic development has been linked to a disproportionate consumption of resources that has exceeded the existing supply in the country. According to Olanipekun et al. (2019), in order to address the problem of environmental degradation, the poverty in African countries must be tackled. To that end, it is essential to adopt environmentally-responsible policies that promote a significant increase in income.

On the contrary, the temporal evolution of efficient nations with ecological surpluses presents a very different pattern. All of these countries tend towards a future equilibrium, so the gap between EF and BC will become ever smaller. However, with the exception of Angola, the gap is not notably narrowing (Graph 7). These are countries whose production and reserves of both gas and oil, although substantial, are much lower than other sub-Saharan African nations such as Nigeria. They are in full development and, therefore, have a greater need for resources, but are not absorbing the existing BC.

Along these lines, the study by Al-Mulali and Ozturk (2015) focused on the MENA region showed that the EF, political stability, energy consumption, urbanization, and trade openness are cointegrated; in addition, they found that whereas the latter three variables worsen environmental damage, political stability reduces it over the long term. All these variables have a causal relationship with EF in the short and long term; as such, the recommendation is once again to reduce energy consumption by implementing measures such as investments that incentivize energy saving, energy efficiency projects, as well as those that prioritize the role of renewable energies. As in the present study, Al-Mulali and Ozturk argue that all this can be made possible by promoting the sustainable development of the industries involving intensive use of labour, thus reducing the need for natural resources.

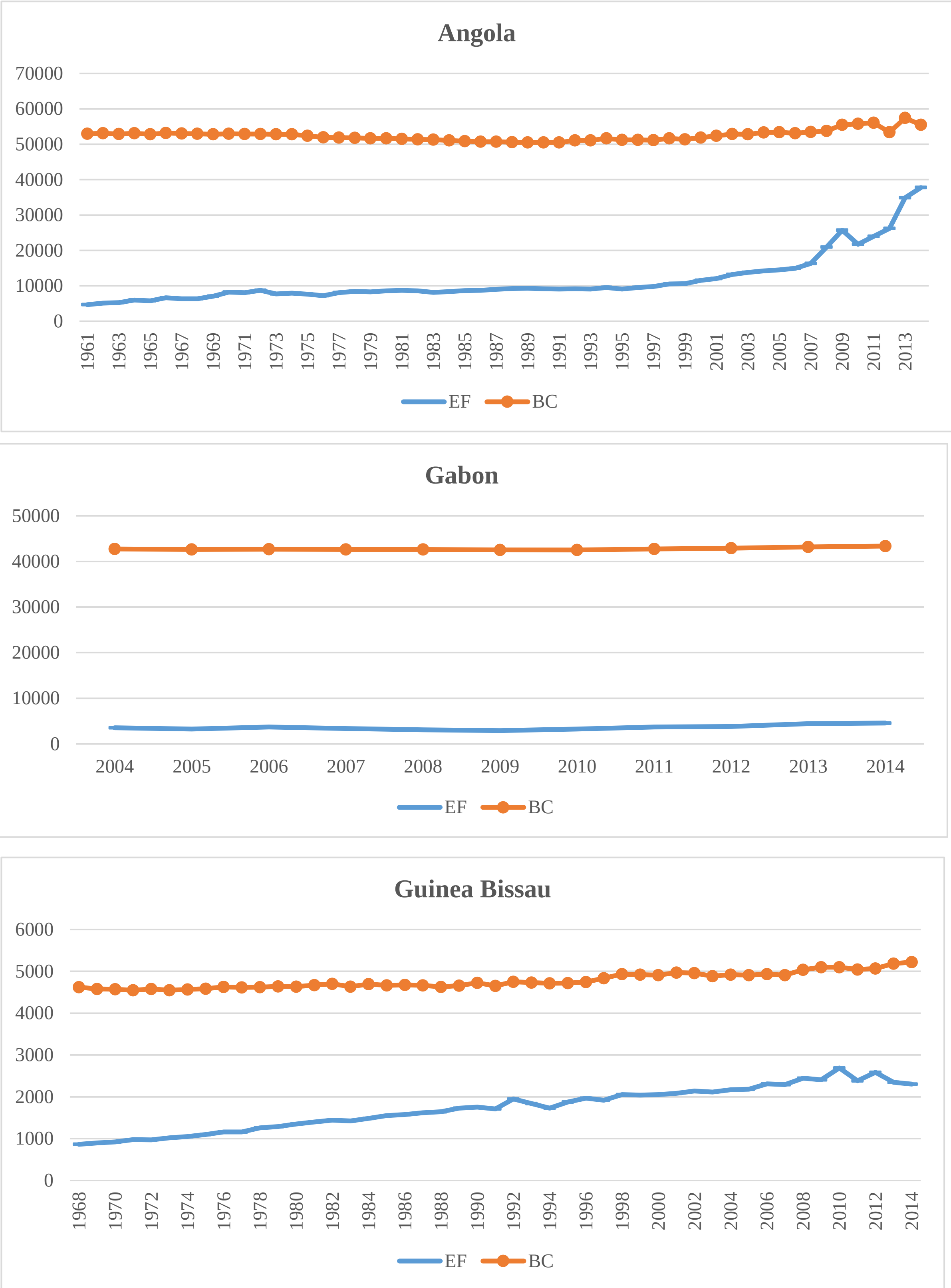
Graph 6: EF and BC trend of efficient and ecologically deficit countries (thousand gha)



