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# The European Union Global Technical Assistance Facility on Sustainable Energy

## *Africa*

*Specific Support Study on hydro reservoir and pumped storage plants. Assignment number: GT088*

*Hydro energy identity and recommendations for Africa*

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| | Clear, logically built and internally coherent | | | |
| | Verification of sources and crosschecking of information | | | |
| | Language and style are unambiguous | | | |
| | Justification for conclusions and recommendations is provided | | | |
| | Recommendations for actions are useful, realistic and hierarchic | | | |
| 3rd level of quality assurance | Formatting is clear and respects the requirements | Quality Manager | | |

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## Abbreviations

| | |
|---|---|
| ANU | Australian National University |
| AU | African Union |
| AUC | African Union Commission |
| AUDA-NEPAD | African Union Development Agency |
| CAPEX | Capital Expenditure |
| CAPP | Central African Power Pool |
| CMP | Continental Power System Masterplan |
| COMELEC | Comité Maghrébin de l'Electricité |
| EAPP | Eastern African Power Pool |
| EPRI | Electric Power Research Institute |
| EU | European Union |
| GIS | Geographic Information System |
| OPEX | Operating Expense |
| PSP | Pumped-Storage Plant |
| PV | Photovoltaic |
| RE | Renewable Energy |
| SAPP | Southern African Power Pool |
| SSS | Specific Support Study |
| STC | Specialized Technical Committee |
| TAF | Technical Assistance Facility |
| WAPP | Western African Power Pool |
| WD-OECM | World Database on Other Effective Area-based Conservation Measures |
| WDPA | World Database on Protected Areas |

# 1. INTRODUCTION

The African Union Development Agency (AUDA-NEPAD) has been assigned by the Africa Energy Ministers, during an African Union (AU) Specialised Technical Committee (STC) meeting on infrastructures in 2018, to develop a Continental Power System (Transmission and Generation) Masterplan (CMP). The European Union (EU) Global Technical Assistance Facility (TAF) for Sustainable Energy, through the ongoing support to the African Union Commission (AUC), has been assisting AUDA-NEAPD in the activities to develop the CMP.

The first phase of the CMP development included the Baseline Study. This study recommended the elaboration of 12 Specific Support Studies (SSS) for the CMP, including this assignment, the **SSS on Hydro Reservoir and Pumped Storage Plants (PSP)**.

This document is the sixth deliverable of the Hydro Reservoir and Pumped Storage Plants study. Its main objective is to provide follow-up actions and recommendations for Pumped Storage Plants development in Africa.

This report presents the main findings of the study, limitations, recommendations for information improvement and pump storage development, follow-up actions and recommendations for further development of PSP projects.

# 2. TECHNOLOGY IDENTITY SHEET

| Technology Name | | Pumped storage | | | | |
|---|---|---|---|---|---|---|
| Technology Description | | Energy storage with closed loop pumped storage technology | | | | |
| Technology Characteristics | | Statistics | Projections | | | |
| | | 2020 | 2025 | 2030 | 2035 | 2040 |
| Total installed capacity in Africa in 2020 (MW), analyzed per region | | 3 377 | | | | |
| Total Generation in Africa in 2020 (GWh) | | 3 944 | | | | |
| Technical Potential (MW) | Planned project (del3) | | 12 296 | | | |
| | Identify by SSS Team (del5) | | 86 800 | | | |
| Electricity production at Technical Potential (GWh) | | | 381 060 | | | |
| Weighted Average Capacity Factor (%) | | | 25% | | | |
| Technical Efficiency[1] | | | 75% | | | |
| Unit investment costs (EUR/kW) | | | | 1 146 | 1 296 | 1 466 | 1 659 |
| Annual O&M costs (EUR/kW$_{inst}$/a) | | | 45 | | | |
| Lifetime (years) | | | 50 | | | |
| LCoE Range (EUR/kWh) in Africa[2] | | | 38.65 to 142.40 (weighted average 51.875) | | | |
| Land use (m$^2$/kW) | | | 1.60 | | | |
| Additional Information | | | | | | |
| Flagship projects in Africa | | Ethiopia / TanaBeles / 460 MW<br>Kenya / Seven Forks /N.A<br>Egypt / Attaqa Mountain / 2400 MW<br>Morocco / El Menzel / 300 MW<br>Morocco / Abdelmoumen / 360 MW<br>Morocco / Ifahsa / 300 MW<br>South Africa / Tubatse PS / 1500 MW<br>South Africa / Kobong PS / 1200 MW<br>South Africa / Ceres PS / 1000 MW<br>Zambia / Kafue Gorge / 1740 MW<br>Zimbabwe / Ngonyezi / 2000 MW<br>Rwanda / Lake Kivu / 36 MW<br>Tunisia / Tabarka / 400 MW<br>Libya / Athrun / 600 MW | | | | |
| Related transmission/other integration issues[3] | | The stability of the networks is still insufficient for the integration of such large powers. Moreover, a pumped storage plant must be integrated in a network with other green energy production means (solar/wind) | | | | |

[1] For generation technologies this should be the average production efficiency, for storage technologies it should be the storage cycle efficiency

[2] 2020 value of cost (Euro), use of 10% annual discount rate (source https://www.iea.org/data-and-statistics/data-tools/levelised-cost-of-electricity-calculator)

| Technology Name | Pumped storage |
|---|---|
| Related regulatory issues | Allowing for private investors is recommended.<br>Lack of widespread long-term policy commitment signal.<br>Lack of mature legal and regulatory framework.<br>Facilitating the land acquisition and licensing process |
| Related financing issues | Big uncertainty on the costs of the projects which are very influenced by the geopolitical context.<br>Lack of information on remuneration mechanisms for pumped storage plants.<br>Lack of stability in countries which may impact on the integration of international capital. |
| Related environmental issues/considerations | Environmental constraints to be taken into account in further studies, particularly on the impact of water storage and micro-organism development. |
| Applicability recommendations for Africa | Study the creation of complete production and storage poles by combining pumped storage and solar and/or wind power in order to reduce the distance between the production area and the storage area.<br>Mobilise PowerPools members to create interconnected networks that can facilitate grid stabilisation and international trade. |

# 3. MAIN FINDINGS OF THE STUDY

## 3.1. REVIEW OF THE STUDY'S RESULT

The potential of a continent for pumped-storage power plants is very important. Looking only at the technique, it would be enough to have a difference in altitude between two areas where it would be possible to build a dam. The initial database (from the Australian national university) identified more than 61,000 sites on the whole African continent.


