AUDA-NEPAD
AFRICAN UNION DEVELOPMENT AGENCY

The African Continental Power Systems Masterplan

Support Studies – Wind power

African Union

THE AFRICA-EU PARTNERSHIP
LE PARTENARIAT AFRIQUE-UE

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Introduction

Development of a continental master plan

The African Union (AU) has articulated a vision for a continent-wide interconnected power system (the Africa Single Electricity Market (AfSEM)) that will serve 1.3 billion people across 55 countries, making it geographically the biggest electricity market in the world. Interconnection offers immense technical and economic opportunity[1], while a fully integrated and competitive market will accelerate development and energy access across the continent. Increasingly, the enhanced system flexibility and resilience of an interconnected power system is also an imperative for a modern power system able to navigate the developments impacting global energy systems. This includes growing shares of low-cost variable renewable energy; commitments to climate change and decarbonisation, decentralisation and democratisation of energy; intelligent grid infrastructure and digitalisation of the energy sector; infrastructure resilience in the face of climate risks; and the rise in energy storage technology and electric vehicles.

Concrete steps have been taken towards realising the broader vision described by the AfSEM together with the AfDB's new deal for energy and clean energy corridor concepts. Among these is the development of a Continental Power System Masterplan (CMP) expected to create the framework conditions that will allow countries to trade electricity to leverage national and regional surpluses and deficits through cross border power exchanges and inter power pool trade. This harmonized platform will aid optimised project decision-making regarding the location, size and timing of generation and transmission infrastructure investments.

The CMP is being developed under the governance structure of AUDA-NEPAD (the African Union Development Agency) with direction from ministerial committees to ensure political and technical alignment. Development of the CMP spans two phases (Figure 1) and is implemented over several years, with targeted completion of the first draft by the end of 2023.

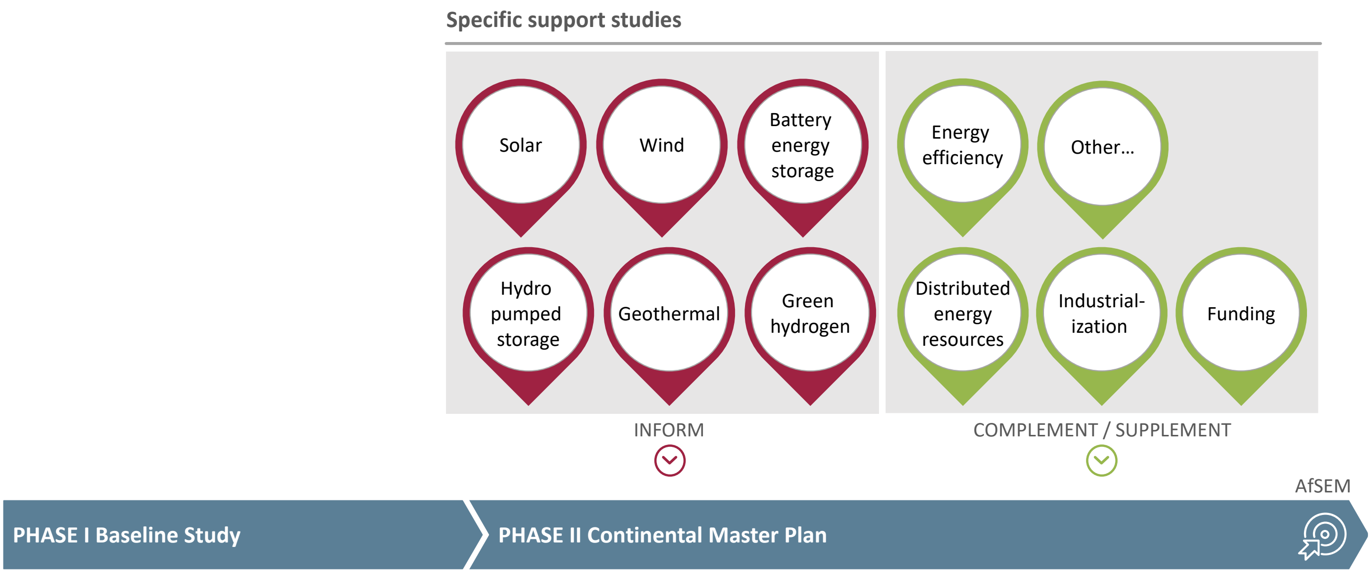

Figure 1: CMP development phases with input from specific support studies

[1] Benefits include increased system reliability; access to more diverse generation resources; enhanced security of supply; improved system flexibility, redundancy, and resilience; reduced or deferred capital investments; diversified loads and improved load factors; and operational and maintenance efficiencies gains, among others.

