SYNERGETIC RENEWABLE RESOURCES IN WEST AND CENTRAL AFRICA

TOWARDS SMART INVESTMENT STRATEGIES AND RESOURCE PORTFOLIOS

Prof. Dr. Sebastian Sterl

WB ROUNDTABLE on the Future of Hydropower in West and Central Africa
July 9th, 2023 - 15:00-17:00

DRIVERS OF HYDRO AND VRE POTENTIAL IN AFRICA

HYDRO-VRE SYNERGIES IN WEST & CENTRAL AFRICA

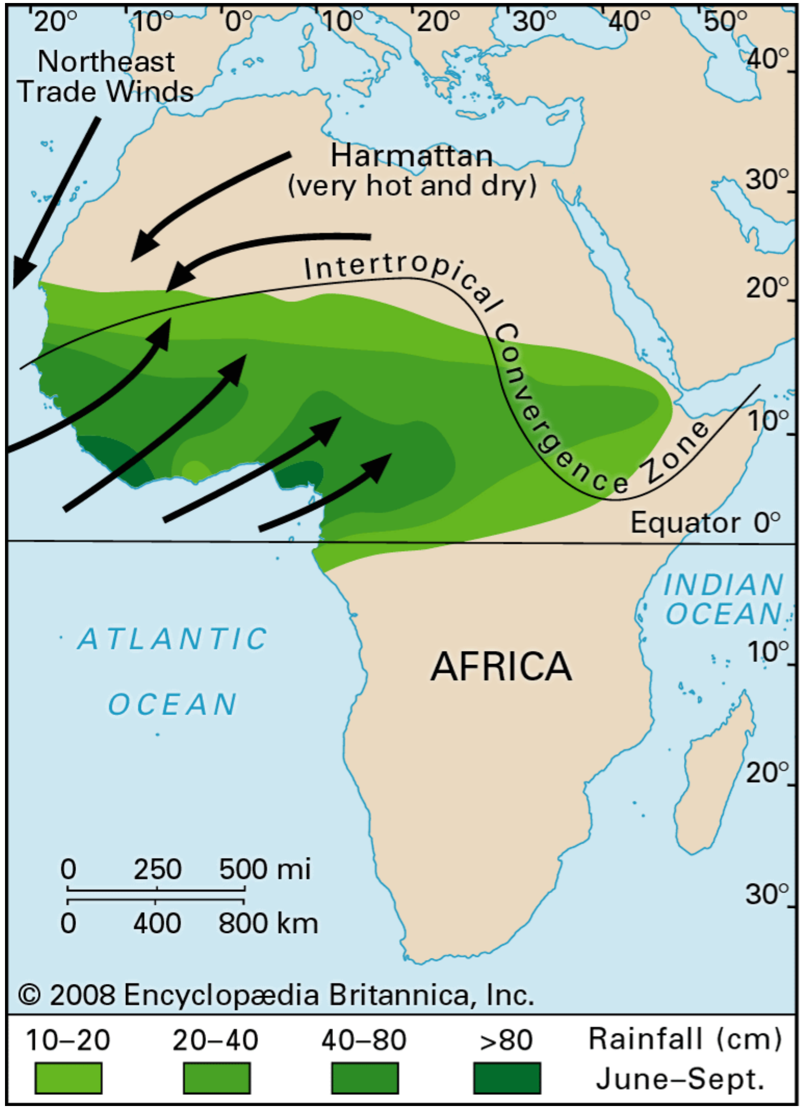
CONSEQUENCES OF JOINT HYDRO-VRE OPERATION

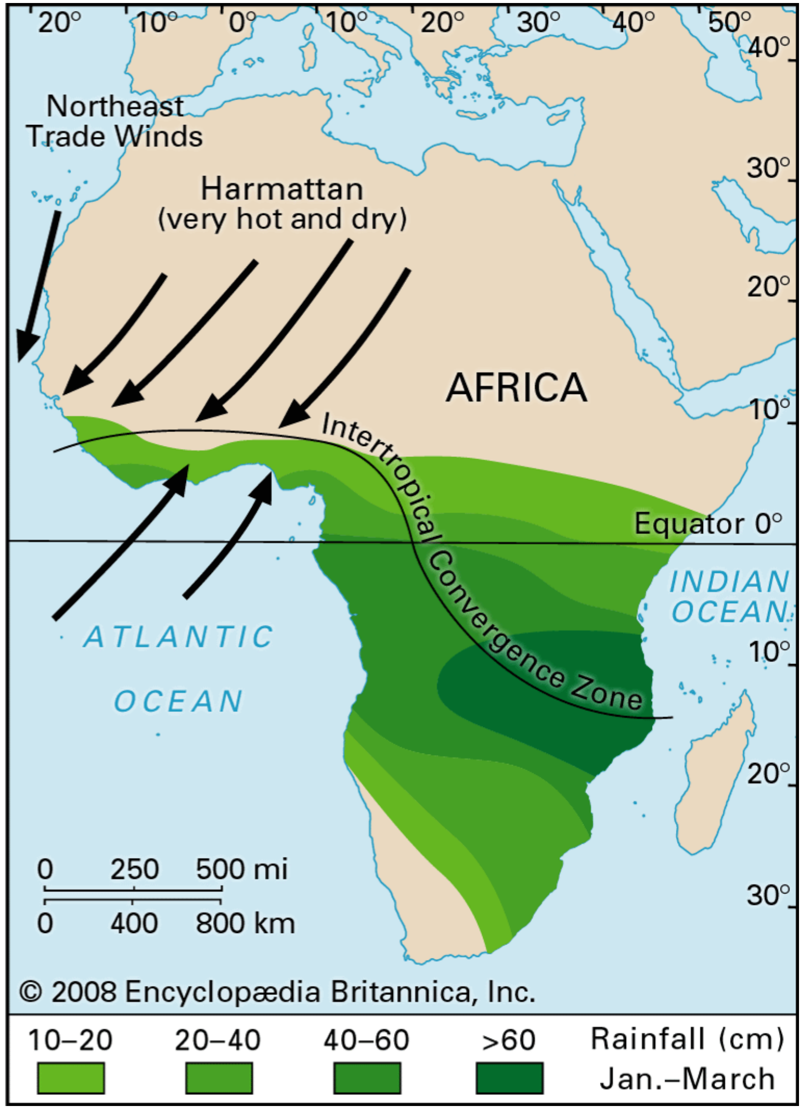
REQUIREMENTS FOR JOINT HYDRO-VRE OPERATION

CLIMATE CHANGE EFFECTS

CONCLUSIONS

THE ITCZ AND MONSOON INFLUENCE

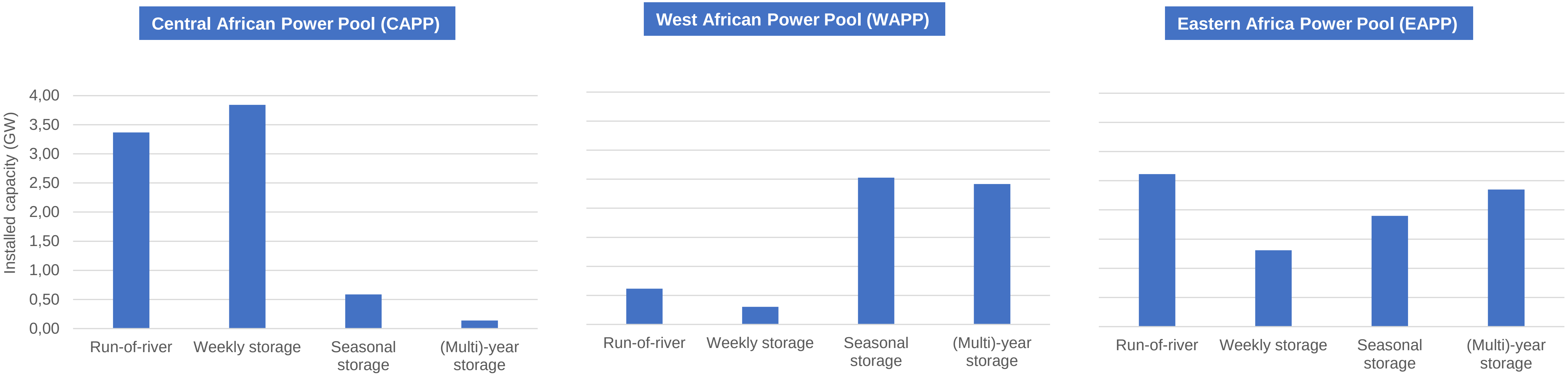




HYDROPOWER DESIGN

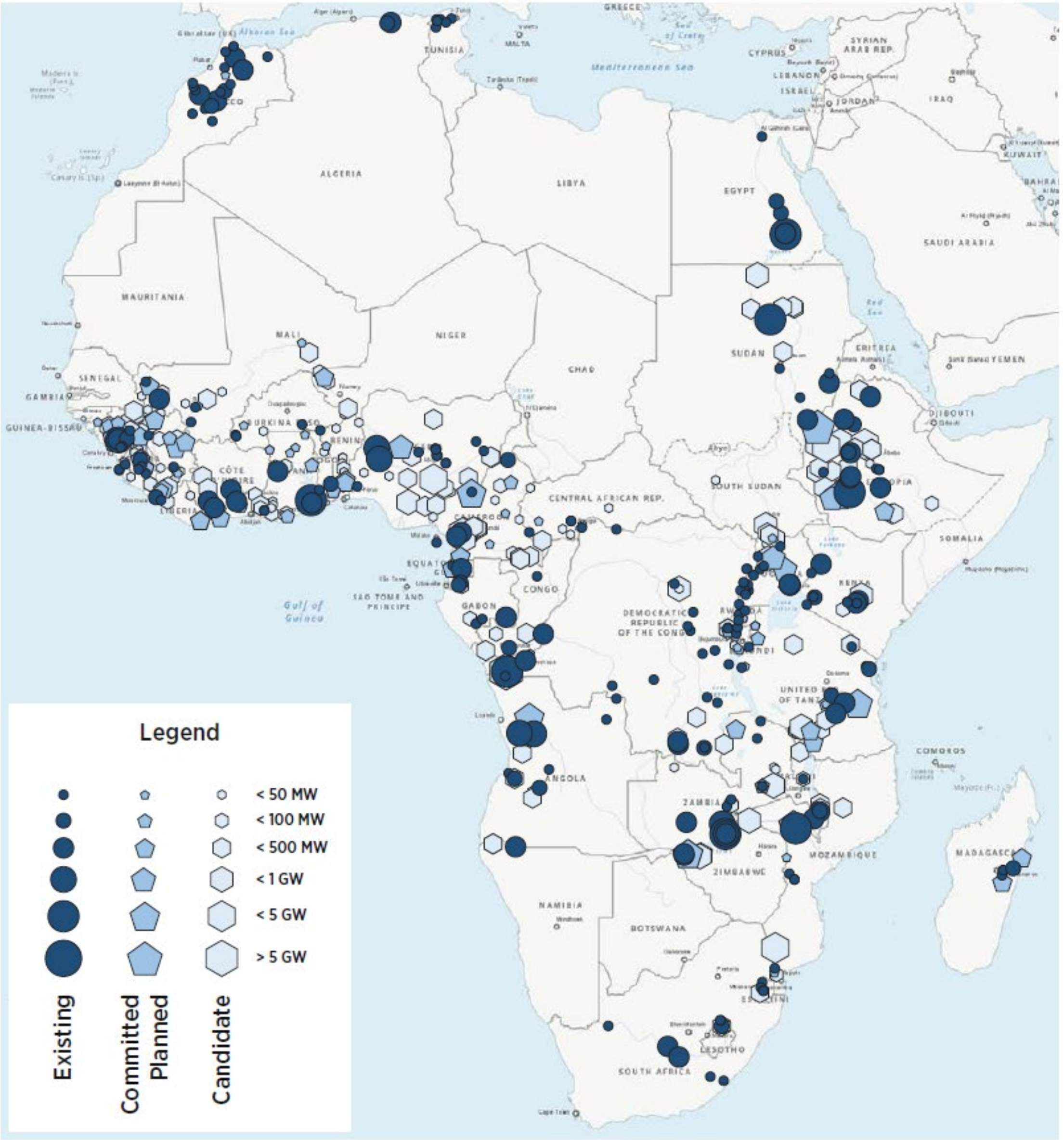
- These dynamics *directly* influence the requirements for hydropower plant design

