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Impact of Electrification on African Development-Analysis with Using Grey Systems Theory

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Abstract: In this paper, the authors discuss the problem of the influence of the level of electrification in African countries on their sustainable development. The first aim of the article is to determine the relationship between changes in the electrification index and changes in the indicators showing individual components of sustainable development for African countries. The analyzed indicators of sustainable development include GDP per capita, Human Deveopment Index (HDI), and the CO_2 emissions per capita indicator. The second goal of the article was to develop a synthetic indicator of sustainable development. This study uses the method of relationship research based on Gray Systems Theory—Gray Incidence Analysis. The main conclusion from the research carried out is that improving access to electricity is a necessary condition for the sustainable development of African countries. The lack of improvement in the availability of electricity is a basic barrier to development, especially in the poorest African countries.

Keywords: Africa; electrification; socio-economics development; grey systems theory; grey incidence analysis

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1. Introduction

More than a billion and a half people around the world lack access to electricity, and another billion suffer intermittent or marginal quality of service due to electrification. The majority of these people live in suburban or rural areas of sub-Saharan Africa and Asia. In highly developed countries, current strategies are more focused on reducing traditional sources of energy to increase the share of renewable sources in the energy mix. Energy development in a modern part of the world is aimed at accelerating the decarbonization process [1]. If the international agenda does not change that course, electrification rates will continue to diverge significantly among regions [2], which will lead to economic and social problems.

If we want to understand the scale of the problem in sub-Saharan Africa, we should compare it to other regions with plenty of developing countries. The level of electricity access in Latin America or Middle East and North Africa countries is approximately 80–90%. Countries such as Algeria, Egypt, Morocco, or Seychelles have full access to electricity, even though they are considered as developing in Africa. However, most sub-Saharan African countries are struggling to escape from "energy poverty", with nearly 70% of their population lacking access to electricity [3]. Scientists claim that most sub-Saharan African states are in the middle of a power crisis [4], and the problem will deepen due to population growth. A power crisis may be characterized by inadequate, unreliable, and costly electricity infrastructure across African countries [5]. According to trends, it will be hard to achieve the goal defined as 45% of African countries will have universal access to electricity by 2050 [6]. However, there are some initiatives that focus on such goals. For example, in 2012, the Sustainable Energy for All initiative which is a global initiative introduced by the United Nations Secretary-General. Its main goal is to provide universal access to modern energy services by 2030. The UN underlined that substantial financial and technological investments would be required at a rate far exceeding historical levels [7].

Thanks to its geographical location Africa has great potential due to renewable sources of energy. Although every country in Africa has a surplus of energy resources, unfortunately, most of them are struggling with the financial issue due to energy sectors. The vast majority of countries, because of that, are far from being able to exploit their energy potential fully [7].

The aim of this paper is to measure the relationship between the dynamics of the access to electricity (% of populations) index and the dynamics in changes of indices mirroring individual components of sustainable development, i.e., the component connected with social development (represented by the HDI index), the component connected with economic development (represented by the GDP per capita index), and the component connected with environmental development (represented by the CO_2 emissions per capita index) for African countries. Moreover, we defined the relationship between the dynamics of the access to electricity (% of populations) index and the dynamics of a synthetic index of sustainable growth proposed by us, based on the HDI, GDP per capita, and CO_2 emissions per capita indices. In this paper, the method of relation research based on the Grey Systems Theory—Grey Incidence Analysis was used. Reaching the assumed goals will make it possible to verify the hypothesis, according to which there is a substantial relation between the increase in access to electricity index value and increase in value of both the indices selected by us and picturing individual components of sustainable development, as well as the increase in the elaborated synthetic index of sustainable development for African countries.

The selection of indices representing components of sustainable development stems from various premises. It is worth mentioning that, in this paper, development is understood in a broad context of economic, social, and environmental changes, which refer to the European understanding of the term "sustainable development". Nowadays, we are experiencing a situation when the sustainable development of the economy and the human society has been under the threats of regional environmental pollution and large-scale ecological destruction at the same time [8,9]. In terms of economic development, the most often used measure is economic growth, understood as gross domestic product or economic growth in percentage values. However, in the case of economies based on raw materials, such as Nigeria, South Africa, and Libya, they are not reliable, even more so if such a country is inhabited by millions. Therefore, to picture the economic condition of a given country in the best possible way, the decision was made to use the gross domestic product per capita index, which represents the wealth distribution in a society.

The fact that development may not be understood solely in economic terms was already noted by A. Smith, who clearly distinguished the notions of material wealth and welfare. The material wealth is manifested in terms of the aforementioned economic measures, but welfare, due to its interdisciplinary character, is much more difficult to be measured. The welfare of a given country may be constituted by education, public health, access to public services, etc. Thus far, the best synthetic measure of welfare understood as social development is the Human Development Index (HDI). Its components are, among others, life expectancy at birth or expected years of schooling. Social orientation is visible. H. Rosling wrote that indices on actual life, especially those measured for children, are a measure of the temperature of an entire society because if a given country can take care of the youngest ones, provide them with good care and access to medications, and invests in their education, such a country will perform well in the international arena.

The final matter is the environment. According to studies, Africa is the most vulnerable to climate change. To the greatest degree, it will impact farming, which is the basic sector in the majority of African economies. In the face of a demographic explosion, violent phenomena—such as floods, droughts, increase in mean annual temperature—millions of people, who already today must survive for less than USD 2 per day, will lose their life opportunities. Nowadays, development with negligence of environmental matters is impossible, for if one lacks proper consideration for the environment today, in a few years, the economic development will be hindered by an ecological disaster. The matter of respect for the natural environment is obvious in highly developed countries but neglected in developing countries. Very often, the authorities and governments in poor countries must choose between economic growth, social development, and environmental protection.

Summing up the aforementioned issues, it seems that adopting a threefold approach makes it possible to describe the connection between electrification and sustainable growth more precisely. One must remember, though, that growth issues in developing countries are a result of historical, economic, political, social, and cultural conditions. Economy, such as social science, uses mathematical and econometric methods to enrich and broaden the researchers' toolset. One cannot neglect the fact, though, that the interpretation of the obtained results should be conducted with due diligence. Human life and a man's chances for improving one's condition may not be unequivocally interpreted based on even the most perfect model.

The major contribution of our paper is founded on three components. First, we have researched the question of the influence of electrification on the sustainable growth of African countries from a new perspective. Until now, studies concentrated on the research of correlation between indices picturing the electrification level and selected indices of economic development. In other words, the researchers usually analyze if, for example, countries with better average access to electricity feature a better average GDP pc index. In our studies, we assumed a different perspective—we checked whether for each African country there is a connection between the access to electricity (% of populations) index and improvement in selected indices mirroring sustainable development. Such an approach to the study was possible owing to the employment of the Grey Incidence Analysis, rendering it possible to research relations between short time series. Secondly, we elaborated a new, synthetic index of sustainable growth, making consideration for three perspectives—economic, social, and ecological. Thirdly, we researched all African countries. Usually, researches are conducted in the context of sub-Saharan Africa, and countries in North Africa are combined with countries from the Arab Peninsula. In this research, all African countries were included for which data were available, which is a novelty approach to the research of electrification issue. The authors hope that this paper will contribute with new input in the discussion over the question of the importance of access to electric energy for the development of African countries.

2. Literature Review

2.1. Impact of Electrification on African Development

In the past few decades, the world's energy demand and consumption maintained an uninterrupted growth [10]. The reason for this is the increasing energy consumption in developing countries that is accelerating economic growth. Moreover, phenomena such as population growth and urbanization have become the main force of world energy consumption growth [11–13].

Developing countries experience the same as some developed global effects such as rapid population growth, urbanization, and more industrialization. Those effects are determined mostly by the infrastructure for electricity, and it has emerged as an important factor in a country's growth prospects for future development. The importance of information and communication technologies causes significant electricity demand [14]. At the same time, in sub-Saharan Africa, approximately 81% of the population relies only on traditional biomass fuels for cooking and heating. Using such type of energy is closely connected with such disadvantages: a significant amount of time spent on maintaining the source of energy, maintain mainly by women and children, on the fuel–wood collection, indoor air pollution, deforestation, and soil degradation [15]. Moreover, such a situation contributes to women's disproportionate lack of access to education or income and inability to escape from poverty [16].

It is worth noticing that electrical energy has more advantages than other types of energy. For example, it enables much more efficient lighting [17], information and communication technologies, and more productive manufacturing of goods [18]. Better access to electricity and electrification, in general, causes energy development. At the same time, energy development has an elaborate impact on economic, social, and environmental development [16].

According to the data, sub-Saharan Africa is the only world region where the per capita consumption of electricity is falling [5]. This phenomenon can be explained by the low access to energy and the demographic boom, which hinders access to energy and causes the statistical inhabitant of Africa to have fewer units of electricity. Because of low electricity consumption across sub-Saharan Africa countries, we can face challenges due to economic growth, but at the same time, it is an insignificant contributor to carbon dioxide emissions and climate change. When we compare that region to all world regions, Africa has the lowest per capita emissions and is among the lowest emissions in terms of GDP output countries [5].

