# МІЖГАЛУЗЕВІ ПРОБЛЕМИ І СИСТЕМНІ ДОСЛІДЖЕННЯ В ПАЛИВНО-ЕНЕРГЕТИЧНОМУ СЕКТОРІ
# CROSS-SECTORAL PROBLEMS AND SYSTEM STUDIES IN THE FUEL AND ENERGY SECTOR

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## INDICATOR-BASED ANALYSIS OF PRECONDITIONS FOR DEPLOYMENT OF INNOVATIVE SOLUTIONS FOR EXPANDING ACCESS TO ELECTRICITY IN SUB-SAHARAN COUNTRIES

*In the article, there was conducted an indicator-based analysis for assessing the preconditions for the deployment of innovative energy solutions in Sub-Saharan countries for extending access of their population to electricity. This type of analysis was used to assess the state of investigated Sub-Saharan countries with certain criteria over a defined period of time regarding their abilities to attract investments in innovative energy solutions for extending access to electricity. The criteria and indicators necessary for assessing preconditions on the deployment of innovative energy solutions in Sub-Saharan countries in the frame of indicator-based analysis were determined. The middle-income economy, the institutional and social stability, the acceptable level of security, the lasting economic growth, and the rate of electrification were chosen as the key criteria attractive for investments in the energy sector. The criteria were based on the set of universal typical indicators that define the state of the economic, institutional and social environment across the countries in the identical qualitative definitions and quantitative features. To avoid the bias of inferences and reduce the vulnerability of the decision-making process, information modeling techniques were applied for data processing. Grounded on these techniques, the binary matrix table was designed to manage and arrange the descriptive informational data about countries. As a result of the indicator-based analysis, the group of Sub-Saharan countries, which confirmed the criteria for attracting investment in innovative energy solutions, was defined. These countries were analyzed in detail regarding the dynamics of the electrification rate. The number of inhabitants without access to electricity and the approximate number of households that need to get access to electricity were evaluated. The possible innovative solutions for improving access to electricity were also considered.*

***Key words**: indicator-based analysis, electrification rate, access to electricity, innovative solutions, Sub-Saharan countries.*

**Introduction**. Economic growth accelerates the industrial and urbanization processes, increases households' purchasing energy that have a strong impact on the level of electricity consumption. As stated by the latest research of the International Energy Agency (IEA) the rapid economic and population growth in Africa will have considerable consequences not only for the regional energy sector but also for the global one. Projected by the International Monetary Fund in 2019, the average economic growth in developing Sub-Saharan countries will rise to 3,6 %. However, the real level of per capita income will significantly vary between the countries in this region. It will be much higher for 24 non-resource-intensive countries with a total population about 500 million people. The average economic growth expected for this group of countries is about 6 %. There is an obvious relationship between economic activity and electricity demand. The use of electrical technologies impacts significantly on the economic productivity that makes a background for increasing economic growth. It is one of the most essential factors that drive progress in the industrial, transport and agriculture sectors and services. As the growth of energy demand in developing countries is accompanied by an existing world trend in decreasing the cost of key renewable technologies, the combination of these two tendencies may open the ways for stimulating consumer interest in the introduction of renewable energy. However, the financial and social measures in developing countries should not be

limited only to the issues on increasing the penetration of renewable energy technologies at themselves. To ensure sustainable economic growth and raise the living standards together with developing green-electricity generation, the modern-day solutions require innovative approaches regarding the new digital technologies for energy service. These matters are crucial and challenging issues for developing economies of Sub-Saharan countries because to solve them efficiently sufficient access to electricity is needed [1-4].

As it is well known the affordable and reliable access to electricity is a foundation of economic development. In the context of Sub-Saharan countries, the most difficult obstacles to ensure universal electricity access are related to economic, social or institutional problems. In 2018, according to IEA data on Sub-Saharan Africa, the average level of electrification was 45%. This level is almost twice lower than the global access level, which equals 87 %. Totally there are about 600 million people without access to electricity in Sub-Saharan countries and more than 80 % of them are living in rural areas. The concept of modern access to electricity covers a wide range of economic activities of market economy entities. Ensuring modern access to electricity is considered both in the context of the activities of individual households and small industrial enterprises or small agricultural firms. Also, the availability of modern access to electricity is an important condition for the provision of various socially significant goods and services by state municipalities: street lighting, the activities of medical institutions, schools, etc. Simultaneously with electricity access, related issues of electricity supply, such as quality, safety, and availability, are often appeared. The range of actions to improve access to electricity is defined not only by economic, regulatory and social factors but also by the characteristics of the spatial factor. This matter is especially true for communities placed in remote and rural areas. In cases where the problem of improvement is considered at the level of regional electricity networks, there is already a significant amount of experience that has been successfully implemented in many countries around the world [2-5].