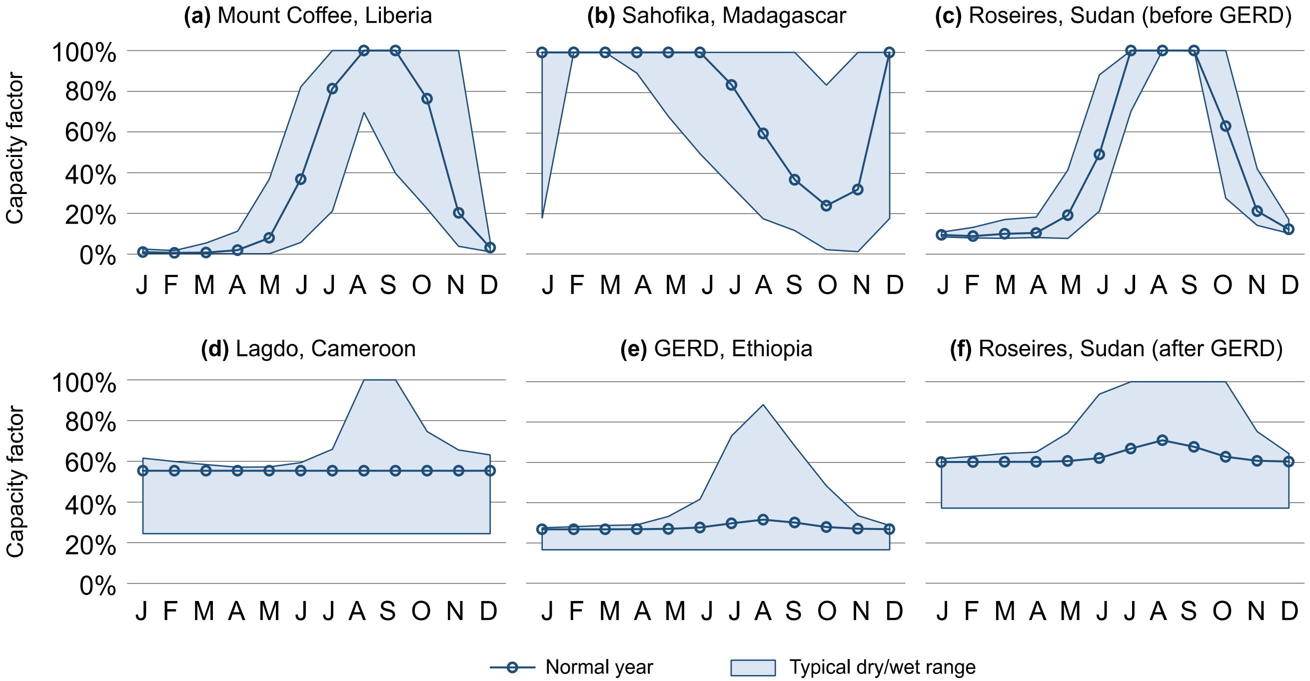
- Example: reservoirs much more useful in *unimodal* (typical in West Africa) than in *bimodal* (typical in Central Africa) rainfall climates



https://www.irena.org/publications/2021/Dec/African-Renewable-Electricity-Profiles-Hydropower

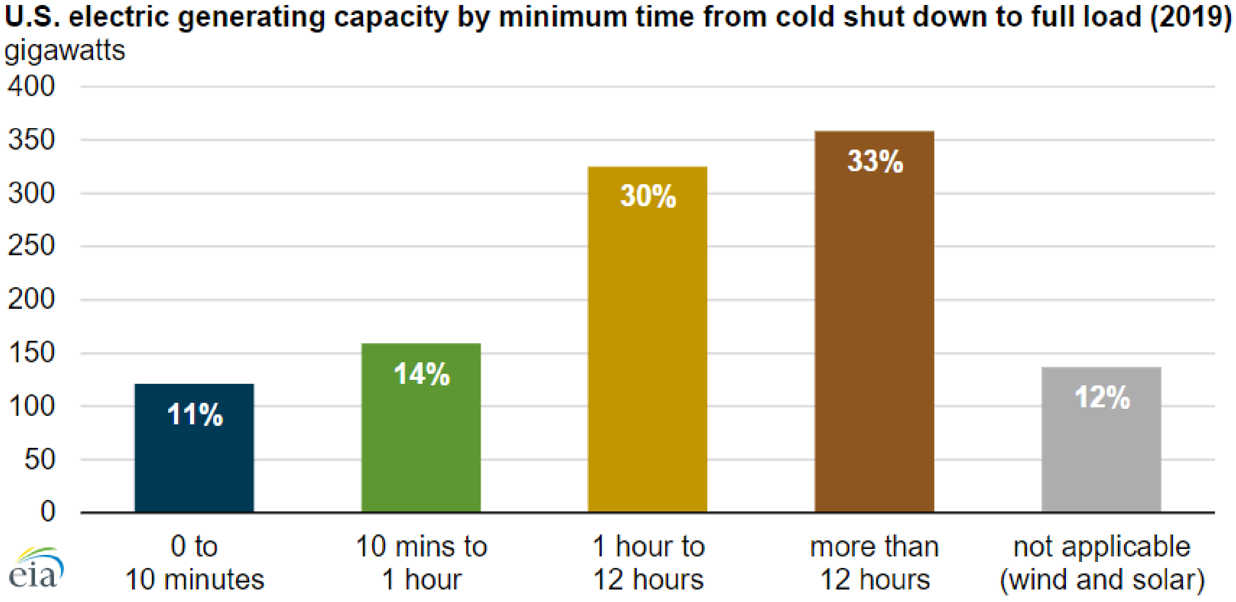
HYDROPOWER GENERATION PROFILES

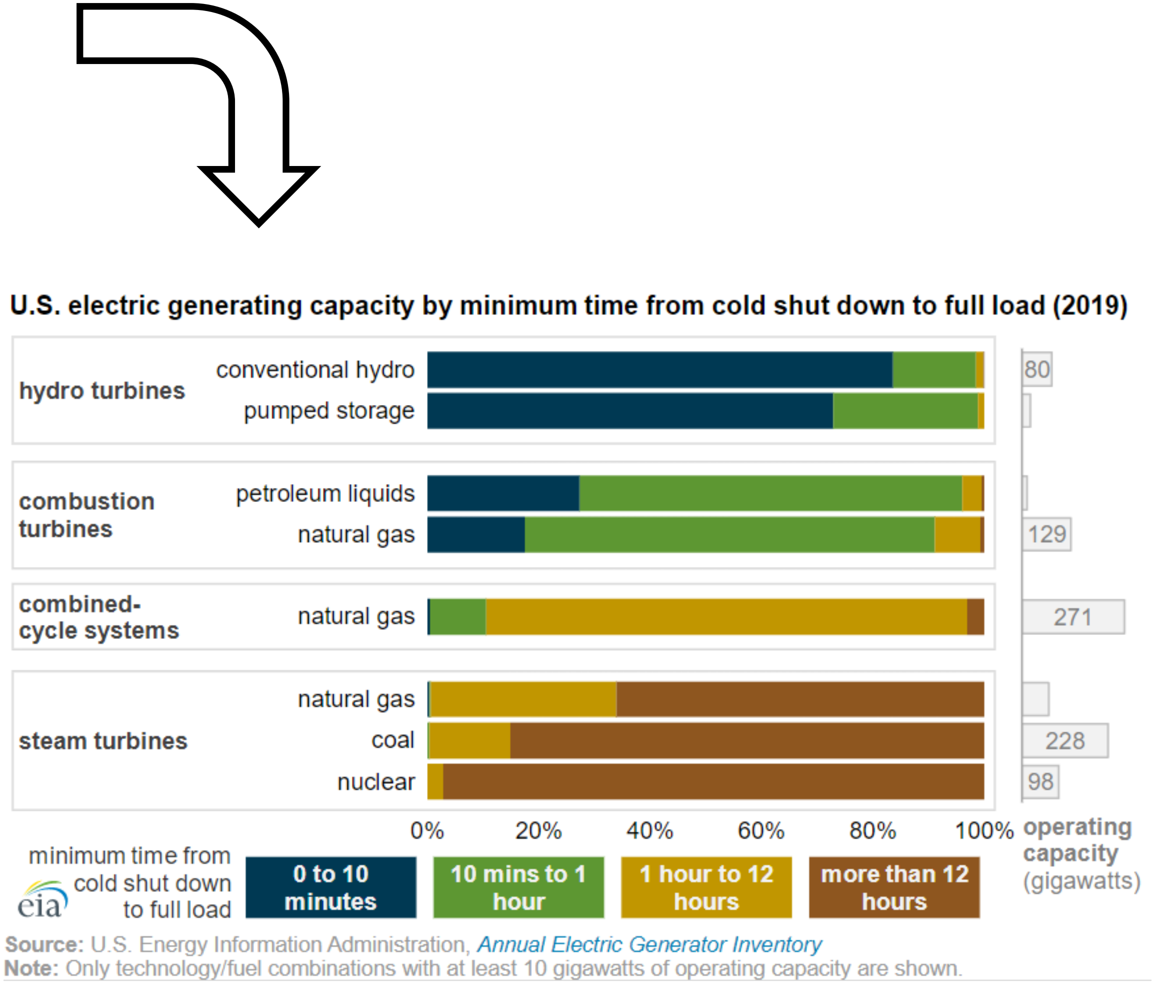




https://www.irena.org/publications/2021/Dec/African-Renewable-Electricity-Profiles-Hydropower