*Figure 1 : Snapshot of Africa potential in Pumped-storage sites (Source: Australian national University - National Map )*

The potential is therefore immense and difficult to analyze. That is why different criteria were applied to favor the feasibility of certain projects. As a reminder, the following methodology was applied to the complete database in order to highlight the best sites on the African continent.

The selection of potential sites consisted in two PSPs, preselection of the most interesting sites in the database followed by an analysis of the following parameters:

- Distance to high voltage power lines.
- Distance to other renewable energy projects (such as solar and wind).
- Concerns regarding with indigenous, environmental, social, heritage, urban, agricultural and land management aspects
- Head, i.e., altitude difference between the upper and lower reservoirs (from the data base).
- Water/rock ratio (from the data base) (This is the ratio between the volume of water stored and the volume of concrete, which means that the higher it is, the more water a small dam can store).

- Waterways steepness and length (from the data base).
- Water availability (to fill the scheme/reservoir).

Only category "A" sites (sites with the best technical and economic potential as per the ANU) resulting from the algorithm used to create the Australian University database are chosen, representing about 14,000 sites. These sites were subjected to a second level of screening considering technical operating issues. Only the sites with 6 hours of electricity production were chosen, because sites with 18 hours of production require much larger pumps to raise the water in just 6 hours. This can lead to much higher cost for the equipment. In addition, the operating model of many similar plants consists of turbine / pump cycles of 6 h / 18 h respectively.

After this preselection the dataset was reduced based in the location of the sites using QGIS software as a tool. Sites were selected at a maximum distance of 50 km from powerlines and 150 km from solar and wind power projects, as well as sites outside protected areas. This process resulted in approximate 170 sites. The following additional criteria apply to identify the most promising sites:

- Head > 300m
- Large water/rock ratio > 10
- Short and steep waterway < 5km
- Steepness of the waterway > 10%

Finally, after applying the recommended criteria, 36 sites are selected.

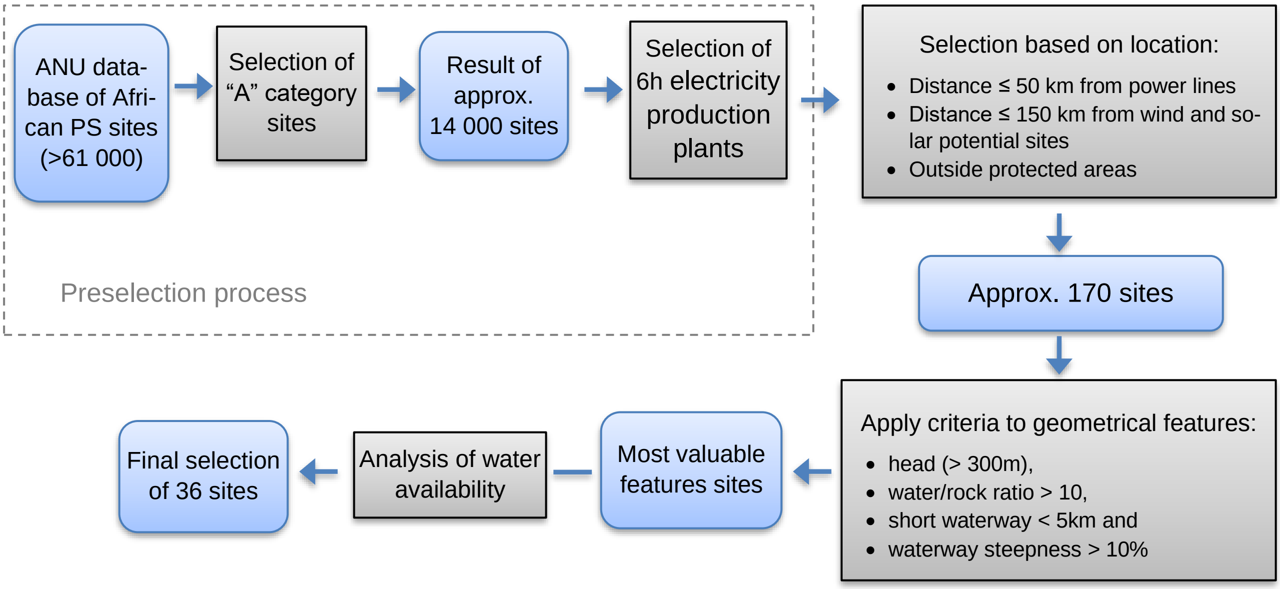


*Figure 2. Process for selecting the highest potential sites from ANU's database for Africa (Source: PSP SSS team)*

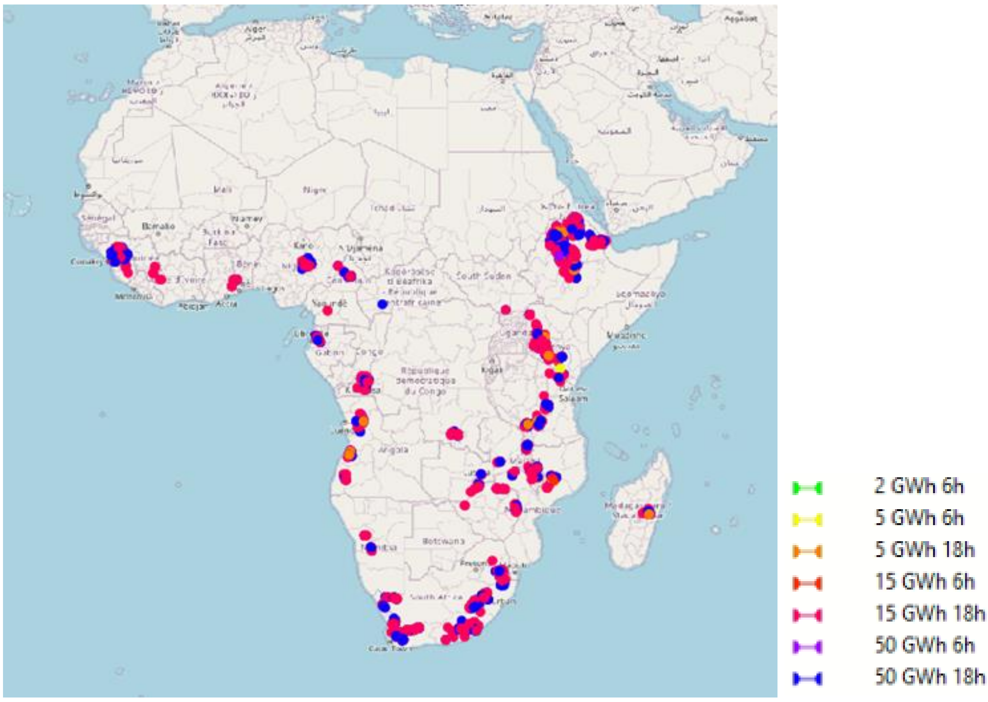


*Figure 3 : Result from preselection of PSP sites from the ANU data base (Source: Exported from the GIS database)*

Most of the sites in Northern Africa have been removed. This does not prevent these regions from being able to host pumped-storage sites. There are, for example, power plants in Morocco, but with capacities lower than those studied in this database.

