CIREG

Climate Information for Integrated Renewable Electricity Generation

Info brief

Climate-smart Co-management of Energy and Water

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ERA4CS European Research Area for Climate Services

JPI Climate

1 Climate-smart co-management of Energy and Water

Preamble

This Info brief reports insights from the *Climate information for Integrated Renewable Electricity Generation* (CIREG) project, for decision and policy makers in Burkina Faso and Ghana. The project aims to discuss these results with all stakeholders and also open questions. These insights are derived from i) thorough analysis of national policies, strategies and plans, ii) modelling results and iii) participatory scenario building through dialogues sessions between scientists and stakeholders in the countries. This brief reflects the *status quo and* includes the results of training workshops held in Accra and Ouagadougou. Itwill be further updated and finallized, before the end of CIREG project,to share outcomes and inform policy making in both countries.

Key messages

- Under climate change, the predominant trend is an increase in rainfall and streamflow on top of rising temperatures.
- Hydropower production mayslightly increase in the 2030s& 2050s and the variability in hydropower production may decrease compared to itscurrent level. This points towards additional future hydropower potential.
- By mid of the century, renewable energies can replace fossil fuels provided i) complementarities of all different renewables are exploited towards a smart energy mix, ii) a transboundary power pool is established across West African countries, iii) decentralized solutions complement the central grid wherever appropriate, and iv) all other available measures are implemented (e.g. demand management, storage).
- Given the many inter-dependencies between energy and water, their co-management holds additional potentials for synergies and improved energy and water security.

Introduction

Centralised grid electricity is still the dominant form of energy supply in West Africa. About 84% of the national population in Ghana had access to electricity (in 2018) and only 20% of Burkina Faso's population had access (in 2016). About 99% of those with access to electricity are served with centralised grid electricity, with only a small proportion of the population, mainly from rural areas, relying on mini-grids and distributed renewable energy systems. Under climate variability and change, the centralised grid systems are facing and may likely continue to face many challenges to meet the rising demand. The challenges will possibly constrain natural resources particularly water resources for hydropower on which the grid electricity strongly relies.

An integration of both centralised and decentralised solutions can provide a long-term solution for sustainable electricity supply under climate change. Building upon on-going experience, fact-checking local cases and testing the effectiveness of these solutions, the CIREG project conducted case studiesbut also installed demonstrators in three locations of West Africa:

- An off-grid photo-voltaic (PV) power plant connectingnot less than 120 households (Sekoukou village, South-West Niamey, Niger), impacting the life of at least 840 people.
- A centralized PV-based borehole water pumping systemwhich is providing access to clean water for consumption and micro-irrigation of the villagers involved in market gardening.At least 60 women are benefiting from the facility in the village of Jamih (East of Niamey, Niger).

- A hybrid Hydropower-solar power generation to provide electricity to a local community business centerin Gbandidi (North-East of Lomé Togo, in the Mono river basin).

In this brief, we look at the "smartness" of the management, provision and use of renewable energy under changing and variable climate. We use multiple tools to assess climate impacts and the inter-linkages between energy and water for alternative pathways to climate-smart and sustainable renewable electricity generation.

Potential of hydropower under climate change

Climate change impacts on hydrology and water resources

- Ten different global climate models (provided by the ISIMIP3b project[1] for the Representative Concentration Pathway (RCP) 2.6 and 7.0, bias-adjusted and downscaled, were used to estimatefuture temperatures, precipitation, river discharge and inflows into the reservoirs (Figure 1: Future projections for rainfall (top) and temperature (bottom) over the Volta basin using an ensemble of climate models for RCP 2.6 and RCP 7.0. Blueish colours in the rainfall plots indicate wet years and reddish colours dry years, respectively.~~Figure 1~~).