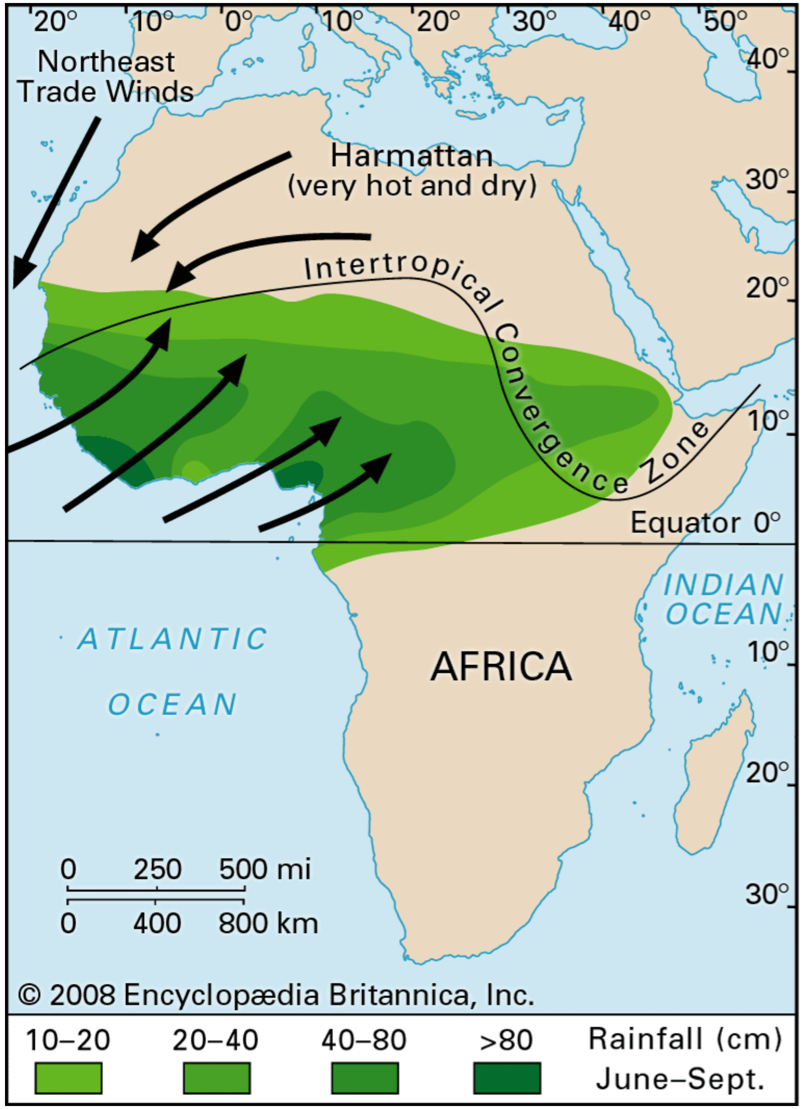
HYDROPOWER FLEXIBILITY

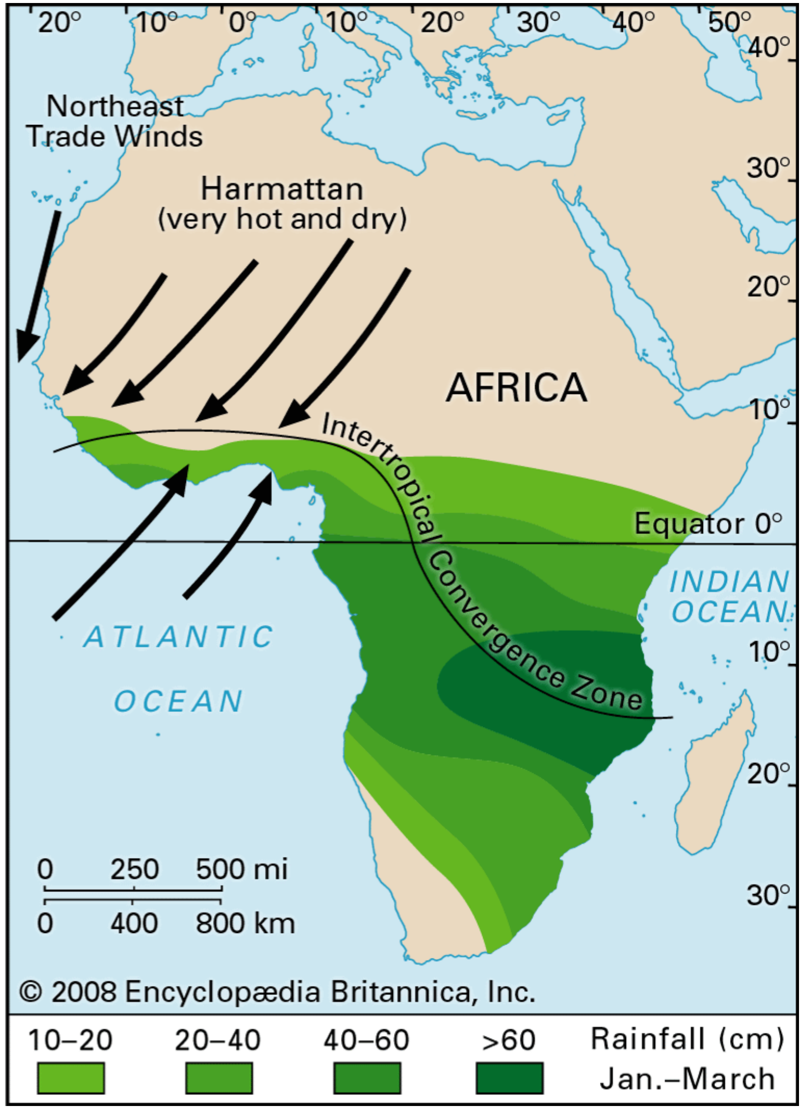




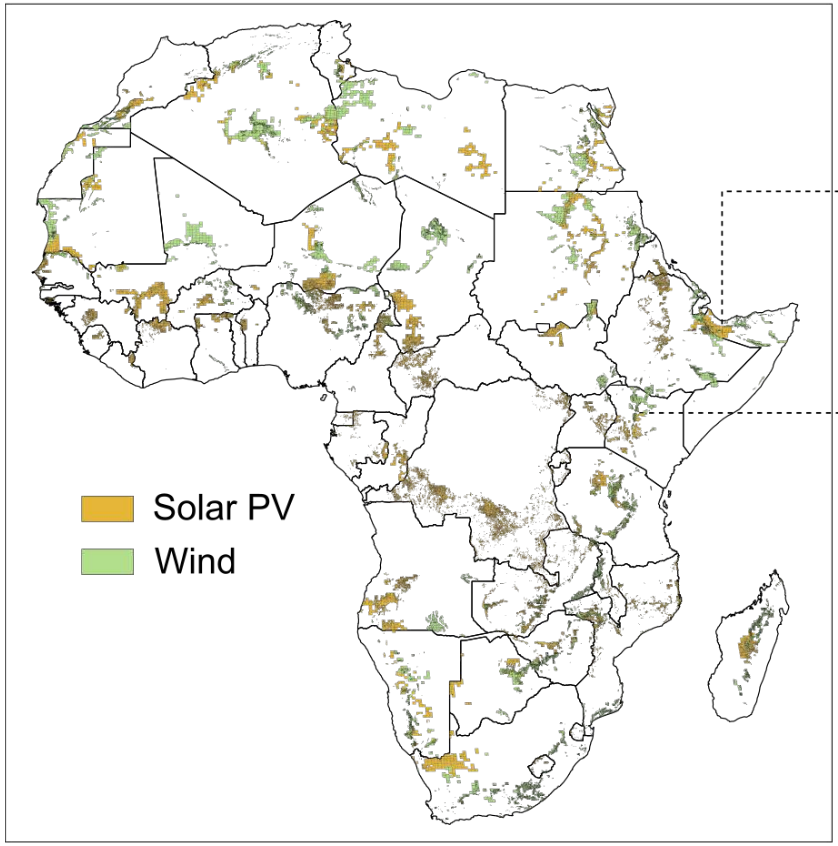
https://www.eia.gov/todayinenergy/detail.php?id=45956

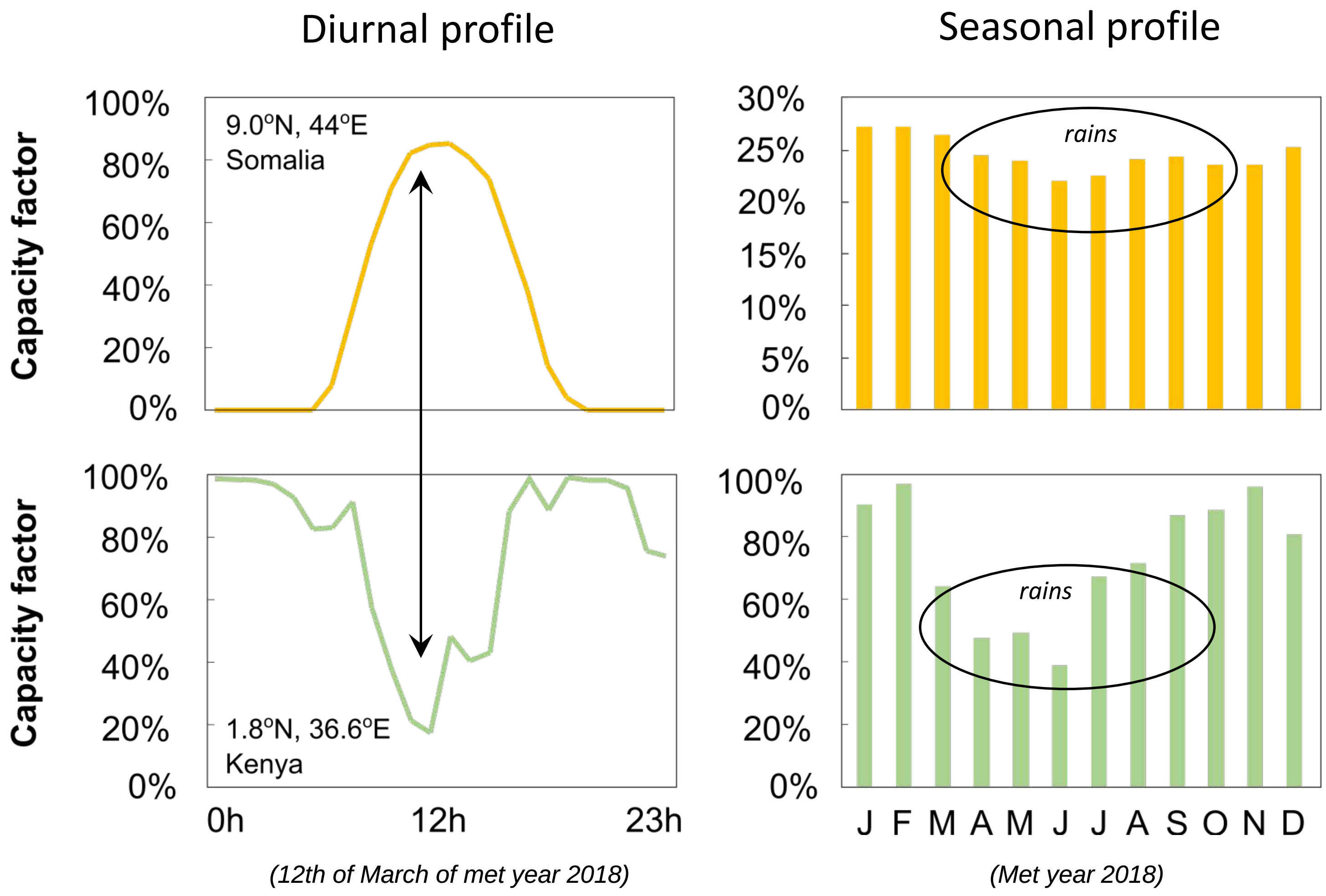
WHAT ABOUT SOLAR AND WIND?





