A Review of Renewable Revolution Towards Sustainable Energy in Africa

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Abstract. Sustainable energy projects are essential for Africa. They offer energy solutions while being environmentally responsible. This review paper shows Africa's growth through renewable energy. Cleaner energy is guided by renewable energy sources. A look into Africa's renewable energy sector shows innovation in solar, wind, and hydro. This completely shows Africa embracing sustainability. The energy environment in Africa is moving toward larger renewable energy projects, such as solar parks, wind farms, and hydropower dams. These projects not only provide access to energy but also protect the environment. Offering ways to reduce energy consumption is important for Africa through energy efficiency initiatives. Africa is on the path to progress. Improvements in energy storage and the integration of renewable sources will lead Africa to a sustainable future.

Keywords: Renewable Energy, Sustainable Energy, Africa.

1 Introduction

Over the last few years, Africa has been building more large renewable energy projects. In 2024 alone, Egypt and South Africa added new solar energy to their renewable energy sector. Adding in more than 40 GW new solar projects [1]. Wind energy is also growing quickly, especially in South Africa, where plans for wind farms grew by 60% in a year [2]. Hydropower is still the most used renewable energy in Africa, with the Grand Ethiopian Renaissance Dam leading the way [3].

The shift to renewable energy is a lengthy process, but for Africa it can be shorter. Africa has an abundance of natural resources that can enhance the continent's energy sector by integrating more renewable energy sources [1]. Some African countries have

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shown their commitment to becoming more sustainable in the near future. They have taken action and are seeing the role renewable energy plays for energy access and being environmentally responsible [3]. Three renewable energy sources and going to be uncovered to show the potential renewables have on Africa. With case studies and energy projects, we see the renewable revolution towards sustainable energy in Africa [2].

2 Africa's Renewable Energy Landscape

In developing economies in Africa, sustainable development is particularly dependent on sustainable energy systems [1]. Developing successful energy policies requires an understanding of the techno-economics of these systems. Using Cameroon as a case study, this research examines the country's progress toward a fully sustainable energy system by 2050. Six key scenarios were modeled using the LUT (Lappeenranta-Lahti University of Technology) Energy System Transition Model, incorporating both sustainability and policy constraints. According to the findings, 86% solar photovoltaics, 8% hydropower, and 5% biofuels would be the most economical and sustainable energy mix for Cameroon to achieve net-zero greenhouse gas emissions by 2050. The modeling results indicate that Cameroon can meet its future energy demands entirely through renewable sources by utilizing locally available solar, hydro, and biomass resources. Furthermore, the scenarios demonstrate economic viability when supported by long-term policy frameworks and investment incentives. This shows that, with the correct governmental backing, a fully sustainable energy system in Cameroon is both technically and financially possible [4].

Microgrid advancements are part of Africa's transition to sustainable energy, as demonstrated by the University of Djibouti's integration of wind and solar PV. To support the deployment of microgrids, a study utilizing eight years of weather data and various classification techniques found that renewable energy sources are highly feasible in the region. Building on these findings, machine learning models were applied to further optimize generation, storage, and distribution strategies for enhanced energy reliability and efficiency. These renewable sources are much more feasible when deep learning and machine learning approaches are used, as within the case of the LSTM method for power prediction [5].

Battery storage can profitably supplement demand response alternatives in power system expansion scenarios in South Africa, according to a study of flexibility resources in scenarios with significant renewable energy penetration. By addressing energy curtailment from solar PV and wind power, the system also reduces reliance on gas-fired turbines. Moreover, the application of efficient sector-coupling techniques enables better utilization of surplus energy, thereby enhancing overall system performance [6].

3 Financial Barriers and Investment Challenges

Africa has strong renewable energy potential, yet financial and investment opportunities remain a big obstacle. One of the main barriers is the high upfront cost of renewable infrastructure facilities for solar, wind, and hydro. Many African countries have limited access to affordable financing. With high interest rates, weak credit ratings, and currency volatility. This makes it difficult to attract long-term investors [7]. Additionally, political instability, underdeveloped transmission infrastructure, with uncertain and changing energy regulations increase the perceived investment risks. This inherently discourages both local and international investors [8].