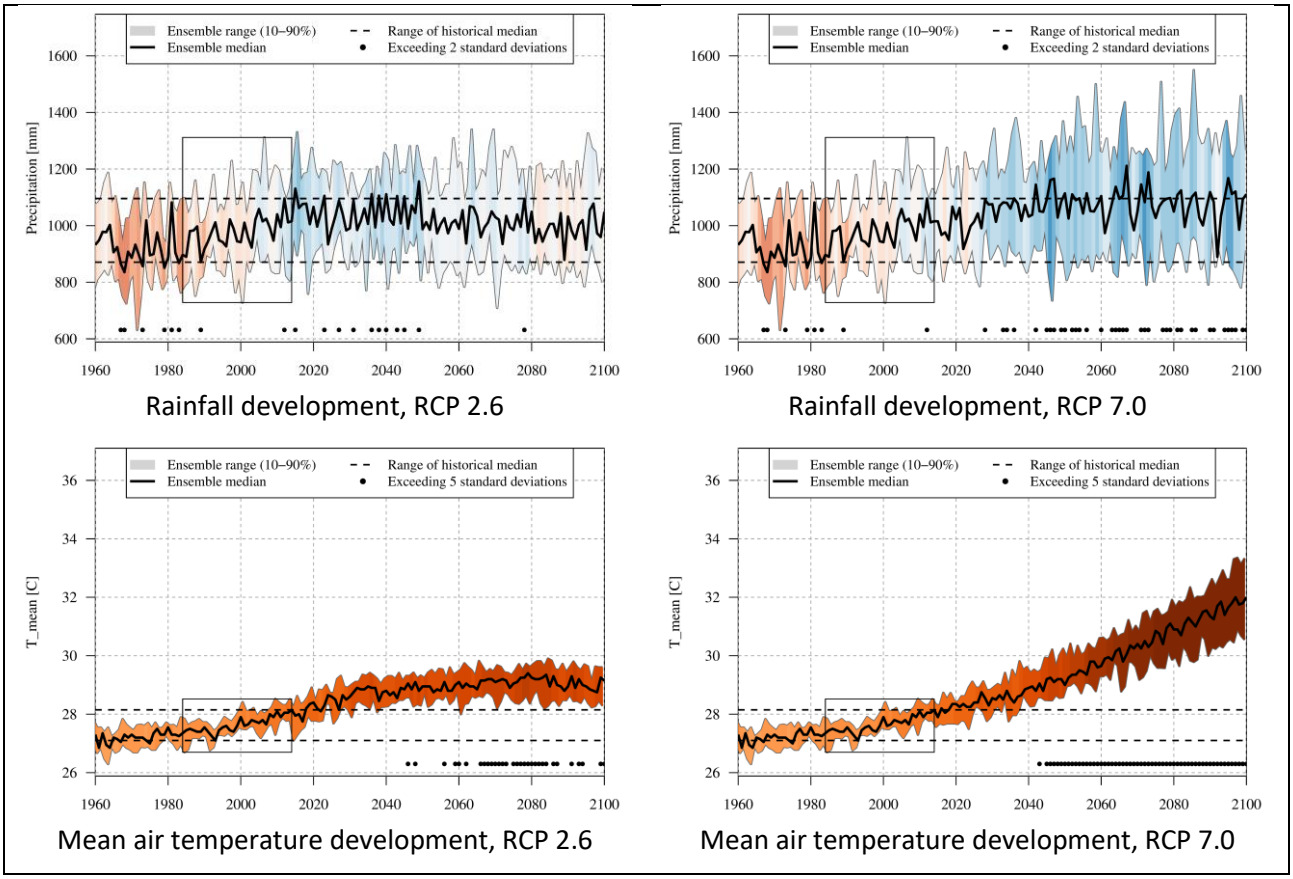


Figure 1: Future projections for rainfall (top) and temperature (bottom) over the Volta basin using an ensemble of climate models for RCP 2.6 and RCP 7.0. Blueish colours in the rainfall plots indicate wet years and reddish colours dry years, respectively.

- Compared to the reference period (1984-2014), average rainfall over the entire Volta basin is projected to increase by about 6-8% by for the time horizon 2030 (years 2015 to 2045) and by 7-10% for the time horizon 2050 (years 2035 to 2065).
- An increase of average air temperature by 0.9°C is expected by 2030 and up to 1.7°C by 2050.