In parallel, several studies are being developed to help refine and enhance the CMP (Figure 1). These specific support studies (SSS) aim to inform or complement the planning of the CMP, providing a clearer understanding of the potential contribution to the continental power system or the potential for adjacent developmental opportunities.

Wind power as part of the energy generation mix

This study, which was developed with support from the European Union Global Technical Assistance Facility (EU-TAF) for Sustainable Energy, focuses on the findings of the wind power SSS, providing an overview of the identified resource potential, opportunities, barriers or challenges and recommendations to achieve an optimal contribution to the CMP.

Global projections to 2040 recognise renewable energy – including wind power – as a critical part of a diversified electricity mix to meet the power needs of the world (Figure 2).

The CMP being developed for the African continent show wind power growing from approximately 4% in 2023 to 23% of the electricity mix planned for 2040.

Current planning for the future diversified energy mix includes mainly onshore wind, with a smaller contributed from offshore wind foreseen at this stage.

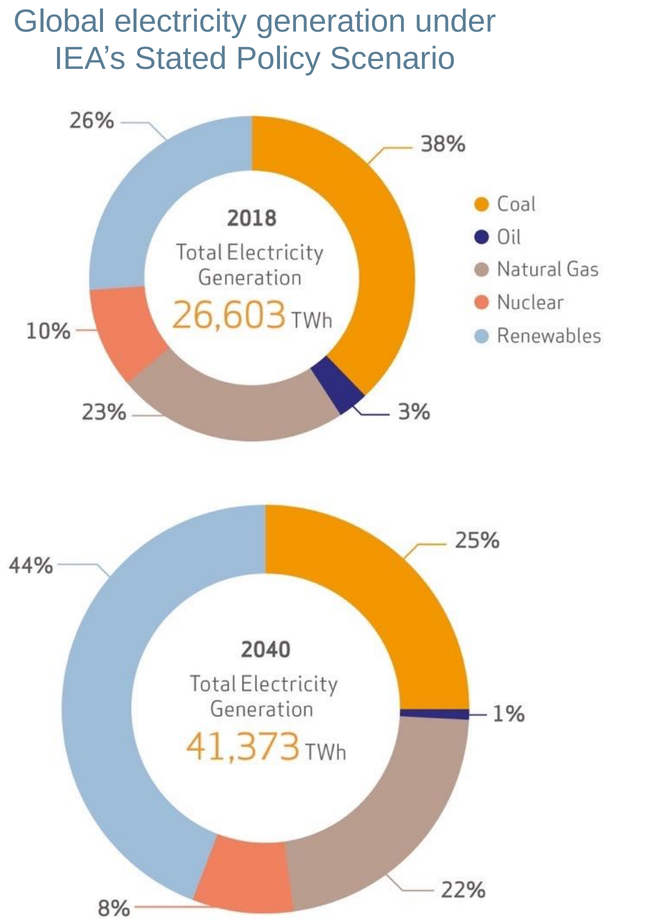

Figure 2: Changes in the global electricity mix[2], 2018 – 2040 (measures in TWh)

