Journal Homepage: http://dergipark.gov.tr/ethabd

DergiPark AKADEMİK

ETHABD
Erciyes Tarım ve Hayvan Bilimleri Dergisi

ISSN:2651-5334

Potential Biomass Energy Generation from Agricultural Production in South Sudan

Araştırma Makalesi/Research Article

Atıf İçin: EISSA M. O. S., Gürdil G. A. K., Demirel B., Dağtekin M., (2024) Güney Sudan'da Tarımsal Üretimden Potansiyel Biyokütle Enerjisi Üretimi, Erciyes Tarım ve Hayvan Bilimleri Dergisi, 7(2):142-148

To Cite: : EISSA M. O. S., Gürdil G. A. K., Demirel B., Dağtekin M., (2024) Potential Biomass Energy Generation from Agricultural Production in South Sudan, Journal of Erciyes Agriculture and Animal Science, 7(2):142-148

Mohamedeltayib Omer Salih EISSA[1,3], Gürkan Alp Kağan GÜRDİL[1], Bahadır DEMİREL[2*], Metin DAĞTEKIN[4]

[1]*Ondokuz Mayis University, Faculty of Agriculture, Department of Agricultural Machinery and Technologies Engineering. Samsun, Turkey*
[2]*Erciyes University, Faculty of Agriculture, Department of Biosystems Engineering. Kayseri, Turkey*
[3]*Bahri University, Faculty of Engineering, Department of Agricultural Engineering. Khartoum Bahri, Sudan*
[4]*Cukurova University, Ceyhan Vocational School Ceyhan, Adana*

***sorumlu yazar**: bahdem@erciyes.edu.tr*

Mohamedeltayib Omer Salih EISSA ORCID No: 0000-0003-0186-1112, Gürkan Alp Kağan GÜRDİL ORCID No: 0000-0001-7764-3977
Bahadır DEMİREL ORCID No: 0000-0002-2650-1167 Metin DAĞTEKIN ORCID No: 0000-0002-1397-1725

Yayın Bilgisi

Geliş Tarihi: 13.08.2024

Revizyon Tarihi: 13.08.2024

Kabul Tarihi: 13.11.2024

doı: 10.55257/ethabd.1532791

Keywords
Sudan, agricultural residue, biomass, energy

Anahtar Kelimeler
Sudan, tarımsal artık, biyokütle, enerji

Abstract

The aim of this study is to assess the capacity of agricultural residues in South Sudan in terms of their types and quantities. The country had limited access to modern energy sources, and most of the population relied on traditional biomass for cooking and heating. However, efforts were being made to explore and develop alternative and sustainable energy sources, including biomass energy. Biomass energy involves the use of organic materials, such as wood, crop residues, and animal waste, to generate heat or electricity. In the context of South Sudan, biomass energy could play a crucial role in meeting the energy needs of the population, especially in rural areas. The quantities of crops cultivated in South Sudan, measured in tons of dry matter per year, were determined through calculations based on production data from the Food and Agriculture Organization Statistical Databases of the United Nations (FAOSTAT) for the 2021 seasonal year. The annual gross potential of agricultural residues was calculated by employing a residue to product ratio. The energy potential of crop residues was computed by multiplying the calorific values of agricultural residues with the available amount of residue. The total energy potential of agricultural residues during the 2021 production period in South Sudan amounted to approximately 112.7 TJ. The total amount of unused agricultural crop residues was estimated to be approximately 8.6 kilo tons (Kt). The proportion of overall residue quantity comprises major crops such as sorghum (78.71%), maize (11.06%), rice (5.66%), and millet (4.36%).