[1] https://www.isimip.org/

- Simulations show increasing annual inflows into the Bagré reservoir and Lake Volta under climate change (Figure 2: Future projections for inflow into the Bagré reservoir (top) and Lake Volta (bottom), from hydrological simulation using an ensemble of climate models under RCP 2.6 and RCP 7.0. Blueish or reddish colours indicate high and low inflows, respectively.~~Figure 2~~).This is mainly due to larger inflows in the rainy season while the changes of inflows during the dry season are considered to be minor.

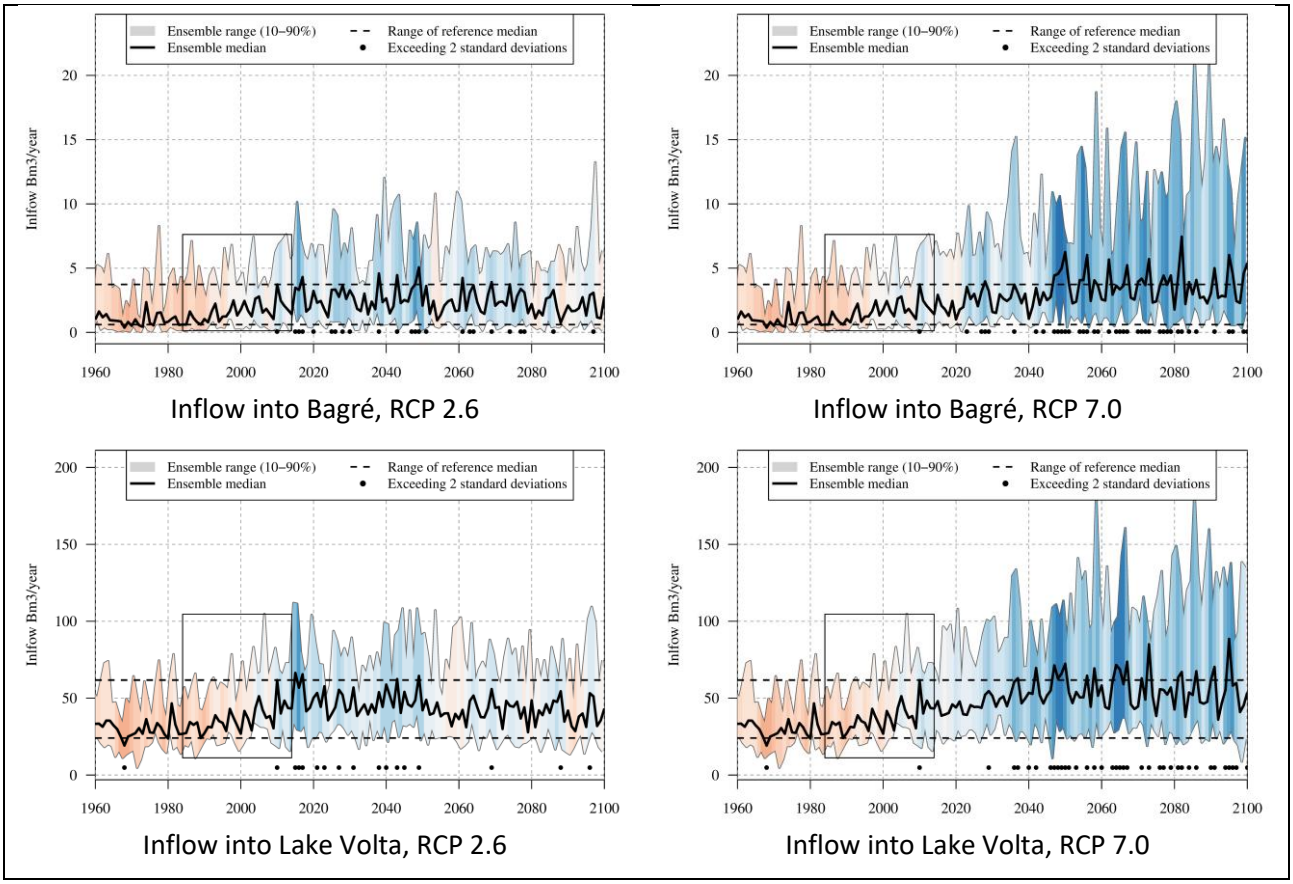


Figure 2: Future projections for inflow into the Bagré reservoir (top) and Lake Volta (bottom), from hydrological simulation using an ensemble of climate models under RCP 2.6 and RCP 7.0. Blueish or reddish colours indicate high and low inflows, respectively.