To address these challenges, many economic incentives and financing opportunities are being introduced. Some governments are offering feed-in tariffs, tax reductions, and support for public-private partnerships to encourage private sector participation. At the international level, institutions like the World Bank and African Development Bank are stepping in with green funds, concessional loans, and technical support to de-risk investments [9]. These efforts strengthen the regulatory framework and improve investor confidence. This will be crucial for scaling up renewable energy deployment across Africa.

4 Renewable Energy: Solar Energy

In Colorado, United States, solar community projects have been made available. In this region, the Community Solar Gardens Act has facilitated the growth of solar projects by requiring utilities to purchase power from shared solar installations [10]. This policy ensures subscriber mobility and provides clear legal definitions. This offers a guaranteed market for solar energy producers. Such targeted and enforceable legislation has proven effective in scaling renewable energy access among households that cannot install solar individually [1].

Adopting similar legislation in African nations could help promote inclusive and scalable solar projects [4], [1]. A policy tailored to the African context could mandate utility buy-back schemes, define the roles of developers and subscribers [10]. This would provide incentives for private investment in microgrid infrastructure. Addressing the issues of affordability, increasing grid stability, and expansion of clean access to energy. Making the policy feasible and impactful to the energy landscape in Africa [4].

Prospects for solar energy in Africa are promising due to declining technology costs and growing awareness of its benefits. But to fully realize its potential, legislators, financiers, and community leaders must work together to create laws that will support solar energy projects and promote investment in them [12]. Africa added 2.5 GW of solar energy capacity in 2024, over 78% was concentrated in two countries, South Africa and Egypt. Showcasing the need for more inclusive financing and technical support in solar. The potential in underserved regions in Africa like West and Central Africa are promising [13]. To achieve universal electrification and sustainable development throughout Africa, solar energy may become increasingly important as solar technology becomes more widely available and affordable and as legislative support increases [10].

5 Renewable Energy: Wind Energy

Renewable energy technologies are expected to be essential in supplying the world's growing energy needs while reducing pollution to the environment [2]. Although many countries are becoming more interested in producing renewable energy, the installation of wind energy in South Africa has been hampered by a growing negative opinion of the technology [5]. However, if there is a vigorous and ongoing conversation among stakeholders, including investors, governmental organizations, municipalities, and local communities, wind energy projects have the potential to greatly contribute to socio-economic development.

South Africa's wind energy sector grew by 60%, 48 GW in 2024. Provided by policy certainty and interest of investment provinces in KwaZulu-Natal and Mpumalanga. This growth is not overall across the continent, where inconsistent policy frameworks and weak grid infrastructure continue to limit wind project development in regions like East and Central Africa [14]. Governmental organizations must take the lead in setting regulations and policies in order to solve the issues preventing the widespread use of wind energy technologies. In the meantime, businesses and academic institutions work together to develop and distribute new technologies that improve productivity and performance in the face of diverse technological, financial, and environmental challenges [15].

Recent advancements in small-scale wind turbine design highlight the necessity for site-specific solutions that incorporate advanced designs and new construction materials to improve performance. Nonetheless, wind energy technology remains complex, with several weaknesses impeding its full potential. These weaknesses include the ratio of technology size to power output, limitations imposed by the Betz criterion, the need for accurate wind condition measurement instruments, the availability of spare parts for effective maintenance, a shorter operational lifetime compared to other renewable technologies, and the extensive land requirements that may necessitate community land expropriation [15]. To overcome these obstacles, engineering disciplines across industrial and academic sectors must work together to minimize technology size through improved materials, component design, and enhanced strength and stability of towers, rotors, and blades.