Güney Sudan'da Tarımsal Üretimden Potansiyel Biyokütle Enerjisi Üretimi

Özet

Bu çalışmanın amacı Güney Sudan'daki tarımsal artıkların kapasitesinin tür ve miktar açısından değerlendirilmesidir. Ülkenin modern enerji kaynaklarına erişimi sınırlıdır ve nüfusun çoğu yemek pişirme ve ısınma için geleneksel biyokütleye bağımlıdır. Ancak, biyokütle enerjisi de dahil olmak üzere alternatif ve sürdürülebilir enerji kaynaklarının araştırılması ve geliştirilmesi için çaba gösterilmektedir. Biyokütle enerjisi, ısı veya elektrik üretmek için odun, ürün artıkları ve hayvan atıkları gibi organik malzemelerin kullanımını içerir. Güney Sudan bağlamında biyokütle enerjisi, özellikle kırsal alanlardaki nüfusun enerji ihtiyaçlarının karşılanmasında çok önemli bir rol oynayabilir. Güney Sudan'da yılda ton kuru madde cinsinden ölçülen mahsul miktarları, Birleşmiş Milletler Gıda ve Tarım Örgütü İstatistik Veri tabanlarından (FAOSTAT) 2021 sezonluk üretim verilerine dayanan hesaplamalar yoluyla belirlenmiştir. Tarımsal kalıntıların yıllık brüt potansiyeli, artık/ürün oranı kullanılarak hesaplanmıştır. Bitkisel artıkların enerji potansiyeli, tarımsal artıkların ısıl değerlerinin mevcut artık miktarıyla çarpılmasıyla hesaplanmıştır. Sonuç olarak, Güney Sudan'da 2021 üretim döneminde tarımsal artıkların toplam enerji potansiyeli yaklaşık 112.7 TJ olarak gerçekleşmiştir. Hiçbir şekilde değerlendirilmeyen tarımsal ürün artıklarının toplam miktarının yaklaşık 8.6 kiloton (Kt) olduğu tahmin edilmektedir. Toplam artık miktarının oranı sorgum için (%78.71), mısır için (%11.06), pirinç için (%5.66) ve darı (%4.36) olduğu tespit edilmiştir.

1. INTRODUCTION

South Sudan, situated between 3° to 13° N latitude and 24° to 36° E longitude, spans a total area of 619,745 〖Km〗^2. The nation is characterized by dense equatorial forests, vast tall savanna grasslands, and expansive wetlands. Its climate is marked by alternating wet and dry tropical conditions. Rainfall in South Sudan is primarily sourced from the Indian Ocean and Atlantic Ocean, transported by westerlies and monsoon winds (Zakaria Lukwasa et al., 2022). South Sudan boasts over 140 distinct mother tongues, positioning it as one of the most linguistically diverse nations globally (Yuot Amogpai et al., 2015).

The condition in South Sudan, the most recent country globally, is exceptional as it lacks any substantial pre-existing energy infrastructure (Thiak & Hira, 2024). South Sudan possesses renewable energy resources that have the potential to address and enhance the current energy landscape. Renewable energy systems (RES) have the capability to harness clean and sustainable energy from various sources like solar, biomass, wind, and hydro, converting them into forms such as thermal, electrical, and others (Aban Ayik et al., 2020). Renewable energy provides sustainable electricity solutions, a critical need for many nations. Unfortunately, South Sudan ranks among the countries with the lowest electricity access globally. Prolonged conflicts have severely hindered infrastructure development across the board, with the electric power sector being notably affected (A. Ayik et al., 2021). Electricity is a fundamental requirement for human survival. Ensuring sustainable access to energy is acknowledged as a basic human right that every community should enjoy. Nevertheless, rural populations in Africa continue to encounter substantial challenges in accessing electricity. The majority of African individuals still rely on conventional energy sources, such as diesel generators, for their energy needs (Ahmed et al., 2023).

