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ESMAP
Energy Sector Management Assistance Program

Hydro-connected solar in West Africa: theoretical framework

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Framework for the project

General objectives of the WB in West Africa

- With rapidly decreasing costs of solar, develop this local source in West African counties

Specific objectives of this project

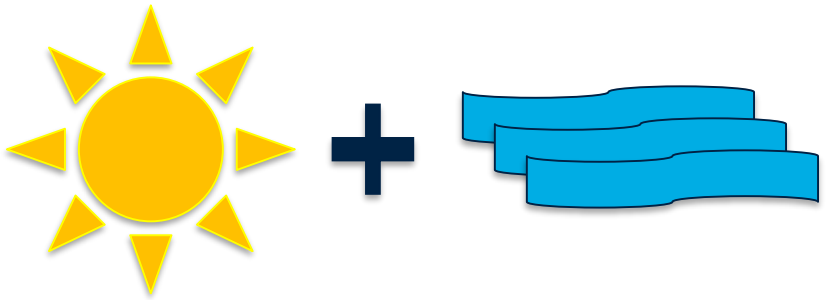
- Assess the solar+hydro hybridization as a tool to accelerate the penetration of solar in the mix

WB approach

- Assess technical and institutional constraints for developing hybrid solar+hydro plants on selected existing dams in Mali, Burkina Faso and Ivory Coast

Key factors related to solar PV deployment

Solar PV advantages	Solar PV drawbacks
Sustainable, local energy with widely available resource (very good in Western Africa)	No production at night
Decreasing cost of PV technology	Clouds impacts production, causing variability
Easy and fast installation	No services to the grid (reserve, frequency and voltage regulation, inertia, …)



Solar + hydro as a possible solution?

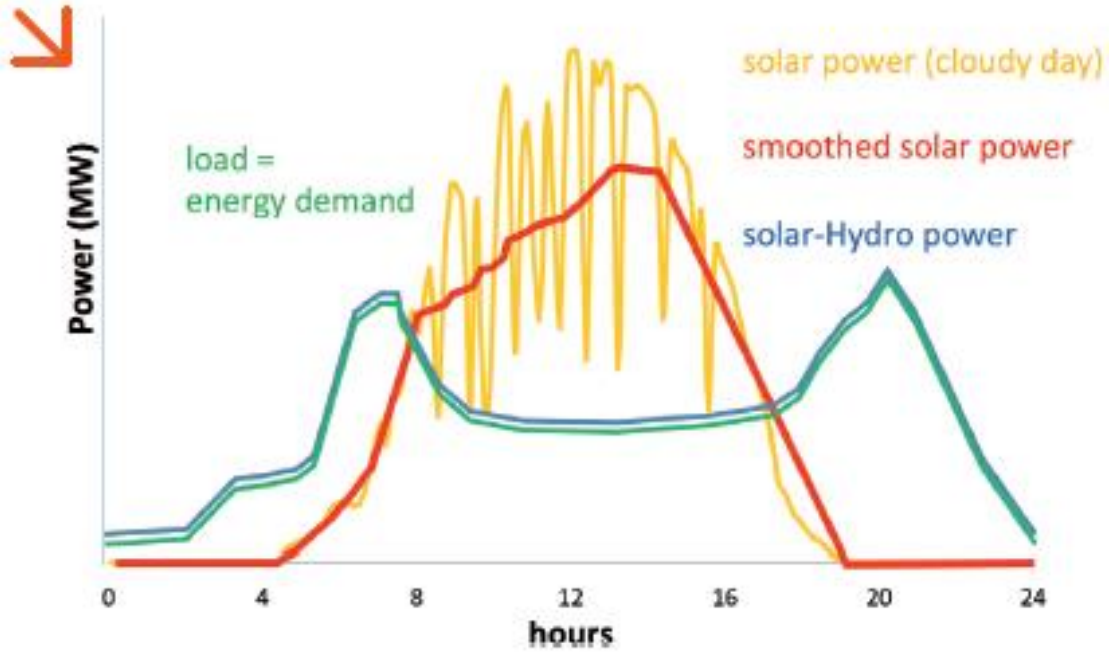
- Solar provides low cost renewable electricity and hydro provide grid services and stability
- Solar plant could be connected to the existing hydro substation and use existing transmission lines with enough wheeling capacity

Key issues – smoothing of solar output for ease of grid integration

Existing hydropower plant with reservoir

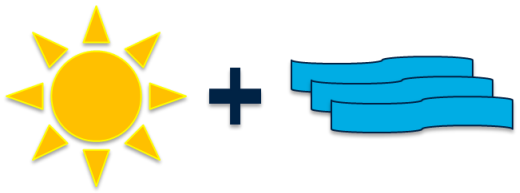
Existing substation with transmission lines

New solar PV plant (ground mounted or floating)



Need specific SCADA for Hydro & Solar hybridazation

Comparison of pure solar and hybrid solar + hydro



Location of PV plant	System operation	PV installation
Near demand centers	Independent operation of solar	Land-based
Next to the hydro power plant	Hybrid operation of solar + hydro	Floating or land-based

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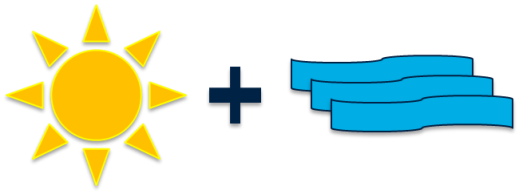
Comparison of pure solar and hybrid solar + hydro