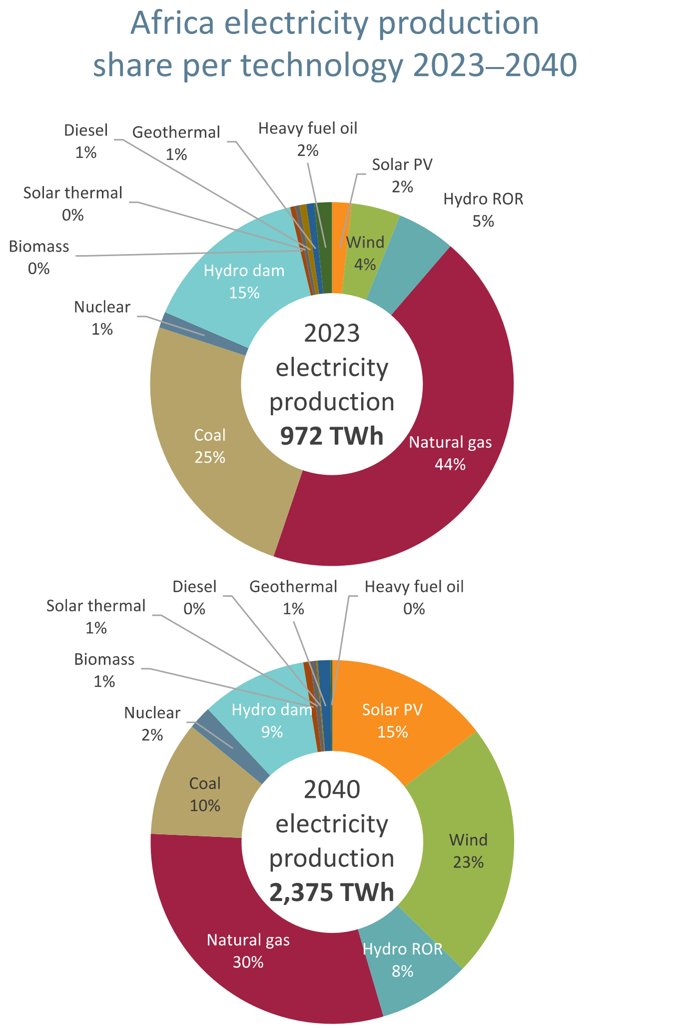

Figure 3: Africa's current and future installed capacity mix, 2020 – 2040 (measured in GW)

[2] International Energy Agency (IEA) World Energy Outlook, 2019 data

Resource potential

Wind resource potential and performance

Multiple assessments[3] have been developed to estimate the wind power potential for Africa, both on and offshore. While exact estimates differ, all datasets recognized significant potential for wind power on the continent, confirming wind power as an abundant and well distributed resource that can contribute significantly to power development on the African continent.

The wind power SSS reviewed the available datasets to validate and refine the technical potential that would inform planning at continental level. It also applied a further screening process to the onshore wind data, considering sensitivities of performance metrics, construction lead times, availability of road and electricity infrastructure and logistics. A total technical potential of 3.38 TW of wind power was confirmed for Africa. Screening extracted a subset of wind power developments **realistically deployable in the medium term**; it found **441 GW of onshore wind power capacity can readily be developed on the continent** – twice more than the maximum wind power currently anticipated by 2040. For offshore wind power the unscreened technical potential is estimated at 423 GW[4].

Box 1. On and offshore wind power

Both on and offshore wind energy resources can play a role in the future African electricity mix by 2040 and beyond to supply a fast-growing demand.

Onshore wind power is generated from turbines located on land. Onshore wind can typically produce power at lower levelized costs of electricity and offer greater and more distributed resource potential.

Offshore wind power is generated by turbines located over open seawater. The cost of offshore development is higher, but it benefits from higher and less varying wind speeds. Offshore turbines can be constructed on fixed-foundations or can be floating. Because floating wind turbines don't need to be grounded in the seabed, they can be sited further out to sea in water deeper than 50m where winds are stronger.

Technology developments

Capacity factor[5] provides an indication of the efficacy and consistency with which turbines can extract energy from variable wind conditions. It is therefore often used as a proxy for wind farm performance. Capacity factors for wind power have steadily increased to average 42.3% in the US in 2020 and projections by the National Renewable Energy Laboratory (NREL) suggesting a further 40% improvement is possible by 2030 – to reach capacity factors of 59%. This will exceed the worldwide average capacity factor for hydroelectricity of 44%[6].

Although capacity factors are partly attributed to technology capability, the quality of the wind resource is an important consideration. On the continent, Eastern and Northern Africa offer the highest and most consistent capacity factors throughout the year (Refer Figure 6).