Impact on hydropower production

- The projected changes in inflows under climate change have been integrated in our simulations with increases in water demands (mainly irrigation and drinking water supply), as well as with the implementation of new dams, to assess the overall impact on hydropower production(Figure 3: Hydropower production for the historical period, horizon 2030 (years 2015 to 2045) and horizon 2050 (years 2035 to 2065) using an ensemble of climate models, pooling together RCP 2.6 and RCP 7.0. The cross and connecting line represent the average monthly production, the box the range containing 50% of the models, the horizontal line in the box the median and the whiskers the extremes of the models' results.~~Figure 3~~).

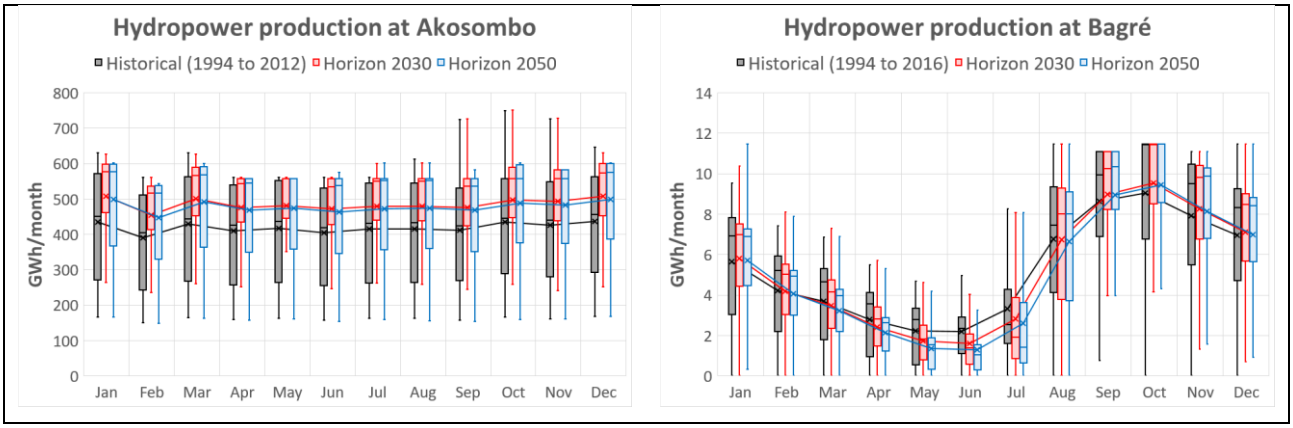


Figure 3: Hydropower production for the historical period, horizon 2030 (years 2015 to 2045) and horizon 2050 (years 2035 to 2065) using an ensemble of climate models, pooling together RCP 2.6 and RCP 7.0. The cross and connecting line represent the average monthly production, the box the range containing 50% of the models, the horizontal line in the box the median and the whiskers the extremes of the models' results.

- The projected increase in streamflows, will accumulate gradually from upstream to downstream of the basin, in the Lake Volta. As a consequence, the hydropower production at Akosombo is projected to increase by about 15% (average production 5,800 GWh/year) and 14% (average production 5,700 GWh/year) for the time horizon 2030 and 2050, respectively, compared to the historical period (5,000 GWh/year, years 1994 to 2012).
- The plans to expand the crop areas irrigated by the Bagré dam, lead to increased water demand. The simulated greater inflow into the reservoir (see above) almost compensates this increase in irrigation water demand, overall leading to a small decrease in hydropower production. The average production is about 62 and 60 GWh/year for the time horizons 2030 and 2050 respectively, as compared to the production during the historical period (63 GWh/year). The reduction in hydropower production is particularly prominent at the end of the dry season, in May and June, following the peak of the irrigation demand, while there is greater hydropower production during the rainy season.
- The variability of hydropower production at Akosombo and Bagré is projected to decrease, as compared to historical values, as shown by the smaller boxes and whiskers for the future time horizons in Figure 3: Hydropower production for the historical period, horizon 2030 (years 2015 to 2045) and horizon 2050 (years 2035 to 2065) using an ensemble of climate models, pooling together RCP 2.6 and RCP 7.0. The cross and connecting line represent the average monthly production, the box the range containing 50% of the models, the horizontal line in the box the median and the whiskers the extremes of the models' results.~~Figure 3~~..
- Hydropower production in the new dams Bagré aval (in Burkina Faso) and Pwalugu (Ghana) is projected to show typical seasonal patterns, the one at Bagré aval being very similar to the production at Bagré (Figure 4: Hydropower production for the time horizons 2030 and 2050 using an ensemble of climate change models, pooling together RCP 2.6 and RCP 7.0, assuming that Bagré aval is commissioned in 2025 and Pwalugu in 2030. The cross and connecting line represent the average monthly production, the box the range containing 50% of the models, the horizontal line in the box the median and the whiskers the extremes of the models' results~~Figure 4~~). The average hydropower production is projected to be about 60 GWh/year (Bagré) and 270 GWh/year (Pwalugu) for both time horizons, 2030 and 2050.

