

# Complementarities and synergies with intermittent renewable energy, related issues - Burkina Faso cases studies

## Complémentarités et synergies avec les énergies renouvelables intermittentes, problèmes spécifiques - études de cas du Burkina Faso

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**Abstract.** Pumped Storage Plants (PSP) offer opportunities for better water mobilization and to unlock the development of hydropower in Burkina Faso. The revolution in photovoltaic energy, which has greatly improved reliability and production costs, has opened up major prospects for the energy development of Sahelian countries with a very large solar energy deposit that has remained fallow for the time being. The lower production cost of solar energy makes it more attractive to mobilize water in offshore (outside rivers) basins and reservoirs in areas where there are few underground water resources and where flat land limits the construction of dams. This paper will develop these perspectives for a country like Burkina and the Sahel in general where access to electricity is one of the lowest in the world which, paradoxically, have a very large solar deposit and insufficient water resource mobilization.

**Résumé.** Le Pompage d'eau et les stations de transfert d'énergie par pompage (STEP) offrent des opportunités pour une meilleure mobilisation de l'eau et pour débloquer le développement de l'énergie hydraulique au Burkina Faso. La révolution de l'énergie photovoltaïque qui a fortement gagné en fiabilité et en coût de production a ouvert de grandes perspectives pour le développement énergétiques des pays du Sahel dotés d'un gisement d'énergie solaire très important pour l'heure resté en jachère. La baisse du coût de production de l'énergie solaire rend plus attractif la possibilité de

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mobiliser l'eau dans des bassins et réservoirs hors rivières dans les zones où les ressources en eaux souterraine sont peu nombreuses, et où les terrains plats limitent la construction de barrage. Cet article développera les perspectives pour un pays comme le Burkina, et le Sahel en général, où l'accès à l'électricité est l'un des plus limité au monde et qui, paradoxalement, dispose d'un gisement solaire très important et d'une mobilisation insuffisante des ressources en eau.

## 1 Introduction

Burkina Faso is located in the semi-arid Sahelian zone of Africa, which is experiencing difficulties in mobilizing water resources for development needs. The country's climate is characterized by high seasonal and interannual variability in rainfall and surface water resources. The geology of Burkina Faso, dominated by crystalline formations, does not offer sufficient and easily mobilized groundwater resources. The relief is made up of plains that do not offer great opportunities for conventional hydroelectric production projects.

To face this situation, Burkina Faso has equipped itself with a large number of dams and water reservoirs since the twenties of the last century. There is today a total of a thousand dams, including about twenty large dams according to ICOLD criteria with a total mobilization capacity of 5.3 billion m<sup>3</sup> for an average annual flow of about 9 billion m<sup>3</sup> with a coefficient of variation greater than 0.5.

The general topography of the country means that the reservoirs are wide, shallow but store huge amounts of water.

The surprising recent progress in the technology and cost of Photovoltaic (PV) electricity seems to be a crucial asset for the hydropower plants development of Burkina. These technological advances are leading to change in the conduct of large dams with hydropower plants by integrating the energy storage approach.

## 2 Energy situation in Sahelian Africa and Burkina Faso

### 2.1 For Africa

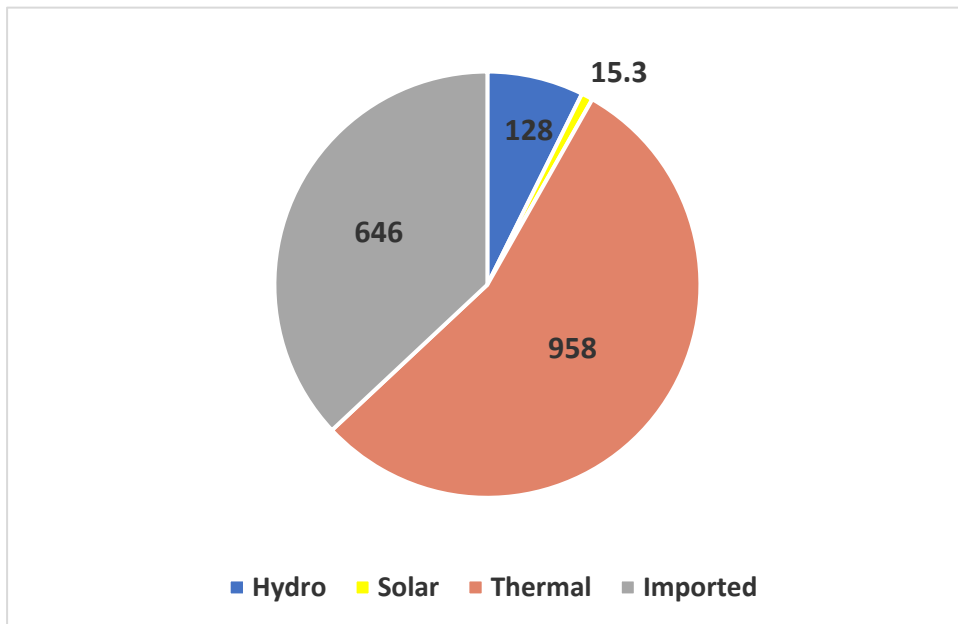
Africa is the least electrified continent in the world. Between 580 and 650 million people have no access to electricity [1], about 70% of the African population. While the rate of electricity supply is close to 100% in North Africa, it is only 32% in Sahelian Africa. This one's electricity generation capacity is about 97 GW. Per capita electricity consumption in sub-Saharan Africa (excluding South Africa) is 180 kWh, compared to 13,000 kWh per capita in the United States and 6,500 kWh in Europe.