After applying the methodology above, 36 sites were defined displaying high potential and likeable to be implemented. These sites characteristics range is wide since energy production varies between 2 GWh to 50 GWh. There is 1 in site in CAPP region with 15 GW, 22 sites in EAPP region for 279 GW, 2 sites in EAPP & SAPP region for 10 GW, 1 site in Eritrea for 5 GW, 4 sites in SAPP region for 65 GW and 6 sites in WAPP region for 90 GW. The total power potential is 464 GW for this study.

The analysis results consist of a GIS database (a shapefile vector layer, and in Excel format). This data is prepared so that it can be used in the CMP model.

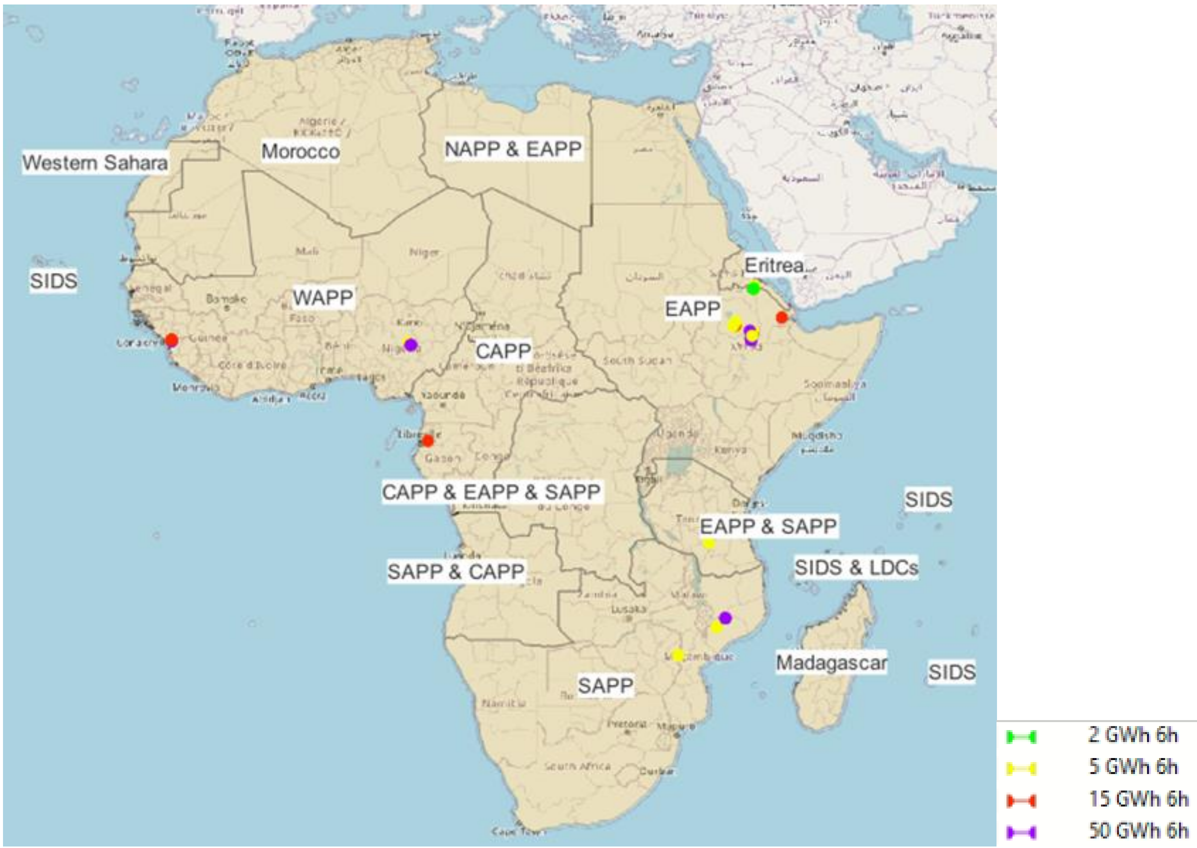


*Figure 4 : Result from the methodology applied to identify the most potential PSP sites (36 sites) (Source: Exported from the GIS database)*

To further analyse the results, two additional parameters were added.

The first is a confidence index. This index is based on visual observation of sites on the map. It considers the following different constraints:

- Penstock construction difficulties (transport and erection)
- Access (existing roads to the site, topography)
- Forest landscape cover

Sites are ranked from 1 to 3 (from lower to highest characteristics).

The second parameter is a calculation of the filling time of the 2 lakes. This parameter is based on the average flow rate of the area provided by the layer (Watergate) presented in *"GT088 - Deliverable 3 - Hydro power plant potential, technology perspectives and cost"*. It identifies sites where the need for water to fill the lakes is too high (presented in *"GT088 - Deliverable 3 - Hydro power plant potential, technology perspectives and cost")* compared to the volume of the pumped storage plant.

For example, 4.624 days are necessary to fill up the reservoirs of the site #5. This value is very high and shows that this project is not feasible. Looking closer, the downstream lake is very large compared to the size of the project. It is therefore possible to study this project in detail to reduce the size of the downstream lake to reduce the filling time.