Successfully addressing the problem of extending access to electricity for rural and remote areas remains a challenge for many developing countries. A possible way, which may be considered as a solution to extend access to electricity, is the transfer and adaptation of innovative technologies and processes, which have shown the positive results in other countries with a similar problem. However, this approach needs significant funding and favorable conditions for investments in innovative energy solutions for extending access to electricity. To define the developing Sub-Saharan African countries, which have the opportunities to attract investment in energy innovations to extend access to electricity, this study was conducted.

**Goal and tasks of research**

The goal of the research is to conduct indicator-based analysis for assessing preconditions for the deployment of innovative energy solutions in Sub-Saharan countries for extending access of the population to electricity.

To achieve the goal the next tasks were defined.

1. To determine criteria and indicators for assessing preconditions for the deployment of innovative energy solutions in Sub-Saharan countries.

2. To conduct an indicator-based analysis comparing the Sub-Saharan countries on their abilities to attract investments in innovative energy solutions for extending access to electricity.

3. To consider the innovative solutions for improving access to electricity for populations in Sub-Saharan countries.

**Materials and results of research**

To solve the problem with limited access to electricity and overcome the barriers to sufficient electricity supply, significant financial support is required for developing Sub-Saharan countries. These countries must meet certain conditions concerning the investment climate. The pattern of these Sub-Saharan countries significantly varies in economic conditions. For identifying the country-specific challenges to meet the key criteria essential for attracting investments in improving access to electricity, the indicator-based analysis was used. This type of analysis is widely used for assessing the state of the investigated countries with certain criteria for defined periods. The criteria must be based on the set of universal typical indicators that define the state of economic, institutional and social environment in the same qualitative definitions and quantitative features. Assessment obtained by indicator-based analysis allows us to avoid the bias of inferences and reduce the vulnerability of the decision-making process.

As the key criteria attractive for investments in the energy sector, the middle-income economy, the institutional and social stability, the acceptable level of security, the lasting economic growth, and the rate of electrification were chosen. The choice of criteria was grounded on the following preconditions. As stated in [6-7], for the middle-income economies there is a strong relationship between income, consumption, and gross domestic product (GDP). The consistent increase in GDP is an attractor of foreign direct investment. In Sub-Saharan countries, the positive relationship between the consumption and the GDP per capita growth is detected as well. These indicators also depend on institutional and social stability. The conflicts lead to a large and persistent decline in the GDP per capita, make strains on countries' public finances, lowering revenue, and take the resources away from economic and social development. Usually, non-resource-intensive countries are more desirable for investments related to energy innovations. And finally, to attract investments in energy solutions it is necessary to have a positive dynamics of the electrification rate that shows the changes in the percentage of the population that got access to electricity in Sub-Saharan countries.

For country grouping and arrangement, the methodological approaches, used by the International Monetary Fund [1] and the World Bank [8], were applied. By these methodologies, all Sub-Saharan countries can be aggregated into a few different groups. One of the groupings divides resource-intensive and non-resource-intensive economies. The oil exporting countries and the non-renewable natural resource exporting countries belong to resource-intensive economies. The countries, which do not belong to the first two groups, are classified as non-resource-intensive economies. Another grouping varies the countries by their income in high-, middle-, and low-income economies. The next type of grouping classifies countries according to levels of institutional and social fragilities, which are identified by public indicators. Finally, the countries are classified as countries affected by conflict and countries not affected by conflict. Thus, to meet the lasting economic growth criterion, the economy of the country must be classified as at least low-middle-income and non-resource-intensive. To meet the criteria of institutional and social stability, there must be absent institutional fragility in the country. To meet the acceptable level of security, the country must be defined as not affected by conflicts. To attract investments, the country must also have a consistent increasing GDP.

Based on the criteria given above, the comparative qualitative and quantitative indicator-based analysis of developing Sub-Saharan countries was conducted. To avoid the bias of inferences and reduce the vulnerability of the decision-making process, information modeling techniques [9] were applied. Grounded on these techniques the binary matrix table was designed to manage and arrange the descriptive informational data about countries. This matrix supported the checkup process regarding the country's conformity to the key criteria. In binary matrix table, the text informational data were converted to numbers by the following rules: if information about the country meets criteria, the value is equal one, and if it does not - the value is equal zero.