Electricity is considered an important driving force to promote economic and social development in countries. The increasing electricity consumption, especially industrial electricity consumption, can be understood as a symbol of a country's economic development level [19]. However, there is too little interested in linking energy consumption with access to electricity. The authors express the view that before examining the relationship between energy consumption and income, it is worth looking at the issues of access to electricity. The level of consumption is determined by the access to electricity, and only then may it increase the income per capita. Access to electricity, as was already emphasized, is very sensitive in sub-Saharan Africa.

Later in this paper, the authors will present a literature review and examine existing researches where other authors linking electricity with economic growth, social development, and environmental issues. Over the past decades, numerous studies were conducted to examine the relationship between electricity consumption and economic growth. Most of them show that there is a strong relationship between electricity consumption and economic growth [20,21]. The electricity infrastructure of the countries is becoming a more and more important component of their economies [21]. Even without scientific research, we can say that electricity has become the preferred and dominant form of energy over the expanding portion of economic life in industrial economies. At the same time, it was a major source of improvement of the standard of living and has played a significant role in the technological and scientific advancement of the economy [22].

Wolde-Rufael [23] conducted a study on 17 African countries with annual data from 1971 to 2001. For cointegration, he used bounds tests [24] and for causality, the WALD test [25]. The cointegration results between electricity consumption and economic growth are not clear-cut among African countries. Only half of them are cointegrated (Benin, Cameroon, Republic of Congo, Gabon, Morocco, Nigeria, Sudan, Zambia, and Zimbabwe). Similar to the previous method, the WALD test shreds of evidence are also non-consensus among the selected countries. Based on the whole research of Wolde-Rufael, we can conclude that electricity consumption and economic growth are not related to Algeria, Congo Republic, Kenya, South Africa, and Sudan [26]. The topic of a causal relationship between energy consumption and income was well-studied in the energy economics literature [27] and environment literature. Different studies focused on different regions, countries, and periods and used different methods and variables for energy consumption and income. In the neo-classical framework, no part of economic growth is attributed to the greater use of energy, and it enters the national accounts only as a part of the economy's output. Such an approach currently is unfortunately not convincing [28].

In many sub-Saharan countries, people are suffering from blackouts. Outages of electricity are frequent and unpredictable. According to the World Bank enterprise surveys, from the years 2006 to 2010, the average length of an outage is 6.6 h [29]. In the same survey, more than 50% of Africa businesses indicated inadequate power supply as a major infrastructure that dampens development [30]. Lack of reliability due to electricity has strong and direct (negative) effects on business activity. Frequent power outages result in foregone sales of goods and services and damaged equipment for businesses. It generated enormous losses for enterprises, calculated as approximately 6% of turnover on average for firms in the formal sector and a round of 16% turnover for informal sector enterprises [4]. Overall, it also affects country economies. Based on data from the World Bank's Investment Climate Assessments and estimations, the lost load or unserved energy due to blackouts cost sub-Saharan African countries an average of 2.1% of GDP (in countries such as Nigeria or Tanzania, it is even more than 4%) [4].

A chronic problem with electricity affecting not only GDP but, in general, weaken economic growth. Mostly it causes by the lower productivity of the economy. Data collected through the World Bank's Investment Climate Assessments by surveys and analyzed by Escribano et al. [31] suggest that in most countries of sub-Saharan Africa, infrastructure accounts for 30–60% of the effect of investment climate on firm productivity. Countries that are experiencing power shortages in Africa can enter into short-term leases with specialized operators who install new capacity. Emergency temporary generators account for an estimated 750 MW of capacity in sub-Saharan Africa and at the same time constitute a significant proportion of total capacity in some countries [5]. Unfortunately, such solutions are expensive, unsurprisingly the most expensive in Africa. Emergency power costs around USD 0.20–0.30 per kWh; meanwhile, the average cost of power in sub-Saharan Africa is USD 0.12 per kWh, twice more expensive than in other developing countries [5]. As it was mentioned before, better access to electricity lowers costs for companies and increases the overall level of investment, which leads to better economic growth [32].

Higher accessibility of electricity boosts the process of meeting social needs such as residential and domestic [29]. Moreover, it contributes to capital and labor productivity and promotes the export potentials of countries [33]. At the same time, it positively affects employment, decreases the poverty level [34], and improves the socio-economic development of a country.

Infrastructure, including electricity infrastructure, is also contributing to human development. The biggest effects we can spot in two main sectors are health care and education. Better access to energy improves health care; for example, hospitals can safely store medicines and vaccines [35]. On the other hand, higher access to electricity positively contributes to literacy and primary school graduation rate because students can read and study at any time during day and night. Many researchers showed that effect in their studies [36,37].

Better access to electricity has a significant impact on social development, but only if it will be undertaken sustainably [7]. It means broader usage of renewable sources of energy. At the same time, renewable energy sources such as solar power, biomass power, wind power, hydro-power, and geothermal energy should be utilized to their full potential to avert the further accumulation of greenhouses gases, promote sustainable development, secure energy supply, and support efforts to attain and contribute to social and economic development [38,39].

Growing demand and consumption of energy, apart from positive effects for economic performance, has a serious influence on the environment, especially the consumption of non-renewable energy on a large scale, which we can experience in many developing countries with plenty of resources such as coal. In many rural areas, people who lived on less than USD 2 per day still depend mostly on wood and other biomass fuels for most of their household and activities, which bring them income [16]. On the other hand, the whole power sector in sub-Saharan Africa accounts for less than one percent of global carbon dioxide emissions, excluding South Africa [40].

Many scientists who analyzed the energy industry believed that not only access to electricity but also energy efficiency is an important issue that should arise in debate. According to them, energy efficiency creates an enormous "win–win" opportunity for countries. On the one hand, the government can save more money, and, on the other hand, it leads to reduce negative externalities associated with energy use. Government intervention focused on energy efficiency can improve people's welfare for two main reasons: Energy-based on the consumption of fossil fuels causes externalities such as harm to human health, climate change, and constraints on the foreign policy objectives of energy-importing countries [41]. Secondly, due to imperfect information, individuals and enterprises may not undertake private investments in energy efficiency. Government intervention due to increasing energy efficiency may use some specific strategies. The government as an entity may invest in energy infrastructure, which benefits efficiency. Additionally, the government may create a special polity that will encourage citizens and companies for private investments, which will benefit the whole economy. Such active intervention of state arises from some economic theories, especially from new structural economy [42].

More energy-efficient technologies offer promise for reducing the financial costs of electricity and environmental damages associated with energy production and usage [43]. Researchers observed that these technologies might not be adopted by individuals and firms due to their financial basis. It is another reason for government intervention in the field of electricity.

Thanks to comparative studies, the authors can demonstrate the ability to examine, compare, and contrast subjects or ideas. Comparative analysis shows how two subjects are similar or show how two subjects are different. Our study uses such an approach on three levels. We contrasted our outcomes with scientists who work separately on electrification and GDP, electrification and social development, and electrification and environmental. It allows a synthetic indicator of sustainable development to be created.

2.2. Essence of Grey Systems

The Grey Systems Theory, when understood as a tool, consists of a series of methods of modeling information uncertainty. It is a complementary theory for statistics, fuzzy logic, and rough set theory. The particular usefulness of the Grey Systems Theory manifests itself in the case of a specific type of uncertainty present in the process of system cognition, that is, the uncertainty that stems from information deficits [44]. These deficits are characterized by a lack of information completeness, little information, and the occurrence of information of a high level of subjectivity. Such an information uncertainty occurs very often in the case of systems, in which people are the key component—that is, economic systems. Due to the aforementioned considerations, the Grey Systems Theory is defined as a methodology being the opposite of the Big Data concept [45]. From a formal point of view, uncertainty modeling with the Grey Systems Theory is executed when analyses are conducted with the use of at least one out of three grey concepts, i.e., grey numbers, whitening function, or distributive understanding of grey.

The Grey Systems Theory, owing to the indicated advantages, is widely used in uncertainty modeling in economic systems. The Grey Systems Theory has been lately used, for example, for problems of:

- sustainable development [46–48];
- analysis of crypto-currencies [49];
- allocation of assets [50,51];
- credit risk evaluation [52];
- innovation and initiative [53];
- product prices settlement [54];
- analysis of product portfolio [55];
- Industry 4.0 [56].

3. Material and Method

3.1. Formal Structure of Models for Relation Analysis in the Grey Systems Theory

In this paper, time series are analyzed, consisting of values of the selected indices of sustainable growth for African countries. Some of the statistics collected and published for African countries feature the character of short time series—often, available data are a dozen or so years old.

In such a case, it is methodologically unreasonable to determine the correlation with the use of statistical measures, such as the Pearson linear correlation index. To verify this paper's hypothesis, a methodology adequate for modeling short time series was used: the Grey Systems Theory.

The group of the Grey Systems Theory models, allowing for the analysis of relations between short series, is defined as the Grey Incidence Analysis. Within its frame, there are three types of models: distance, area, and panel. First and foremost, time series are modeled with the use of relation area models.

In area models, the similarity between two series is represented by an area plotted between two vectors illustrating subsequent values in the time series. This issue is presented in Figure 1.