The CMP study recommends capacity factors of 38% for onshore and 41% for offshore wind generation in Africa. For planning and modelling purposes, the study also opted for the most conservative projections, cautious not to overstate the generation potential from wind power on the continent. It provided for capacity factors increasing by 4.9% between 2020 and 2030 and 5.5% between 2030 and 2050 (refer Table 1).

Table 1: Capacity factors and anticipated improvements for wind power in Africa

Capacity factor (%)	Capacity Factor	Improvements (%)	
		2020 – 2030	***2030 – 2050***
Overall wind (IRENA data)	40.5%	*4.9% (42.5%)*	*5.5% (45%)*
Onshore wind	38%		
Offshore wind	41%		

[3] Onshore datasets included IRENA's updated dataset, the International Finance Corporation (IFC) estimates and the REZoning tool (ESMAP). Offshore datasets included a) the Global Offshore Wind Technical Potential by the World Bank, b) a study performed by Paul Elsner (Elsner, 2019), and c) ESMAP's REZoning tool.

[4] 162 GW fixed and 281 GW floating turbines beyond 50m of water depth.

[5] Capacity factor is the ratio of a generator's annual power production to the power it could have produced if it ran at 100% rated capacity 24/7.

[6] Average capacity factors for hydropower range from 32 to 55%. http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch05.pdf, Chapter 5.

This is lower than what is already being achieved in experienced markets globally. This conservative approach takes cognisance of potential infrastructure challenges and a learning rate among authorities and industry. As developers and authorities gain experience and infrastructure is developed, Africa can benefit from improved performance and lower electricity production costs.

Cost developments

Wind energy prices have achieved substantial cost reductions between 1980 and 2020, achieving lower costs for both installation (CAPEX) and operations (OPEX). Figure 4 shows comparative price trends for different generation technologies since 2009, showing wind as one of the lowest cost technologies in the market today. Expectations are that technology improvements and breakthroughs will provide further cost reductions in the medium and long term.

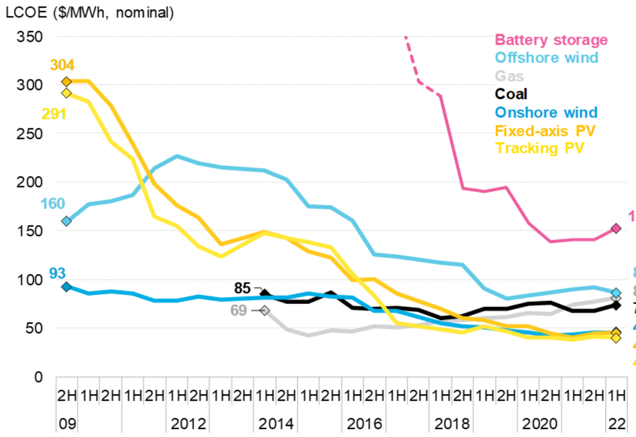

Figure 4: Global average levelized costs of electricity benchmarks, 2009 – 2022[7]

The cost of wind power in Africa varies substantially between countries, largely dependent on the maturity of the market. Costs are further affected by country risks, grid access, and infrastructure challenges. Notably, the construction or upgrade of roads to transport large turbine components add a premium to development costs.

Levelized cost of electricity (LCOE) ranged between 48 and 116 USD/MWh for viable wind project sites. On the low end, it is globally competitive, but at USD 116/MWh the electricity is 2.5 times more expensive than the global average for onshore wind (USD 46/MWh).

Opportunities

Development pipeline

Just more than 7.7 GW of wind power was operational on the continent in 2022, located primarily in eight countries: Egypt, Ethiopia, Kenya, Morocco, Senegal, South Africa, Tunisia, and Western Sahara. Approximately 1.8 GW of wind power was under construction with much of this new capacity being built in Ghana, Mauritania and Sudan. An additional 12.7 GW are in earlier stages of development and announcements have been made for another 4 GW of planned wind power developments.

Several project developers are involved in these developments across the continent.

The distribution and capacity of all known projects are mapped in Figure 5, with colour coding showing project status – red (operating), yellow (under construction), green (in development), light blue (announced), purple (shelved), and black (cancelled). Evident from the map is the concentration of development in South Africa, Morocco and Egypt, together representing 77% of all operational wind farms in Africa.