One crucial element for attaining sustainable development is ensuring access to clean and dependable energy sources (Aban Ayik et al., 2020). Energy plays a pivotal role in economic advancement, with a discernible connection between energy usage and quality of life standards (Demirel et al., 2019). Energy sources are categorized into three groups: fossil fuels, renewable sources, and nuclear sources. While fossil fuels continue to dominate as the primary energy source, their drawbacks such as high cost, depletion, and environmental harm have prompted scientists to seek alternative sources that are low-cost, sustainable, and environmentally friendly (Gudo et al., 2020). Renewable energy is a sustainable energy source that is generated without concerns of resource depletion, common types include hydropower, wind, solar, geothermal, tidal, and biomass energy (Abdalla & Qarmout, 2023). Renewable energy sources have emerged as potential alternatives for diverse energy needs, driving the initiation of numerous research initiatives (Karaca, 2015b). The utilization of renewable energy sources in electricity production has garnered significant attention owing to its various benefits, including positive environmental impacts, cost-effectiveness, reliability, and potential for renewal and reuse (Ladu et al., 2022). Although South Sudan is a relatively new nation, it possesses vast and varied energy potential, spanning both nonrenewable and renewable sources. It boasts substantial reserves of oil and promising opportunities in solar, wind, hydropower, and geothermal energy. However, despite these significant advantages in energy resources, the state of South Sudan encounters several hurdles that impede its energy security. These challenges include the absence of adequate energy infrastructure, persistent internal instability, mismanagement of energy resources, and heavy reliance on external partners (Bilali, 2020). South Sudan is grappling with a significant energy shortage driven by several factors, including prolonged conflicts and heavy dependence on fossil fuels. It boasts the lowest energy consumption rate across Africa while bearing the highest burden in energy production costs (Report, 2018). South Sudan primarily relies on diesel generators, fuelwood, crop residue, and charcoal for its energy needs, all of which emit carbon dioxide (CO_2) during combustion (Santino et al., 2021). Incorporating renewable energy into the power generation mix must be coupled with efforts to minimize generation costs. This approach enhances sustainability and competitiveness, ensuring that renewable energy can compete effectively with low-cost fossil fuel-based power generation (Ali & Gamil, 2023).

Biomass energy encompasses a range of organic materials derived from biological sources, including agricultural residues, household waste, wood fuel, animal waste, and other forms of biofuels (Karaca, 2015a). The majority of South Sudanese people depend on traditional fuel sources like firewood to meet their daily energy needs. The country's natural conditions are conducive to the development of biomass energy, with approximately 33 percent of its land covered by forests. This abundance of forested areas makes biomass energy readily accessible and represents the most rapid and secure means of sustaining the population's energy consumption in South Sudan (Bilali, 2020).

The primary aim of this study was to ascertain the viable and accessible actual potential of annual crop residues in South Sudan and utilizing these wastes for energy. Because in some areas of South Sudan people primarily relies on diesel generators, fuelwood, crop residue, and charcoal for its energy needs, all of which emit carbon dioxide (CO_2) during combustion.

2. MATERıAL AND METHOD

1. Agricultural Areas in South Sudan

Agriculture represents a crucial aspect for both developed and developing nations, with its profound connections to political and social stability (Osman et al., 2023). In South Sudan, agriculture contributes to 36% of the non-oil Gross Domestic Product (GDP), and the majority of the population, about 80%, resides in rural areas, relying heavily on subsistence farming. Despite ample water resources, only 5% of the available arable land, which amounts to 30 million hectares, is currently cultivated (Asad et al., 2018). The agricultural sector in South Sudan is defined by a subsistence-oriented method, limited productivity, inadequate infrastructure and market systems, minimal technology and resources utilization, and significant vulnerability to rainfall patterns. Rain-fed subsistence farming and heavy dependence on forests for energy and environmental resources are primary contributors to the reliance of 95% of the population on climate-sensitive natural resources (Kose & Kongas, 2023). South Sudan faces considerable limitations in agricultural productivity despite its vast expanses of natural vegetation, suggesting substantial agricultural promise. However, transforming these areas into cultivable land is hindered by significant obstacles such as substantial physical investments and the complexity of determining optimal farming methods and crop selections (Gani et al., 2016). The map below shows the distribution of agricultural lands in South Sudan.