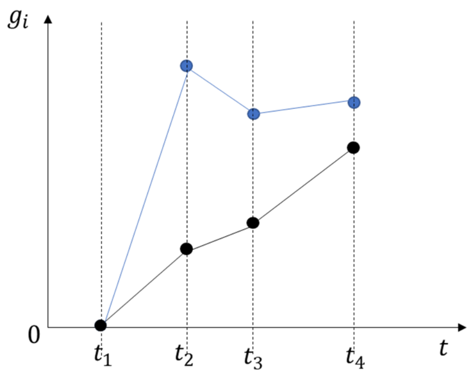

Figure 1. The idea of the area model in graphic form. Source: own work.

In this paper, the most effective model of the Grey Incidence Analysis was used, based on the determination of the relative degree of grey incidence index. Moreover, a methodological triangulation concept was used, consisting in this case in the determination of three variants of the relative degree of the grey incidence index. Each of the variants differs in the method of unitarization of variables. Such an approach provides the possibility of verifying the stability of individual models, especially in the context of an answer to the question of whether the method of scaling variables influences the obtained results considerably.

The formal model of determining the relative degree of the grey incidence index may be presented as a procedure consisting of 5 steps.

Step 1. Determination of the time series set, for which the relative degree of grey incidence indices is determined.

Determination of geometrical probability between charts illustrating time series is plotted in pairs. In each pair, one of the time series is treated as a reference vector, and the other series is treated as an empirical vector. Reference vectors in the proposed model are time series presenting the access to electricity (% of populations) for each of the African countries included in the research. Empirical vectors are, on the other hand, time series presenting one by one: HDI (a social component of sustainable growth), GDP per capita (an economic component of sustainable growth), and CO_2 emissions per capita (environmental component of sustainable growth) indices, as well as time series presenting a synthetic index of sustainable growth (the methodology of its determination is presented in Section 3.2).

$$X_k^{\text{ref}} = \left[x_{k1}^{\text{ref}},\ x_{k2}^{\text{ref}},\ \ldots,\ x_{kj}^{\text{ref}}, \ldots, x_{kl}^{\text{ref}}\right] \tag{1}$$

X_k^{ref}—reference vector for a kth object, where $k = 1, 2, \ldots, m$
J—j-th value in the reference series for k-th object $j = 1, 2, \ldots, l$

The set of the remaining vectors is as follows:

$$X_k^{\mathrm{i}} = \left[x_{k1}^{\mathrm{i}},\ x_{k2}^{\mathrm{i}},\ \ldots,\ x_{kj}^{\mathrm{i}}, \ldots, x_{kl}^{\mathrm{i}}\right] \tag{2}$$

X_k^{ref}—reference vector for a kth object, where $k = 1, 2, \ldots, m$
J—j-th value in the reference series for k-th object $j = 1, 2, \ldots, l$

Step 2. The first stage of time series standardization.

The first stage of time series standardization in the relative degree of the grey incidence model was conducted with three methods, obtaining three models: (a), (b), and (c).

(a) Standardization that included the division of all terms in the series by their initial values, according to Equations (3) and (4):

$$Y_k^{\mathrm{ref}} = \left[\frac{x_{k1}^{\mathrm{ref}}}{x_{k1}^{\mathrm{ref}}}, \frac{x_{k2}^{\mathrm{ref}}}{x_{k1}^{\mathrm{ref}}}, \ldots, \frac{x_{kj}^{\mathrm{ref}}}{x_{k1}^{\mathrm{ref}}}, \ldots, \frac{x_{kl}^{\mathrm{ref}}}{x_{k1}^{\mathrm{ref}}}\right] = \left[y_{k1}^{\mathrm{ref}},\ y_{k2}^{\mathrm{ref}},\ \ldots, y_{kj}^{\mathrm{ref}}, \ldots, y_{kl}^{\mathrm{ref}}\right] \tag{3}$$

$$Y_k^{\mathrm{i}} = \left[\frac{x_{k1}^{\mathrm{i}}}{x_{k1}^{\mathrm{i}}}, \frac{x_{k2}^{\mathrm{i}}}{x_{k1}^{\mathrm{i}}}, \ldots, \frac{x_{kj}^{\mathrm{i}}}{x_{k1}^{\mathrm{i}}}, \ldots, \frac{x_{kl}^{\mathrm{i}}}{x_{k1}^{\mathrm{i}}}\right] = \left[y_{k1}^{\mathrm{i}}, y_{k2}^{\mathrm{i}},\ \ldots, y_{kj}^{\mathrm{i}}, \ldots, y_{kl}^{\mathrm{i}}\right] \tag{4}$$

(b) Standardization that included the division of all terms in the series by arithmetic means for all values, according to Equations (5) and (6):

$$Y_k^{\mathrm{ref}} = \left[\frac{x_{k1}^{\mathrm{ref}}}{\overline{x}_k^{ref}}, \frac{x_{k2}^{\mathrm{ref}}}{\overline{x}_k^{ref}}, \ldots, \frac{x_{kj}^{\mathrm{ref}}}{\overline{x}_k^{ref}}, \ldots, \frac{x_{kl}^{\mathrm{ref}}}{\overline{x}_k^{ref}}\right] = \left[y_{k1}^{\mathrm{ref}},\ y_{k2}^{\mathrm{ref}},\ \ldots, y_{kj}^{\mathrm{ref}}, \ldots, y_{kl}^{\mathrm{ref}}\right] \tag{5}$$

$$Y_k^{\mathrm{i}} = \left[\frac{x_{k1}^{\mathrm{i}}}{\overline{x}_k^{i}}, \frac{x_{k2}^{\mathrm{i}}}{\overline{x}_k^{i}}, \ldots, \frac{x_{kj}^{\mathrm{i}}}{\overline{x}_k^{i}}, \ldots, \frac{x_{kl}^{\mathrm{i}}}{\overline{x}_k^{i}}\right] = \left[y_{k1}^{\mathrm{i}}, y_{k2}^{\mathrm{i}},\ \ldots, y_{kj}^{\mathrm{i}}, \ldots, y_{kl}^{\mathrm{i}}\right] \tag{6}$$

(c) Standardization that included the division of all terms in the series by maximum values, according to Equations (7) and (8):

$$Y_k^{ref} = \left[\frac{x_{k1}^{ref}}{x_{k-max}^{ref}}, \frac{x_{k2}^{ref}}{x_{k-max}^{ref}}, \ldots, \frac{x_{kj}^{ref}}{x_{k-max}^{ref}}, \ldots, \frac{x_{kl}^{ref}}{x_{k-max}^{ref}}\right] = \left[y_{k1}^{ref},\ y_{k2}^{ref},\ \ldots, y_{kj}^{ref}, \ldots, y_{kl}^{ref}\right] \tag{7}$$

$$Y_k^{i} = \left[\frac{x_{k1}^{i}}{x_{k-max}^{i}}, \frac{x_{k2}^{i}}{x_{k-max}^{i}}, \ldots, \frac{x_{kj}^{i}}{x_{k-max}^{i}}, \ldots, \frac{x_{kl}^{i}}{x_{k-max}^{i}}\right] = \left[y_{k1}^{i}, y_{k2}^{i},\ \ldots, y_{kj}^{i}, \ldots, y_{kl}^{i}\right] \tag{8}$$

Step 3. The second stage of time series standardization.

Then, in the second stage of the standardization procedure, from each value in the time series, their initial values are deducted, which is described as zeroing initial elements of the time series. After the standardization process, the time series assumes the form presented by Equations (9) and (10). This stage is common for each of the three models described in Step 2: (a), (b), and (c).

$$Y'^{\mathrm{ref}}_k = \left[y_{k1}^{\mathrm{ref}} - y_{k1}^{\mathrm{ref}},\ y_{k2}^{\mathrm{ref}} - y_{k1}^{\mathrm{ref}},\ \ldots, y_{kj}^{\mathrm{ref}} - y_{k1}^{\mathrm{ref}}, \ldots, y_{kl}^{\mathrm{ref}} - y_{k1}^{\mathrm{ref}}\right] = \left[y'^{\mathrm{ref}}_{k1},\ y'^{\mathrm{ref}}_{k2}, \ldots, y'^{\mathrm{ref}}_{kj}, \ldots, y'^{\mathrm{ref}}_{kl}\right] \tag{9}$$

$$Y'^{\mathrm{i}}_k = \left[y_{k1}^{\mathrm{i}} - y_{k1}^{\mathrm{i}},\ y_{k2}^{\mathrm{i}} - y_{k1}^{\mathrm{i}},\ \ldots, y_{kj}^{\mathrm{i}} - y_{k1}^{\mathrm{i}}, \ldots, y_{kl}^{\mathrm{i}} - y_{k1}^{\mathrm{i}}\right] = \left[y'^{\mathrm{i}}_{k1},\ y'^{\mathrm{i}}_{k2}, \ldots, y'^{\mathrm{i}}_{kj}, \ldots, y'^{\mathrm{i}}_{kl}\right] \tag{10}$$

Step 4. Determination of model parameters $|s'_{\mathrm{ref}}|$, $|s'_i|$, $|s'_{\mathrm{ref}} - s'_i|$.