Moreover, the electrification of rural areas is much lower than that of cities.

### 2.2 About Burkina Faso

According to the last survey of life conditions in Burkina Faso, only 29% of the populations have access to electricity (46% of the population in urban areas and less than 2% of the population in rural area). Electricity net generation is about 80 kWh per capita. Only three regions, including the Centre, the Hauts Bassins and the Cascades, have electrification rates above 20% while the remaining 10 regions have electricity access rates below 10% [2].

The country has three sources of electricity production: thermal, hydroelectricity, solar and importation (from Côte d’Ivoire, Ghana and Togo). The situation for the Year 2019 [3] is presented in the figure below:



**Fig. 1.** Electricity Production (Gwh) in Burkina in 2019.

The cumulative rated capacity of 355 MW for the National Grid and Electricity cooperative and 250 MW for the private sector giving a total of 607 MW. This includes thermal generation of 293 MW, hydroelectric generation of 32 MW and solar generation of 20 MW.

### 3 Hydraulic and solar Potentials

Africa is endowed with a huge energy potential - renewable energy in particular - but it currently uses only part of it. Hydropower provides about one-fifth of current capacity, but the potential used is not even one-tenth of the total. The technical potential of solar, wind and geothermal energy and bioenergy is also significant.

#### 3.1 Hydropower potential

The hydropower potential [4] is characterized by the following facts:

- Low and limited potential linked to the country's topographical configuration and the weak character of rivers
- Hydraulic potential estimated at 600GWh based on projects and sites identified in various studies
- No exhaustive inventory

- Only four hydropower plants are in exploitation (Bagré, Kompienga, Tourni and Niofila with a total installed power of 30 MW and a few are under construction or planned projects: Samendeni, Bougouriba, Bassiéri, Bonvalé, Ouessa, Bontioli, Gongourgou and Folonzo.

The table below shows some hydroelectricity project site identified:

**Table 1.** Hydroelectricity project site identified.

Sites	River basin	Annual yields of the river (hm <sup>3</sup> )	Power capacity (MW)	Forecast production (GWh/year)
<b>Bon</b>	Mouhoun	1670	7,8	29,1
<b>Gongourgou</b>	Poni	425	5	17,7
<b>Folonzo</b>	Comoé	790	10,8	27,3
<b>Bagré Aval</b>	Nakanbé	730	14	37,3
<b>Bontioli</b>	Bougouriba	855	5,1	11,7
<b>Kirgou</b>	Faga	530	2,1	9,9
<b>Badongo</b>	Nazinon	284	3	10,2
<b>Bittou</b>	Nouhao	328	1,6	6,2
<b>Douna</b>	Léraba	600	2	10
<b>Moussodougou</b>	Comoé	600	1,5	7
<b>Koutseni</b>	Dienkoa	155	0,5	2,2
<b>Arli</b>	Doudobo	200	0,9	2,7
<b>Baoue</b>	Baoué	68	0,3	0,90
<b>Bonvalé</b>	Siou	71	0,3	0,51