To provide the investigation, the informational and statistical open databases [1, 8] were used. The most recent qualitative and quantitative information was given by these sources for 2018.

In 2018 there were 48 developing Sub-Saharan countries and all these countries must be evaluated by macroeconomic, institutional, and social criteria. At using the binary matrix table, the checkup process was started with the primary criterion - an economy with at least low-middle-income. This criterion was confirmed only for 18 countries, which made it possible to reduce the list of the examined countries by almost 2.5 times. The results of the checkup process, obtained for 18 countries on their confirmation to key criteria, were performed as a binary matrix and given in Table 1.

Table 1. Evaluation of Sub-Saharan countries on confirmation to economic, institutional, and social criteria required for investments in innovative energy solutions (state on 2018)

| **Countries** | **Criteria** | | | |
|---|---|---|---|---|
| | middle-income economy | non-resource-intensive | absence of institutional fragility | not affected by conflicts |
| Angola | 1 | 0 | 1 | 1 |
| Botswana | 1 | 0 | 1 | 1 |
| Cabo Verde | 1 | 1 | 1 | 1 |
| Cameroon | 1 | 0 | 1 | 0 |
| Côte d'Ivoire | 1 | 1 | 0 | 1 |
| Equatorial Guinea | 1 | 0 | 1 | 1 |
| Eswatini | 1 | 1 | 1 | 1 |
| Gabon | 1 | 0 | 1 | 1 |
| Ghana | 1 | 0 | 1 | 1 |
| Kenya | 1 | 1 | 1 | 1 |
| Lesotho | 1 | 1 | 1 | 1 |
| Mauritius | 1 | 1 | 1 | 1 |
| Namibia | 1 | 0 | 1 | 1 |
| Nigeria | 1 | 0 | 1 | 0 |
| Republic of Congo | 1 | 0 | 0 | 1 |
| São Tomé & Príncipe | 1 | 1 | 0 | 1 |
| Senegal | 1 | 1 | 1 | 1 |
| Seychelles | 1 | 1 | 1 | 1 |

The comparative cross-country analysis of the data in the matrix table showed that there were only seven countries from eighteen examined ones that completely confirmed the requirements of criteria. These countries are Cabo Verde, Eswatini, Kenya, Lesotho, Mauritius, Senegal, and Seychelles. According to the World Bank data, the

economies were specified as a lower-middle-income for Cabo Verde, Eswatini, Kenya, Lesotho, Senegal, and as an upper middle-income for Mauritius. The level of the economy for Seychelles was classified as a high-income economy.

To evaluate the lasting economic growth, the next step was related to the analysis of the annual rate of GDP growth in the group of selected countries in 2018. The annual percent changes in GDP growth for these countries are given from the highest to the lowest values: Senegal - 6.7%; Kenya - 6.3 %; Cabo Verde - 5.1%; Seychelles - 4.1%; Mauritius - 3.8%; Lesotho - 2.8% and Eswatini - 2.4%.

The group of Sub-Saharan countries, for which the key criteria were confirmed, was analyzed in detail regarding the dynamics of the electrification rate. There are three types of indicators that describe the electrification rate in the country. The total access to electricity reflects the percentage of the country's population with access. The urban access to electricity shows the percentage of the population with access in urban areas. The rural access to electricity is stated by the percentage of the population with access in rural areas. For analysis, the more recent data on access to electricity offered by [10] were used.

In Fig. 1 the comparative diagram about the levels of access to electricity in investigated countries is given from the highest level of electrification to the lowest one.