Model parameters, i.e., $|s'_{\mathrm{ref}}|$, $|s'_i|$, $|s'_{\mathrm{ref}} - s'_i|$ for each of the three decision models, (a), (b), and (c), are determined with Equations (11)–(13).

$$|s'_{\mathrm{ref}}| = \left| \sum_{j=2}^{l-1} y'^{\mathrm{ref}}_{kj} + 0.5 \cdot y'^{\mathrm{ref}}_{kl} \right| \tag{11}$$

$$|s'_{\mathrm{i}}| = \left| \sum_{j=2}^{l-1} y'^{\mathrm{i}}_{kj} + 0.5 \cdot y'^{\mathrm{i}}_{kl} \right| \tag{12}$$

$$|s'_{\mathrm{ref}} - s'_i| = \left| \sum_{j=2}^{l-1} \left(y'^{\mathrm{i}}_{kj} - y'^{\mathrm{ref}}_{kj} \right) + 0.5 \cdot \left(y'^{\mathrm{i}}_{kl} - y'^{\mathrm{ref}}_{kl} \right) \right| \tag{13}$$

Step 5. Calculation of the relative degree of grey incidence $r_{\mathrm{ref}-i}$

The relative degree of grey incidence $r_{\mathrm{ref}-i}$ is determined with Equation (14).

$$r_{\mathrm{ref}-i} = \frac{1 + |s'_{\mathrm{ref}}| + |s'_{\mathrm{i}}|}{1 + |s'_{\mathrm{ref}}| + |s'_{\mathrm{i}}| + |s'_{\mathrm{ref}} - s'_i|} \tag{14}$$

The values, which may assume the relative degree of grey incidence, are from the range of (0–1). The lower the $r_{\mathrm{ref}-i}$ index value, the smaller the geometrical similarity of the two time series. The higher the $r_{\mathrm{ref}-i}$ index value, the greater the geometrical similarity of two time series.

3.2. Development of Synthetic Index of Sustainable Growth

The synthetic index of sustainable growth is determined based on three components:

Index $r_{\mathrm{ref}-i}$ for the relation of access to electricity—HDI;

Index $r_{\mathrm{ref}-i}$ for the relation of access to electricity—GDP pc;

Index $r_{\mathrm{ref}-i}$ for the relation of access to electricity—CO_2 emissions pc.

Each of the three indices is plotted on a radar graph (Figure 2). The maximum field area that is possible to be obtained is assigned with 100%. This field may be determined with the use of the analytical method of calculating the areas of polygons (Gaussian elimination):

$$F = \frac{1}{2} \left| \sum_{i=1}^{n} X_i (Y_{i+1} - Y_{i=1}) \right| \tag{15}$$

where:

- F—calculated area;
- X_i, Y_i—coordinates of the ith vertex; vertices are numbered one by one, from 1 to n.

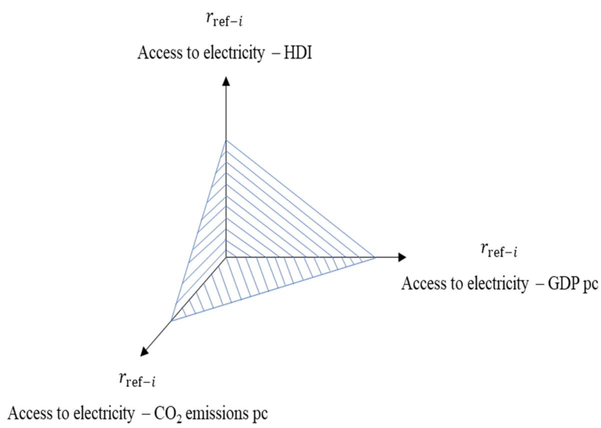

Figure 2. Graphical interpretation of the synthetic index of sustainable growth. Source: own work.

The value of the synthetic index of sustainable growth for individual objects is defined through the determination of a ratio of the area (in percent) plotted on the radar graph with values of component indices to the maximum area possible to be obtained.

4. Empirical Results

4.1. Characteristics of Research Sample

The study makes consideration for results obtained for 50 African countries. Two (2) countries, Burundi and Somalia, were excluded from the study. The reason for the exclusion was data deficits that rendered it impossible to execute the calculation procedure described in Chapter 3. The final set of African countries, constituting the research sample included, is as follows: Algeria (o_1), Angola (o_2), Benin (o_3), Botswana (o_4), Burkina Faso (o_5), Cameroon (o_6), Central African Republic (o_7), Chad (o_8), Comoros (o_9), Congo, Dem. Rep. (o_{10}), Congo, Rep. (o_{11}), Cote d'Ivoire (o_{12}), Djibouti (o_{13}), Egypt, Arab Rep. (o_{14}), Equatorial Guinea (o_{15}), Eritrea (o_{16}), Eswatini (o_{17}), Ethiopia (o_{18}), Gabon (o_{19}), Gambia (o_{20}), Ghana (o_{21}), Guinea (o_{22}), Guinea-Bissau (o_{23}), Kenya (o_{24}), Lesotho (o_{25}), Liberia (o_{26}), Libya (o_{27}), Madagascar (o_{28}), Malawi (o_{29}), Mali (o_{30}), Mauritania (o_{31}), Mauritius (o_{32}), Morocco (o_{33}), Mozambique (o_{34}), Namibia (o_{35}), Niger (o_{36}), Nigeria (o_{37}), Rwanda (o_{38}), Senegal (o_{39}), Seychelles (o_{40}), Sierra Leone (o_{41}), South Africa (o_{42}), South Sudan (o_{43}), Sudan (o_{44}), Tanzania (o_{45}), Togo (o_{46}), Tunisia (o_{47}), Uganda (o_{48}), Zambia (o_{49}), Zimbabwe (o_{50}). Data from the period of 2010–2018 were used in the research.

4.2. Research Results

Step 1. Determination of the time series set, for which the relative degree of grey incidence indices is determined.

For each country, a database was compiled, in which the values of the following indices were collected:

- Access to electricity (% of the population)—as a reference time series (X_k^{ref});
- HDI—as the first empirical time series (X_k^1);
- GDP per capita—as the second empirical time series (X_k^2);
- CO2 emissions per capita—as the third empirical time series (X_k^3).

Sample values of individual time series for selected African countries are presented in Table 1.

Table 1. The set of time series for two selected African countries, for which the relative degree of grey incidence indices is determined. Source: own study based on data from: [57].

Algeria	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Access to electricity	98.878	99.050	98.765	99.539	99.841	99.931	99.990	100.000	100.000
HDI	0.721	0.728	0.728	0.729	0.736	0.74	0.743	0.745	0.746
GDP pc	13.096	13.500	13.303	13.057	13.003	12.016	11.624	11.551	11.750
CO_2 emissions pc	3.275	3.268	3.427	3.472	3.679	3.796	3.67	3.707	3.891
Angola	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Access to electricity	33.394	34.600	35.667	36.872	32.000	42.000	40.668	41.963	43.259
HDI	0.517	0.533	0.544	0.555	0.565	0.572	0.578	0.582	0.582
GDP pc	6588	6711	7413	7682	8179	7338	7103	7311	7097
CO_2 emissions pc	1.236	1.252	1.346	1.277	1.642	1.219	1.183	1.257	1.223

Step 2. The first stage of time series standardization.

(a) Sample results of standardization that included the division of all terms in the series by their initial values, according to Equations (3) and (4) for selected African countries, are presented in Table 2.

Table 2. Time series standardized against their initial values for two selected African countries. Source: own calculated.

Algeria	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**
Access to electricity	1.011	1.011	1.011	1.011	1.010	1.007	0.999	1.002	1.000
HDI	1.035	1.033	1.031	1.026	1.021	1.011	1.010	1.010	1.000
GDP pc	0.897	0.882	0.888	0.918	0.993	0.997	1.016	1.031	1.000
CO_2 emissions pc	1.188	1.132	1.121	1.159	1.123	1.060	1.046	0.998	1.000
Angola	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**
Access to electricity	1.295	1.257	1.218	1.258	0.958	1.104	1.068	1.036	1.000
HDI	1.126	1.126	1.118	1.106	1.093	1.074	1.052	1.031	1.000
GDP pc	1.077	1.110	1.078	1.114	1.242	1.166	1.125	1.019	1.000
CO_2 emissions pc	0.989	1.017	0.957	0.986	1.328	1.033	1.089	1.013	1.000

(b) Sample results of standardization that included the division of all terms in the series by arithmetic mean for all values in the series, according to Equations (5) and (6) for selected African countries, are presented in Table 3.

Table 3. Time series standardized against their arithmetic means for two selected African countries.

Algeria	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**
Access to electricity	1.004	1.004	1.004	1.004	1.003	1.000	0.992	0.995	0.993
HDI	1.015	1.013	1.011	1.007	1.001	0.992	0.990	0.990	0.981
GDP pc	0.937	0.921	0.927	0.958	1.037	1.041	1.060	1.076	1.044
CO_2 emissions pc	1.088	1.037	1.026	1.061	1.029	0.971	0.958	0.914	0.916
Angola	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**
Access to electricity	1.144	1.109	1.075	1.110	0.846	0.975	0.943	0.915	0.883
HDI	1.042	1.042	1.035	1.024	1.011	0.993	0.974	0.954	0.925
GDP pc	0.976	1.006	0.977	1.009	1.125	1.057	1.020	0.923	0.906
CO_2 emissions pc	0.946	0.972	0.915	0.943	1.270	0.988	1.041	0.968	0.956

(c) Sample results of standardization that included the division of all terms in the series by maximum values, according to Equations (7) and (8) for selected African countries, are presented in Table 4.