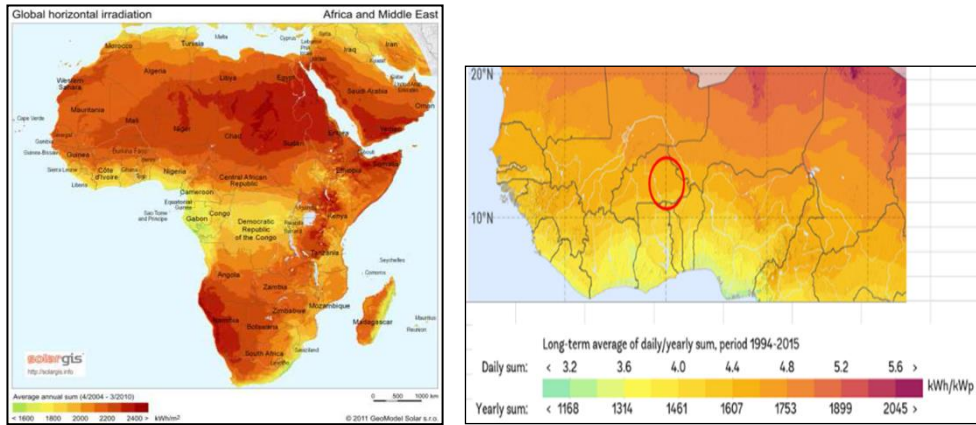
It can be seen from this table that the hydroelectric potential is low.

### 3.2 Solar potential

Africa has an exceptional solar potential. The sunshine is among the highest on the planet, with around 3,000 hours of sunshine per year. The theoretically available and exploitable reserves have been estimated at nearly 60 million TWh/year, placing Africa far ahead of Asia (37.5 million TWh/year) and Europe (3 million TWh/year). The continent holds a total of more than 40% of the world's solar potential - mainly in the African countries that are part of the global sun belt, the Earth's sun belt - a reservoir that is capable of making it the leading continent in terms of solar energy production in the coming decades. 7 African countries among the sunniest countries on the planet: **Egypt (2<sup>nd</sup>)**, **Sudan (3<sup>rd</sup>)**, **Chad (4<sup>th</sup>)**, **South Africa (5<sup>th</sup>)**, **Niger (6<sup>th</sup>)**, **Madagascar (8<sup>th</sup>)** and **Kenya (9<sup>th</sup>)**.

Burkina Faso, like most African countries, is in the sunniest regions of the world. The country benefits from average daily sunshine of 5.5 kWh/m<sup>2</sup>, up to 6 kWh/m<sup>2</sup> during the months of strong sunshine from February to June. This sunshine reaches 3,000 to 3,500 hours per year.

European Commission, Joint Research Centre - Energy Efficiency and Renewables Unit



**Fig. 2.** Solar Map of Africa.

## 4 PSP for energy storage: opportunities for electrification of Sahelian Africa and Burkina Faso

The astonishing recent progress in the technology and cost of photovoltaic (PV) electricity seems to be a capital asset for the economic development of Africa, whose population is likely to double in a few decades.

The leaders of the most industrialised countries, which use 5,000 to 15,000 kWh of electricity per capita annually, are advocating energy savings and 100% renewable energy by 2050. This is totally unsuitable for Africa, which consumes on average just over 500 kWh per capita and 750 TWh in total. More than 2 billion Africans will need before the end of the century 10,000 TWh/year, in 2050 nearly 5,000 TWh (2,500 kWh per capita).

In 2010, Africa had no resources and no solution adapted to this objective. It can now benefit from the PV Miracle and has the major advantage of benefiting from it all year round. The direct cost in a few decades will be between 20 and 40 \$/MWh depending on the country.

The population density, lower than in Europe or Asia, facilitates the installation of power lines and the long-distance transport of high power.

As the direct use of PV is limited to about 10 hours a day and the hydroelectric production capacity is limited, a significant complement will be necessary at night. Batteries will have a role off-grid or for peaks, but pumped storage (PSP) appears to be the best solution for daytime needs. They are not economically suitable for monthly and seasonal balancing, and a large capacity of little-used thermal power plants will still be needed for safety over several decades before the costly use of hydrogen.

About Burkina Faso, the country is the one in the world that most needs electricity storage.

It is therefore already very interesting, as soon as possible, to provide an important part of the electricity for 8 or 10 hours a day, by photovoltaic, initially keeping the petroleum-based for night supply.