The escalating demand for renewable energy technologies that adhere to sustainable and low-energy designs is at the forefront of the wind technology manufacturing industry. Wind turbine towers must be engineered to endure the primary design loads transmitted from the rotor and nacelle, alongside those imposed directly on the tower [15]. However, the unpredictable dynamic behavior of a complete wind turbine complicates the simulation of all operational parameters, including wind speed, rotor angular speed, tower vibration, and resonance. Consequently, the design of the tower primarily aims to capture the maximum wind possible, with the available power output being a function of several variables, including the power coefficient (Cp), wind speed (v), swept area (A), wind density (ρ), and turbine efficiency (η).

Power production is significantly influenced by the relationship between wind speed and height since, generally speaking, wind speed increases with height but wind density decreases. This means that wind technology tower designs must be carefully considered, particularly in topographically diverse areas. A modern wind farm is made up of several carefully placed wind turbines, with interactions between the turbines affecting wear loads and power output. The wake effects produced by turbines upstream can result in reduced power output for turbines located downstream. Optimizing wind farm performance requires an understanding of and commitment to managing these interactions [15].

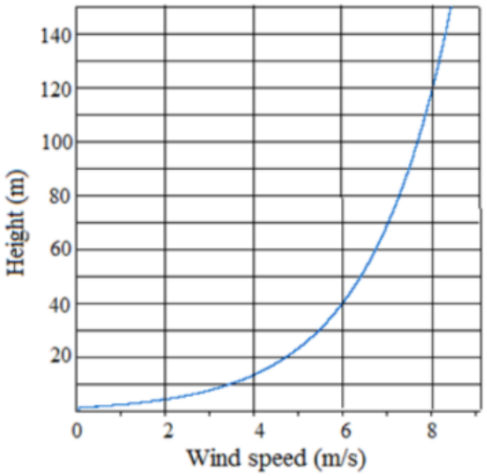


Fig 1. Variation of wind speed with height

The development of various wind turbine types has been driven by the necessity to optimize power generation. Wind turbines are broadly categorized into horizontal axis and vertical axis models. The performance of an aerodynamic surface is heavily influenced by its cross-sectional shape, which directly impacts the power coefficient (Cp) and the amount of power extracted from the wind [15]. Fig 2, shows the variation of wind speed with height.

Achieving widespread adoption of these technologies requires collaboration and commitment across all sectors of society [2]. The successful integration of wind turbines and optimization of their size and power output can reduce the land footprint needed for wind farms, thereby minimizing conflicts between investors and communities [15].

Due to the inherent unpredictability of wind as a natural resource, precise evaluations of the wind conditions particular to a given site are essential for efficient power generation planning. Wind energy has many benefits, but for South Africa to

successfully adopt it, its technological shortcomings must be addressed [2], [5]. Realizing the goal of using only renewable energy sources in the country and promoting a sustainable energy future worldwide would require cooperation from all parties involved [15].

6 Renewable Energy: Hydro Energy

Given the sporadic nature of resources like solar and wind energy, the necessity for efficient energy storage solutions has received a lot of attention as the focus on renewable energy sources (RESs) has grown. Hydropower is Africa's most dominant renewable energy source. Making up nearly two-thirds of installed capacity as of 2023 [16]. Many hydropower projects are highly vulnerable to drought and changing rainfall patterns due to climate change. Recent hybrid models, like South Africa's Boston Hydro project that combines hydro, wind, and solar, showcases the potential of diversified systems to improve resilience. This approach could be scaled continent-wide [17]. Due to its high energy density and flexible production methods, hydrogen has become a viable option for tackling these issues [11]. Storing extra energy created during peak renewable production times is critical as the globe moves closer to net-zero emissions. By using the hydrogen that has been stored, the gap between the production and consumption of energy can be filled at times when demand is high [18].

The remarkable energy density of hydrogen (120 MJ/kg) highlights its potential as an energy storage solution and makes it a desirable substitute for traditional storage techniques. Hydrogen can be produced by employing several cutting-edge methods, such as solid-state materials, gasification, and water electrolysis. When excess renewable energy is available, electrolysis—the process of using electricity to split water into hydrogen and oxygen—becomes very significant [18]. This makes it possible to store excess energy effectively, which can subsequently be used by fuel cells to generate electricity again when demand is high or production is low [11].