Step 3. The second stage of time series standardization.

In Step 3, for each model: (a), (b), and (c) is a result of Step 2 of the procedure, the second stage of standardization is executed with deduction of initial values from every value in the time series, which is defined as zeroing of initial elements of the time series. The results of the second stage of standardization for all models are presented in Tables 5–7.

Table 4. Time series standardized against their maximum values for two selected African countries. Source: own calculations.

Algeria	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**
Access to electricity	1.000	1.000	1.000	0.999	0.998	0.995	0.988	0.990	0.989
HDI	1.000	0.999	0.996	0.992	0.987	0.977	0.976	0.976	0.966
GDP pc	0.870	0.856	0.861	0.890	0.963	0.967	0.985	1.000	0.970
CO_2 emissions pc	1.000	0.953	0.943	0.976	0.946	0.892	0.881	0.840	0.842
Angola	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**
Access to electricity	1.000	0.970	0.940	0.971	0.740	0.852	0.824	0.800	0.772
HDI	1.000	1.000	0.993	0.983	0.971	0.954	0.935	0.916	0.888
GDP pc	0.868	0.894	0.868	0.897	1.000	0.939	0.906	0.820	0.805
CO_2 emissions pc	0.745	0.766	0.720	0.742	1.000	0.778	0.820	0.762	0.753

Table 5. The results of the second stage of standardization for model (a) for two selected African countries. Source: own calculations.

Algeria	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**
Access to electricity	0.011	0.011	0.011	0.011	0.010	0.007	−0.001	0.002	0.000
HDI	0.035	0.033	0.031	0.026	0.021	0.011	0.010	0.010	0.000
GDP pc	−0.103	−0.118	−0.112	−0.082	−0.007	−0.003	0.016	0.031	0.000
CO_2 emissions pc	0.188	0.132	0.121	0.159	0.123	0.060	0.046	−0.002	0.000
Angola	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**
Access to electricity	0.295	0.257	0.218	0.258	−0.042	0.104	0.068	0.036	0.000
HDI	0.126	0.126	0.118	0.106	0.093	0.074	0.052	0.031	0.000
GDP pc	0.077	0.110	0.078	0.114	0.242	0.166	0.125	0.019	0.000
CO_2 emissions pc	−0.011	0.017	−0.043	−0.014	0.328	0.033	0.089	0.013	0.000

Table 6. The results of the second stage of standardization for model (b) for two selected African countries. Source: own calculations.

Algeria	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**
Access to electricity	0.011	0.011	0.011	0.011	0.010	0.007	−0.001	0.002	0.000
HDI	0.034	0.033	0.030	0.026	0.020	0.011	0.010	0.010	0.000
GDP pc	−0.107	−0.123	−0.117	−0.086	−0.007	−0.003	0.017	0.032	0.000
CO_2 emissions pc	0.172	0.121	0.110	0.146	0.113	0.055	0.043	−0.002	0.000
Angola	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**
Access to electricity	0.261	0.227	0.192	0.228	−0.037	0.092	0.060	0.032	0.000
HDI	0.116	0.116	0.109	0.098	0.086	0.068	0.048	0.029	0.000
GDP pc	0.070	0.099	0.071	0.103	0.219	0.151	0.113	0.017	0.000
CO_2 emissions pc	−0.010	0.016	−0.041	−0.013	0.314	0.032	0.085	0.012	0.000

Table 7. The results of the second stage of standardization for model (c) for two selected African countries.

Algeria	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**
Access to electricity	0.011	0.011	0.011	0.011	0.010	0.007	−0.001	0.002	0.000
HDI	0.034	0.032	0.029	0.025	0.020	0.011	0.009	0.009	0.000
GDP pc	−0.100	−0.114	−0.109	−0.080	−0.007	−0.003	0.015	0.030	0.000
CO_2 emissions pc	0.158	0.111	0.102	0.134	0.104	0.051	0.039	−0.002	0.000
Angola	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**
Access to electricity	0.228	0.198	0.168	0.199	−0.032	0.080	0.053	0.028	0.000
HDI	0.112	0.112	0.105	0.095	0.082	0.065	0.046	0.027	0.000
GDP pc	0.062	0.088	0.063	0.092	0.195	0.134	0.101	0.015	0.000
CO_2 emissions pc	−0.008	0.013	−0.032	−0.010	0.247	0.025	0.067	0.010	0.000

Step 4. Determination of model parameters $\left|s'_{\text{ref}}\right|$, $\left|s'_i\right|$, $\left|s'_{\text{ref}} - s'_i\right|$.

The results of the fourth step of the proposed model are presented in Table 8.

Table 8. Model components for the determination of the relative degree of grey incidence $r_{\text{ref}-i}$ for two selected African countries. Source: own calculations.

Access to Electricity—HDI						
Model parameters		Algeria			Angola	
	(a)	(b)	(c)	(a)	(b)	(c)
$\left\|s'_{\text{ref}}\right\|$	0.056	0.056	0.055	1.047	0.924	0.808
$\left\|s'_i\right\|$	0.159	0.156	0.153	0.662	0.613	0.588
$\left\|s'_{\text{ref}} - s'_i\right\|$	0.103	0.100	0.098	0.384	0.311	0.219
Access to Electricity—GDP pc						
Model parameters		Algeria			Angola	
	(a)	(b)	(c)	(a)	(b)	(c)
$\left\|s'_{\text{ref}}\right\|$	0.056	0.056	0.055	1.047	0.924	0.808
$\left\|s'_i\right\|$	0.328	0.342	0.318	0.892	0.808	0.718
$\left\|s'_{\text{ref}} - s'_i\right\|$	0.383	0.398	0.373	0.155	0.116	0.089
Access to Electricity—CO_2 Emissions pc						
Model parameters		Algeria			Angola	
	(a)	(b)	(c)	(a)	(b)	(c)
$\left\|s'_{\text{ref}}\right\|$	0.056	0.056	0.055	1.047	0.924	0.808
$\left\|s'_i\right\|$	0.733	0.672	0.617	0.419	0.400	0.315
$\left\|s'_{\text{ref}} - s'_i\right\|$	0.677	0.616	0.562	0.628	0.524	0.493

Step 5. Calculation of the relative degree of grey incidence $r_{\text{ref}-i}$.

Table 9 presents the determined values of the relative degree of grey incidence indices between the access to electricity and the HDI, GDP pc, and CO_2 emissions pc indices for two selected African countries.

Table 9. Values of the relative degree of grey incidence r_{ref-i} indices for two selected African countries. Source: own calculations.

r_{ref-i}	Algeria			Angola		
	(a)	(b)	(c)	(a)	(b)	(c)
Access to electricity—HDI	0.922	0.924	0.925	0.876	0.891	0.916
Access to electricity—GDP pc	0.783	0.779	0.786	0.950	0.959	0.966
Access to electricity—CO_2 emissions pc	0.725	0.737	0.749	0.797	0.816	0.812

According to the procedure presented in Section 3.2, and based on the relative degree of grey incidence r_{ref-i} indices for the relation between the dynamics of changes in access to electricity (HDI), access to electricity (GDP pc), and access to electricity (CO_2 emissions pc), the values of synthetic growth index were determined for each of the studied African countries in three variants: (a), (b) and (c).

Table 10 and Figures 3–5 presents cumulative results for values of synthetic sustainable growth indices for the studied African countries in 2010–2018.

Table 10. Cumulative results for values of synthetic sustainable growth indices for the studied African countries in 2010–2018. Source: own calculations.

Country	(a)	Rank (a)	(b)	Rank (b)	(c)	Rank (c)
Algeria	37.10%	14	37.93%	17	39.79%	20
Angola	55.26%	4	59.78%	4	62.49%	4
Benin	52.22%	6	56.07%	6	59.43%	6
Botswana	46.09%	10	51.24%	9	56.46%	9
Burkina Faso	47.31%	8	53.81%	7	57.86%	8
Cameroon	32.40%	18	34.56%	19	38.16%	22
Central African Republic	0.57%	48	2.24%	49	4.51%	49
Chad	2.70%	44	3.83%	46	6.04%	46
Comoros	37.57%	13	40.71%	13	45.03%	14
Congo, Dem. Rep.	17.60%	31	22.27%	30	27.47%	32
Congo, Rep.	13.76%	34	17.41%	33	19.91%	37
Cote d'Ivoire	25.00%	24	31.55%	24	37.36%	23
Djibouti	15.28%	32	15.76%	35	18.46%	38
Egypt, Arab Rep.	37.57%	12	39.56%	15	41.04%	17
Equatorial Guinea	23.59%	26	21.39%	31	26.80%	33
Eritrea	31.15%	20	36.95%	18	40.31%	18
Eswatini	6.64%	40	9.21%	43	12.53%	44
Ethiopia	9.85%	37	14.87%	36	16.90%	39
Gabon	33.44%	16	32.59%	22	34.06%	27
Gambia, The	11.12%	36	12.35%	39	14.45%	41

