AUDA-NEPAD
AFRICAN UNION DEVELOPMENT AGENCY

The African Continental Power Systems Masterplan

Support Studies – Pumped Storage Hydropower (PSP)

African Union

THE AFRICA-EU PARTNERSHIP
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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 (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.

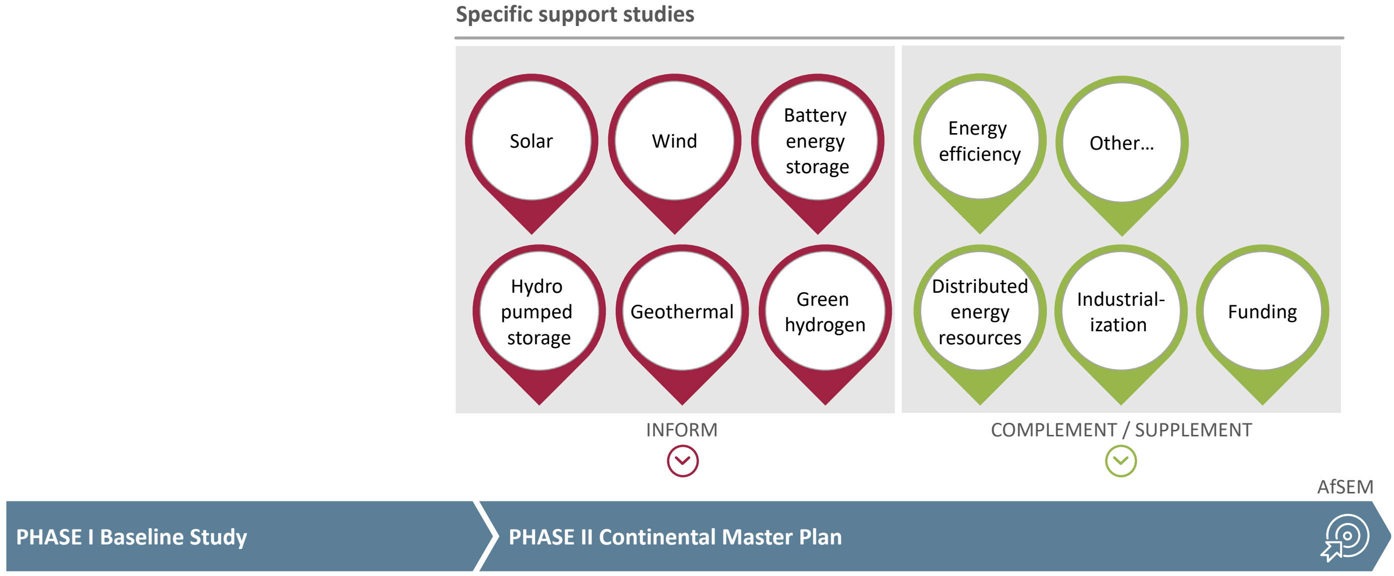


Figure 1: CMP development phases with input from specific support studies

[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.

Pumped storage hydropower as part of the energy generation mix

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

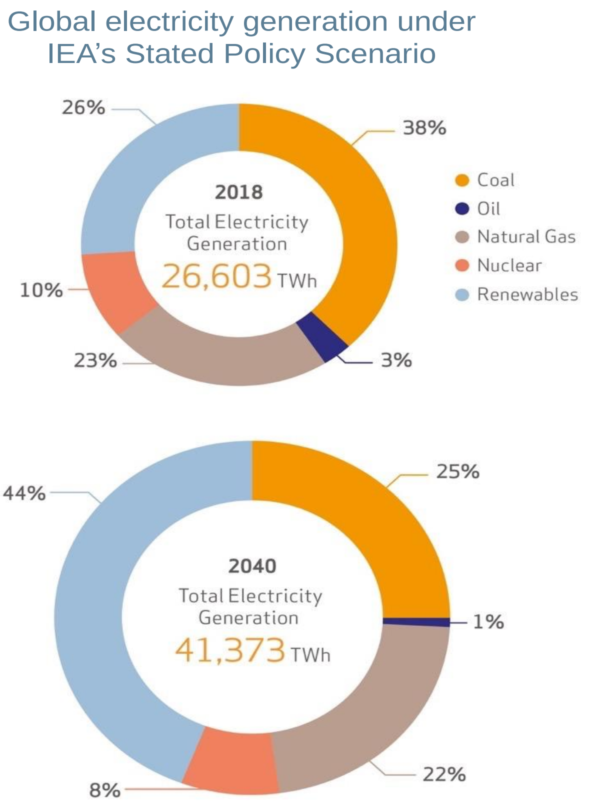


Figure 3: Changes in the global electricity mix[2], 2018 – 2040 (measures in TWh)