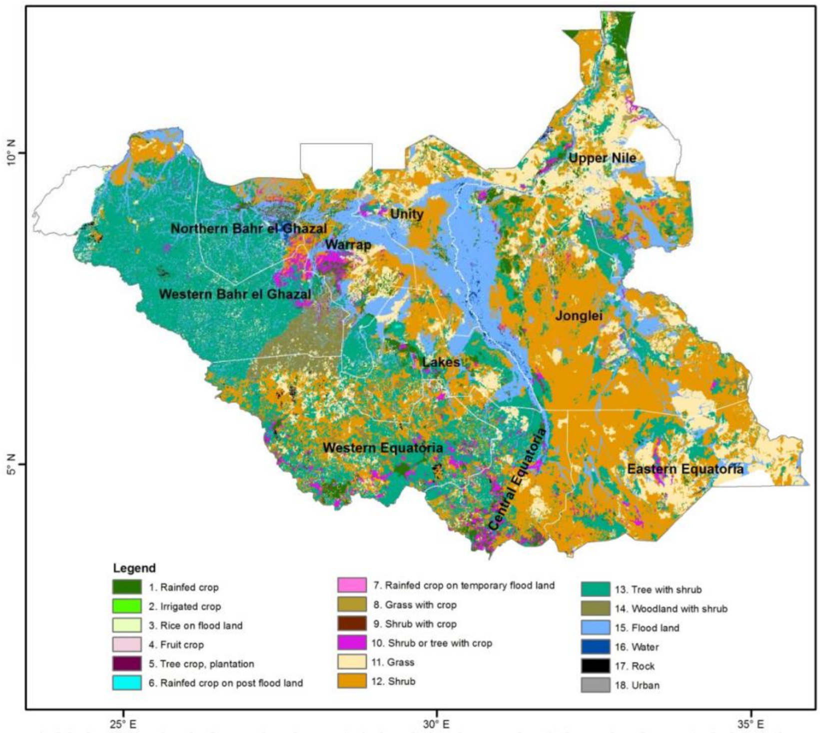

Figure: 1 illustrates the spatial distribution of various aggregated land use types (Gani et al., 2016)

2. Assessment of Biomass Potential from Agricultural Residues

Biomass resources are commonly utilized for heating, cooking, and similar applications using traditional methods. However, there are significant limiting factors for the use of biomass in energy applications on a commercial scale. These factors particularly include low bulk density and non-optimal structural characteristics for feeding, transportation, and handling (Aktaş, 2022). In 2014, biomass accounted for a significant portion, approximately 70 percent, of South Sudan's total energy consumption (Bilali, 2020).

Agricultural wastes represent a particularly intriguing raw material due to their high volume of generation (Trejo-Zamudio et al., 2022). Agricultural residues have significant potential as a renewable energy source because they are abundant, widely available, and often currently underutilized or treated as waste. Advances in technology for biomass conversion and utilization can also influence the potential for utilizing agricultural residues for energy production. Improvements in biomass conversion technologies, such as gasification, pyrolysis, and anaerobic digestion, can increase the efficiency and viability of using agricultural residues for energy.

The quantities of residues from the primary crops grown in South Sudan were determined by analyzing crop production data from the Food and Agriculture Organization Statistical Database (FAOSTAT) for the 2021 agricultural season. The yearly total agricultural residue potential was calculated through the utilization of the residue-to-product ratio (RPR) as outlined in Table 1 (Karaca et al., 2017).

The residual net capacity was assessed by considering the residue's availability, which indicates the portion left unused. The attainable capacity of agricultural wastes in each region of the province is computed according to Equation 1 (Karaca, 2017).

$$AAR_i = ACP_i \times RPR_i \times A_i \quad (1)$$

In this equation, AAR_i represents the available quantity of agricultural residues from the i^{th} crop in tons; ACP_i denotes the amount of crop production in tons; RPR_i signifies the residue-to-product ratio of the i^{th} crop, and A_i stands for the residue availability (Karaca, 2017), (Karaca et al., 2017), (Karaca, 2015a), (Demirel et al., 2019), (Trejo-Zamudio et al., 2022).