Source: Own Elaboration

Note: The years analysed in each country depend on publicly available information

Graph 7: EF and BC trend of efficient and ecologically surplus countries (thousand gha)



Source: Own Elaboration

Note: The years analysed in each country depend on publicly available information

5. Conclusions

The growing consumption of natural resources and their availability is an issue of great relevance today for both developed and emerging countries. Recent studies reveal that humanity is consuming an amount of natural resources equivalent to 1.6 planets' worth and, if this continues, this figure would reach 1.75 in 2020 and 2.5 in 2050. A change in mentality is required, with a shift towards a greater awareness of the need for sustainable development in all countries, otherwise their environmental degradation could hinder the technological advances demanded by society.

This article focuses on the African continent due to the diversity of countries that coexist there, some with ecological deficits and others with surpluses. This allows for a differentiated analysis of the environmental efficiency of the two groups. According to the Director of the Global Footprint Network and co-inventor of the Ecological Footprint concept, "There is a strong international commitment to improve human well-being in Africa and to advance the Millennium Development Goals to reduce poverty, hunger and disease. But to be successful in the long term we need to work with rather than against ecological limits."

The paper makes it possible to quantify environmental diversity among African countries using data provided by the NFA. This source of data is very valuable because it provides information on a huge number of countries over a long time horizon. Based on the EF/BC ratio, it has been concluded that 60% of African countries have ecological deficits, as do advanced economies in Europe and North America. The remaining 40% have ecological surpluses, i.e. their BC is higher than their EF; they can thus be considered potential refuges and sources of wealth for the African continent. This classification has made it possible to obtain homogeneous groups and thus carry out an efficiency analysis under optimum conditions.

Applying the DEA methodology to the set of deficit countries has revealed that Mauritius, Nigeria, Gambia, South Africa and Swaziland are fully efficient in that their excessive consumption of resources is sufficient to obtain their production volume. This is why all of these countries need technological advances that foster economic and sustainable development and facilitate their adaptation to the existing BC. The other group includes Angola, Gabon and Guinea-Bissau, which, although they use their inputs appropriately, are capable of consuming less than the existing supply.

In addition, it has been demonstrated that the development strategy followed by Mauritius has allowed it to outperform the other countries. It has been used as a benchmark by the vast majority of inefficient deficit countries in determining their levels of efficiency. This is a country whose lack of BC has prompted it to strengthen the human and social factor as opposed to resorting to ecological exploitation.

Similarly, Gabon has been the benchmark country for the efficiency analysis of surplus countries. However, Gabon will have to take care not to overexploit its resources and to avoid excessive dependence on foreign capital, as its growth model could be exhausted in the not-too-distant future.

The inefficient countries of both groups have become heavily populated with an excessively high EF for the production level reached in 2014. The data reveal that there is an urgent need to put a brake on both variables in order to improve the efficiency of these nations. Currently, 1.2 billion people live in Africa, 16% of the world's population. Moreover, if no action is taken in this respect, the UN expects this figure to exceed 4.5 billion in 2100, that is, 40% of the world’s total. This issue is also highlighted by Venter et al. (2016), who stress the need to stop the unchecked growth of the African population, as well as reduce the demand from rich countries that overexploit the existing resources in this continent.