AFRICA'S SOLAR AND WIND POTENTIAL





Good day-night synergies between solar and wind power are the norm, not the exception!

https://www.nature.com/articles/s41597-022-01786-5
https://iopscience.iop.org/article/10.1088/2515-7620/ac71fb

SUMMARY

- Many hydropower plants in Africa have pronounced seasonal production profiles
- Superimposed on that seasonality, hydropower plants with storage could deliver flexibility to support VRE integration
- VRE have their own seasonal production profiles, which tend to be low when hydro is high, and vice versa
- Solar and wind can support each other mutually on day-night scales in many cases
- Opportunities to be harvested?

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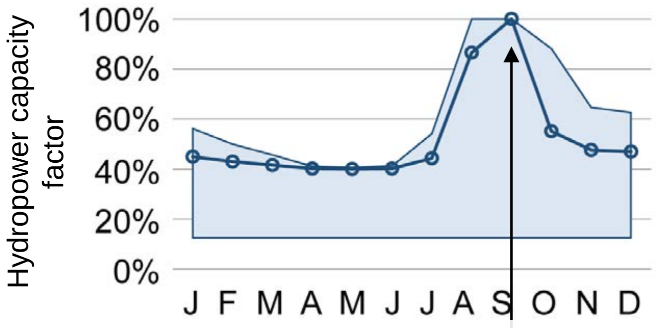
Hydro and solar are complementary: Liberia

Sources: Sterl et al. 2020 (REVUB model simulations on hydro-solar mixes), Sterl et al. 2021 & IRENA 2022 (African Hydropower Atlas), Sterl et al. 2022 (solar PV model supply regions for Africa)

Spatial complementarity

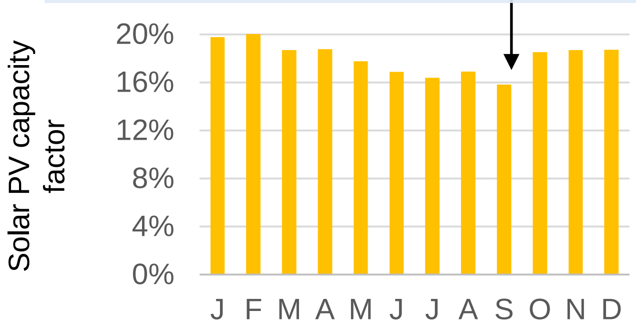
Liberia's best regions for **solar PV** plants touch the Côte d'Ivoire & Guinea borders where **interconnections** are planned

Seasonal complementarity



(illustrative profile of Liberian reservoir plant)

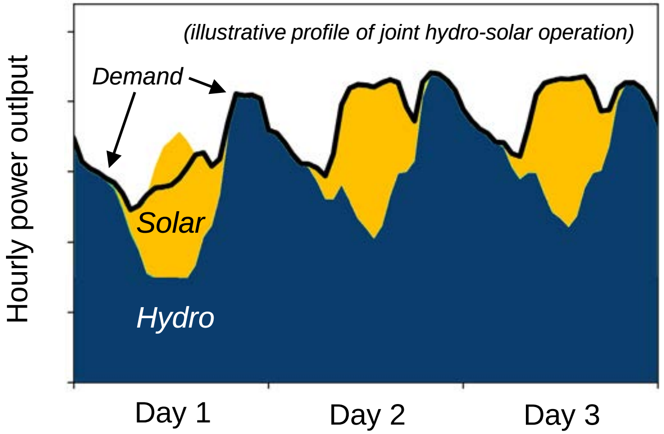
The West African monsoon drives seasonal river flows in Liberia, which gives a seasonality to **hydropower** generation



(illustrative profile of Liberian solar PV plant)

Solar power in Liberia is similarly influenced by the monsoon, but inversely: when hydro peaks, solar output is lowest

Diurnal complementarity



Hydropower can further support **solar power** through night-time dispatch and meeting peak demand through flexible release of water. The seasonal complementarity **keeps lake levels higher** on average, as lake emptying/filling becomes more concentrated in the wet season.

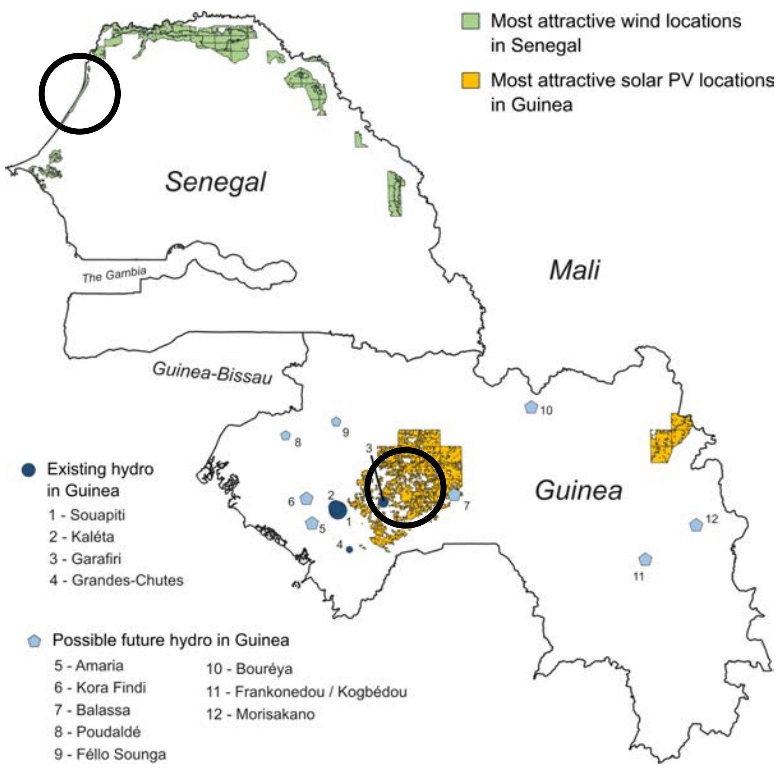
This requires

- a certain water **storage volume** (not pure run-of-river)
- turbines that allow for sufficient **ramping speed** (e.g. through refurbishment)

Hydro, solar and wind are complementary: Senegal & Guinea

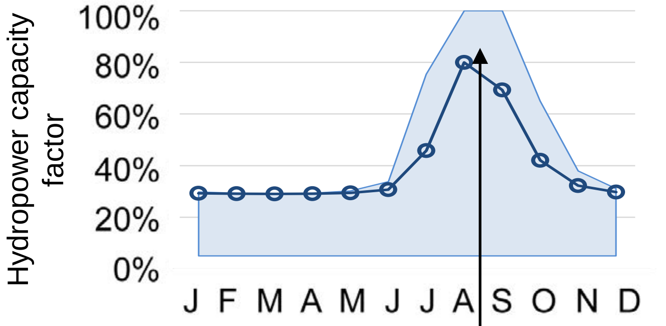
Sources: Sterl et al. 2020 / Sterl et al. 2021 (REVUB model simulations on hydro-solar-wind mixes), Sterl et al. 2021 & IRENA 2022 (African Hydropower Atlas), Sterl et al. 2022 (solar & wind model supply regions for Africa)

Spatial complementarity



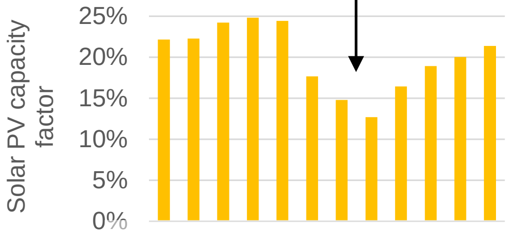
Guinea's best **solar PV** resources are located close to most of Guinea's existing and potential **hydropower** sites. Senegal's **wind** power potential is concentrated along the Atlantic coast and the Senegal river, which originates in Guinea.

Seasonal complementarity

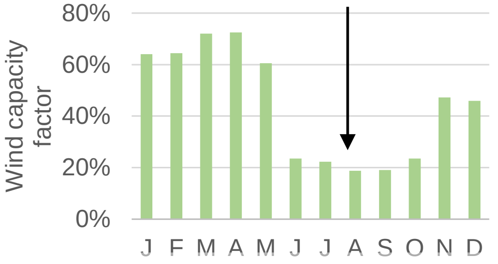


(illustrative profile of Guinean reservoir plant - Garafiri)

River flows in Guinea are subject to strong seasonalities. **Solar PV** in Guinea and **wind** in Senegal have an opposite seasonality.

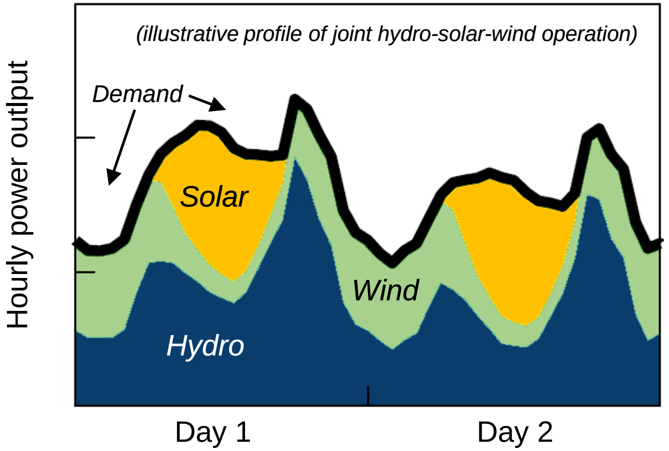


(illustrative profile of Guinean solar PV)



(illustrative profile of Senegalese wind power)

Diurnal complementarity



Solar power in Guinea and **wind** power in Senegal complement each other, as the wind blows mostly during night-time. Guinean **hydropower** could provide support to a solar-wind mix through flexible dispatch.