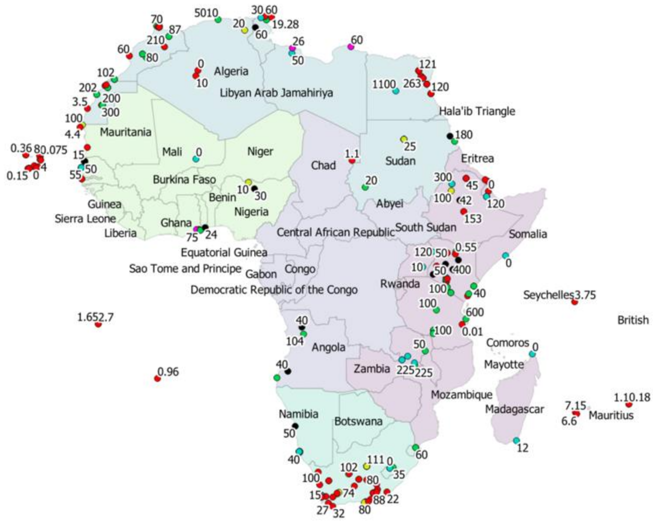

Figure 5: Locations of wind projects in Africa (November 2022, Source: Elaborated by TAF)

The combined capacity of all (i) operational, (ii)

[7] Source: BloombergNEF. Note: The global benchmark for PV, wind and storage is a country-weighted average using the latest annual capacity additions. Storage LCOE is reflective of utility-scale Li-ion battery storage system with 4-hour duration running daily cycle and includes charging costs.

under construction, (iii) under development and (iv) announced wind power projects is 28.2 GW.

If this pipeline is realised it will constitute 3% of the global installed capacity in 2022 (906 GW)[8]. More significantly, it will have unlocked less than 6.5% of the readily deployable wind resource potential on the continent (refer earlier assessment of resource potential), pointing to the significant untapped potential for wind power still available on the continent.

Power system integration

Unlike solar power that follows a distinct daily pattern, wind power is more intermittent due to the natural variability of the wind. Wind integration studies therefore give special consideration to the contribution of variable-output wind power in the power system.

Modelling for the CMP demonstrated the benefit of **interconnecting wind power across a larger and more diverse geographical area**, with significantly enhanced availability of wind power achieved when integrating at regional level.

Figure 6 demonstrates the potential for continent-wide interconnection to balance seasonal variability across regions, for example:

- The high wind season in East Africa coincides with the low wind season in Central and West Africa, and
- North Africa's best wind period generally corresponds with lower wind production in Southern Africa.

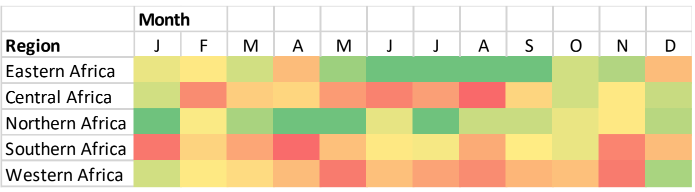

Figure 6: Indication of regional capacity factors (Green-high, Red-low)

Modeling also highlighted the benefit integrating wind and solar power. Daily wind variability patterns complement the availability of solar power; with solar power confined to daylight hours, wind delivers higher capacity factors at night.

Opportunities for offshore wind and hybrid systems

The opportunity for wind power is further enhanced by the following developments or opportunities:

Offshore wind. The opportunity for offshore wind was noted while not currently a significant part of energy planning on the continent. The global market is expanding, and technological developments and operational efficiencies are boosting the outlook for offshore wind. Newer floating foundations are also less dependent on the depth of the seabed and terrain.

Offshore wind farms along the African coastline are expected to have higher capacity factors than onshore developments. Higher production will offset the higher cost of development which can assist with more competitive electricity costs. Off-shore wind power is a promising, but currently underexplored energy source for the continent.

They study specifically noted that wind power may be locally relevant in coastal countries with high electricity demand, such as South Africa.

Wind, solar, and/or energy storage hybrid systems. Wind and solar PV power production were shown to be fully complementary. Hybrid plants that combine wind and solar power can exploit this complementarity and share the same substation, cables and grid connection, reducing the requirements on grid and other infrastructure.