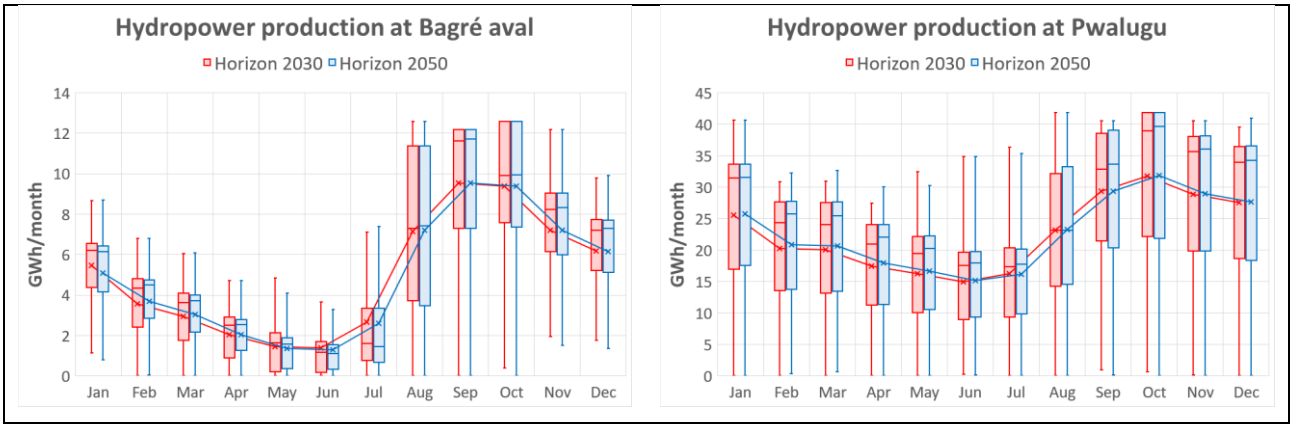


Figure 4: Hydropower production for the time horizons 2030 and 2050 using an ensemble of climate change models, pooling together RCP 2.6 and RCP 7.0, assuming that Bagré aval is commissioned in 2025 and Pwalugu in 2030. The cross and connecting line represent the average monthly production, the box the range containing 50% of the models, the horizontal line in the box the median and the whiskers the extremes of the models' results

The future of electricity generation in Ghana and Burkina Faso

- Extrapolation of trends in domestic electricity consumption would lead to a demand of 23 thousand GWh in 2030 and 46 thousand GWh in 2050 in Ghana and 5 thousand GWh in 2030 and 15 thousand GWh in 2050 in Burkina Faso.
- Ghana and Burkina Faso are struggling with electricity losses, on average 29% and 17% respectively for both transmission and distribution losses, calling for efficiency in the grid consequently high generation requirement. To cover for these losses, the generation output must be of 34 thousand GWh in 2030 and 66 thousand GWh in 2050 for Ghana, and 6 thousand GWh in 2030 and 18 thousand GWh in 2050 for Burkina Faso.
- Inorder to mitigate further climate change, the world will need to bring down fossil fuel use to zero by mid-century. Yet, both Ghana and Burkina Faso still rely mainly on fossil fuel. Model projections show that the share of fossil fuel in electricity production will increase to 73% and 56% in Ghana and Burkina Faso respectively until 2030 (**Error! Reference source not found.**~~Figure 5~~).In Burkina Faso, there is also an increase in other renewables (solar and small hydropower), while the share of large hydropower is expected to drop even further to only 6% in 2020 and then increase to 8% in 2030 by the commissioning of Bagreaval (14MW) power plant in 2025.