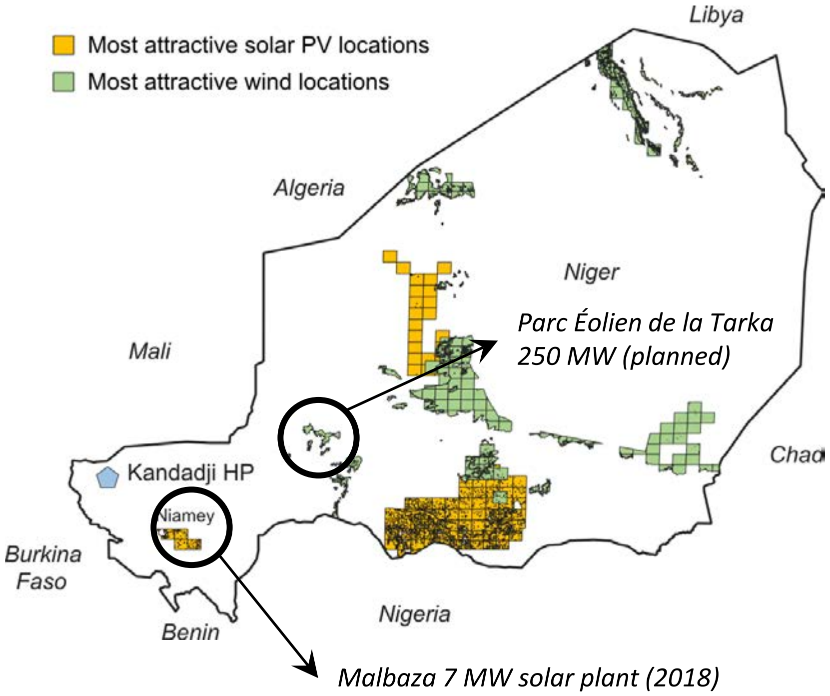
To achieve such a mix would require

- **interconnections** between Guinea & Senegal
- a smart choice of **solar/wind** portfolios
- a certain water **storage volume**
- hydroturbines that allow for sufficient **ramping speed** (e.g. through refurbishment)

Hydro, solar and wind are complementary: Niger

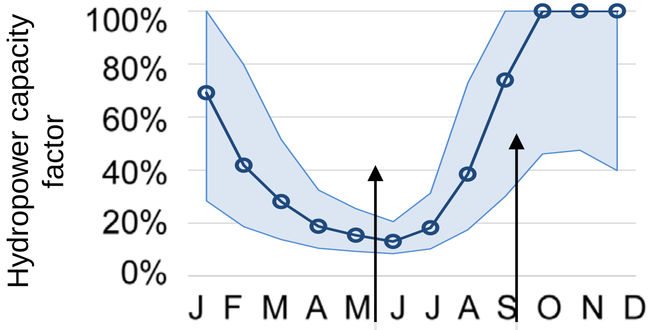
Sources: Sterl et al. 2020 / Sterl et al. 2021 (REVUB model simulations on hydro-solar-wind mixes), Sterl et al. 2021 & IRENA 2022 (African Hydropower Atlas), Sterl et al. 2022 (solar & wind model supply regions for Africa)

Spatial complementarity



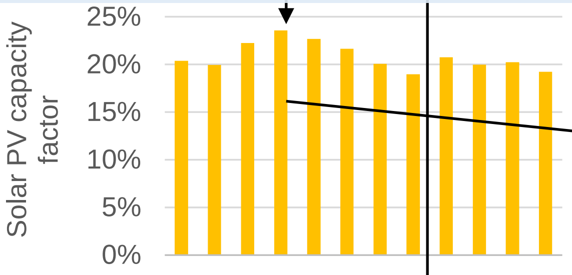
Niger's only hydro potential is on the Niger river, in the extreme southwest, notably the Kandadji plant. Niger's best **solar PV** resources are generally co-located with concentrations of population. Niger's **wind** power potential is concentrated somewhat further north, e.g. around Tahoua and Agadez.

Seasonal complementarity

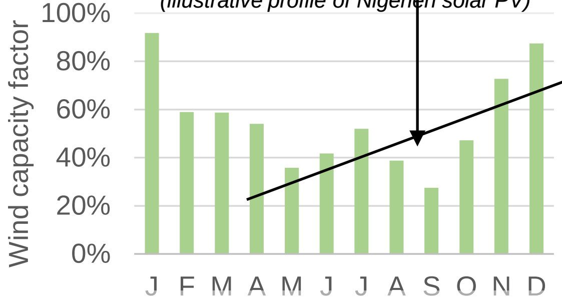


(illustrative profile of Nigerien reservoir plant - Kandadji)

The strongest solar season in Niger coincides with the weakest hydro season. Wind is at its weakest when hydro is increasing again later in the year.

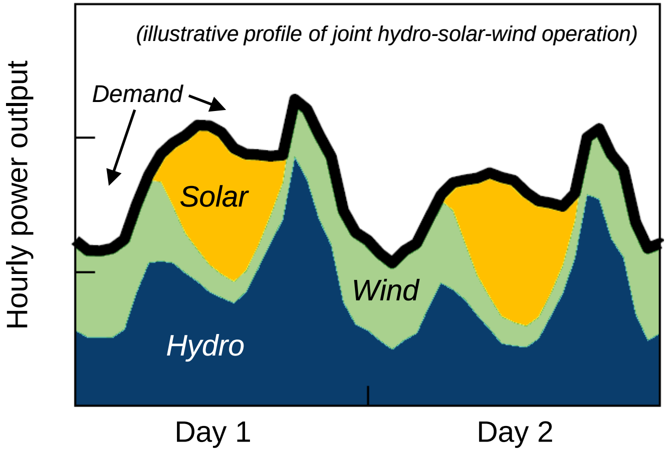


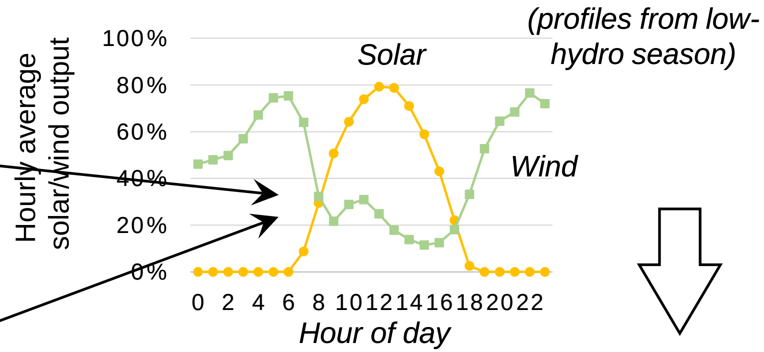
(illustrative profile of Nigerien solar PV)



(illustrative profile of Nigerien wind power)

Diurnal complementarity





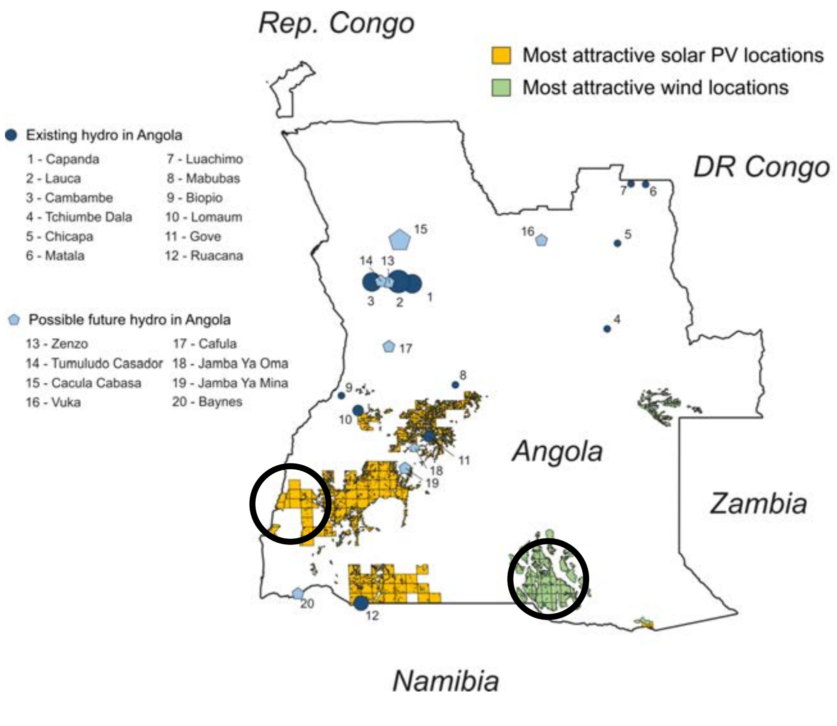
To achieve such a mix would require

- **Expanding Niger's grid** to interconnect its currently independent four grids (river, south, south-east, north)
- a smart choice of **solar/wind** portfolios
- hydroturbines that allow for sufficient **ramping speed** at Kandadji

Hydro, solar and wind are complementary: Angola

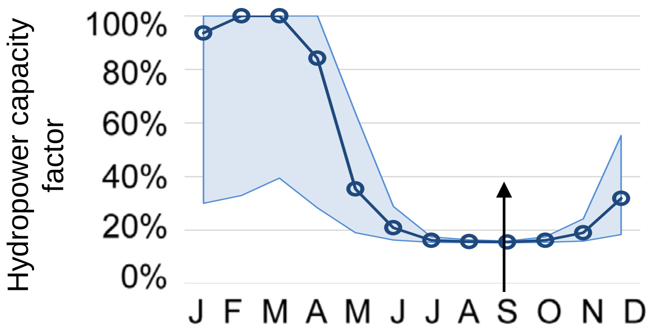
Sources: Sterl et al. 2020 / Sterl et al. 2021 (REVUB model simulations on hydro-solar-wind mixes), Sterl et al. 2021 & IRENA 2022 (African Hydropower Atlas), Sterl et al. 2022 (solar & wind model supply regions for Africa)

Spatial complementarity



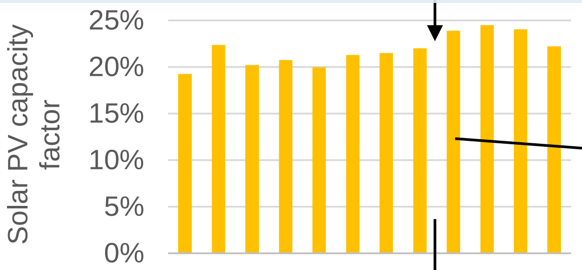
Angola's best **solar PV** resources are partly co-located with good **hydropower** sites, and generally along the North-South axis connecting Luanda with the Namibia border. Angloa's **wind** power potential is concentrated in higher-lying areas towards the east and south of the country.