Further opportunity lies in combining wind, solar and energy storage on a single site, for a "hybrid renewable generation-plus-storage" solution. The inclusion of storage can assist with smoothing out intermittency and be used for grid balancing and ancillary grid services.

Barriers or challenges

Wind power plants have exceptionally short development lead times and can typically deliver electricity within 12 and 24 months after start of

[8] Global Wind Energy Council (GWEC), Global Wind Report 2023

construction. Deployment of the considerable wind energy potential on the continent is however dependent on (i) the readiness of the wind industry and (ii) the existence of suitable legal and regulatory frameworks to enable development.

Legal and regulatory frameworks and capacity

The study noted the need for more in depth, country specific assessments of the policy, legal and regulatory environment. An initial high-level assessment found few countries to have established enabling policy, legal and regulatory framework conditions.

In making this assessment, the Electricity Regulatory Index (ERI) was used as an indicator. The ERI is an annually updated composite index developed by the African Development Bank to provide a comparable metric describing the quality and scope of regulations in African power systems[9]. It is constructed via an extensive survey and the 2021 Edition covers 43 countries. The core dimensions are the governance (legal mandate and role), the substance (decisions and actions) and the outcome (impact on utilities).

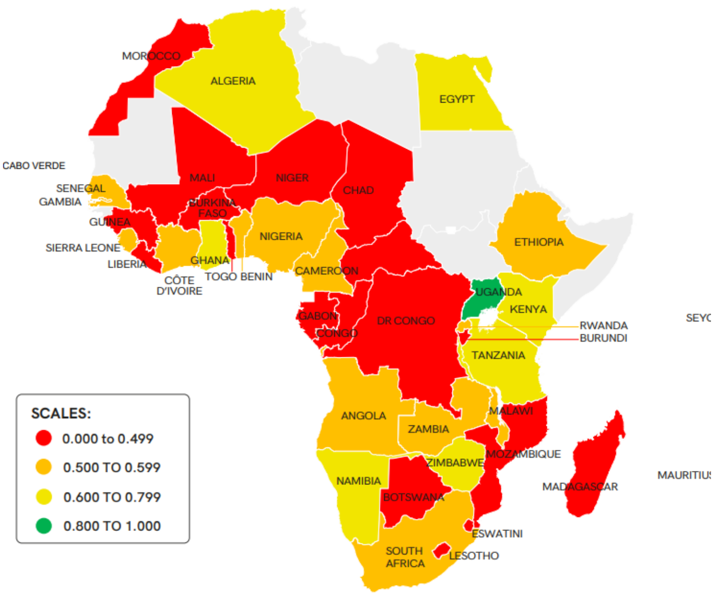

Figure 7: Overall Electricity Regulatory Index 2021 (Source: ERI for Africa, 2021 Edition)

The index describes four stages of regulatory framework development: low (red), medium (orange), substantial (yellow) and high (green) level of regulatory development. The index reveals that the level of regulatory development remains low or at the medium level in most countries which will present a barrier to a fast deployment of renewable energy and specifically wind power.

Enabling environments were found to be lacking around four aspects:

Enabling policies. Enabling policies for renewable energy projects, including wind energy IPP projects, should demonstrate a strong and lasting strategic governmental commitment to the deployment of renewable energy projects in the respective host country.

Institutional and organizational framework. Host countries should provide an institutional/organizational framework that clearly allocates the institutional responsibilities of different public institutions and other public and private entities within the electricity sector supply chain.

Enabling national legal and regulatory rules. The framework should provide adequate legal and regulatory rules ensuring that the electricity sector of the host country is competitive and sustainable and that IPPs are provided with framework conditions that are favourable for their deployment.

Procurement framework for IPPs. An effective procurement framework should enable wind energy IPP projects to be procured based on competitive tendering.

Technical barriers

Despite the vastly enhanced methods and tools available for assessing regional wind resources, the study highlighted the critical importance of **site-specific data and wind measurements** for plant design, noting that local terrain characteristics and wind conditions will greatly influence energy output at wind farm level.