Table 10. *Cont.*

Country	(a)	Rank (a)	(b)	Rank (b)	(c)	Rank (c)
Ghana	20.73%	27	28.20%	26	31.44%	28
Guinea	30.60%	21	33.43%	21	39.99%	19
Guinea-Bissau	0.39%	49	2.92%	48	5.62%	48
Kenya	2.00%	46	8.15%	44	14.37%	42
Lesotho	4.77%	41	10.57%	41	21.01%	36
Liberia	2.16%	45	9.97%	42	24.50%	34
Libya	30.20%	22	22.51%	29	30.20%	29
Madagascar	18.66%	30	23.44%	28	28.86%	31
Malawi	14.35%	33	19.13%	32	36.45%	26
Mali	24.89%	25	31.66%	23	42.12%	16
Mauritania	46.53%	9	51.72%	8	58.88%	7
Mauritius	13.55%	35	14.81%	37	16.64%	40
Morocco	59.95%	3	62.05%	3	64.23%	3
Mozambique	20.20%	28	31.01%	25	39.76%	21
Namibia	55.05%	5	59.02%	5	60.89%	5
Niger	33.04%	17	40.00%	14	43.52%	15
Nigeria	31.27%	19	34.45%	20	36.94%	24
Rwanda	4.30%	42	13.46%	38	24.28%	35
Senegal	85.42%	1	86.74%	1	86.69%	1
Seychelles	47.73%	7	50.79%	10	52.00%	11
Sierra Leone	27.42%	23	39.28%	16	55.12%	10
South Africa	45.26%	11	45.52%	11	46.00%	13
South Sudan	0.01%	50	0.61%	50	1.77%	50
Sudan	34.68%	15	41.42%	12	47.04%	12
Tanzania	8.66%	38	16.23%	34	28.87%	30
Togo	7.02%	39	10.66%	40	12.65%	43
Tunisia	67.59%	2	67.85%	2	68.85%	2
Uganda	1.22%	47	3.53%	47	10.03%	45
Zambia	19.63%	29	27.36%	27	36.48%	25
Zimbabwe	3.66%	43	4.81%	45	5.96%	47

Where: (a) a standardization model that breaks down all terms in the series by their initial values; (b) a model to substantiate standardization, which included the division of all terms in the series by arithmetic means for all values in the series; (c) a model to support standardization by dividing all terms in a series by the maximum values in the series.

4.3. Results Discussion

The first aim of this paper was to define the relationship between the dynamics of the access to electricity (% of populations) index and the dynamics in changes in indices mirroring individual components of sustainable development, i.e., component connected with social development (represented by the HDI index), component connected with economic development (represented by the GDP per capita index), and component connected with environmental development (represented by the CO_2 emissions per capita index) for African countries.

Relationships between dynamics of individual indices were defined through the determination of values of the relative degree of grey incidence indices. This index is determined for two time series—it may assume a value in the range of 0.5–1.0. The higher value of the index, the more extensive the relation between the dynamics of the researched time series. If for a given country, there would be extensive relations between, for example, the dynamics of the access to electricity (% of populations) index and the dynamics of the HDI index, it would mean that considerable improvement in the access to electricity index influences the considerable improvement of the HDI index for the country. Additionally, analogously, if there were extensive relations between the dynamics of the access to electricity (% of populations) index and the dynamics of the GDP pc index, it would mean that the considerable improvement in the access to electricity (% of populations) index influences the considerable improvement in the GDP pc index.

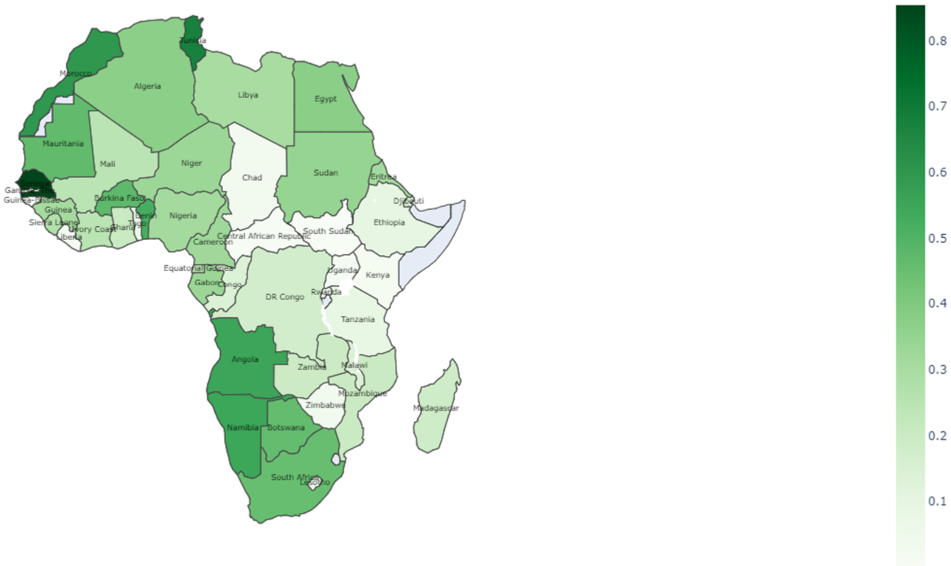

Figure 3. Cumulative results for values of synthetic sustainable growth indices for the studied African countries in 2010–2018—a standardization model that breaks down all terms in the series by their initial values (a). Source: own work.

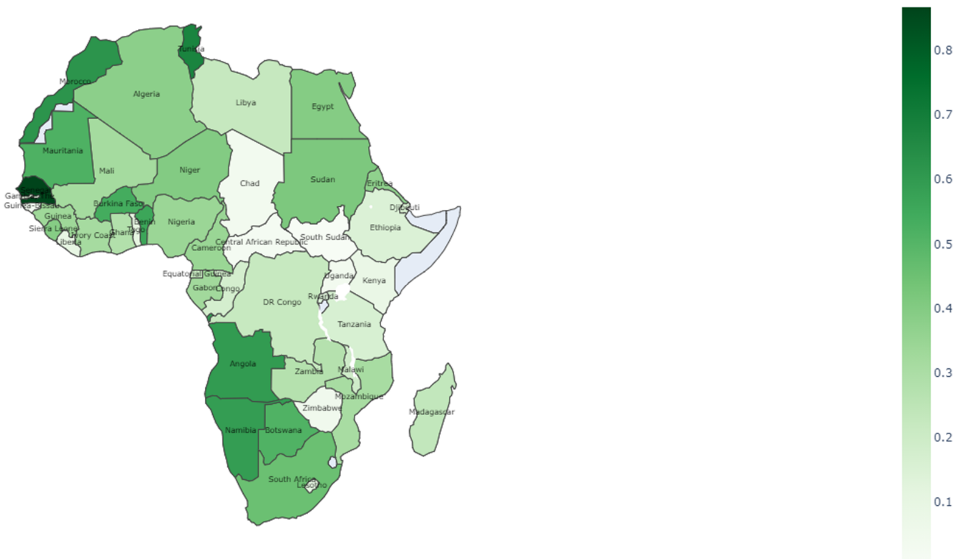

Figure 4. Cumulative results for values of synthetic sustainable growth indices for the studied African countries in 2010–2018—a model to substantiate standardization, which included the division of all terms in the series by arithmetic means for all values in the series (b). Source: own work.

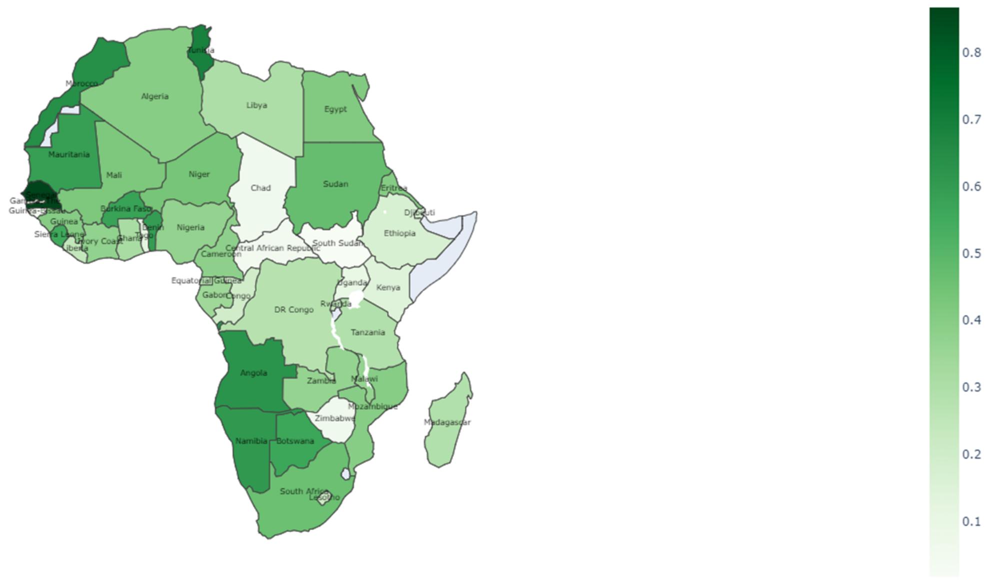

Figure 5. Cumulative results for values of synthetic sustainable growth indices for the studied African countries in 2010–2018—a model to support standardization by dividing all terms in a series by the maximum values in the series ©. Source: own work.