Seasonal complementarity

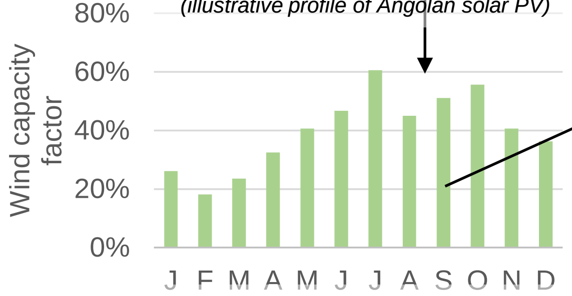


(illustrative profile of Angolan reservoir plant - Capanda)

River flows in Angola are subject to strong seasonalities. **Solar PV** and **wind** in Angola have an opposite seasonality.

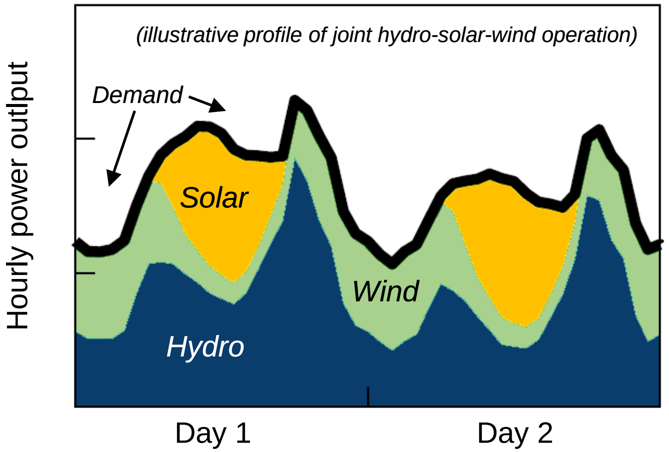


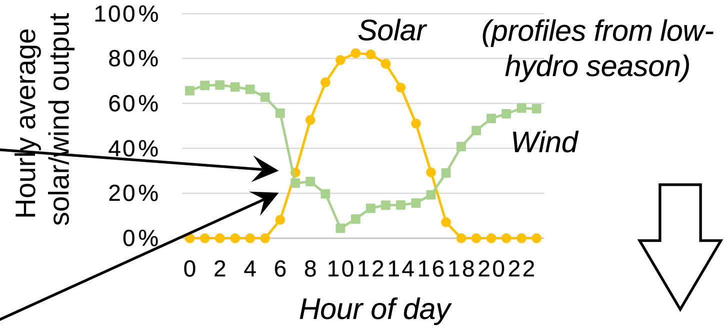
(illustrative profile of Angolan solar PV)



(illustrative profile of Angolan wind power)

Diurnal complementarity





To achieve such a mix would require
- **Connecting solar/wind areas** close to Angola's existing/planned grid
- a smart choice of **solar/wind** portfolios
- hydroturbines that allow for sufficient **ramping speed** (e.g. through refurbishment)

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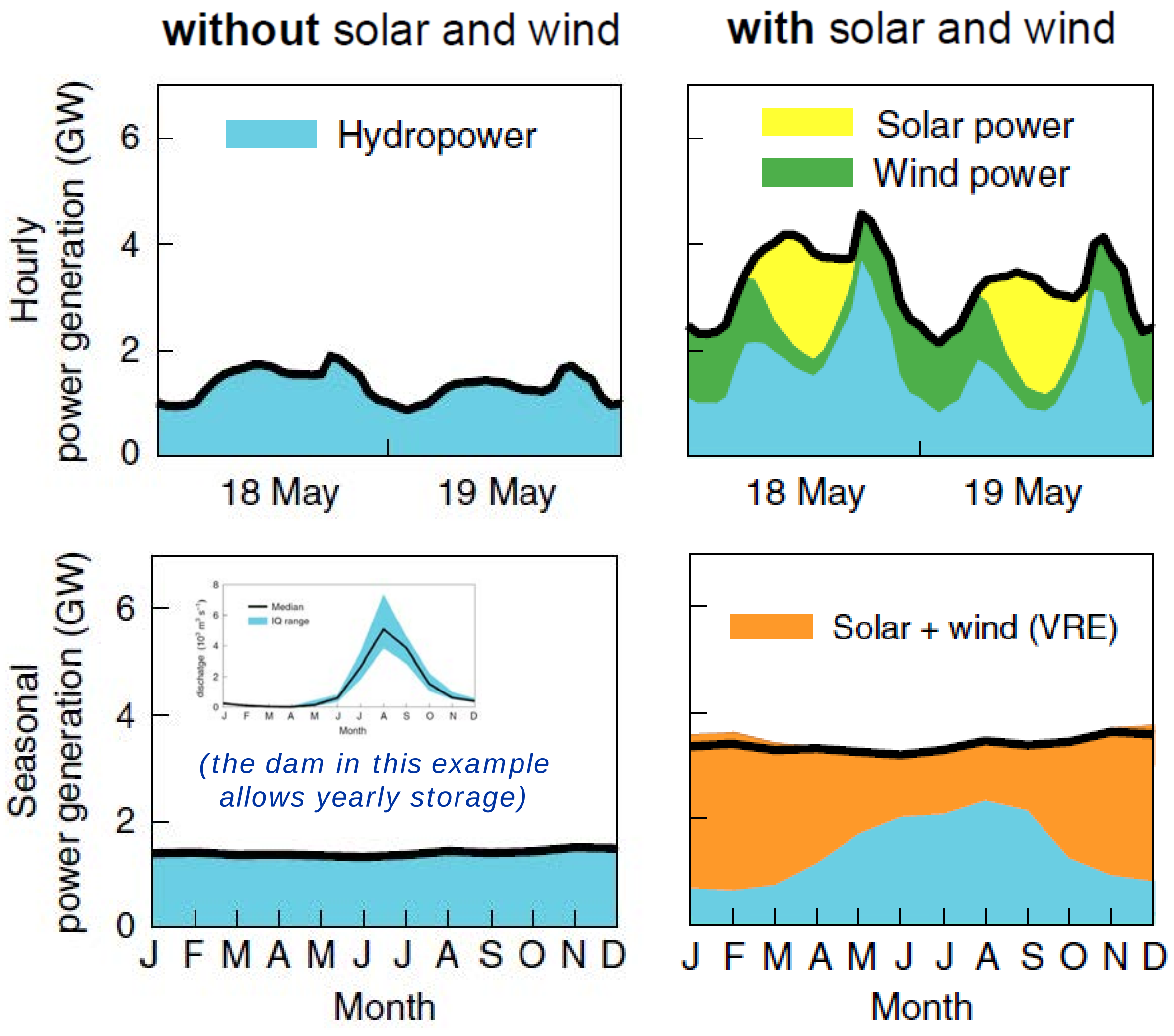
CONSEQUENCES: RIVER FLOW