Global projections to 2040 recognise renewable energy – including PSP 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 hydropower run of the river (ROR) to grow from 5% to 8% of the electricity mix planned for 2040.

Current planning for the future diversified energy mix supports the expansion of PSP to countries with a high potential but with little to no existing generation.

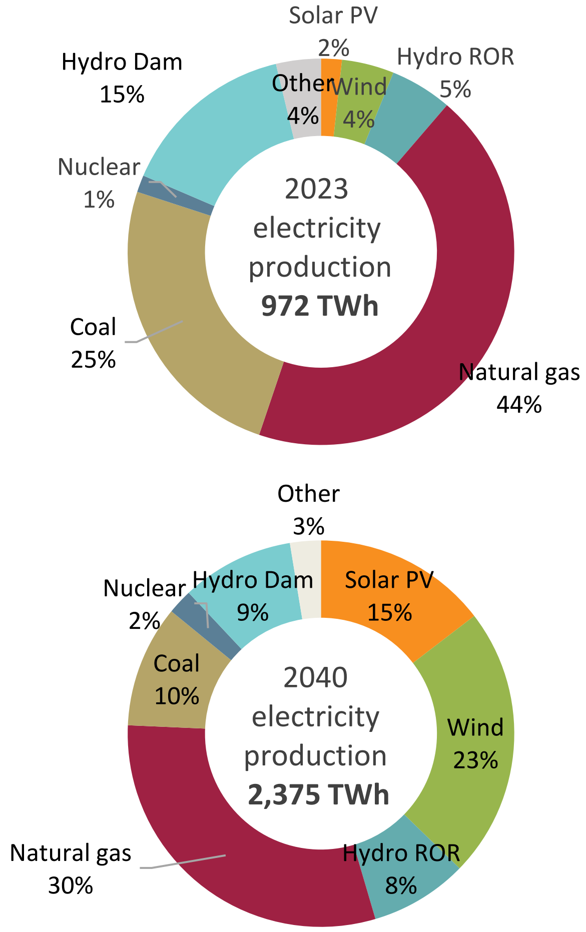


Figure 2: Africa electricity production share per technology 2023–2040

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

Resource potential

Current forecasts are that Africa is set to increase its renewable energy (RE) capacity by 176 GW in 2040, whilst its peak demand will grow to 413 GW. Simultaneously, many existing generation plants (all fuel types) will be decommissioned during this period as they reach their end of life, resulting in a peak supply gap from 2030. Energy storage can alleviate these shortages through energy balancing. Indeed, PSP has an established track record in Africa with the first plant commissioned in South Africa in 1979. In 2023 there are five operational plants with an installed capacity of 3.3 GW (four in South Africa totalling 2.9 GW, and one in Morocco with 0.5 GW); and eight countries with thirteen plants, at various stages of development, targeting more than 12.3 GW – all of which were excluded from the potential sites assessed under this study.

The Australian National University 2019 global study of closed loop PSP sites employing a geographic information system (GIS) identified more than 616 000 sites globally, of which 61 000 are in Africa – as can be seen in the map. The information collected includes important features needed for project decision making – altitude, head, slope, water volume, water area, rock volume, dam wall length, water/rock ratio, energy storage potential and site categorization based on costs and ranked in five categories to an approximated cost model – Class A to E.

It is important to note that the GIS sites do not consider existing reservoirs, only greenfield projects. Such vast potential makes analysis difficult and necessitated the use of pre-determined selection criteria to prioritise a smaller selection (refer Figure 4). The first level As of screening was to limit the study to Class A sites with six hours of electricity production. This set was then reduced further by only considering locations with proximity to high voltage lines (<50km), distance to RE projects (<150km) and excluding culturally and environmental sensitive areas (national parks, indigenous / heritage sites, agriculture). This reduced the total to 170 of the more viable sites.