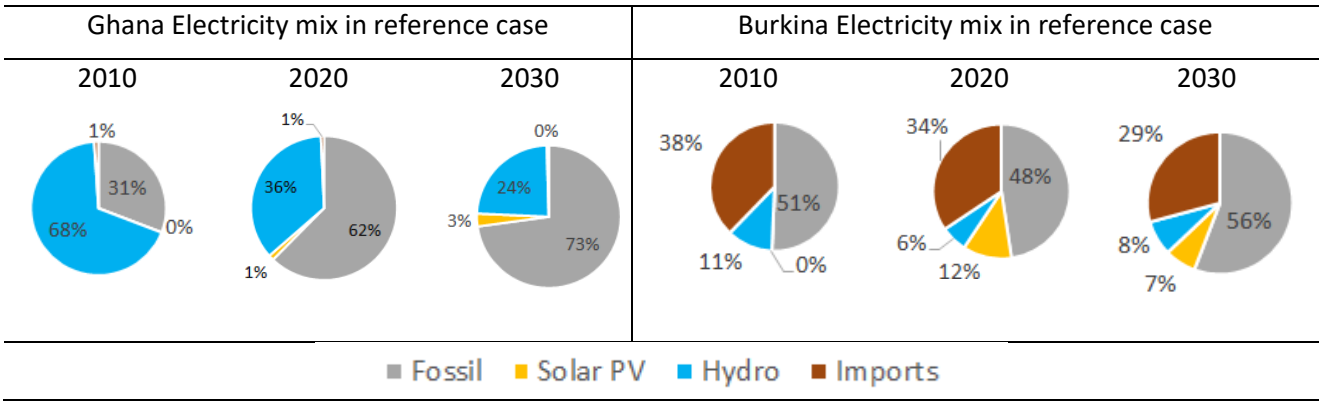


Figure 5: Historical and projected changes in grid electricity mix in Ghana and Burkina Faso, assuming implementation of renewable energy continues at a low rate as per historic trends

- Of the 645GWh of electricity imported by Burkina Faso in 2017, 90% of came from Ivory Coast, 9% from Ghana and 1% from Togo.According to the Institute for Global Environmental Studies (IGES),

the grid GHG emission factors for Ivory Coast and Ghana is 0.63 and 0.47 respectively, meaning that over 50% of Burkina Faso's imported electricity is fossil-based, which therefore increases Burkina's carbon footprints[2](Institute for Global Environmental Strategies, 2020) and the total contribution of fossil fuels to Burkina's electricity generation is even larger than shown in Figure 5.

- The projected increase of inflow at Akosombo leads to an opportunity to increase the hydropower production from about 55% of its operational capacity to 68%, while still maintaining the dam levels and buffers. This would raise hydropower generation by about 800 GWh/year in 2030 and 700 GWh/year in 2050.
- Realizing this potential of running Akasombo and Bui closer to operational capacity, in combination with fully implementing the national renewable energy master plan (REMP, 2019) can reduce fossil fuel use further, from projected 73% to 56% in 2030 (assuming 30% hydropower and 13% other renewables and business-as-usual demand growth).
- At Bagré and Bagré aval, no significant increase in hydropower generation is projected for the 2030 time horizon. The average annual maximum available capacity in the climate change scenarios is 57% and 50% - slightly higher than the historic average (year 2010) - for Bagre and Kompienga respectively.