But it is certainly also very interesting to provide part of the night electricity from photovoltaic electricity stored for 8 hours in full sunlight. Classical hydropower will play a marginal role in term of supply but can help for the stability of the Grid.

#### **4.1 Electricity in Burkina Faso in 2050**

Current consumption is approaching 2 TWh/year. Its rapid increase is crucial for economic development. The use of photovoltaics (PV) with batteries to store from day to night can develop quickly and decentrally.

Before the middle of the century, we can aim for much higher consumption, in the order of 50 TWh/year, because the cost per kWh will be much lower than at present. This will be the direct cost of the PV, in the order of 0.06 US\$/kWh plus the cost of storage for out-of-sun consumption, about half of the total consumption.

It will be necessary to keep some electricity per oil (10%) because there may be a week with little sunshine.

Storage can be by battery but for 10 or 15 hours storage, PSP seem more economical.

50 TWh/year is about 6 GW x 8,760 hours, but the annual peak can reach 10 GW after sunset, requiring nearly 10 GW of thermal power plants or PSP or batteries.

A PSP capacity of at least 5 GW seems desirable and very cost-effective. It reduces the capacity and cost (excluding oil) of thermal power plants by 5 GW and the annual cost of a PSP (depreciation, operation, maintenance) can be of the same order. And it replaces the supply of oil with PV power, 5 or 10 times cheaper.

PSP can be used 10 hours a day to pump and a little more to turbinate. They can be supplemented by batteries for peak consumption.

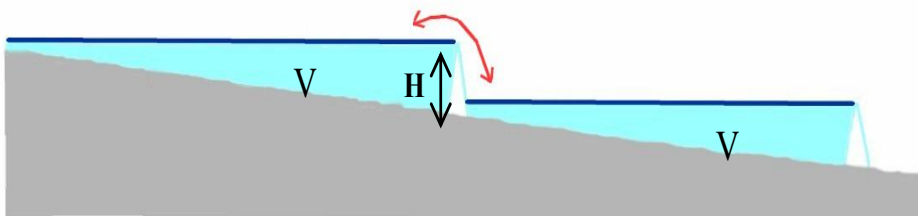
#### **4.2 Potential sites for PSP implementation**

The approach to the implementation of dams must change. Indeed, with the installation of pumped storage power plants, it will be possible to operate the dams every day, in association with solar energy.

In the case of Burkina Faso, the relief is flat but the volumes of water stored are enormous and the country benefits of a lot of sunshine. Some existing dams have characteristics favourable to the implementation of PSP systems (Bagré, Samendeni, Kompienga, Comoé, etc.). For the identified hydroelectric potential sites mentioned in the table 1 above, integrating the PSP approach, it would be possible to produce clean electricity in quantity and at a lower cost.

#### **4.3 Which PSPs in Burkina Faso?**

The relief being relatively flat, the best solution can be the "Twin Dams": 2 similar reservoirs associated along a river.



**Fig. 3.** "Twin Dams".

Every day, using solar energy, the upper part of the lower reservoir can be pumped to the upper reservoir and at night it can be turbined in the opposite direction.

In addition to “twin dams”, off-river storage or storage in a reservoir by construction of dam on a tributary of the main dam's river are also other options.

## 5 Case studies: Bagré & Bassiéri dams

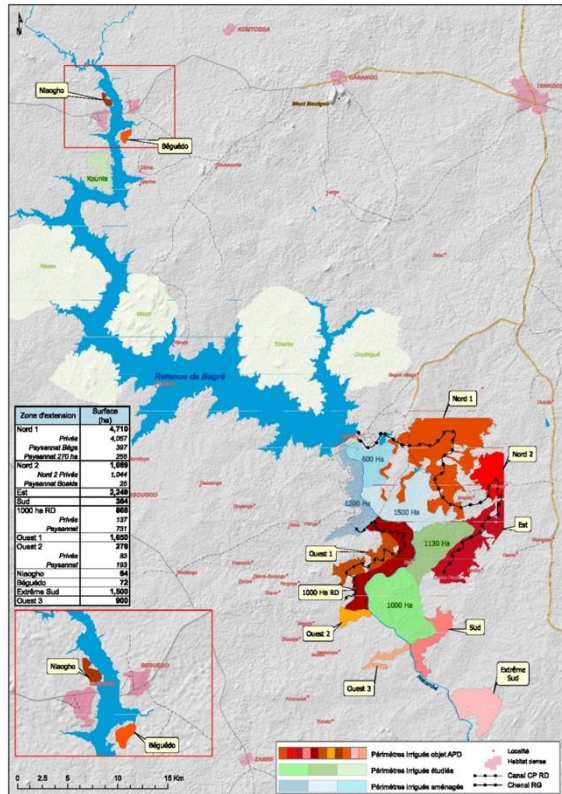
### 5.1 PSP to Bagré Dam

#### 5.1.1 Short presentation of Bagré Dam, a multipurpose dam

The Bagré dam is located on the Nakanbé River in Burkina Faso, whose former and international name is the White Volta, a tributary of the Volta River on which the Akosombo dam is located in Ghana.