FC	R	RPR	A (%)	LHV
Beans	Stalks	0.007	65	16.15
Maize	Stalks	0.009	60	17.95
Millet	Straw	0.013	60	12.39
Rice	Straw	0.031	60	14.92
Sorghum	Straw	0.019	60	12.40

FC: Field Crops, R: Residues RPR: Ratio of Product to Residue, A: Availability, LHV; Lower Heating Value (MJ.kg-1).

A variety of agricultural wastes find application in households for tasks such as heating, livestock feed, and as bedding material. These residues predominantly stem from industrial crops such as hazelnut shells, paddy straw, maize stalks, sunflower stalks, cereal straw, pruning, among others, which are often left on fields after harvest.

The energy potential of residues was determined by multiplying the heating values of various agricultural residues, obtained from (Table 1), with the respective available amounts of residue (as per Equation 2).

$$EP_i = AAR_i \times LHV_i \quad (2)$$

where EP_i the total The energy potential of agricultural residues of i^{th} crop in GJ, AAR_i is the available amount of agricultural residues of i^{th} crop in tons and LHV_i lower heating value of air dry residues of i^{th} crop in MJ. Kg^{-1}.

3. RESULTS AND DISCUSSION

The combined quantity of agricultural wastes, encompassing annual crop residues such as beans, maize, millet, rice, and sorghum, was estimated to be approximately 8.6 kilo tons in South Sudan (as indicated in Table 2).

FC	ACP	R	AR	AAR
Beans	3804.3	Stalks	28.54	17.31
Maize	175454	Stalks	1645.5	947.45
Millet	47851	Straw	602.47	373.24
Rice	26024	Straw	795.83	484.04
Sorghum	591004	Straw	11606.17	6737.44
Total	**844137.3**	**Residues**	**14678.51**	**8559.48**

FC: Field Crop, ACP: Amount of Crop Production (tons), R: Residue, AR: amount of Residue (tons) AAR: Available Amount of Residue (tons).

The proportion of overall residue quantity comprises major crops such as sorghum (78.71%), maize (11.06%), rice (5.66%), and millet (4.36%).

It was calculated that the total heating value of agricultural residues during the 2021 production period in South Sudan amounted to approximately 112.7 TJ. The energy value for each agricultural residue is detailed individually in Table 3.

FC	R	EP (GJ/Kg)
Beans	Stalks	279.56
Maize	Stalks	17006.73
Millet	Straw	4624.44
Rice	Straw	7221.88
Sorghum	Straw	83544.26
Total	**Residues**	**112676.87**

FC: Field Crop, R: Residue, EP: Total Energy Value (GJ/Kg).

The relationship between amount of residues and the available amount of agricultural residues can be shown below.