What is important, the direction of reasoning assumed in this paper is different from the correlation between two selected indices often adopted in studies. We did not want to verify if, for example, countries with better average access to electricity feature a better average GDP pc index. For the aforementioned example, our direction of reasoning pertains to the question of whether, for each country, there is a relation between the improvement of the access to electricity (% of populations) index and improvement of the GDP pc index.

For subsequent ranges of values of the relative degree of grey incidence r_{ref-i} index, we have assumed the following scale of relation extent:

- $r_{ref-i} \in (0.5 \div 0.6)$ —very weak impact of the access to electricity onto a selected index;
- $r_{ref-i} \in (0.6 \div 0.7)$ —weak impact of the access to electricity onto a selected index;
- $r_{ref-i} \in (0.7 \div 0.8)$ —moderate impact of the access to electricity onto a selected index;
- $r_{ref-i} \in (0.8 \div 0.9)$ —strong impact of the access to electricity onto a selected index;
- $r_{ref-i} \in (0.9 \div 1.0)$ —very strong impact of the access to electricity onto a selected index.

The scale shows that, for example, if for a given country the index between the dynamics of the access to electricity (% of populations) and the dynamics of the GDP pc amounts to 0.95, then there is a highly positive relationship between them—in other words: there is a very strong impact of the access to electricity index improvement onto the improvement of the GDP pc index. As a consequence, the dynamics of the GDP pc index are fundamentally influenced by the dynamics of the access to electricity (% of populations) index.

As a result of the conducted research, the highest values of indices were featured by the most developed African countries, for example, Senegal, Ivory Coast, Libya, Morocco, and Tunisia. All fragmentary results are presented in Tables 11–13. This means that the very strong impact on the dynamics of their indices, picturing individual components of sustainable growth, is exerted by the improving access to electric energy. The worst performing countries in the setups are especially: South Sudan, Guinea-Bissau, and Liberia. This means that in the face of lack of improving access to electric energy, these countries feature the worst dynamics of indices picturing individual components of sustainable growth (in the research, we used HDI, GDP per capita, and CO_2 emissions per capita indices). In the context of the conducted studies, it must be stated that improving access to electricity is the prerequisite for both the development itself and especially for the sustainable growth of African countries. A lack of improvement in access to electric energy is the fundamental barrier in development, especially in the case of the poorest African countries. The investments in the development alone, for example, the development understood economically, do not contribute to the improvement of the quality of human life. For instance, in Nigeria, in 2015, the GDP value was higher than in Poland, and in the same year, the GDP per capita amounted to USD 5500, and 80 million people (of which 75% were inhabitants of rural areas) were lacking access to electric energy. Nigeria is an example of a country with an economy based on raw materials, which generates the vast majority of its GDP from the export of crude oil and petroleum products. An increase in electrification should not be the sole goal in itself but a step forward on the path of building better foundations for economic growth and social development. The second aim of this paper was to define the relationship between the dynamics of the access to electricity (% of populations) index and the dynamics of a synthetic index of sustainable growth proposed by us, based on HDI, GDP per capita, and CO_2 emissions per capita indices. Irrespective of the used model variant ((a), (b), or (c)), the highest values of the synthetic index of sustainable growth were featured by three countries: Senegal, Tunisia, and Morocco. The countries with the worst values of this index were South Sudan, Guinea-Bissau, and the Central African Republic. Thus, the research results for the elaborated synthetic index of development confirm the relations observed during studies on relations between the dynamics of the access to an electric energy index and individual indices illustrating the dynamics of subsequent components of sustainable growth.

Table 11. Cumulative results for the index of access to electricity—HDI. Source: own calculations.

Country	(a)	Rank (a)	(b)	Rank (b)	(c)	Rank (c)
Algeria	0.9219	13	0.9236	13	0.9249	14
Angola	0.8758	17	0.8908	15	0.9161	15
Benin	0.9354	9	0.9419	9	0.9618	9
Botswana	0.9337	10	0.9409	10	0.9630	8
Burkina Faso	0.7400	30	0.7676	26	0.7965	25
Cameroon	0.9527	8	0.9576	8	0.9692	6
Central African Republic	0.5381	46	0.5774	48	0.6099	48
Chad	0.6495	35	0.6875	35	0.7343	35
Comoros	0.9682	5	0.9712	5	0.9882	2
Congo, Dem. Rep.	0.6915	34	0.7203	34	0.7488	34
Congo, Rep.	0.6977	32	0.7313	33	0.7709	29
Cote d'Ivoire	0.9982	2	0.9985	2	0.9987	1
Djibouti	0.8041	20	0.8145	20	0.8200	22
Egypt, Arab Rep.	0.8819	15	0.8847	17	0.8871	17
Equatorial Guinea	0.9272	11	0.9282	11	0.9286	12
Eritrea	0.7508	22	0.7676	25	0.7843	27
Eswatini	0.6920	33	0.7351	32	0.7650	30
Ethiopia	0.8792	16	0.8857	16	0.8626	19
Gabon	0.7470	26	0.7489	30	0.7525	33
Gambia, The	0.7277	31	0.7441	31	0.7617	31
Ghana	0.7444	27	0.7646	27	0.7816	28
Guinea	0.8046	19	0.8306	19	0.8938	16
Guinea-Bissau	0.5260	49	0.5737	49	0.6081	49
Kenya	0.5370	47	0.5838	46	0.6246	47
Lesotho	0.5918	42	0.6427	42	0.7069	38

Table 11. *Cont.*

Country	(a)	Rank (a)	(b)	Rank (b)	(c)	Rank (c)
Liberia	0.5318	48	0.5781	47	0.6352	46
Libya	0.9866	3	0.9837	4	0.9866	4
Madagascar	0.7427	28	0.7582	28	0.8007	24
Malawi	0.7410	29	0.7742	23	0.8787	18
Mali	0.6251	40	0.6532	39	0.6961	40
Mauritania	0.7491	24	0.7705	24	0.7928	26
Mauritius	0.7486	25	0.7509	29	0.7538	32
Morocco	0.9851	4	0.9863	3	0.9880	3
Mozambique	0.6429	37	0.6791	36	0.7108	36
Namibia	0.9077	14	0.9169	14	0.9353	11
Niger	0.7757	21	0.8044	21	0.8231	21
Nigeria	0.8249	18	0.8423	18	0.8552	20
Rwanda	0.5456	45	0.5933	45	0.6389	45
Senegal	0.9987	1	0.9998	1	0.9849	5
Seychelles	0.9631	6	0.9642	6	0.9636	7
Sierra Leone	0.6048	41	0.6521	40	0.7002	39
South Africa	0.9574	7	0.9591	7	0.9545	10
South Sudan	0.5050	50	0.5469	50	0.5823	50
Sudan	0.7492	23	0.7742	22	0.8145	23
Tanzania	0.5887	43	0.6305	43	0.6805	42
Togo	0.6257	39	0.6631	38	0.6847	41
Tunisia	0.9255	12	0.9266	12	0.9278	13
Uganda	0.5617	44	0.6046	44	0.6776	43
Zambia	0.6323	38	0.6714	37	0.7079	37
Zimbabwe	0.6434	36	0.6509	41	0.6592	44

Where: (a) standardization model that included the division of all terms in the series by their initial values, (b) standardization model that included the division of all terms in the series by arithmetic means for all values in the series, (c) standardization model that included the division of all terms in the series by maximum values in the series.

Table 12. Cumulative results for the index of $r_{\text{ref}-i}$ access to electricity—GDP pc. Source: own calculations.

Country	(a)	Rank (a)	(b)	Rank (b)	(c)	Rank (c)
Algeria	0.7830	19	0.7785	22	0.7864	26
Angola	0.9500	2	0.9594	2	0.9658	2
Benin	0.7935	17	0.8160	17	0.8305	18
Botswana	0.8155	14	0.8365	14	0.8477	14
Burkina Faso	0.8908	6	0.9045	5	0.9028	9
Cameroon	0.7968	16	0.8200	16	0.8405	16
Central African Republic	0.5237	49	0.5455	49	0.5642	49
Chad	0.5648	45	0.5792	45	0.5970	46