Pumped storage hydro power technologies

The primary PSP technology types are:

1. Open and closed loop PSP: The former relies on a naturally flowing river, whereas the latter constantly transfers water between an upper and lower reservoir, without a river.

2. Fixed speed PSP: The power output of the generator is a function of the hydraulic head and flow rate. The power consumption of the motor is constant.

3. Variable speed PSP: Adjustable control of the unit speed and power consumption during pumping mode is best suited when there is a high penetration of variable renewables

4. Ternary and quaternary PSP: Ternary consists of a separate turbine and pump on a single shaft with an electric machine that can operate as either a generator or a motor. By combining an adjustable-speed pump unit and conventional hydropower turbine unit in quaternary configuration the technology provides faster power support response for RE variability.

Only closed loop PSP schemes were considered in this study.

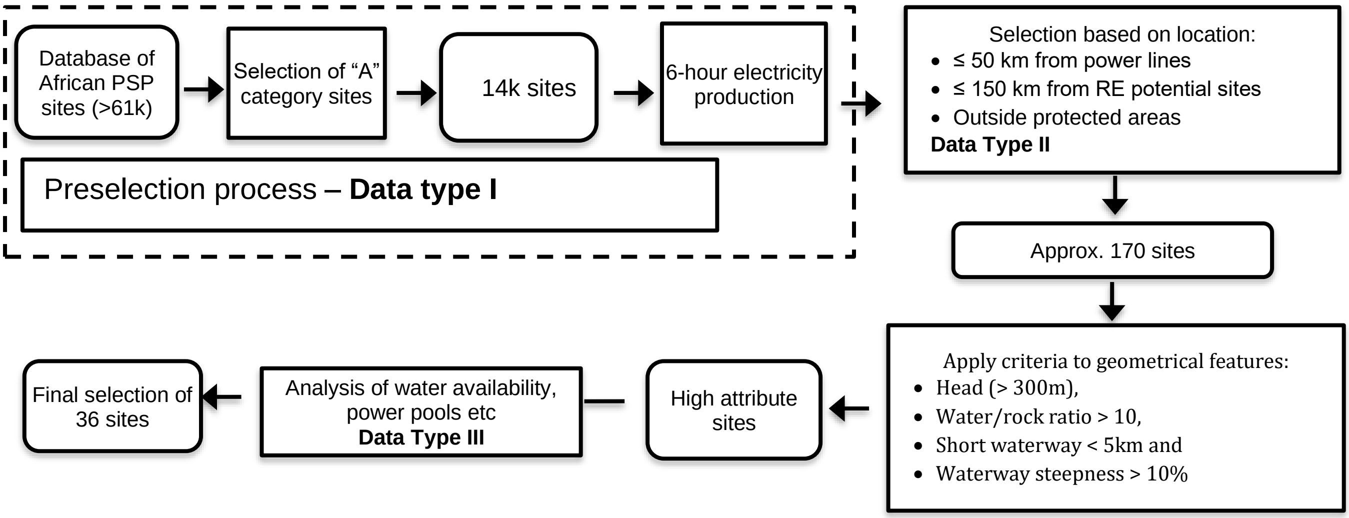


Figure 4: GPP development phases and duration

A final short list was established by applying the following further screening criteria: i) Head > 300m; ii) Large water/rock ratio > 10; iii) Short and steep waterway < 5km; iv) Steepness of the waterway > 10%. This identified the 36 sites expected to offer the most likely and cost-effective opportunities for the development of PSP.