However, on average, the required reductions in population and EF are so high (around 67% and 58%, respectively) that they will be difficult to achieve simply by means of stringent birth control and a more rational use of natural resources. The enormous active population must benefit the continent, and it is essential to implement technological advances that allow countries to increase their potential production while complying with established sustainability standards.

Along with other developing countries, African nations face a great ecological challenge; Africa needs innovation that allows it to achieve a per capita EF no higher than the per capita BC of its continent. The aim is to raise levels of human development without increasing EF, as was the case in the vast majority of high-income countries. To sum up, Africa must tackle a dual challenge: first, to develop policies and strategies that will minimize the impact of the growing scarcity and cost of ecological resources on the well-being of its population; and second, along with the rest of the world, to help slow and eventually reverse the global ecological overshoot. Fortunately, African nations have many options in address sing these challenges.

References

Al-Mulali, U., Oztuk, I., 2015. The effect of energy consumption, urbanization, trade openness, industrial output, and de political stability on the environmental degradation in the MENA (Middle East and North African) region. Energy 84, 382-389. https://doi.org/10.1016/j.energy.2015.03.004

Aydin, C., Esen, O., Aydin, R., 2019. Is the ecological footprint related to the Kuznets curve a real process or rationalizing the ecological consequences of the affluence? Evidence from PSTR approach. Ecol Indic. 98, 543-555. https://doi.org/10.1016/j.ecolind.2018.11.034

Bagliani, M., Bravo, G., Dalmazzone, S., 2008. A consumption based approach to environmental curves using the ecological footprint indicator. Ecol Econ. 65, 650-661. https://doi.org/10.1016/j.ecolecon.2008.01.010

Banker, R.D., Charnes R.F., Cooper, W.W., 1984. Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. Manage Sci. 30, 1078-1092. http://www.jstor.org/stable/2631725

Cano, A., Díaz, S., 2010. Crisis ambiental y cambio climático en Africa. CEPRID (10th November).

Chang, MC., 2015. Room for improvement in low carbon economies of G7 and BRICS countries based on the analysis of energy efficiency and environmental Kuznets curves. J. Clean Prod. 99, 140–151. https://doi.org/10.1016/j.jclepro.2015.03.002

Charfeddine, L., Mrabet, Z., 2017. The impact of economic development and social-political factors on ecological footprint: A panel data analysis for 15 MENA countries. Renew. Sust. Energ. Rev. 76, 138-154. https://doi.org/10.1016/j.rser.2017.03.031

Charnes, A., Cooper W.W., Rhodes E., 1978. Measuring the efficiency of decision making units. Eur. J. Oper. Res. 2, 429-444. https://doi.org/10.1016/0377-2217(78)90138-8

Coelli, TJ., 2006. A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program. CEPA Working Paper 96/8, Department of Econometrics, University of New England, Armidale NSW Australia.

Dios, R., Martínez, JM., 2011. Technical, quality and environmental efficiency of the olive oil industry. Food Policy. 36, 526-534. https://doi.org/10.1016/j.foodpol.2011.04.001

Farrell, M.J. 1957. The measurement of productive efficiency. J. R. Stat. Soc. 120 (A), 253-281. doi:10.2307/2343100.

Fu, W., Turner, JC., Zhao, J., Du, G., 2015. Ecological Footprint (EF): An expanded role in calculating resource productivity (RP) using China and the G20 member countries as examples. Ecol Indic. 48, 464-471. https://doi.org/10.1016/j.ecolind.2014.09.023

Galli, A., Kitzes,J., Niccolucci, V., Wackernagel, M., Wada, Y., Marchettini, N., 2012. Assessing the global environmental consequences of economic growth of emerging countries: China and India. Ecol Indic. 17, 99-107. doi:10.1016/j.ecolind.2011.04.022

Giner, C., Muñoz A. 2008. ¿Son los clubes de futbol eficientes? Aplicación del análisis DEA a los equipos de la liga profesional de fútbol de España. Universia Bus Rev. Primer Trimestre, 12-25.

Global Footprint Network (2018). National Footprint Accounts, 2018th ed.; Global Footprint Network: Oakland, CA, USA.