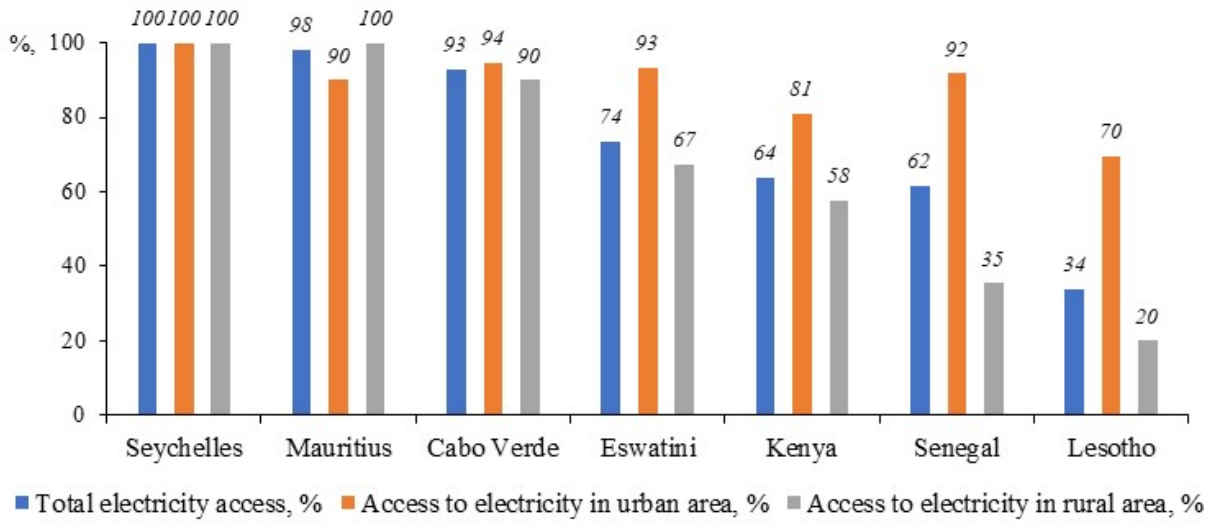


Figure 1 – The level of access to electricity in the selected group of developing Sub-Saharan countries, 2017

The comparative analysis of countries' indicators showed that among these countries Seychelles has reached universal access. With having 98% of total access to electricity and 100% access to electricity for the rural population, Mauritius is also on the way to achieve it soon. Cabo Verde can be considered as a country where access to electricity for total, urban and rural populations is higher than the average global level of electrification rate equal to 87 %. Other countries, in 2017, had the levels of total access to electricity lower than the global one, and significantly lower access was observed for the rural population compared to the urban population.

At the same time, it should be noted that during the two last decades all countries had considerable progress in solving the access problem and undertaken activities to expand access. For Eswatini the first available data about electricity access are dated by 2001 when the level of total access to electricity was only 27%. In 2017, it grew up to 74% with rising the urban access from 53% to 93% and the rural access from 19% to 67%. From 2000 to 2017 Kenya has also shown a high-positive dynamic with a rising access level for the total population from 15% to 64%. The access level for urban population grew up almost twice – from 50% to up 81 %, and the access level for the rural population – from 7% to 58%. Today, the country's energy policy is aimed to reach universal access by 2022, and the grid would be the main least-cost solution for most of the population with lacking access. In Senegal, the total access level was increased from 38% in 2000 to 62% in 2017, wherein the access level in urban areas increased from 75% to 92%, and the access level in rural areas rose from 13% to 35%. With a successful energy policy regarding the electrification and the adoption of a comprehensive integrated plan, it is planned to achieve full access in 2025. The grid represents the least-cost option for most of the population in this country, which are currently without access to electricity. For rural and most remote areas the decentralized solutions are foreseen. In 2000, among these countries, the worst situation with electrification was in Lesotho, where only 4% of the total population had access to electricity. In 2017 this indicator grew up to 34 % together with rising level of access for the urban population from 14% to 70%, and for the rural population – from 2% to 20%. A few years ago, Lesotho established its energy policy for 2015-2025 with the target of reaching total access to electricity for 40% of the total population for 2020. In the country's energy policy, renewable energies were indicated as one of the tools for increasing access

to electricity and it was also planned to develop the program on renewable energy feed-in-tariffs to attract investments.

The selected countries varied significantly not only in the electrification rate but also by numbers of inhabitants and the pattern of population. Defining the number of people and households without access to electricity in selected developing Sub-Saharan countries can be used as a background for further studying the projected electricity demand caused by electrification. From the practical point of view, defining the value of electricity demand projected for the country under its electrification will help to evaluate the installation capacities needed to cover demand as well as the necessary investment. Based on the average household size and amount of populations in these countries [11-12], the number of people and households without access to electricity were calculated. The results are given in Table 2.

Table 2. Populations and households without access to electricity in selected countries, 2017

| Country | Average household size | Population without access, mln | | | households without access, mln | | |
|---|---|---|---|---|---|---|---|
| | | total | urban | rural | total | urban | rural |
| Cabo Verde | 4.2 | 0.04 | 0.020 | 0.019 | 0.009 | 0.005 | 0.004 |
| Eswatini | 4.7 | 0.30 | 0.018 | 0.282 | 0.064 | 0.004 | 0.060 |
| Lesotho | 3.3 | 1.40 | 0.181 | 1.212 | 0.423 | 0.055 | 0.367 |
| Senegal | 8.3 | 6.07 | 0.621 | 5.411 | 0.732 | 0.075 | 0.652 |
| Kenya | 3.9 | 18.60 | 2.630 | 15.912 | 4.769 | 0.674 | 4.080 |

The worst state with access to electricity in the number of populations and households was observed for Kenya. In 2017, in this country, the number of populations without access was equal to 18.60 million people.