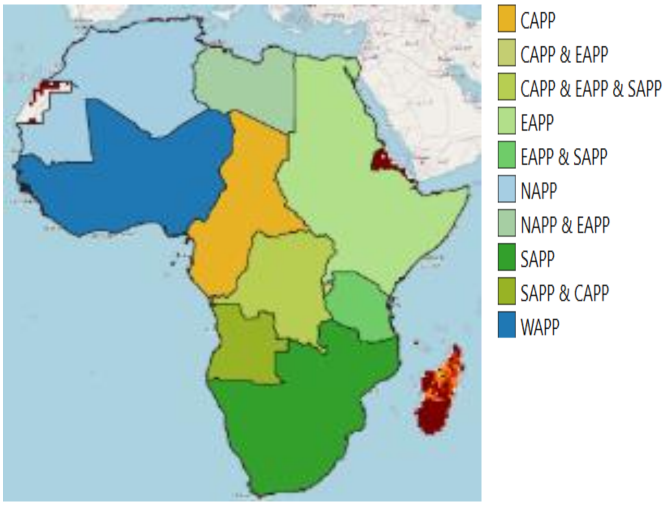


Figure 5: Distribution of shortlisted PSP sties across the continent by power pool

The 36 shortlisted sites are of varying dimensions ranging between 2 GWh and 50 GWh of energy production capacity. They are however not ideally geographically dispersed to serve all the large energy consumers across the continent, as can be seen in the table below. By means of an example, there are only eight countries represented out of a total of 54 on the continent, and 21 of the 36 sites are located in Ethiopia.

Power Pool	Sites	Capacity	Country
CAPP	1	2.6	Gabon
EAPP	24	47.4	Ethiopia (21), Djibouti
Eritrea	1	0.9	
SAPP	4	12.7	Mozambique (3), Zimbabwe
WAPP	6	23.4	Guinea (4), Nigeria (2)
Total	36	87 (GW)*	

**87GW refers to maximum stored energy if upward reservoirs are full. This implies that you can turbine 87GW of energy every hour for 5-6 hours, equating to 464 GWh of electricity.*

Opportunities and Costs

Further assessment was done for the 36 short listed sites by applying two parameters. The first, a confidence index which estimated three constraints:

i) potential penstock (pipe that transports water from the source to the turbine) and construction difficulties (transport and erection)
ii) site access (existing roads and topography)
iii) forest landscape cover.

The second, calculated the filling time of each reservoir in days, by considering the average flow rate. Although both parameters were somewhat subjective it does immediately identify major challenges (no roads or excessively long filling time) which would increase project costs, time and reliability possibly making smaller sites more attractive.

A basic traffic light colour index of green, amber and red was used for parameter 1 and four colour index for parameter 2 – dark green, light green, amber and red.

Red / Red	0
Red / Amber	6
Red / Light Green	1
Red / Dark Green	0
Amber / Red	0
Amber / Amber	6
Amber / Light Green	1
Amber / Dark Green	6
Dark Green / Red	1
Dark Green / Amber	8
Dark Green / Light Green	2
Dark Green / Dark Green	5
	36

Figure 6: Confidence and filling time for 36 sites

The outcomes of the colour indexing are consolidated in Figure 6. The five projects that scored highest (i.e. allocated a dark green rating for both parameters) and therefore presented the highest likely potential for development are located in Ethiopia (2), Guinea (2) and Nigeria. All five sites are however relatively small, with only two of these with a potential capacity greater than 2 GW while the other three less than 1 GW.

Having identified and estimated the potential for large PSP the next consideration was cost. Historical data (1975 to 2015), which analysed performance, cost, overrun cost, overrun time and avoided CO_2 emissions of 57 hydropower projects, delivered a real economic rate of return of 17.3%. However, as only three PSPs formed part of the 57 projects, the cost of USD511/kW was not deemed to be reflective or realistic. PSPs are highly dependent on civil works which can vary significantly and coupled with limited data on costs make it difficult to estimate. For example, South Africa's 1.5 GW Tubatse PSP has a cost estimate of USD763/kW, whereas the Attaqa plant (Egypt, 2.4 GW) is over EUR1 080/kW[3] and Morocco's Abdelmoumen 350 MW plant is estimated at EUR811/kW.

To obtain indicative costs, cost curves were developed for the four main PSP components (dam, hydraulic circuits, civil construction and equipment) for each of the 36 sites. The cost modelling also incorporated related costs such as fieldwork, treatment of foundations and the design, manufacture, transport, and installation of equipment. Modelling for the 36 sites found very different levels of size and capital expenditure, ranging between EUR418M and EUR8 262 in terms of CAPEX for PSP plants ranging from 0.33 GW to 8.65 GW in size. The average CAPEX per MW was found to be EUR1 060/kW. International experience estimates typical OPEX costs to range between 1% and 3% of CAPEX, therefore a rate of 1.5% was applied for the modelling.