This parameter is based on an average flow over a year, so it can vary depending on dry seasons or rainy seasons.

| ANU Database (Global properties) | | Index | |
|---|---|---|---|
| Site number | Country | Confidence index (3 is the better) | Filling time of the 2 lakes (in days) (estimation) |
| 1 | Ethiopia | 1 | 92.7 |
| 2 | Gabon | 3 | 1.5 |
| 3 | Guinea | 2 | 0.7 |
| 4 | Ethiopia | 3 | 16.9 |
| 5 | Djibouti | 3 | 4624.0 |
| 6 | Ethiopia | 3 | 1.0 |
| 7 | Guinea | 3 | 0.7 |
| 8 | Ethiopia | 1 | 8.8 |
| 9 | Ethiopia | 1 | 3.3 |
| 10 | Nigeria | 3 | 0.9 |
| 11 | Ethiopia | 3 | 13.0 |
| 12 | Mozambique | 2 | 0.6 |
| 13 | Ethiopia | 2 | 0.5 |
| 14 | Ethiopia | 2 | 83.2 |
| 15 | Mozambique | 1 | 2.0 |
| 16 | Guinea | 3 | 0.2 |
| 17 | Ethiopia | 2 | 0.3 |
| 18 | Eritrea | 2 | 17.5 |
| 19 | Tanzania | 3 | 12.2 |
| 20 | Ethiopia | 1 | 4.5 |
| 21 | Tanzania | 3 | 2.8 |
| 22 | Ethiopia | 3 | 5.2 |
| 23 | Ethiopia | 1 | 4.3 |
| 24 | Ethiopia | 3 | 3.0 |
| 25 | Zimbabwe | 2 | 1.3 |
| 26 | Ethiopia | 2 | 4.3 |
| 27 | Ethiopia | 2 | 0.3 |
| 28 | Ethiopia | 3 | 0.4 |
| 29 | Ethiopia | 2 | 5.6 |
| 30 | Ethiopia | 2 | 0.7 |
| 31 | Ethiopia | 3 | 121.2 |
| 32 | Mozambique | 2 | 18.5 |
| 33 | Ethiopia | 3 | 32.0 |
| 34 | Guinea | 3 | 1.9 |
| 35 | Ethiopia | 2 | 38.7 |
| 36 | Nigeria | 1 | 17.0 |

*Table 1 : Database with 2 parameters added (Source: Exported from the GIS database)*

This method made it possible to estimate the potential for very large pumped storage plants.

In order to create the most complete database possible, a cost calculation algorithm (presented in the GT088 - Deliverable 4 - Regulatory, financing, market and technical integration Issues rev0) was added, in which a wide range of investment cost per installed power was used, depending on the site configuration. The cost must be conformed through in-depth studies. The algorithm gives a budget estimate of:

• Dams:

• Hydraulic circuits:

• Hydroelectric plants (civil construction)

• Hydroelectric plants (equipment)

As the design of these infrastructures cannot be completed at this stage, the model uses parametric cost curves to estimate the CAPEX and OPEX of each project for each component of the hydroelectric plants based on homogeneous criteria and consequently allowing a comparison between plants.

These cost curves were based on previous studies using database of developed projects. The cost curves were updated with inflation to include the additional costs of developing a hydro project in Africa.

The budget estimate remains very preliminary at this stage and must be recalculated upon basic design at further development stage. The purpose of the "cost curve" exercise is to give a very rough estimate of the project cost and to allow a comparison between the different projects according to their key characteristics.

The calculations are detailed in deliverable "*GT088 - Deliverable 3 - Hydro power plant potential, technology perspectives and cost".*

The analysis shows that the budget estimates for the selected projects cover a wide range between 418 (M€) to8.262 (M€) in terms of CAPEX and 0,33GW to 8,65 GW in terms of installed capacity. The average CAPEX per MW is 1,06 €M/MW

*Table 2 : CAPEX database (Source: Exported from the GIS database (GT088 - Deliverable 3 - Hydro power plant potential, technology perspectives and cost §5.3)*

| # | Power (GW) | Total Capex (€M) | Capex/MW (€M/MW) |
|---|---|---|---|
| **1** | 2,65 | 2 361,41 | 0,89 |
| **2** | 2,58 | 2 621,72 | 1,02 |
| **3** | 2,59 | 2 221,81 | 0,86 |
| **4** | 2,56 | 2 438,18 | 0,95 |
| **5** | 2,63 | 2 492,95 | 0,95 |
| **6** | 2,59 | 2 227,88 | 0,86 |
| **7** | 2,53 | 2 402,75 | 0,95 |
| **8** | 0,33 | 434,85 | 1,31 |
| **9** | 0,34 | 418,20 | 1,21 |
| **10** | 0,81 | 984,29 | 1,21 |
| **11** | 0,87 | 910,07 | 1,05 |
| **12** | 0,84 | 979,71 | 1,16 |
| **13** | 0,83 | 979,54 | 1,19 |
| **14** | 0,87 | 943,14 | 1,08 |
| **15** | 0,83 | 981,55 | 1,19 |
| **16** | 0,81 | 956,59 | 1,18 |
| **17** | 0,82 | 970,27 | 1,18 |
| **18** | 0,88 | 981,21 | 1,11 |

| # | Power (GW) | Total Capex | Capex/MW (€M/MW) |
|---|---|---|---|
| **19** | 0,84 | 965,00 | 1,15 |
| **20** | 0,85 | 985,92 | 1,15 |
| **21** | 0,86 | 971,53 | 1,13 |
| **22** | 0,85 | 994,08 | 1,18 |
| **23** | 0,84 | 964,84 | 1,15 |
| **24** | 0,85 | 1 006,85 | 1,19 |
| **25** | 0,88 | 972,68 | 1,11 |
| **26** | 0,87 | 927,51 | 1,07 |
| **27** | 0,82 | 947,86 | 1,16 |
| **28** | 0,86 | 887,64 | 1,03 |
| **29** | 0,88 | 1 036,19 | 1,18 |
| **30** | 0,88 | 1 018,51 | 1,16 |
| **31** | 8,65 | 7 005,31 | 0,81 |
| **32** | 8,52 | 7 649,66 | 0,90 |
| **33** | 8,32 | 7 454,81 | 0,90 |
| **34** | 8,35 | 7 036,09 | 0,84 |
| **35** | 8,24 | 7 084,80 | 0,86 |
| **36** | 8,27 | 8 262,05 | 1,00 |

Regarding OPEX, based on the analysis of various hydro projects developed worldwide, the annual operational expenditure for hydropower projects range between 1% and 3% of CAPEX. A level of 1.5% was assumed for the purpose of this study.