The Bagré dam is a 4.5 km long zoned earth dam with a maximum height of 40 m from the lowest foundation level and a fill volume of nearly 3.4 million m<sup>3</sup>. The capacity of the reservoir at the normal operating level of 235 is 1700 hm<sup>3</sup> for a water area of 255 km<sup>2</sup>. Construction of the dam began in September 1989 and the dam was commissioned on July 1992 and the reservoir impounded in the same period. The power plant came into service in March 1993. The dam studies were carried out during the period covering the 1970s to the mid of 1980s for the entire design cycle (Inception studies up to the tender documents).

The Bagré dam is a multi-purpose dam with however two essential components which are the development of irrigation on a potential of 30 000 ha located upstream and downstream and the production of hydroelectricity with an average yearly production of 44 GWh.



**Fig. 4.** Overall plan for the Bagré Dam project

**5.1.2 Possibility of PSP to Bagré Dam**

There are in fact many pumping station solutions using the reservoir of Bagré as low reservoir. Very large areas around the reservoir are more than 40 m above and large surfaces up to 100 m above. We can therefore create either to large basins outside the Bagré reservoir or close a part of the reservoir “twin dams” or combine the two one. And we can certainly make successive developments up to a few hundred MW each depending on the needs.

Step 1:

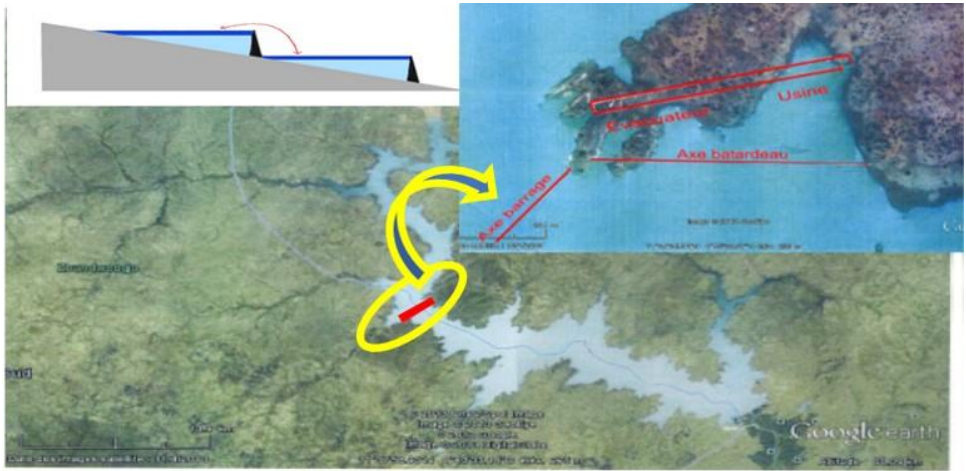
- Build a dam - upstream plant;
- Raising the upstream NR to 245 with a storage gain of 500 hm<sup>3</sup>;
- Installed capacity of 20 MW;
- Protect Beguedo village with a 4m high dyke in 2025.

Step 2: Construction of a 200 MW PSP to produce 3 GWh per day in 2030

Step 3: Increase the power of the PSP to 500 MW to store the night requirements of 2040

Step 4: Construction of the high reservoir on the Lenga village after 2040.





**Fig. 5.** PSP implementation for Bagré Dam Steps 1 to 3.



**Fig. 6.** PSP implementation for Bagré Dam Step 4.

## 5.2 PSP to Bassiéri Dam [5]

### 5.2.1 Short presentation of Bassiéri Dam, a multipurpose dam

Bassiéri dam site is located in the eastern region of Burkina Faso. The capacity of the reservoir is 660 million cubic meters for a surface area of 170 km<sup>2</sup> with an average water depth of 3.9 m. The dam is a zoned earthen embankment about 2.7 km long, with a maximum height of 18 m.