Hérnandez-Sancho, F., Molinos-Senante, M., Sala-Garrido, R. 2011. Energy efficiency in Spanish wastewater treatment plants: A non-radial DEA approach. Sci of Total Environ. 14 (15), 2693-2699. https://doi.org/10.1016/j.scitotenv.2011.04.018

Jorgenson, A.K., Burns, T.J., 2007. The political-economic causes of change in the ecological footprints of nations, 1991-2001: a quantitative investigation. Soc. Sci. Res. 36, 834-853. https://doi.org/10.1016/j.ssresearch.2006.06.003

Klumpp, M., 2017. Do Forwarders Improve Sustainability Efficiency? Evidence from a European DEA Malmquist Index Calculation. Sustain. 9 (842), 1-33. https://doi.org/10.3390/su9050842

Lacko, R., Hajduová, Z., 2018. Determinants of environmental efficiency of the EU countries using two-step DEA approach. Sustain. 10, 3525. https://doi.org/10.3390/su10103525

Li, M., Mi, Z., Coffman, D., Wei, Y. 2018. Assessing the policy impacts on non-ferrous metals industry's CO2 reduction: Evidence from China, J. Clean Prod. 192, 252-261. https://doi.org/10.1016/j.jclepro.2018.05.015

Lin, D., Hanscom, L., Murthy, A., Galli, A., Evans, M., Neill, E., Mancini, MS., Martindill, J., Medouar, F.Z., Huang, S., Wackernagel, M. 2018. Ecological Footprint Accounting for Countries: Updates and Results of the National Footprint Accounts, 2012-2018. Resources 7(58), 1-22. https://doi.org/10.3390/resources7030058

Marquart-Pyatt, S., 2015. Environmental Sustainability: The Ecological Footprint in West Africa. Hum Ecol Rev 22(1), 73-94. https://www.jstor.org/stable/24875149

Mungai, C. 2015. Which countries are in ecological debt? Mail&Guardian African. 21 Aug.

Mzoughi, N. 2011. Farmers adoption of integrated crop protection and organic farming: Do moral and social concerns matter? Ecol. Econ. 70, 1536-1545. https://doi.org/10.1016/j.ecolecon.2011.03.016

Nhemachena, C., Matchaya, G., Nhemachena, C.N., Karuaihe, S., Muchara, B., Nhelengethwa, S. 2018. Measuring Baseline Agriculture-Related Sustainable Development Goals Index for Southern Africa. Sustainability, 10(840). https://doi.org/10.3390/su.10030849

Niccolucci, V., Tiezzi, E., Pulselli, F.M., Capineri, C., 2012. Biocapacity vs Ecological Footprint of world regions: A geopolitical interpretation. Ecol. Indic. 16, 23-30. https://doi.org/10.1016/j.ecolind.2011.09.002

Olanipekun, I., Olasehinde-Williams, G., Alao, R., 2019. Agriculture and environmental degradation in Africa: The role of income. Sci. Total Environ. 692 (20), 60-67. https://doi.org/10.1016/j.scitotenv.2019.07.129

Oppon E., Acquaye, A., Ibn-Mahammed, T., Koh, L., 2018. Modelling multi-regional ecological exchanges: The case of UK and Africa. Ecol Econ. 147,422-435. https://doi.org/10.1016/j.ecolecon.2018.01.030

Ozcan, B., Ulucak, R., Dogan, E., 2019. Analyzing long lasting effects of environmental policies: evidence from low, middle and high income economies. Sustain. Cities Soc. 44, 130-143. https://doi.org/10.1016/j.scs.2018.09.025

Peris, M.B., 2017. Aplicación de la técnica DEA en la medición de la eficiencia de los países de la Unión Europea. Revista digital de Medio Ambiente Ojeando la agenda 46, 1-13.

Rees, WE. 1992. Ecological footprint and appropriated carrying capacity: what urban economics leaves out. Environ. Urbanization 4 (2), 121-130. https://doi.org/10.1177/095624789200400212

Rees, W.E., Wackernagel, M., 1994. Ecological footprint and appropriated carrying capacity: measuring the natural capital requirements of the human economy. In: Jansson, AM., Hammer, M., Folke, C., Costanza, R. (Eds) Investing in Natural

Capital: The Ecological Economics Approach to Sustainability. Island Press, Washington, DC, 362-390.