*Table 3 : OPEX Database (Source: Exported from the GIS database (GT088 - Deliverable 3 - Hydro power plant potential, technology perspectives and cost §5.4)*

| # | Power (GW) | Total Capex (€M) | OPEX (€M) | # | Power (GW) | Total Capex | OPEX (€M) |
|---|---|---|---|---|---|---|---|
| 1 | 2,65 | 2 361,41 | 35,42 | 19 | 0,84 | 965,00 | 14,48 |
| 2 | 2,58 | 2 621,72 | 39,33 | 20 | 0,85 | 985,92 | 14,79 |
| 3 | 2,59 | 2 221,81 | 33,33 | 21 | 0,86 | 971,53 | 14,57 |
| 4 | 2,56 | 2 438,18 | 36,57 | 22 | 0,85 | 994,08 | 14,91 |
| 5 | 2,63 | 2 492,95 | 37,39 | 23 | 0,84 | 964,84 | 14,47 |
| 6 | 2,59 | 2 227,88 | 33,42 | 24 | 0,85 | 1 006,85 | 15,10 |
| 7 | 2,53 | 2 402,75 | 36,04 | 25 | 0,88 | 972,68 | 14,59 |
| 8 | 0,33 | 434,85 | 6,52 | 26 | 0,87 | 927,51 | 13,91 |
| 9 | 0,34 | 418,20 | 6,27 | 27 | 0,82 | 947,86 | 14,22 |
| 10 | 0,81 | 984,29 | 14,76 | 28 | 0,86 | 887,64 | 13,31 |
| 11 | 0,87 | 910,07 | 13,65 | 29 | 0,88 | 1 036,19 | 15,54 |
| 12 | 0,84 | 979,71 | 14,70 | 30 | 0,88 | 1 018,51 | 15,28 |
| 13 | 0,83 | 979,54 | 14,69 | 31 | 8,65 | 7 005,31 | 105,08 |
| 14 | 0,87 | 943,14 | 14,15 | 32 | 8,52 | 7 649,66 | 114,74 |
| 15 | 0,83 | 981,55 | 14,72 | 33 | 8,32 | 7 454,81 | 111,82 |
| 16 | 0,81 | 956,59 | 14,35 | 34 | 8,35 | 7 036,09 | 105,54 |
| 17 | 0,82 | 970,27 | 14,55 | 35 | 8,24 | 7 084,80 | 106,27 |
| 18 | 0,88 | 981,21 | 14,72 | 36 | 8,27 | 8 262,05 | 123,93 |

## 3.2. LIMITATIONS OF THE STUDY

Defining the pumped storage potential of a territory as large and heterogeneous as Africa is a complex task. Several barriers have been identified during the study. The main barrier is the access to different data and the accuracy of these data. For example, finding information on ongoing projects, costs and progress is not a simple task.

The estimate of the African pumped storage potential and selected projects is based on an existing database of large size potential projects, which depends on the size of the most appropriate reservoir size, which shall be optimized at latest stage.

The database does not take into account open loop projects, particularly as the ANU database did not identify such projects. The study of a single type of pumped storage is not representative of the full potential of such an area.

As explained in the methodology of the *study §3.3 "GT088 - Deliverable 3 - Hydro power plant potential, technology perspectives and cost", selection criteria (such as head, penstock length, water/rock ratio, etc.) settings are important to identify the most appropriate scenarios. Shifting a parameter would lead to a different output (list of selected projects).*

As the ANU database is based on a satellite terrain survey, the water levels of the existing lakes are considered to be the ground altitude, not the water surface altitude. This problem is common to both LIDAR and Satellite surveys and prevents the database algorithm from defining an existing lake (or the sea) as a potential lake for a pumped storage station. The study therefore does not take into account all the existing water bodies in the world. However, an update of the database is in preparation during 2023 in order to modify the algorithm and to take into account the existing lakes. (https://re100.eng.anu.edu.au/bluefieldatlas/). This new database, generated by the Australian National University, will complete the existing database, and add possible connection scenarios between existing and future reservoirs to reduce the pumping storage cost.

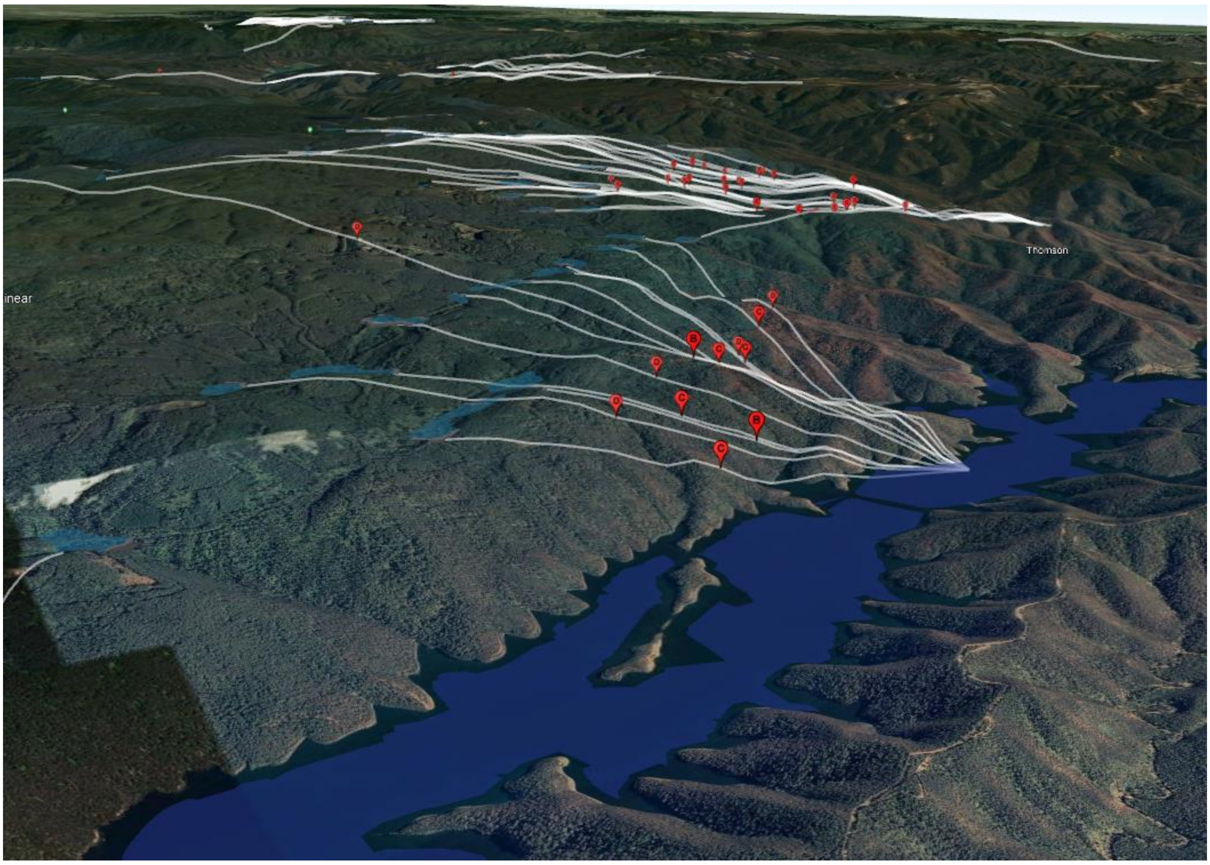


*Figure 5 : Project example from the new ANU algorithm (Source: Australian National University)*

In the above example (*Figure 5*), the downstream lake already exists. The algorithm therefore looks for possibilities to create upstream lakes. The possibilities are almost infinite depending on the terrain. The system will then proceed in the same way as for the database used in the study. It will calculate the various characteristics of the projects and apply average costs in order to rank the sites between A and E in order to identify the best and worst sites. This new database would complete the study and give the full pumped storage potential in Africa.