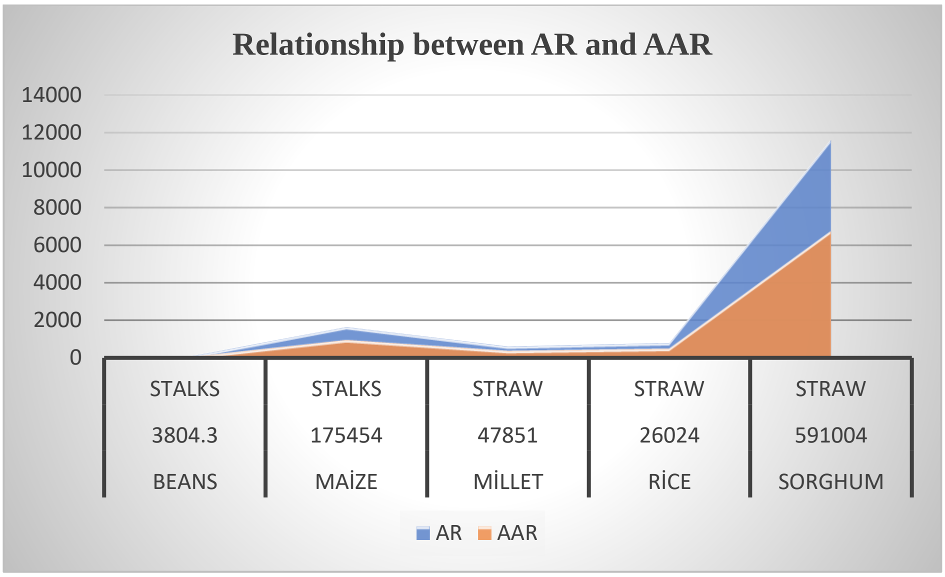

Figure 2: The relationship between AR and AAR

The figure below displays the energy potential for the different crop residues mentioned above.

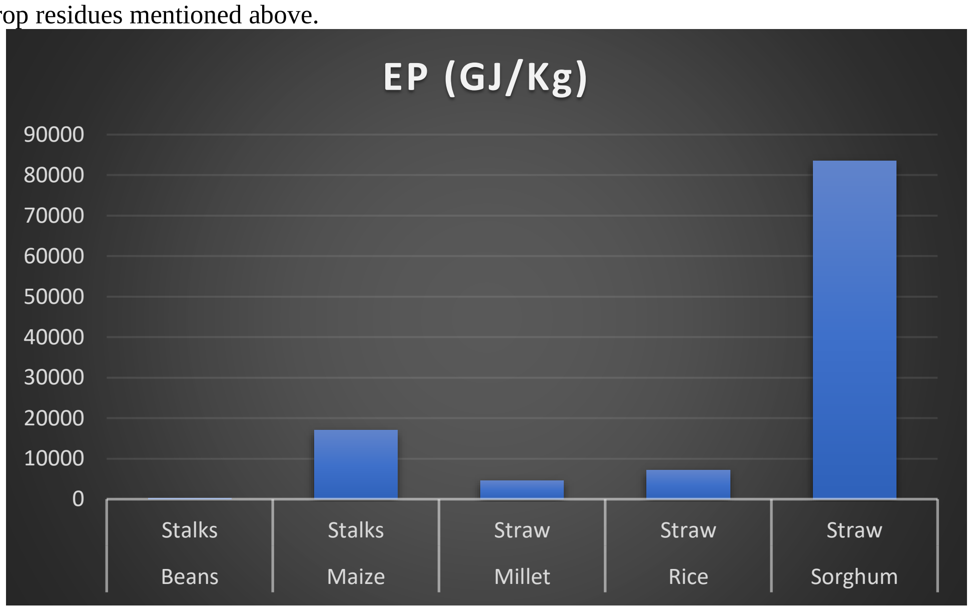

Figure 3: Energy potential of the crop residues.

In South Sudan, for the year 2021, the total energy potential from agricultural residues of specified crops mentioned above was approximately 112.7 terajoules (TJ). However, in Sudan, for the production period of 2016, the total calorific value of agricultural residues amounted to around 154 petajoules (PJ) (Demirel et al., 2019), which is substantially higher than South Sudan's figure. It seems there's a notable difference in the total energy potential of agricultural residues between South Sudan and Sudan. This suggests that Sudan had a significantly larger amount of agricultural residue energy potential compared to South Sudan. The difference in energy potential could be influenced by various factors such as agricultural practices, crop types, land availability, and efficiency of biomass utilization. Understanding these differences can provide insights into optimizing biomass energy production and utilization in both countries.

3.1 CONCLUSION

The objective of this research was to assess the biomass energy derived from crop residues in South Sudan. This matter has gained significance, particularly as South Sudan, being an energy-importing nation, faces growing energy challenges. Hence, agricultural residues emerge as a highly appealing option, particularly concerning the utilization of sorghum crop residues, given their sustainability, eco-friendliness, and familiarity as an energy source for South Sudan.