Location of PV plant

Near demand centers

Location of the PV plant near to demand centers means less losses on transmission lines

Next to the hydro power plant

Location of the PV next to the hydro power plant brings opportunities to share substation, transmission lines, etc and require small investment integration

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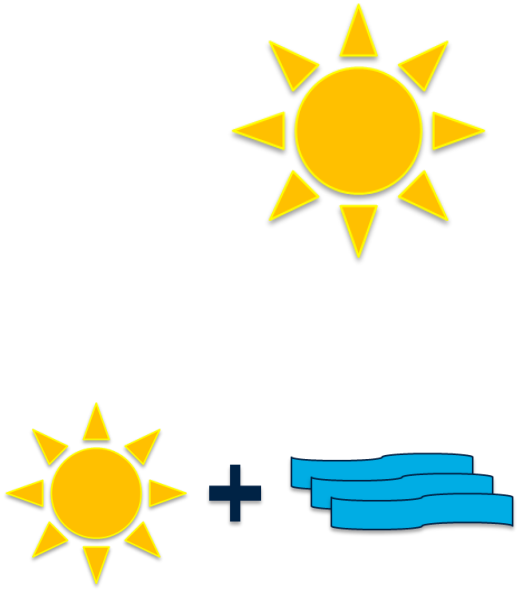
Comparison of pure solar and hybrid solar+hydro



PV installation

Land-based

Floating or land-based

Proven mature technical option

Land-use advantages of floating solar:

- less social impacts
- costs of floats & anchors are partliay or fully compensated by avoided costs of land acquisition and land preparation

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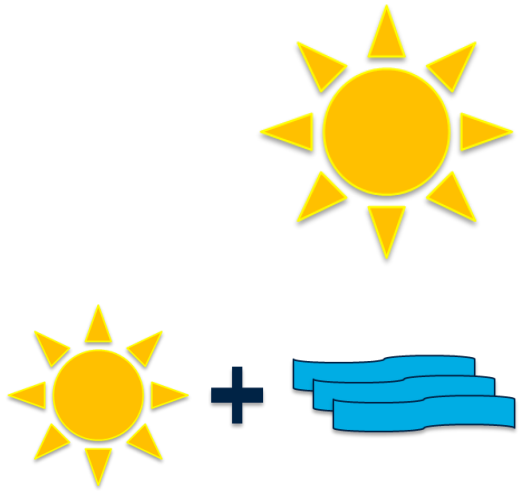
Hybrid system operation

Hybrid operation is beneficial for solar and hydro:

- Solar is variable => hydropower might provide flexibility to deal with variations
- Water resources are sometimes overused or affected by climate change : Solar might help spare some of them

Benefits at every time scale …



minutes	/ hours	/ months
Cloud effect	**Daily load adjustment**	**Seasonal mix**
Fast variations of solar power	Daily solar production vs. daily load curve	Most countries: sunny season max solar power
Regulation by turbine gates (*)	Daily storage using the hydro reservoir	rainy season max hydro power

(*) depending on the hydropower plant specific features

Hybrid system operation

Pros and cons of hybrid hydro + solar plant vs independent hydro and solar:

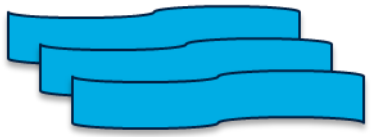
PROS:

- Expected higher output (dynamic management of primary reserve)
- A large hybrid plant is easier to integrate than a large solar plant (less variability)
- Impacts of hybrid solar + hydro plant operation are limited to one hydro plant (e.g. frequent variations of water discharge with impacts on hydro equipment and on river downstream, incl. social impacts, impacts on irrigations, etc.)

CONS:

- If a large capacity solar plant is planned, possible strong impacts on the hydro plant equipment
- Less spatial distribution of solar implies higher overall variability from cloud effect

Institutional structuring



	Design and construction of PV plant	Operation of the solar PV plant	Operation of hydropower plant	Management of the reservoir
Pure public option	**Public entity**			
Two operators: public and private	**Private operator**		**Public entity**	
Hybrid system operation by a private operator	**Private operator**			**Public entity**

Quick check list for site selection

Technical criteria:

- Expected installed PV capacity
- Solar potential
- Capacity factor of hydro plant
- Downstream impact
- Grid connection

Economic criteria:

- Expected LCOE of solar

Legal aspects:

- Legal options for institutional structuring

Environmental and social criteria:

- Upstream land availability
- Downstream land availability
- Upstream impact on populations
- Downstream impact on population
- Upstream impact on physical and biological environment
- Downstream impact on physical and biological environment

Others:

- Alternatives for water use
- Proximity to demand centers

Conclusions

Hybridization may help increasing solar penetration, especially in case of:

- Existing reservoirs with water scarcity during the dry season
- Large reservoirs that may accommodate floating PV panels and that may store water on seasonal basis
- Reservoirs where disturbance of downstream flow regime is minimal (e.g. secondary reservoir)
- Cases where hybrid operation can be handled to one single operator with specific grid requirements

But technical aspects of hybridization are not the only criteria…

- Legal system of the country and laws/regulations governing the existing hydropower play a big role
- Institutional structuring that makes also technical sense can sometimes be hard to achieve (e.g. hydropower operator would have to operate also PV under existing regulations but operator has no capacity to deal with solar)
- Prices of existing hydro contract vs expected solar costs play a big role
- Alternative uses of water (e.g. irrigation) may have priority over power generation objectives