It is important to note that this new database is not available for Africa yet.

# 4. DEMAND AND NEED OF COUNTRIES IN AFRICA (EXAMPLE WITH GABON)

Electricity demand varies between the different regions of Africa.

Several meetings with the Power Pools, the countries and the different expert teams during the study led to identify the real energy needs in different countries.

For example, Gabon’s electricity comes from renewable energy.

These renewable energies are used as follows:

- Hydroelectricity to support industrial and domestic demand in large urban consumption centers;
- Solar photovoltaic energy for the electrification of remote rural areas;
- Biomass (sugar cane bagasse and oil palm residues) for self-generation of electricity in the agri-food industry

Gabon's annual production is 2,115 GWh for a consumption of 2,066 GWh (source: Power Pools meeting with Gabon). The country is therefore an energy exporter. However, most of the hydroelectric facilities are currently run-of-river and therefore cannot store energy.

Finally, Gabon is planning to install solar power plants. In order to temporary store this energy, it is recommended to include a storage process with non-regular renewable energy production plants (wind and solar).

*This identified site (see “GT088 - Deliverable 3 - Hydro power plant potential, technology perspectives and cost rev1”* and *“GT088 - Deliverable 5 - Key Inputs for the modelling of CMP rev1”*) could provide for storage needs of the new solar power plants planned by the country.

This site is located approximately 100 km from Libreville.

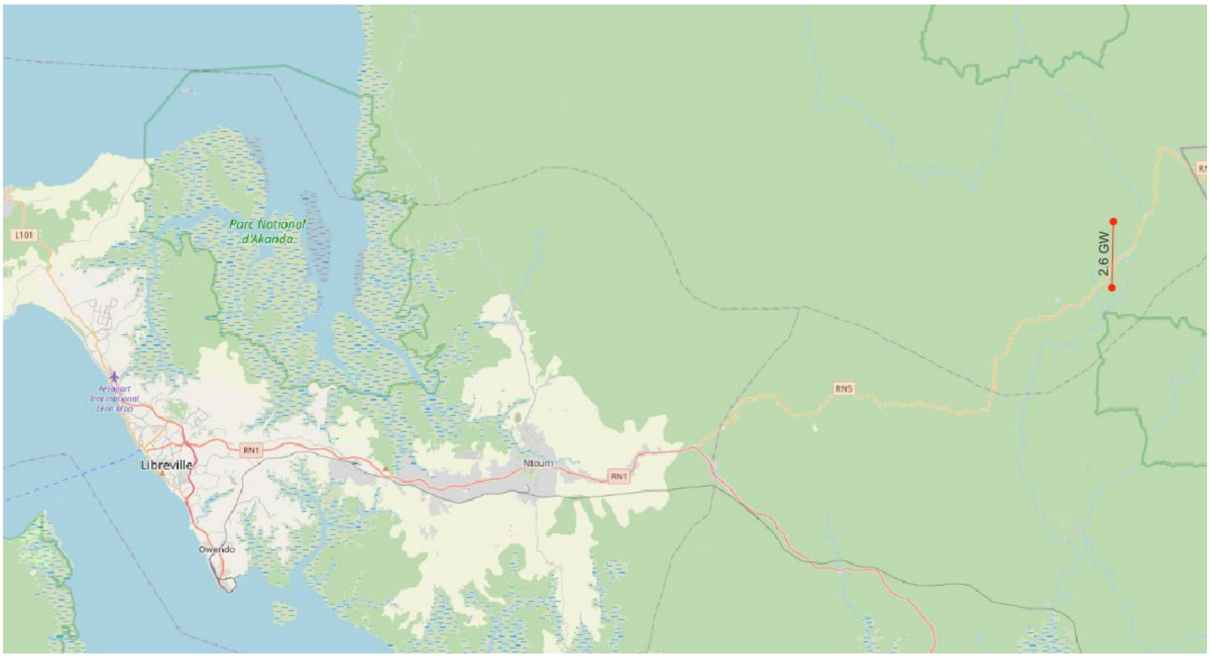


*Figure 6 : Site localization (Source : Exported from the GIS database)*

The characteristics of the site are as follows:

| | |
|---|---|
| **Country:** | Gabon |
| **Localization of the upper reservoir:** | 0.5892,10.2306 |
| **Localization of the lower reservoir:** | 0.535,10.2294 |
| **Capacity:** | 15.48 GWh |
| **Nominal Power:** | 2.58 GW |
| **Head:** | 461 m |
| **Discharge:** | 570.6 m3/s |
| **Number of turbines:** | 9 |
| **Power per turbine:** | 300 MW |
| **Number of penstocks:** | 7 |
| **Penstock diameter:** | 3.5 m |
| **Length of the penstock:** | 2 km |
| **CAPEX:** | 2619.1 M€ |

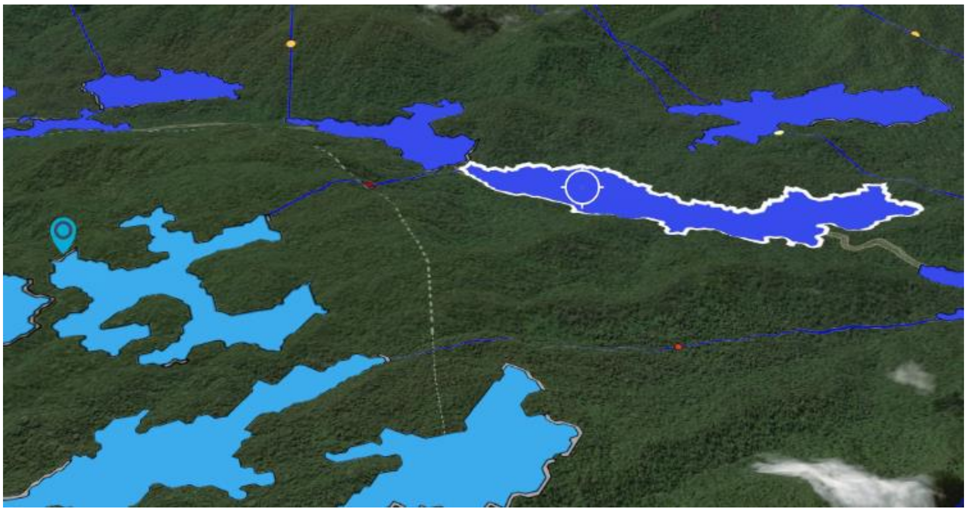

*Figure 7 : Site 2 Project localization (upper reservoir in light blue with the pins, lower reservoir in dark blue and white) (Source : Australian Government. National Map)*

This project could be part of a renewable energy development scheme in Gabon to provide a large-scale storage solution.