Table 12. *Cont.*

Country	(a)	Rank (a)	(b)	Rank (b)	(c)	Rank (c)
Comoros	0.7140	25	0.7388	27	0.7552	31
Congo, Dem. Rep.	0.8750	8	0.9044	6	0.9337	4
Congo, Rep.	0.5673	44	0.5729	47	0.5871	48
Cote d'Ivoire	0.6251	39	0.6664	38	0.7108	36
Djibouti	0.6923	27	0.7122	31	0.7329	35
Egypt, Arab Rep.	0.6641	32	0.6795	36	0.6878	39
Equatorial Guinea	0.6760	29	0.6622	39	0.6908	38
Eritrea	0.7675	20	0.8005	19	0.8277	19
Eswatini	0.6832	28	0.7259	28	0.7597	30
Ethiopia	0.5944	43	0.6312	41	0.6573	41
Gabon	0.8071	15	0.8061	18	0.8100	22
Gambia, The	0.6019	42	0.6011	43	0.6114	45
Ghana	0.6701	31	0.7257	29	0.7430	32
Guinea	0.9955	1	0.9953	1	0.9834	1
Guinea-Bissau	0.5528	47	0.6363	40	0.6730	40
Kenya	0.6390	35	0.7479	26	0.7937	25
Lesotho	0.7025	26	0.7784	23	0.8729	13
Liberia	0.6021	41	0.7099	32	0.8228	20
Libya	0.6361	36	0.5850	44	0.6361	43
Madagascar	0.7496	22	0.7652	24	0.8062	24
Malawi	0.6717	30	0.6998	34	0.7771	29
Mali	0.7465	23	0.7841	21	0.8336	17
Mauritania	0.8651	10	0.8815	10	0.8864	11
Mauritius	0.6103	40	0.6248	42	0.6409	42
Morocco	0.8692	9	0.8805	11	0.8946	10
Mozambique	0.8401	11	0.8766	12	0.9074	8
Namibia	0.8276	13	0.8471	13	0.8463	15
Niger	0.7339	24	0.7627	25	0.7796	28
Nigeria	0.9052	3	0.9172	3	0.9245	5
Rwanda	0.6257	38	0.7195	30	0.7817	27
Senegal	0.8933	5	0.9034	7	0.9169	6
Seychelles	0.6453	34	0.6695	37	0.6933	37
Sierra Leone	0.8303	12	0.8865	8	0.9605	3
South Africa	0.8751	7	0.8818	9	0.8816	12
South Sudan	0.5032	50	0.5175	50	0.5312	50
Sudan	0.7866	18	0.8222	15	0.8198	21
Tanzania	0.6328	37	0.6871	35	0.7429	33
Togo	0.7540	21	0.7999	20	0.8086	23

Table 12. *Cont.*

Country	(a)	Rank (a)	(b)	Rank (b)	(c)	Rank (c)
Tunisia	0.9032	4	0.9050	4	0.9103	7
Uganda	0.5415	48	0.5715	48	0.6223	44
Zambia	0.6573	33	0.7004	33	0.7417	34
Zimbabwe	0.5609	46	0.5792	46	0.5940	47

Where: (a) standardization model that included the division of all terms in the series by their initial values, (b) standardization model that included the division of all terms in the series by arithmetic means for all values in the series, (c) standardization model that included the division of all terms in the series by maximum values in the series.

Table 13. Cumulative results for the index of $r_{\mathrm{ref}-i}$ access to electricity—CO_2 emissions pc. Source: own calculations.

Country	(a)	Rank (a)	(b)	Rank (b)	(c)	Rank (c)
Algeria	0.7254	24	0.7371	25	0.7485	28
Angola	0.7970	18	0.8161	17	0.8116	23
Benin	0.8620	11	0.8706	14	0.8699	14
Botswana	0.7788	19	0.8036	20	0.8238	20
Burkina Faso	0.9138	6	0.9394	5	0.9497	7
Cameroon	0.6449	34	0.6450	36	0.6561	38
Central African Republic	0.5544	46	0.6081	40	0.6535	39
Chad	0.5492	47	0.5520	49	0.5682	49
Comoros	0.7662	21	0.7716	23	0.7868	25
Congo, Dem. Rep.	0.6062	37	0.6249	37	0.6438	40
Congo, Rep.	0.8392	14	0.8738	12	0.8512	15
Cote d'Ivoire	0.7007	28	0.7311	26	0.7467	29
Djibouti	0.6132	36	0.5977	44	0.6157	45
Egypt, Arab Rep.	0.9012	8	0.9035	9	0.9089	8
Equatorial Guinea	0.6686	30	0.6542	34	0.6925	34
Eritrea	0.8212	15	0.8462	15	0.8417	17
Eswatini	0.5389	48	0.5346	50	0.5479	50
Ethiopia	0.5803	41	0.6179	39	0.6340	42
Gabon	0.8157	17	0.8032	21	0.8149	22
Gambia, The	0.6827	29	0.6968	32	0.7123	31
Ghana	0.7748	20	0.8095	18	0.8189	21
Guinea	0.5982	38	0.6054	42	0.6249	43
Guinea-Bissau	0.5197	49	0.5565	48	0.5834	47
Kenya	0.5560	44	0.6215	38	0.6702	36
Lesotho	0.5585	43	0.5939	45	0.6387	41
Liberia	0.5968	39	0.7025	30	0.8060	24
Libya	0.7574	22	0.7246	27	0.7574	26
Madagascar	0.6613	31	0.7051	29	0.7050	33

Table 13. *Cont.*

Country	(a)	Rank (a)	(b)	Rank (b)	(c)	Rank (c)
Malawi	0.6605	32	0.6871	33	0.7568	27
Mali	0.9193	5	0.9435	4	0.9728	5
Mauritania	0.9201	4	0.9366	7	0.9837	4
Mauritius	0.7066	26	0.7123	28	0.7254	30
Morocco	0.8167	16	0.8234	16	0.8275	19
Mozambique	0.7129	25	0.7971	22	0.8435	16
Namibia	0.8798	10	0.8899	10	0.8915	13
Niger	0.8598	12	0.8879	11	0.8917	12
Nigeria	0.6409	35	0.6522	35	0.6619	37
Rwanda	0.6547	33	0.7572	24	0.8398	18
Senegal	0.9984	1	0.9970	1	0.9968	2
Seychelles	0.9778	2	0.9770	2	0.9573	6
Sierra Leone	0.8930	9	0.9378	6	0.9861	3
South Africa	0.7017	27	0.6975	31	0.7053	32
South Sudan	0.5063	50	0.5588	47	0.5944	46
Sudan	0.8521	13	0.8727	13	0.8977	11
Tanzania	0.7402	23	0.8065	19	0.9079	9
Togo	0.5545	45	0.5671	46	0.5767	48
Tunisia	0.9047	7	0.9042	8	0.9066	10
Uganda	0.5637	42	0.6077	41	0.6785	35
Zambia	0.9364	3	0.9596	3	0.9968	1
Zimbabwe	0.5915	40	0.6049	43	0.6174	44

Where: (a) standardization model that included the division of all terms in the series by their initial values, (b) standardization model that included the division of all terms in the series by arithmetic means for all values in the series, (c) standardization model that included the division of all terms in the series by maximum values in the series.

5. Conclusions

In this paper, we researched how the change in the dynamics of the electrification level influences the dynamics of indices picturing the sustainable growth of African countries. We utilized the approach based on the analysis of short time series with the Grey Incidence Analysis method. This is quite a novelty in comparison to the hitherto studies, based on statistical analyses, requiring large trial samples.

Until now, studies mostly concentrated on the analysis of the correlation between indices picturing the electrification level and selected indices of economic development. Owing to our approach, we could analyze the connection between the increase (or decrease) in the electrification level (access to electricity) and values of sustainable development indices (HDI, GDP per capita, and CO_2 emissions per capita) for each individual African country. Moreover, we defined the relationship between the dynamics of the access to electricity index and the dynamics of a synthetic index of sustainable growth proposed by us, based on the HDI, GDP per capita, and CO_2 emissions per capita indices. The studies were conducted for a group of all African countries, for which the data on the electrification level indices and the components of synthetic development are published.

The obvious practical implication of the obtained model is the recommendation for governments of African countries to invest in the development of the power sector and electrification on a wide scale. The conducted research allowed us to Equationte a thesis that the increase in the electrification level may favor a considerable increase in all indices of sustainable growth. As was stressed at the beginning, only Algeria, Egypt, Morocco, and Seychelles feature full, 100% access to electric energy. The problems, however, include deficiencies of governmental institutions and a high level of corruption. This spurs the lack or too low an interest in the matters of access to electric energy among local economic decision-makers. This is, however, a clear signal for international institutions, such as the UN, World Bank, and Development Assistance Committee, providing development assistance. The development assistance donors, when investing in Africa, focus mainly on the social infrastructure (20–30% of funds from development assistance financing), such as investments in education, access to water, and public services. These are important aspects, but based on the elaborated model, the investments in electrification will bring both an improvement of economic indices (GDP per capita) and a higher HDI index level, thus contributing to the development. Moreover, apart from the improvement in the quality of people's lives, improved access to electricity will spur growth in entrepreneurship and facilitate running a business. It is thus recommended for donor countries and institutions providing multilateral assistance to develop specific projects and programs facilitating the development of electrification in African countries.

The great advantage of the proposed method is that it enables the analysis of short time series (thanks to the application of the method based on the gray systems theory). However, in the case of long time series, it becomes possible to use statistical-based studies (e.g., correlation studies). In this case, the advantages of the developed method are limited. Considering, however, that most of the world's data on the issues of sustainable development are short-term in nature, the developed method has a significant advantage over statistical methods.

Conclusions drawn from the study indicate that electrification should be a priority for governments of African countries. For the authors, however, the notion of electrification was understood as the access to energy, irrespective of its origin. Due to the global climate agenda, which aims at achieving climatic neutrality through the reduction in CO2 emission, as well as the potential of African countries (climatic conditions), it seems reasonable to conduct future research with differentiation between the traditionally sourced energy (e.g., consumption of hard coal or brown coal) and energy from renewable sources. The research could deliver recommendations for concrete African countries, which electric energy type they should invest in to maximize benefits (including the economic ones) and, at the same time, minimize losses (mainly environmental ones). Such research would have to make consideration for access to raw materials (many African countries have considerable coal beds) and varied potential for renewable energy sources (insolation, winds frequency and speed, water resources).

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