However, while hydrogen presents numerous advantages, there are notable challenges to its widespread adoption [11]. High production costs, especially in the context of electrolysis and other generation methods, currently limit its economic feasibility. Additionally, hydrogen's use for energy purposes remains relatively nascent in many countries, with the majority of its applications still concentrated in industrial sectors such as oil refining, ammonia production, and food processing. Integrating hydrogen into existing electricity grids also presents hurdles, as current infrastructure often lacks the necessary flexibility to accommodate fluctuating renewable energy inputs [18].

Numerous practical techniques for storing hydrogen have been identified through thorough investigation, including material-based storage systems, compressed gas storage, and liquid hydrogen storage. Every strategy has its own advantages and difficulties. For instance, fuel cells frequently employ compressed gas storage, which makes refilling simple and quick [11]. On the other hand, it has problems with weight, bulk, and leak potential. However, liquid hydrogen storage has a higher energy density per volume but necessitates energy-intensive, labour-intensive cryogenic liquefaction

procedures. The last method is solid-state storage, which uses materials to store hydrogen at room temperature. It is safe and effective, although it has drawbacks with regard to reversibility and release kinetics [18].

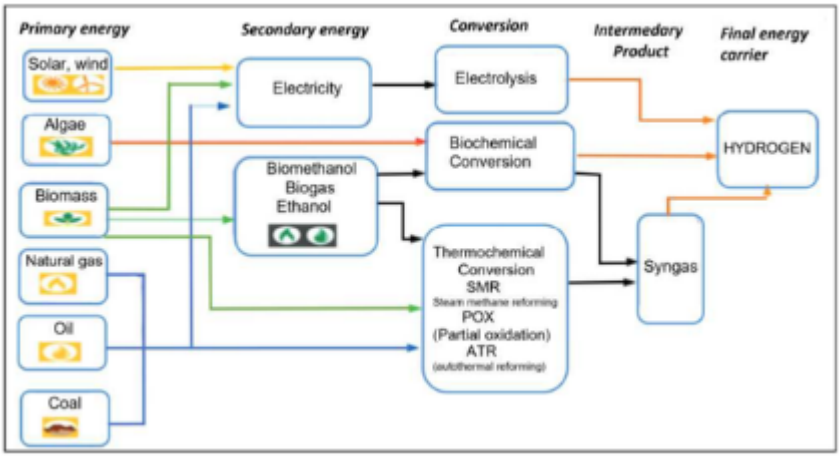


Fig 2. Overview of hydrogen production techniques

In addition to hydrogen production and storage, the role of hydrogen in power generation is increasingly being recognized (see Fig 2). Fuel cells convert hydrogen back into electricity with high efficiency and low emissions, presenting a promising avenue for integrating hydrogen into the broader energy landscape [11]. Furthermore, hydrogen can be blended with natural gas, facilitating its use within existing natural gas infrastructure, which could enhance the transition toward a more sustainable energy future [18].

7 Conclusion

Africa's transition to a sustainable energy future is being driven by developments in solar, wind, and hydro projects. When secured by reliable regulations and investments, case studies like Cameroon's plan to use only renewable energy by 2050 demonstrate the continent's potential. Solar energy is particularly scalable and economical. Whereas wind energy is expanding due to improved design and cooperation. And hydro energy is still in the lead despite climate-related issues. Inconsistency may be resolved with the combination of hybrid systems and hydrogen storage. Yet, there are still large gaps in infrastructure, regulation, and funding. African countries must prioritise inclusive legislative structures, and increase collaboration between the private and public sectors. While making investments in cutting-edge energy solutions if Africa wants to hasten the renewable transition. Africa can become a global leader in renewable development and meet its energy needs sustainably with determinate action.

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