# 5. RECCOMENDATIONS FOR FUTHER IMPROVEMENT

## 5.1. ADVANTAGES AND DRIVERS FOR PSP

Pumped storage benefits from mature and time-tested technologies. Indeed, the machines used can be the same as the high head hydroelectric plants in case the turbine and the pump are dissociated. For pump-turbines the technology is now widely used in various modern power plants around the world. For example, the Nant de Drance power plant in Switzerland has just been commissioned with 6 reversible turbines (turbine-pump) of 150 MW, for a total capacity of 900 MW. This capacity may seem far from the capacity of the sites studied, however, the Bath County power plant in the United States is equipped with 6 reversible Francis turbines of 500 MW each for a total capacity of 3,000 MW (3 GW). This capacity is comparable to the sites studied in the database. These reversible turbines have the advantage of being both pump and turbine, which simplifies the overall system by having only one impeller to install for both pumping and turbining. The disadvantage is that the pumping efficiency and the turbine efficiency is slightly lower than a pump alone or a turbine alone.

The other components of hydropower plants are elements that have been in common use in projects around the world since the 1850s, so there is a lot of feedback to improve projects over time.

The advantage of a pumped storage plant over a normal dam is that the PSP can operate independently of the flow of the nearest river or river on which the plant is installed. Indeed, the river is needed to fill the power plant, but afterwards, the river is only used to top up the water lost through evaporation, leakage and other losses. This allows the pumped storage plant to operate throughout the year when needed.

The development of a green energy production and storage hub is beneficial for the social development of an area, or a country. This development is accompanied by improvements to existing infrastructure such as roads, electricity transmission lines, and freight and passenger transport routes.

Finally, pumped storage technology is flexible and allows the development of all types of time cycles ranging from several hours to several weeks for a few MWh to GWh. This makes it possible to store energy and also to regulate the network, as it only takes a few seconds to launch the plant and inject electricity into the network.

### 5.2. BARRIERS TO PSP

Developing a pumped storage power plant can be complex for various reasons. Such a power plant is composed of two lakes requiring a very important wetted surface. The environmental impact is therefore not to be neglected. In addition, it may impact on local populations or existing infrastructure. It is best to use existing lakes or areas already impacted by man, such as former mines.

Finally, the power developed by the projects identified in the database is significant. This means that the network must be designed to accommodate this type of power, and if it is not, a new network must be built and managed. The cost of high voltage lines over a territory as large as Africa is very constraining. Indeed, it is necessary to distribute the energy produced so as not to overload the network. The demand for electricity must therefore be equal to the production.

## 6. FOLLOW UP ACTIONS

This study answered questions regarding the state of art, potential and costs of pumped storage plant technology in the African continent. As data regarding potential sites for PSP was limited, the main goal of the study was to use a worldwide database, based on GIS algorithm developed by Lu et al (2018), to select potential sites. The screening process, to select the most appropriate sites, has been based on analysis of global scale data. The following steps require more detailed analysis.

The HydroWIRES (Water Innovation for a Resilient Electricity System) Initiative specify four research areas that tackle industry challenges (WPTO, 2022). This provides a research outline focusing on hydropower and pumped storage hydropower's role as an integrator of variable renewables. The identified research areas intend to answer in the following chronological order:

1. What will be the grid needs?
2. What are the hydropower capabilities (including potential)?
3. How the hydropower capabilities can serve the needs?
4. What is the technology innovation that can leverage hydropower capabilities to meet the grid needs?

In the case of the CMP, the first point can be compared with the demand forecast and resource assessment presented by TAF (TAF, 2022a and TAF, 2022b). The Hydro Reservoir and Pumped Storage Plants study SSS mostly covers point two for the African continent. This study results on a list of potential and most attractive sites for PSP projects as described on section 2. The third step is to use these inputs in the CMP model to identify which proposed sites offer the highest potential to become flagship large scale pumped storage hydro projects in Africa. The last step is to find the most efficient manner to integrate the PSP in the grid enhancing its flexibility and assuring the increment in a sustainable and reliable way of other RE sources.

The following actions for PSP development are described below from two perspectives:

1. In general, as steps and timelines for the development of hydro PSP.
2. And in the context Africa's RE development efforts with EU or other donors support.

### 6.1. GENERAL STEPS AND TIMELINES FOR THE DEVELOPMENT OF PSP

Once projects are prioritized, the focus should be on developing:

1. Prefeasibility studies
2. Feasibility studies
3. Detailed studies

In between these high level stages, several activities have to be accomplished including, e.g. bank/financing or licensing.. In the 2020 report entitled "*Pumped Storage Hydropower FAST Commissioning Technical Analysis*", it is stated that a typical PSP often takes 10 years or more to be developed, from preliminary activities to commissioning. The time to develop the most time-consuming components, upper and lower reservoirs, water conveyances, and transmission interconnection, can be reduced not only by innovation in construction technologies, but also by logistical approaches in terms of scheduling the construction of the components (Hadjerioua et al., 2020). Thus, PSP development can benefit from early assessment, being planned in alignment with transmission lines and the growth of access to electricity. According to IFC, the prefeasibility study of a large hydropower takes three to six months to be prepared, as for the feasibility study, nine to eighteen months. The same document states that "*Developing a detailed design for a small HPP takes a few months and for a large HPP, more than a year*" (IFC, 2015). These time periods may differ in the African context, as sometimes data is scarce and measurements are needed. The studies that should be developed for the PSP sites are:

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

Each stage will require a level of detail for the relevant studies. As the project advances more data must be collected to develop the project.

Regarding the costs that a PSP project development requires, the "*Pumped Storage Hydropower FAST Commissioning Technical Analysis Report*" provides an indicative value of up to 7% of the total CAPEX, for a close loop PSP (Hadjerioua et al., 2020). The IFC (2015) mentions that the average cost for the development is 9.2% of the CAPEX and the median 7.5%.