The most productive sites may not be located within proximity of **existing road and transmission infrastructure**. The state of infrastructure, notably road infrastructure to

[9] https://africa-energy-portal.org/reports/electricity-regulatory-index-eri-africa-2021-edition

transport equipment and parts, was identified as a major hurdle for development and a significant contributor to costs.

Technological issues of grid support associated with wind turbines have largely been resolved. Wind variability requires due consideration, particularly for higher penetration levels of wind power. Changing paradigms in system operation and advances in controls and inverters, are anticipated to address issues of grid frequency control and variability. Most importantly, wind power is recognised as part of a diverse energy mix, complementary to other generation sources and energy storage systems.

What is needed to unlock the potential?

Enabling policy, legal and regulatory framework conditions contribute to derisk a wind power project and make it bankable, thereby encouraging investment decisions from developers, and private and institutional investors and lenders.

Accordingly, advancing the policy, legal and regulatory framework is critical for rapid and sound deployment of wind energy on the continent. Priority interventions should include:

- Establishment of an **institutional structure with clear mandates and tasks**: (i) Ministry of energy (overall oversight and responsibility), (ii) an independent regulatory authority (ensure compliance among legal entities), (iii) transmission and/or distribution system operators (TSO/DSO) (transmission and distribution infrastructure and operation), power generators (producers of electricity), and a designated off-taker or single buyer (purchaser of electricity).
- Defining of (i) sectoral planning rules, (ii) clear functional framework rules for the different segments of the electricity sector supply chain, (iii) a clear licensing framework including generation, transmission, distribution, supply, import and export of electricity.
- Provision of an adequate set of **legal and regulatory rules designed for renewable energy systems** that includes, for example, (i) a general purchase obligation for renewable electricity, (ii) direct sale option for renewable electricity through bilateral contracts, (iii) guaranteed and non-discriminatory grid connection and grid access and, ideally, (iv) system priority for renewable electricity in the event of dispatch.
- Provision of clear, coherent and transparent **technical rules** regarding the transmission and distribution of generated electricity, ideally established by a grid code.
- Establishment of a **suitable procurement framework**, preferably using competitive renewable energy auctions as a procurement instrument. The study gave strong preference to renewable energy auctions and recommended a two-stage bidding process with pre-qualification phase drawing on the experience and learnings from the South Africa's renewable energy IPP procurement programme.

Finally, the importance of **public sector engagement and political sponsorship was recognised as essential to boost investor confidence** and mitigate the political, legal and economic risks.

Conclusion

The immense wind resource potential on the African continent has been confirmed with a technical potential of 3.4TW for onshore wind and another 423 GW possible from offshore wind. Further screening of this dataset identified at least 441 GW of the onshore capacity that can realistically and readily be developed in the short to medium term. This capacity can be developed to deliver electricity at low cost as demonstrated by wind power plants on the continent achieving LCOEs of USD48/MWh.

It is therefore reasonable to expect that wind power can make an important contribution to electricity production on the continent. Because of the rich resource and large geographic dispersion, wind power can contribute diversity in source and distribution to the African energy mix.

Wind power is a mature technology with a long track record of electricity production across the world. The technology has, and continues to make, significant advances producing more electricity from fewer wind turbines at lower costs. Capacity factors – a measure of efficiency with which power can be harvested from wind resources – are expected to make more material gains in the next two decades. Technological and grid integration challenges presented by the intermittency of wind power have largely been resolved.

A remaining consideration relates to the inherent variability of wind. This study showed that interconnecting wind power plants across a larger geographic footprint, dampens the impact of variability, delivering an enhanced capacity factor for the fleet of wind farms. Similarly, interconnection with other generation options can improve the overall system availability – co-location or hybrid solutions incorporating solar and battery energy storage were specifically considered.

The remaining hurdles for unlocking this potential electricity source for the continent relate mainly to limitations of the policy, legal and regulatory environment. Establishing sound building blocks that can derisk the investment environment is crucial for the rapid and sound deployment of wind energy.

The study found an existing ecosystem of developers that are active in several African countries with tentative project pipelines of hundreds of MWs potential. These developments will benefit from strong public sector commitment that can boost investor confidence and mitigate the political, legal and economic risks.

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