### 5.2.2 Different components of the project

Bassiéri dam is a multipurpose dam with several components.

**Hydropower component:** the hydropower project is composed of two options. A classic option with a hydropower plant at the toe of the dam producing 8.4 GWh / year and an installed capacity of 3.5 MW. An innovative variant option with a PSP. This one is developed above.

**Water supply component:** this component consists of a drinking water production, transport and storage system for a population of around 200,000 people by 2050.

**Agricultural component:** this component consists in the implementation of a hydro-agricultural development of 1500 ha with a view to developing the water resources that will be mobilised by the construction of the dam.

**Fishing component:** the presence of the dam's water reservoir offers great opportunities for the development of fish farming by: (i) the construction of fish farming infrastructures, (ii) the equipment of fish farming infrastructures, (iii) capacity building in fish farming techniques. fish production is estimated at around 1000 tonnes / year.

**Livestock component:** the objective of this component is the development of livestock in the project area. It is based on strategies to strengthen the capacities of stakeholders in the livestock sector, secure and sustainably manage pastoral resources, increase animal productivity, improve the competitiveness of animal products and improve the income of agropastoralists.

### 5.2.3 Possibility of PSP to Bassiéri Dam

The innovative option of PSP to Bassiéri dam operates by turbine-pumping between the left bank upstream reservoir and the main downstream reservoir, in coupling with a solar power plant:

- Solar energy production during the day and pumping thanks to the excess energy in the upper reservoir;
- Production of energy by hydroplant to the lower reservoir at night, when the solar power plant is not producing.

The turbinning pumping station is located at the foot of the upper dam.

The basic solution is composed of the lower dam with a hydroelectric power plant at the downstream of 3.5 MW of installed capacity and a production capacity of 10.5 GWh/year.



**Fig. 7.** PSP implementation for Bassiéri Dam.

The characteristics of this solution are:

- Maximum daily tidal range of the upper retention of 1.5m;
- Guaranteed injection power: 60 MW;
- Solar power: 350 MWp (floating technology - 250 to 350ha);
- Energy supplied: 590 GWh/year.

### 5.3 Investment cost

For 50 TWh/year, 10 GW of thermal power plants or PSP must be invested. The investment per GW may be a little more important for a PSP but the operating and maintenance cost is lower; the difference in cost between oil and PV recovers the investment of a PSP in a few years.

The investment of a PSP can be in the order of 10 cents of dollars per kWh.

The cost of electricity production in 2050 can be 5 cents of dollars of direct PV per kWh plus 5 cents of dollars of storage and 0.8 cents of dollar of loss for half, or nearly 10 cents of dollars.

But oil will also be kept for at least 10% and the total cost will be around 10 cents of dollars per kWh, a third of the current cost.

## 6 Conclusions

Solar energy solutions have become interesting, thanks to technological progress (lower costs, easier maintenance, etc.) and renewed interest in preserving the environment.

The PSPs offer an opportunity for Burkina Faso to develop electricity production at competitive costs and in large quantities. The main constraint is the importance of the investments to be made, which are very important.

The implementation of PSPs can be considered for existing dams such as Bagré, Komienga, Samendéni dams.

It is necessary to conduct a systematic study of the country's hydroelectric potential and the PSP Potential to facilitate the development of solar energy, whose potential is almost unlimited in Burkina Faso and in Sahelian Africa. As Sahelian Africa is not very mountainous, the best potential for PSPs may be twin dams on new sites or by adapting existing large reservoirs.

There is also great potential for sites using the sea or a large natural lake as a low reservoir and placing the high reservoir on a cliff or cliff edge.

Within a few decades Africa could have all the electricity it needs at a total cost of \$50/MWh with a very acceptable five percent use of fuel oil or gas, eventually replaced by the costly use of hydrogen.

Energy storage is becoming a strategic key to the development of Electrical Energy.

## References

1. “AfDB Group's Energy Sector Policy Report”
2. Sonabel, « Rapport annuel 2016 » (2016)
3. ARSE, « Rapport annuel d'activités 2019 » (2019)
4. F. Millogo, M. Kabore, “Hydropower in Burkina Faso Status and development” (2013)
5. Ifec & Isl Ingénierie & Emergence Ingénierie, “Feasibility report on the Bassiéri Dam and Hydroelectric Power Plant”