Finance, Regulatory and Technical Integration Barriers

The SSS considered Africa's PSP generation potential and the expected costs. This was done within the confines of limited primary data and relied largely on desktop research and a global database of which the outputs were screened to meet the objectives of the study. Within this context, more detailed analysis is required to gain a more complete picture about how the identified sites can be integrated cost effectively into the CMP so it can contribute to the continent's overall objectives and aspirations to support the grid.

Should a specific site(s) be identified for development, detailed feasibility studies would

[3] Exchange Rate March 2023 USD1.06/EUR

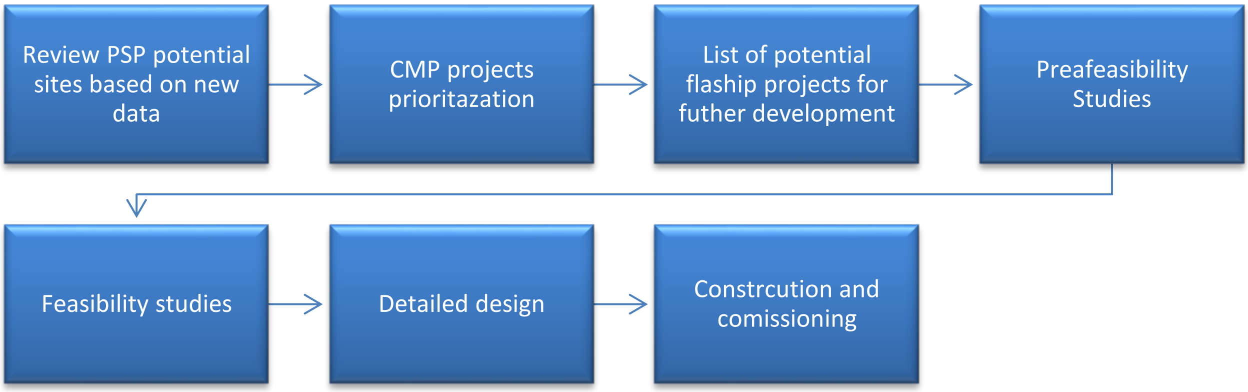
have to be undertaken, which at a minimum include:

1. Demand study
2. Hydrological study
3. Topographical surveys
4. Geological study
5. Environmental and social study
6. Budget
7. Economic and financial study

In conclusion, the following recommendations are proposed for the development of PSP:

1. **Identify PSP schemes** – this study limited itself to closed loop schemes, the other available schemes should be explored as they may offer performance and / or cost advantages. Moreover, the global databases are continuously updated and expanded and this information should be considered
2. **Water storage of closed loop schemes** – These schemes have the lowest impact on scarce water resources and lower environmental impact, but they still require to be replenished due to evaporation and process losses. It is crucial that the long term impacts of climate change are considered in estimating the sustainability of the sites' water balances.
3. **Energy technology innovation** – PSP offers many advantages, however ways to reduce costs, improve dispatchability, improve efficiency and incorporating hybrid plants should be evaluated regularly.
4. **Grid needs and operation** – A detailed understanding of the grid's consumption profiles is crucial in conjunction with existing and planned transmission lines.
5. **Legal and regulatory** – Hydropower is well established and PSP can benefit from existing frameworks and established practices

The following schematic lists the next steps for the development of PSP from the CMP perspective.



Conclusion

The study successfully demonstrated that PSP has a high potential in Africa and can play an important and cost-effective role to support the CMP. However, due to study limitations in terms of scope (not all available technologies considered); and, employing technical performance and other criteria but not proximity to major demand centres has resulted in site clustering (Ethiopia 21 and Guinea 4), which may not offer a cost-effective service once transmission costs are considered. Moreover, based on identified success factors for financial viability it is deemed that at this stage of Africa's energy planning, PSP should be driven at a country level. Once a 'baseload' of PSP has been established, the technology can be more readily expanded to service respective power pool and ultimately the continent.

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