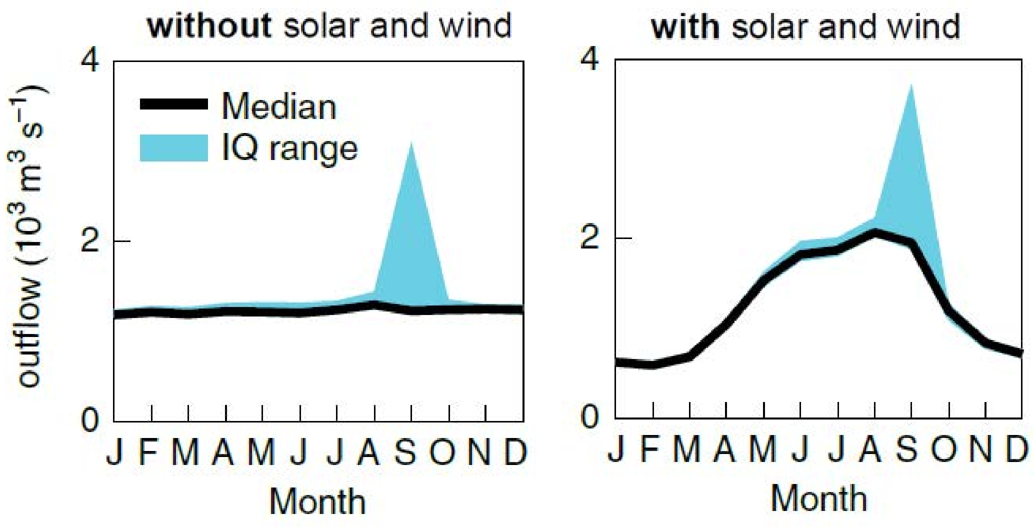
Power generation



Seasonal profile is absent

Seasonal profile is reintroduced

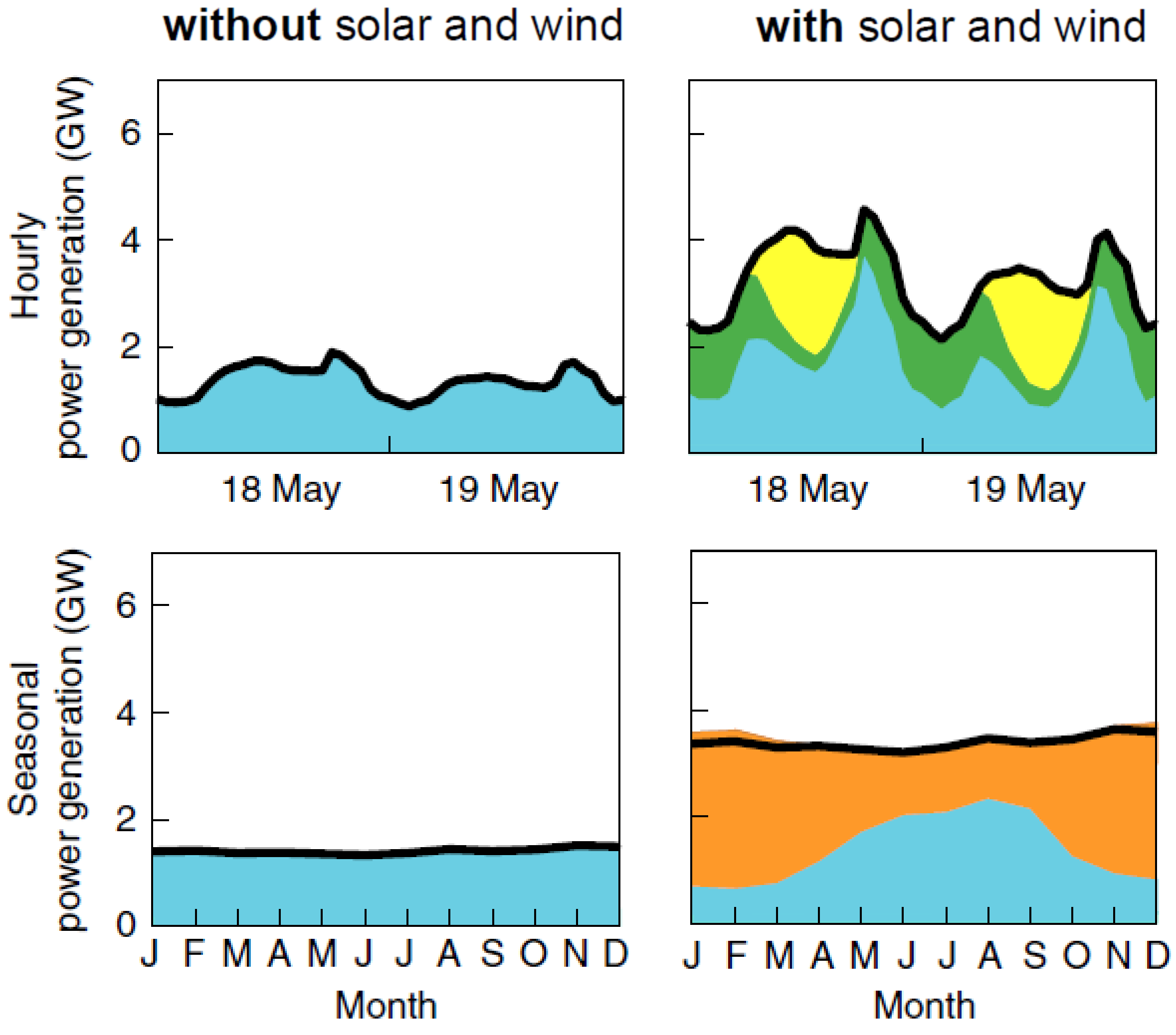
River flow



- For very large dams, hydro-VRE operation can be well harmonised with certain environmental goals

CONSEQUENCES: PEAKING

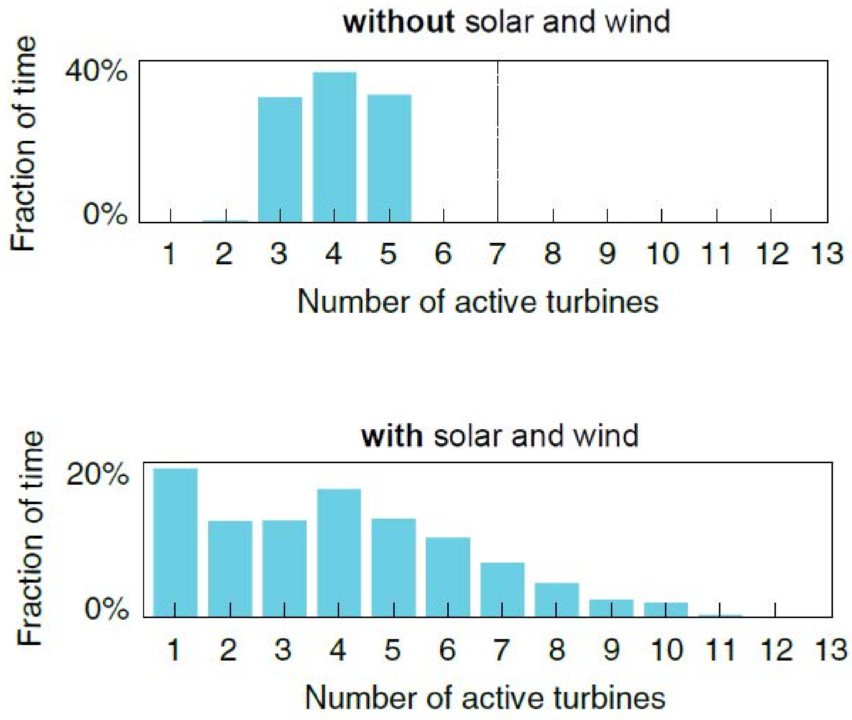
Power generation



Seasonal profile is absent

Seasonal profile is reintroduced

Turbine use



- Under VRE integration, the number of periods with *low* and *high* number of turbines active simultaneously will increase

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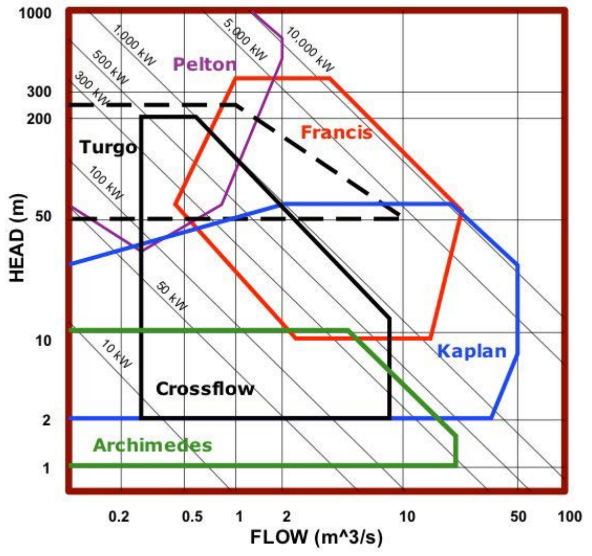
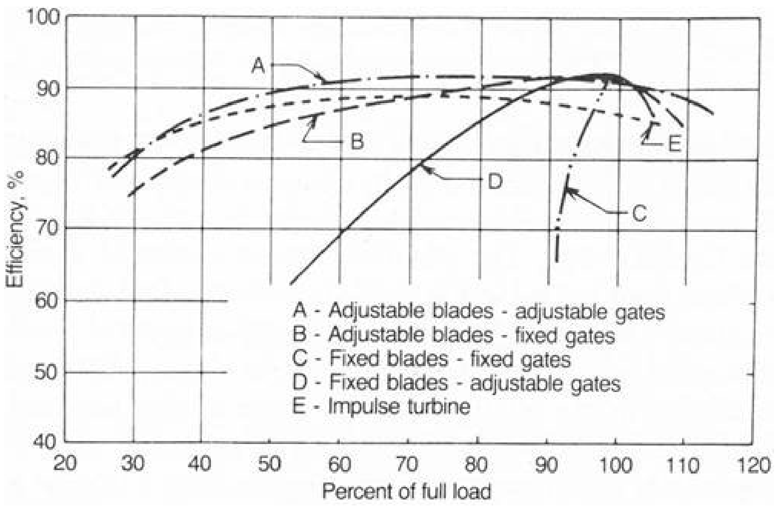
HYDROPOWER CHARACTERISTICS

What hydropower characteristics are needed to increase complementarity with VRE?

- Site determines turbine category (Kaplan/Francis/…)
- For VRE integration, turbine selection must allow high efficiency at part-load operation (→ basic design element)
- Turbine & waterway design must allow sufficient ramping speed (MW/min) & be adapted to frequent start/stop
- Increased operation & maintenance due to higher wear & tear of equipment (frequent start-stopping & faster ramping)
- Retaining correct balance between flexibility/reserves and baseload



https://handoutset.com/wp-content/uploads/2022/05/Guidelines-for-design-of-small-hydropower-plants-Helena-Ramos..pdf



https://www.renewablesfirst.co.uk/wp-content/uploads/Kaplan-turbine-efficiency-curve-comparisson.jpg

HYDROPOWER CHARACTERISTICS

What does it cost operationally? Example →

Start/stop costs including
- Ramping costs
- Increased maintenance
- Accelerated equipment degradation/lifetime
- Reduced efficiency

- Effect on LCOE?

Cost category	Value
Typical CAPEX	$2500 – 3000 per kW
Typical OPEX	$70/kW/year (fixed) $0.003/kWh (variable)
CF	50%
Cost of capital	10%
Lifetime	50

https://researchportal.vub.be/en/publications/the-feasibility-of-solar-pv-to-replace-the-koukoutamba-hydropower

All else being equal, LCOE jumps by less than 1% when including costs of 4 start/stops per day
(generic: 0.2 USD/MWh for each additional daily start/stop)

⇩

The **market signal** of remuneration of flexibility services is likely to be substantially more important than the additional OPEX of flexibility

Assumption	Value
Start/stop costs	$274 - $411 per start/stop for 150 MW plant (*)
Number of start/stops	4 per day

(*) U.S. Department of the Interior, Bureau of Reclamation (2014). Hydrogenerator Start/Stop costs.

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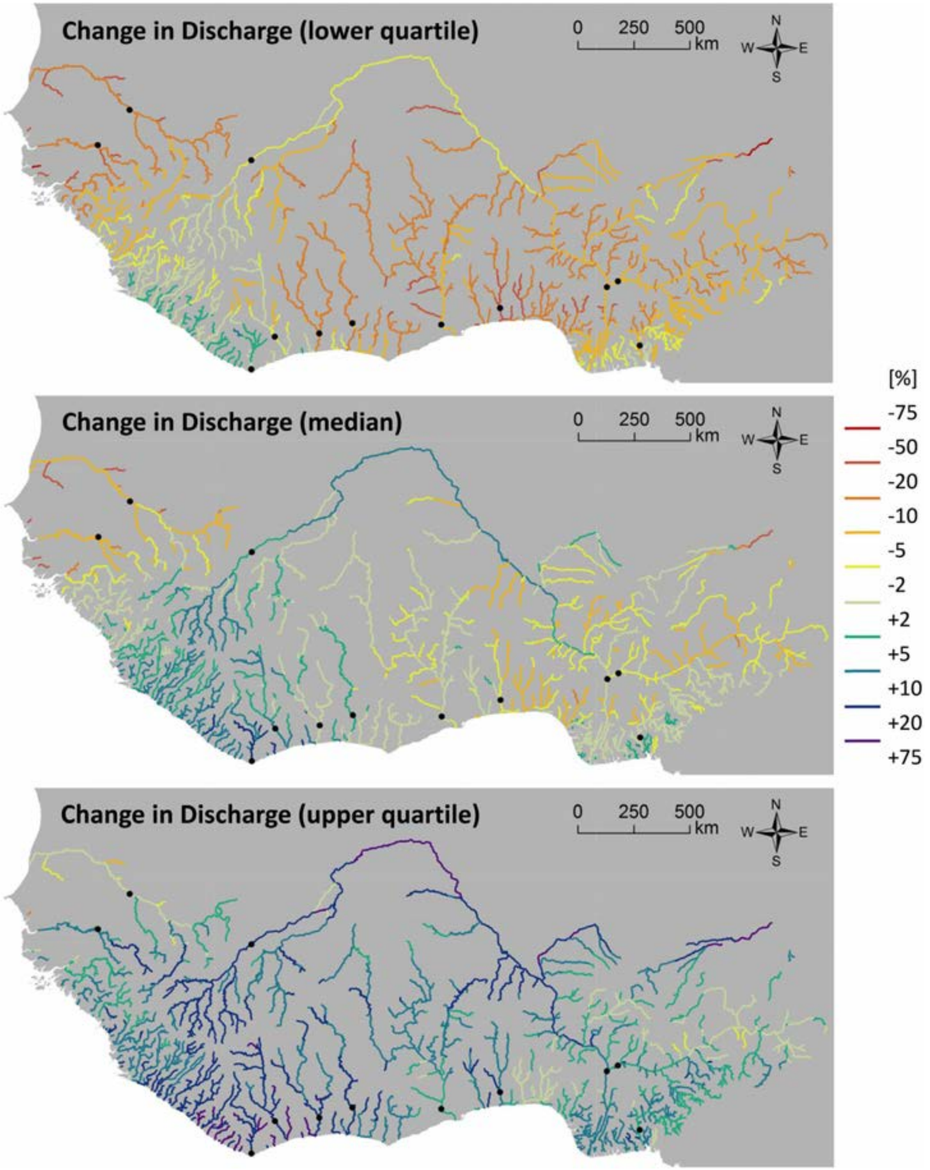
- **CLIMATE CHANGE EFFECTS**
- CONCLUSIONS