The quantitative indicators obtained, together with the values of average annual electricity consumption per capita or per household, will make it possible to make forecasts regarding the demand for electricity caused by electrification in the investigated countries.

Today the implementation of targets on improving access to electricity needs the deployment of innovative energy solutions. They are conducted in the context of the existing Agenda about the sustainable economic development of Sub-Saharan countries and addressing access to electricity. There exist significant opportunities for these countries in the renewable energy sector, but this potential remains mostly unused. The development of society and the formation of sustainable economies require reforms in the electricity sector. The global tendencies in innovative energy solutions must also be launched for the energy transition in these countries to implement the following tasks: decarbonization, decentralization and digitization. Over the past decade, innovative reform in energy sectors has widely deployed throughout the world. Recently, there has been growing interest in the development and implementation of innovative approaches to the organization and functioning of electricity markets. Significant attention is paid to the formation of energy communities and local electricity markets. All these tendencies must be taken into account under the implementation of innovative energy solutions in Sub-Saharan countries. Based on Sustainable Development Goal 7 on ensuring access to affordable, reliable, sustainable and modern energy for all, the several options have been modelled by IEA for improving the electrification of the Sub-Saharan countries. The further discussion about the deployment of energy innovations for improving access to electricity is given together with technical measures projected by the IEA modelling and opinions concerning the economic viability of suggested solutions [13-16].

According to the IEA projections, there is no single universal approach regarding access to electricity and the practical solutions will be different in different countries. There are three options for improving access to electricity in Sub-Saharan countries. By the first on-grid option, access to electricity for households will be provided through a connection to the local network, which is linked to the transmission network, or through the extension of the existing grid. For this case, electricity supply is usually provided through the operation of large centralized power plants operating on typical conventional resources such as coal, natural gas, and hydro. However, in some circumstances, the improvement of access in the frame of this option will be realized through the implementation of distributed generation. This case involves the installation of solar photovoltaic systems or biogas plants and connection to the grid at low voltage. The on-grid option of extending access to electricity is considered by the IEA as the least costly. But investments in the development of transmission and distribution networks will have economic benefits only under certain conditions. The most important among them are the high density of potential consumers, their closeness to existing networks, as well as the appropriate region terrain.

The second option for extending access to electricity is the installation of mini-grid systems. This option is offered for those areas where, for various reasons, electricity supply cannot be provided with the on-grid option. Thus, mini-grid system is a local solution for electrification designed to serve customers in a certain region. Technically, a mini-grid system can be described as a combination of three subsystems: a production system for

generating electricity, a distribution system for delivering electricity to customers, and an end-user system for connecting and providing customers with electricity. This type of system does not have infrastructure for electricity transmission outside the served region. Mini-grid systems operate due to a set of small-scale electricity generators based on available renewable energy resources (such as solar photovoltaic modules, wind turbines, small-scale hydropower plants etc.) as well as the diesel generators. But electricity generation by solar and wind installations is intermittent and cannot be completely predictable. For the stable operation of mini-grid systems, small low-power diesel generators and energy storages (like back-up battery systems) are also required. From an economic point of view, supplying electricity to customers via mini-grid system usually requires higher costs. To attract investment, an initial level of demand for electricity in the served region is needed. In most cases, this must be confirmed by a certain level of electrical load of public, industrial and commercial facilities and services. The mini-grid option will also give economic benefits when trading in electricity in rural areas with a fairly dense population.

The third option for extending access to electricity is related to off-grid systems or stand-alone systems. This option will be the most cost-effective for electrification of sparsely populated and remote areas. Technically, the stand-alone system is composed of one or more electrical generators and is not connected to transmission and distribution systems. It operates independently by providing electricity to several individual households. One of the benefits of stand-alone systems with renewable energy technologies is that they can be designed for any scale to cover basic household electricity needs, and can be scaled-up in the event of increasing demand. From an economic point of view, stand-alone systems can be considered as a cost-competitive solution under declining the cost of the components that make up off-grid systems. However, among the other available options for extending access to electricity, the levelised costs of electricity, considered as the ratio of the sum of all costs over the lifetime to the total amount of electricity generated over the lifetime, is still the highest for stand-alone systems.