Rudolph, A., Figge, L. 2017. Determinants of Ecological Footprints: What is the role of globalization? Ecol. Indic. 81, 348-361. https://doi.org/10.1016/j.ecolind.2017.04.060

Solarin, S.A., Bello, M.O., 2018. Persistence of policy shocks to an environmental degradation index: the case of ecological footprint in 128 developed and developing countries. Ecol. Indic. 89, 35-44. https://doi.org/10.1016/j.ecolind.2018.01.064

Sun, M., Wang, Y., Shi, L., Klemeš, JJ. 2018. Uncovering energy use, carbon emissions and environmental burdens of pulp and paper industry: A systematic review and meta-analysis. Renew. Sust. Energ. Rev, 92, 823-833. https://doi.org/10.1016/j.rser.2018.04.036

Ulucak, R., Apergis, N., 2018. Does convergence really matter for the environment? An application based on club convergence and on the ecological footprint concept for the EU countries. Environ. Sci. Policy 80, 21-27. https://doi.org/10.1016/j.envsci.2017.11.002

Ulucak, R., Lin, D. 2017. Persistence of policy shocks to ecological footprint of the USA. Ecol. Indic. 80, 337-343. https://doi.org/10.1016/j.ecolind.2017.05.020

Venter, O., Sanderson, E.W., Magrach,A., Allan, J.R., Beher, J., Jones K.R., Possingham, H.P., Laurance, W.F., Wood, P., Fekete, B.M., Levy, M.A., Watson, J.E.M. 2016. Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. Nature Communications. doi 10.1038/ncomms12558.

Wang, K., Lu, B., Wei, Y.M., 2013. China's regional energy and environmental efficiency: A range-adjusted measure based analysis. Appl Energy. 112, 1403–1415. doi: 10.1016/j.apenergy.2013.04.021.

White, T.J., 2007. Sharing resources: the global distribution of the ecological footprint. Ecol. Econ. 64, 402-410. https://doi.org/10.1016/j.ecolecon.2007.07.024

WWF, 2010. Living Planet Report. Worldwide Fund for Nature, Gland, Switzerland.

Yilanci, V., Gorus, MS., Aydin, M. 2019. Are shocks to ecological footprint in OECD countries permanent or temporary?. J. Clean. Prod. 212, 270-301. https://doi.org/10.1016/j.jclepro.2018.11.299

Zeng, S., Jiang, C., Ma, C., Su, B. 2018. Investment Efficiency of the New Energy Industry in China, Energy Economics, 70, 536-544. https://doi.org/10.1016/j.eneco.2017.12.023

Zeng, S., Nan, X., Liu, C., Chen J, 2017. The response of the Beijing carbon emissions allowance price (BJC) to macroeconomic and energy price indices, Energy Policy. 106, 111-121. https://doi.org/10.1016/j.enpol.2017.03.046

Zhang, N., Kong, F., Choi, Y. 2014. Measuring sustainability performance for China: A sequential generalized directional distance function approach. Econ. Mod. 41, 392–397.

Appendix

Table 1A. Efficiency Results

Africa deficit	Efficiency
Gambia	1
South Africa	1
Swaziland	1
Mauritius	1
Nigeria	1
Algeria	0.849
Tunisia	0.836
Morocco	0.815
Lesotho	0.775
Egypt	0.579
Sudan	0.507
Libyan	0.498
Kenya	0.453
Rwanda	0.395
Ghana	0.366
Senegal	0.359
Zimbabwe	0.342
Togo	0.340
Burundi	0.336
Malawi	0.263
Benin	0.258
Mali	0.222
Uganda	0.218
Burkina Faso	0.189
Somalia	0.168
Ethiopia	0.158
Niger	0.102

Africa surplus	Efficiency
Angola	1
Gabon	1
Guinea-Bissau	1
Eritrea	0.998
Namibia	0.851
Botswana	0.835
Zambia	0.541
Liberia	0.461
Central African Rep.	0.438
Mauritania	0.433
Congo	0.375
Cameroon	0.364
Côte d'Ivoire	0.359
Sierra Leone	0.356
Guinea	0.190
Mozambique	0.177
Chad	0.174
Madagascar	0.168

Source: Own Elaboration