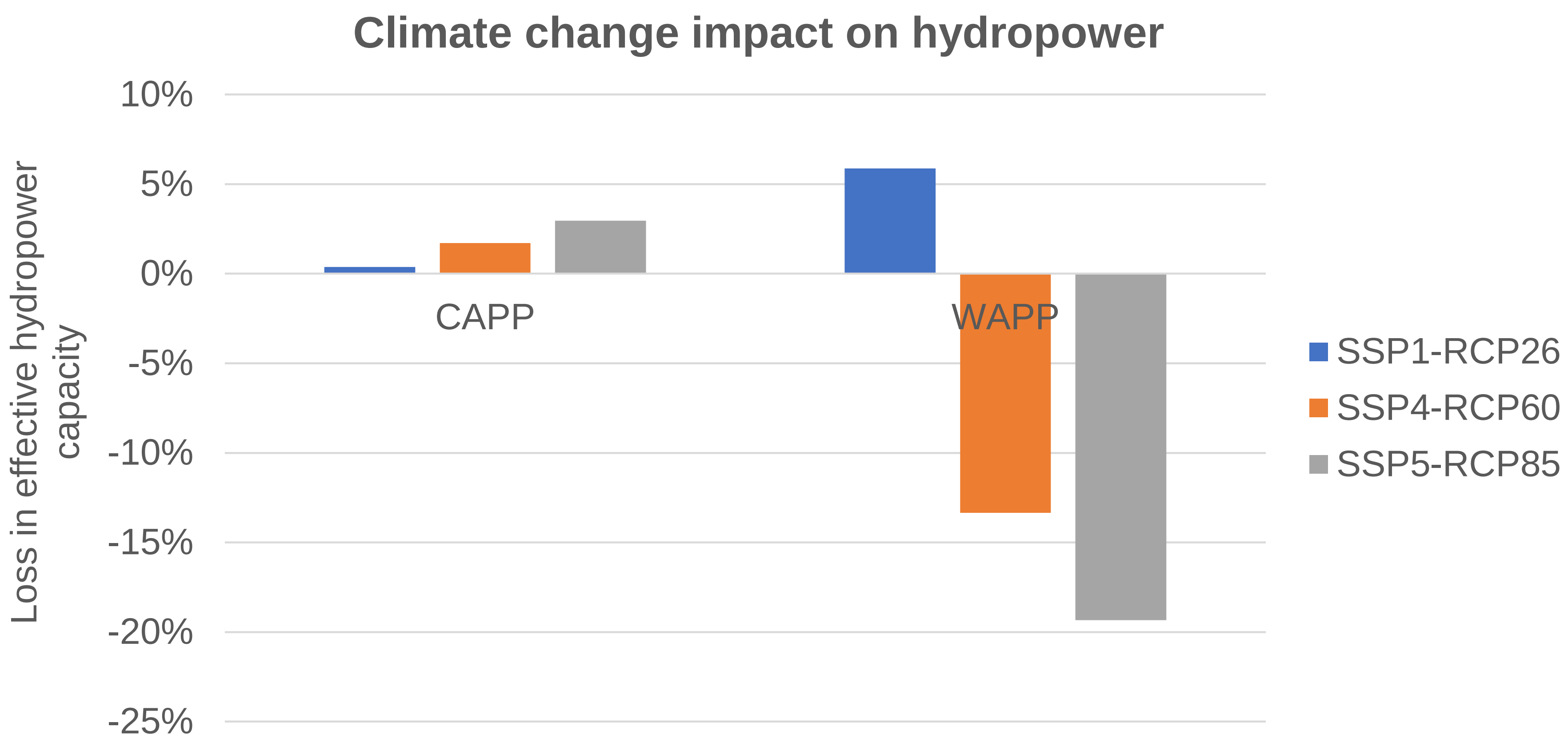
IMPACTS OF CLIMATE CHANGE



https://www.sciencedirect.com/science/article/pii/S2405880717300894

- Impact of climate change on river flow depends on specific river basin
- Many river basins have diverging model predictions; uncertain whether discharge will increase or decrease
- Impact of climate change will be superimposed on impact of land use change

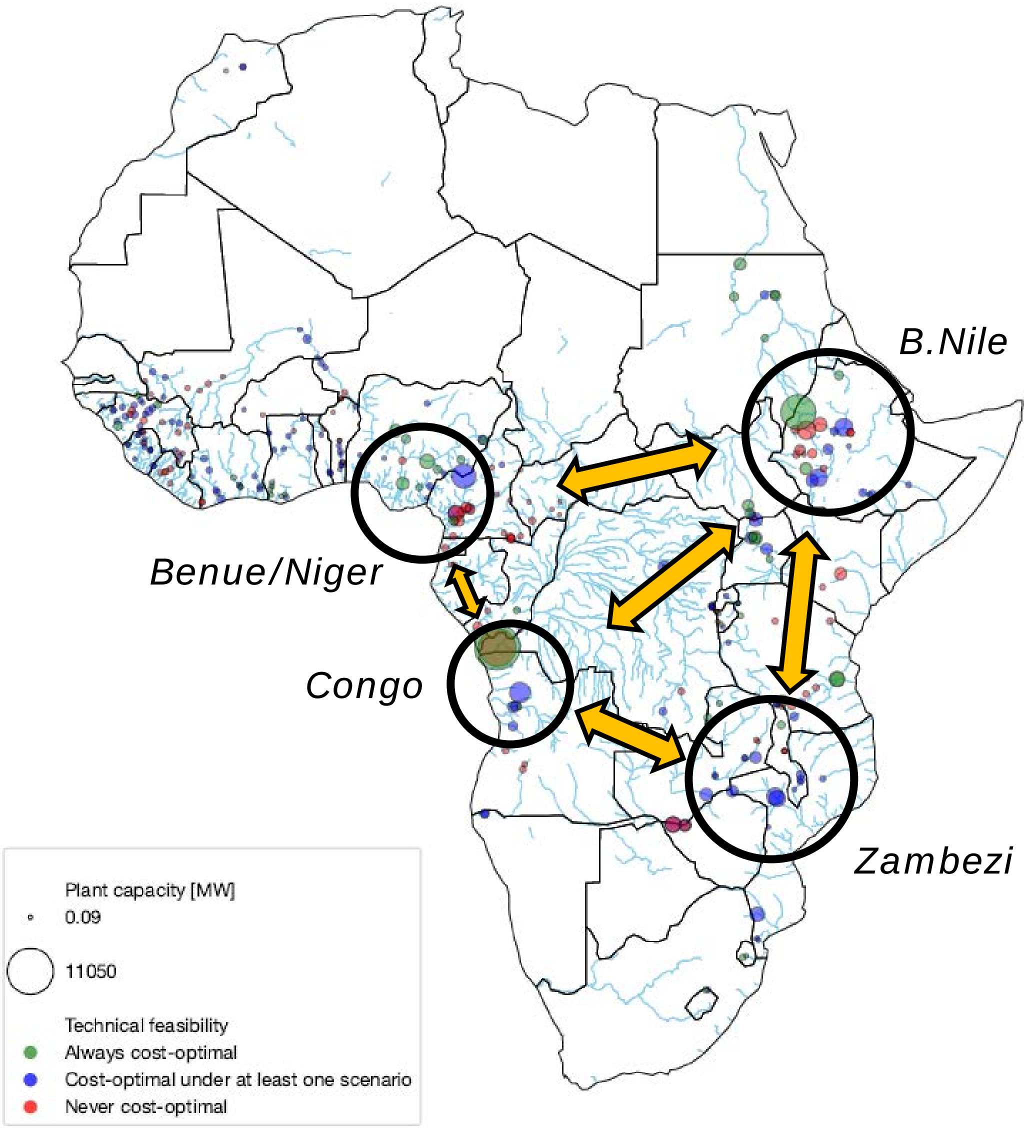
IMPACTS OF CLIMATE CHANGE



- ➢ Graph includes existing and candidate hydropower
- ➢ Central Africa most likely not affected negatively
- ➢ West Africa hydro may suffer harsh consequences under climate change → diversification is generally prudent strategy

https://www.irena.org/publications/2021/Dec/African-Renewable-Electricity-Profiles-Hydropower

RESILIENCE AGAINST CLIMATE IMPACTS



Carlino et al. (2023). *Declining cost of renewables and climate change curb the need for African hydropower expansion*. Forthcoming in *Science*.

- Forthcoming paper in *Science*: which future hydro plants in Africa are cost-optimal?
- Most attractive hydro concentrated in few basins (Blue Nile, Zambezi, Congo, Niger/Benue)
- Interconnections are of importance to avoid concentration of *impacts*!
- Diversification of power supplies away from hydro-dominance
- VRE is <u>highly useful</u> to diversify & complement hydro in general, although not a safeguard against very dry hydro years

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SUMMARY OF BENEFITS OF HYDRO-VRE SYNERGIES

Complementary hydro-VRE planning and operation in West & Central Africa would have various advantages:

- ✓ Provides a "**capacity credit**" to VRE by absorbing it into firm and reliable portfolio; helps keep hydro **lake levels** relatively more stable year-round
- ✓ Synergises with increased **interconnection efforts** underway—needed to fully exploit hydro-VRE synergies and make system resilient to hydro shocks
- ✓ Synergises well with **environmental flow requirements** downstream of hydro
- ✓ Includes additional O&M and costs, but these are likely to remain small in comparison to **market signals** on flexibility remuneration
- ✓ Hydro-VRE potential is <u>not</u> enough to cover 100% of future demand growth in Africa, but can provide important low-hanging **push to kickstart VRE growth** in many countries