*Figure 8* below presents a scheme on the next steps proposed for the development of PSP under the CMP perspective. First, the potential sites for PSP should be reviewed with new data presented in the sections 2 (new database). This review will allow to extend the potential to open loop ("twin dams") and semi-open loop (nearby existing hydropower reservoir) projects, as well as explore Bluefield projects. After this screening, the selection of projects should be made modelling the CMP to identify the highest potential sites to become flagship projects. These projects can then be developed further. The feasibility study phase is generally where the involvement of the financing institution begins.

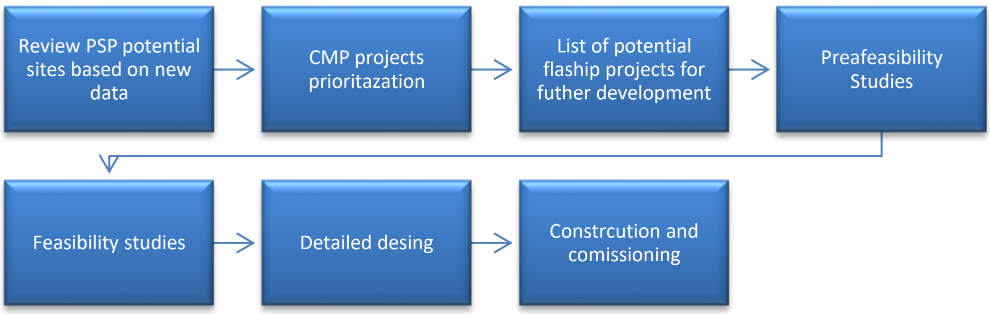


*Figure 8 : Next steps for the development of PSP (Source: MHYD Group 2022)*

## 6.2. NEXT STEPS FOR AFRICA TO START PSP PROJECTS

1. Inform national institutions about the importance of data (hydrologic, topographic, geologic, social, etc);
2. Instrument and perform measuring campaigns on the sites that are interesting for development;
3. Assist national and regional institutions about the needed regulation and legislation to increase the share of RE and particularly PSP projects;
4. Work with focus groups of different regions to understand the needs of energy and expectations;

# 7. RECOMMENDATION FOR THE DEVELOPMENT OF PSP

For further development of PSP under the CMP perspective, the following recommendations are given:

- **Explore the different type of schemes of PSP**

  In this study, the pumped storage potential estimation is based on an existing database of sites for closed looped schemes. PSP technology has a diversity of possibilities: open, closed and semi-open loop schemes, using existing natural lakes and HPP reservoirs, seawater PS schemes, retrofitting PSP using open pit or underground mine, compressed air, etc. For the geographical scale that this study addresses, it would not be feasible, with the existing resources, to do an analysis of all these alternative schemes. Still, there are some schemes that should still be explored.

  A review of the PSP potential is recommended, with the aim of exploring open and semi-open looped schemes using existing reservoirs (natural or artificial lakes). This will be facilitated with new available (or soon available) data mentioned in the prior section 2.

  The forms to continue exploring other PSP potential sites are:

  i. The new Bluefield PHES Atlas database from ANU will complement the existing and first greenfield close loop databased. Thus, a similar approach to the one that was applied in this study, with the greenfield database, can be applied to the new database. Relevant places can be selected using a list of criteria.

  ii. Another approach could be to pair the Global resource potential of seasonal pumped hydropower storage data base (Hunt et al.,2020) with the existing IRENA AfREP Hydro database and database on large bodies of water. This approach could simply be based first on geographical distance, and then on topography. After this, the paired sites can be analysed with more specific criteria such as the one used on this study.

  iii. As for future interest on retrofitting abandoned mine sites, a database could be created with countries' information about existing abandoned mines, their features, and state. The creation of this database could encounter challenges with respect to the level of different national information across the African continent.

- **Water storage aspects of the closed loop schemes**

The reservoir filling is an aspect that should be evaluated, especially considering semi-arid/arid regions. One of the positive aspects of closed loop schemes is that it requires water only for the initial filling and is therefore considered to have less impact on stream's discharge, fish migration, sediment passage and also more resilient to climate change. However, a closed loop still requires small refilling to compensate evaporation and process losses. The balance between water losses and accretion is advisable for in the assessment of potential sites, as this affects the refilling costs and PSP efficiency. Connected to this is an aspect that is already a big topic on hydropower, climate change. Climate change impacts on the variables that affect the water balance. The suggested recommendations for these schemes are:

i. Estimate the water balance for the reservoirs of the closed loop schemes for estimating the yearly water losses.
ii. Evaluate climate change impact on the long-term PSP water balance.
iii. Assess sources of refilling, such as sea water and grey water.
iv. Evaluate water losses impact on powerplant efficiency and create mitigation plan for it.

- **Explore energy technology innovation**

PSP as a storage technology has many advantages compared to other: large power capacity, long lifetime, large range of storage duration, close to zero self-discharge (World Energy Council, 2019 and EESI, 2019), far lower environmental impact compared to chemical processes. These characteristics and others can be improved in the future. Recommendations are to search for ways to reduce PSP costs, improve dispatchability, improve efficiency and look at hybrid plants (that improve operation). Thus, the highlighted suggestions are:

i. Propose schemes that will reduce costs, particularly the civil works component, as this weighs more on CAPEX.
ii. Explore technology innovation to facilitate operation and improve dispatchability.
iii. Explore technology innovation to improve efficiency.
iv. Propose hybrid plant, coupling PSP hydropower with VRE (wind and solar)

- **Explore grid needs and operation**

i. For a better definition of the storage needs in the grid and to propose better storage solutions, it is necessary to know the daily, weekly, and yearly energy consumption profiles. This allows to better understand the operation requirements.
ii. The PSP is a large-scale storage, and as so should be planned along with transmission lines. As different grids are interconnected, PSP will guarantee reliability of the grid.
iii. Assessment of the different ways of implementing PSP in the grid should be made, such as another buyer/seller or as TSO's own facilitator of grid operation.

- **PSP legal aspects**

Hydropower is mature and well-developed technology, including that robust experience of hydro is present in the continent and specific knowledge can be outsourced easily. This is true not just from the technological perspective but also from the legal aspects. It is suggested to look at the legal framework of hydropower and how it can be applied to the specific case of PSP.

Prioritization of PSP selected projects should also be made using multicriteria analysis, along with the CMP model. Aspects to be explored in this analysis are legal, technological and finance mechanisms at country/regional level.

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