In developing countries, the imperative to convert biomass into electricity is becoming increasingly evident due to rising environmental concerns and the need for energy security. However, despite the potential of biomass resources, their utilization remains limited due to various challenges. This study has identified several crops, including beans, maize, millet, rice, and sorghum, as viable options for energy production. Yet, obstacles such as inadequate infrastructure, technological limitations, and insufficient investment hinder their widespread adoption of electricity generation. Although biomass amount may vary among different crops in South Sudan, the cumulative biomass quantity still holds the potential to generate a substantial amount of renewable energy. In the paper, the total energy potential of agricultural residues from the specified crops in South Sudan was reported to be approximately 112.7 terajoules (TJ). As a result, agricultural residues emerge as an exceedingly appealing option for South Sudan. They offer economic viability, sustainability, environmental friendliness, and familiarity as an energy source. Utilizing agricultural residues for energy production aligns with the country's needs and circumstances, presenting a practical and advantageous solution to address energy demands while promoting sustainable development.

REFERENCES

Abdalla, M., and Qarmout, T., 2023. An analysis of Sudan ' s energy sector and its renewable energy potential in a comparative African perspective. International Journal of Environmental Studies, 80(4), 1169–1187. https://doi.org/10.1080/00207233.2023.2177417

Ahmed, E. E. E., Demirci, A., and Tercan, S. M., 2023. Optimal sizing and techno-enviro-economic feasibility assessment of solar tracker-based hybrid energy systems for rural electrification in Sudan. Renewable Energy, 205(September 2022), 1057–1070. https://doi.org/10.1016/j.renene.2023.02.022

Aktaş, T., 2022. Tarım Makinaları Bilimi Dergisi Türkiye ' de İmal Edilen Odun Pelet Örneklerinin Kalite Özelliklerinin ve Standartlara Uygunluğunun Belirlenmesi Determination of Quality Characteristics and Compliance with Standards of Wood Pellet Samples Produced in Turk. 8(1), 25–40.

Ali, B., and Gamil, A., 2023. Scenario-Based Optimization towards Sustainable Power Generation in Sudan. Sustainability, 15(20), 14954. https://doi.org/10.3390/su152014954

Asad, S. Q., Adam, J. A., and Lona, A. T., 2018. Farmers perceptions, practices and proposals for improving agricultural productivity in South Sudan. African Journal of Agricultural Research, 13(44), 2542–2550. https://doi.org/10.5897/ajar2018.13525

Ayik, A., Ijumba, N., Kabiri, C., and Goffin, P., 2021. Preliminary wind resource assessment in South Sudan using reanalysis data and statistical methods. Renewable and Sustainable Energy Reviews, 138(December 2020), 110621. https://doi.org/10.1016/j.rser.2020.110621

Ayik, Aban, Ijumba, N., Kabiri, C., and Goffin, P., 2020. Selection of Off-Grid Renewable Energy Systems Using Analytic Hierarchy Process: Case of South Sudan. 2020 IEEE PES/IAS PowerAfrica, PowerAfrica 2020, 2–6. https://doi.org/10.1109/PowerAfrica49420.2020.9219858

Bilali, B., 2020. Energy Security in South Sudan: Potentials and Challenges. Turkish Journal of Political Science, 3(1), 1–16.

Demirel, B., Alp, G., Gürdil, K., Gadalla, O., Üniversitesi, E., Fakültesi, Z., Bölümü, B. M., Kayseri, T. /, Ondokuz, T., Üniversitesi, M., Makinaları, T., Bölümü, T., & Bilgisi, Y. 2019. Biomass energy potential from agricultural production in sudan. Erciyes Tarım ve Hayvan Bilimleri Dergisi ETHABD, 2(2), 35–38.