Nevertheless, reforming the energy sectors using any of the previously discussed options requires modern solutions that should not be limited to existing traditional measures on improving access to electricity. Delivering modern energy services to rural communities and remote areas also requires the dissemination of digital technologies in Sub-Saharan countries.

The growing rate of electrification will lead to an increasing demand for electricity. As shown above, the practical realization of an innovative solution will also require forecasts regarding electricity demand, which should be met along with improved access to electricity.

**Conclusions**

For future growth, overcoming poverty, and private sector development, innovative solutions are needed to expand access to electricity. The indicator-based qualitative and quantitative analysis was applied to compare Sub-Saharan countries by their ability to attract investments in innovative energy solutions. The middle-income economy, the institutional and social stability, the acceptable level of security, the lasting economic growth, and the rate of electrification were chosen as the key criteria attractive for investments in the energy sector.

Matching the results of the indicator-based qualitative and quantitative analysis of Sub-Saharan countries, it is possible to say that only 7 countries from 48 examined ones – Cabo Verde, Eswatini, Kenya, Lesotho, Mauritius, Senegal, and Seychelles – have the highest potential to attract investments in innovative energy solutions to expand access to electricity. Over the past two decades, in these countries, the level of access to electricity for the entire population, urban and rural population, has been constantly increasing. Such tendencies were also enforced by the respective goals and strategic plans of the energy policies of these countries.

Since there is no single universal approach regarding access to electricity and practical solutions to this problem will be different in different countries, three main options as innovative solutions for improving access to electricity in selected Sub-Saharan countries may have the following order of priority from a technical point of view, namely: stand-alone (off-grid) systems, mini-grid systems, and on-grid systems. But from an economic point of view, they may have the opposite order of priority and will have economic benefits only under certain conditions, such as the high density of potential consumers, their closeness to existing networks, the appropriate region terrain, and the cost of elements that make up the system.

Increasing rates of electrification will increase electricity demand. Any practical realization of any of the innovative solutions will require forecast of electricity demand, which must be met along with improved access to electricity. Defining the level of access to electricity for selected developing Sub-Saharan countries together with the suggested indicators can be used as a background for forecasting electricity demand in countries under electrification.

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# ІНДИКАТОРНИЙ АНАЛІЗ ПЕРЕДУМОВ РОЗГОРТАННЯ ІННОВАЦІЙНИХ РІШЕНЬ ДЛЯ РОЗШИРЕННЯ ДОСТУПУ ДО ЕЛЕКТРОЕНЕРГІЇ В КРАЇНАХ НА ПІВДЕНЬ ВІД САХАРИ

*У статті було проведено індикаторний аналіз оцінки передумов розгортання інноваційних енергетичних рішень в країнах на південь від Сахари для розширення доступу їх населення до електроенергії. Цей тип аналізу був використаний для оцінки стану досліджуваних країн на південь від Сахари за певними критеріями протягом визначеного періоду часу щодо їх здатності залучати інвестиції в інноваційні енергетичні рішення для розширення доступу до електроенергії. Визначено критерії та показники, необхідні для оцінки передумов розгортання інноваційних енергетичних рішень у країнах на південь від Сахари в рамках індикаторного аналізу. В якості ключових критеріїв, привабливих для інвестицій в енергетику, були обрані економіка із середнім рівнем доходу, інституційна та соціальна стабільність, прийнятний рівень безпеки, тривале економічне зростання та динаміка електрифікації. Критерії ґрунтувалися на наборі універсальних типових показників, які визначають стан економічного, інституційного та соціального середовища в різних країнах в однакових якісних визначеннях та кількісних ознаках. Щоб уникнути упередженості висновків та зменшити вразливість процесу прийняття рішень, для обробки даних були застосовані засоби інформаційного моделювання. Гуртуючись на цих засобах, була розроблена бінарна таблична матриця для управління та упорядкування описових інформаційних даних про країни. В результаті індикаторного аналізу була визначена група країн на південь від Сахари, яка підтвердила критерії для залучення інвестицій в інноваційні енергетичні рішення. Ці країни були детально проаналізовані щодо динаміки електрифікації. Було оцінено кількість жителів без доступу до*

*електроенергії та приблизну кількість домогосподарств, яким потрібно отримати доступ до електроенергії. Також були розглянуті можливі інноваційні рішення для поліпшення доступу до електроенергії.*

***Ключові слова:*** *індикаторний аналіз, рівень електрифікації, інноваційні рішення, країни на південь від Сахари.*

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