Gani, R., Devi, S., Goundar, S., Reddy, E., Saber, F., Cheng, Y.-L., Lee, C.-Y., Huang, Y.-L., Buckner, C. A., Lafrenie, R. M., Dénommée, J. A., Caswell, J. M., Want, D. A., Gan, G. G., Leong, Y. C., Bee, P. C., Chin, E., Teh, A. K. H., Picco, S., Mathijssen, R. H. J., 2016. We are IntechOpen , the world ' s leading publisher of Open Access books Built by scientists , for scientists TOP 1 %. Intech, 11(tourism), 13. https://www.intechopen.com/books/advanced-biometric-technologies/liveness-detection-in-biometrics

Gudo, A. J. A., Deng, J., Belete, M., and Abubakar, G. A., 2020. Estimation of small onshore wind power development for poverty reduction in Jubek state, South Sudan, Africa. Sustainability (Switzerland), 12(4). https://doi.org/10.3390/su12041483

Karaca, C., 2017. Determining and mapping agricultural biomass energy potential in Samsun Province of Turkey. ICOEST 3rd International Conference on Environmental Science and Technology, October, 190–194. https://www.researchgate.net/publication/322118421_Determining_and_mapping_agricultural_biomass_energy_potential_in_Samsun_Province_of_Turkey

Karaca, C., 2015a. Mapping of energy potential through annual crop residues in. 8(2), 104–109. https://doi.org/10.3965/j.ijabe.20150802.1587

Karaca, C., 2015b. Mapping of energy potential through annual crop residues in Turkey. International Journal of Agricultural and Biological Engineering, 8(2), 104–109. https://doi.org/10.3965/j.ijabe.20150802.1587

Karaca, C., Kağan Gürdil, G. A., and Ozturk, H. H., 2017. The Biomass Energy Potential from Agricultural Production in the Black Sea Region of Turkey. ICOEST 3rd International Conference on Environmental Science and Technology, October. https://www.researchgate.net/publication/3221181

89_The_Biomass_Energy_Potential_from_Agricultural_Production_in_the_Black_Sea_Region_of_Turkey

Kose, M., and Kongas, K., 2023. The Challenges and Prospects of South Sudan Agriculture. 2, 101–108.

Ladu, N. S. D., Samikannu, R., Gebreslassie, K. G., Sankoh, M., Hakim, L. E. R., Badawi, A., and Latio, T. P. B., 2022. Feasibility study of a standalone hybrid energy system to supply electricity to a rural community in South Sudan. Scientific African, 16, e01157. https://doi.org/10.1016/j.sciaf.2022.e01157

Osman, I. M., Acar, R., Suleiman, E., Babiker, N., and Direk, M., 2023. Agricultural Production Systems in Sudan. 3(1).

Report, S., 2018. Transitioning to Renewable Energy : An Analysis of Energy Situation Special Report || Special Report ||. 1–29.

Santino, N., Ladu, D., and Samikannu, R., 2021. A Review of Renewable Energy Resources . Its Potentials , Benefits , and Challenges in South Sudan. 2021 International Conference on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA), 1–6. https://doi.org/10.1109/ICAECA52838.2021.9675574

Thiak, S., and Hira, A., 2024. Strategic options for building a new electricity grid in South Sudan: The challenges of a new post-conflict nation. Energy Research and Social Science, 109(January), 103417. https://doi.org/10.1016/j.erss.2024.103417

Trejo-Zamudio, D., Gutiérrez-Antonio, C., García-Trejo, J. F., Feregrino-Pérez, A. A., and Toledano-Ayala, M., 2022. Production of fuel pellets from bean crop residues (Phaseolus vulgaris). IET Renewable Power Generation, 16(14), 2978–2987. https://doi.org/10.1049/rpg2.12365

Yuot Amogpai, A. R., Gabriel Carmona, L., Whiting, K., Amogpai, A., and Esser, L. J., 2015. South Sudan: A Review of the Challenges and Prospects in the Development of Sustainable Energy Policy and Practices South Sudan: A Review of the Development of Sustainable Energy Policy and Practices Sudán del Sur: Una revisión de los retos para el desarr. April 2015. https://www.researchgate.net/publication/301614191

Zakaria Lukwasa, A., Ayal, D. Y., Zeleke, T. T., and Beketie, K. T., 2022. Spatio-temporal rainfall variability and its linkage with large scale climate oscillations over the Republic of South Sudan. Climate Services, 28(September), 100322. https://doi.org/10.1016/j.cliser.2022.100322