Solar-wind-hydro complementarities in renewable electricity generation

- Exploiting the complementarities of solar, wind and hydropower presents a unique opportunity to increase renewable electricity generation further. Building on the approach described by Sterl et al. (2020) we implement complementary hydropower and solar photovoltaic operation to increase the share of solar PV. More specifically, we implemented solar power generation as complemented by dammed hydropower (bridging gaps in solar power generation) for Akosombo and Bui hydropower plants in Ghana, and Bagré and Kompienga hydropower plants in Burkina Faso. In practice, this comes down to increasing hydropower generation during evening peak demand and night-time, when solar power is unavailable, and ramping hydro plants back down during daytime to make space for the solar contribution.
- Implementing the Renewable Energy Master Plan for Ghana and the Plan d'Action National des Energies Renouvelables (PANER) for Burkina Faso, while taking into account these solar-hydro complementarities, increases the possible renewable electricity contribution to the grid from 27% to 58%in Ghana by 2030, and from 15% to 31% in Burkina Faso by 2030 (Figure 6~~Figure 6~~).

Ghana electricity mix projection in 2030 with complementary hydro-solar strategies	Burkina Faso electricity mix projection in 2030 with complementary hydro-solar strategies

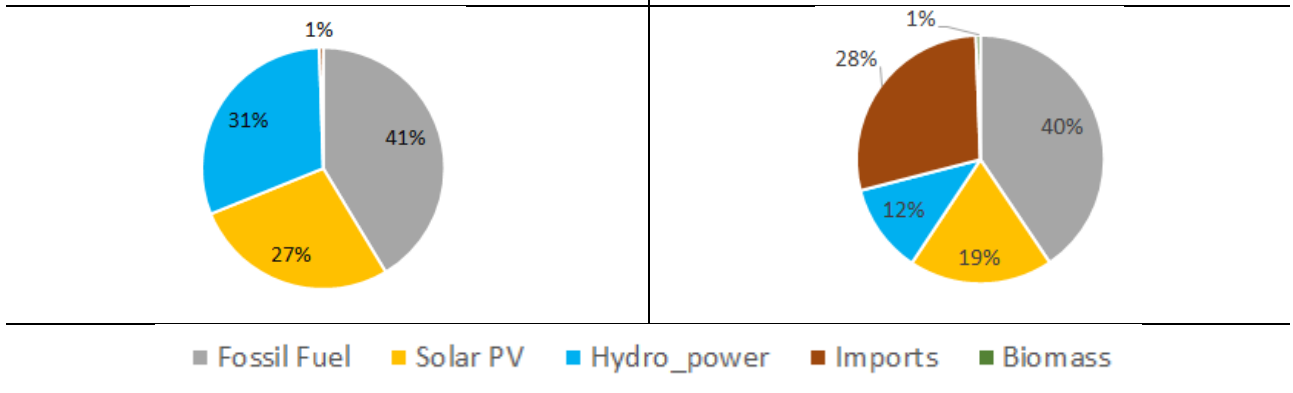


Figure 6: Harnessing complementarity of renewable electricity between hydropower and solar for Ghana and Burkina Faso.

[2][1]Institute for Global Environmental Strategies, 'IGES List of Grid Emission Factors' 10.9 (2020): 5.

Phasing out fossil fuels – closing the gap

- Greater transformative ambitions to replace fossil fuels completely with renewable energy are necessary worldwide and hence also in Ghana and Burkina Faso. Variable Renewable Electricity (VRE) sources, such as solar PV, can be integrated into national grids while safeguarding grid stability with a variety of tactics: generation-based, storage-based and demand-based.
- Among the generation-based tactics, as a first step, the flexibility of existing plants (mostly natural gas and hydropower) can be used to compensate such variability, as demonstrated above for complementary hydro-solar operation. Further, implementing trans-national power pools and electricity trade also holds great promises for exploiting renewables' complementarity, also in West Africa (Sterl et al. 2020).
- Among the storage-based tactics, battery storage solutions currently appear to be the most promising option, with strongly decreasing costs in the last years showing no signs of abating (Lazard Ltd., 2020)[3]. Solar-plus-battery solutions have been suggested to become the most important power generating source across West Africa by 2050, with large-scale deployment starting post-2030 to achieve zero-carbon power systems by mid-century (Oyewo et al. 2020)[4].
- Among the demand-based tactics, demand response to better match VRE production profiles with demand may play an important role in the future, as may energy efficiency measures to lower the growth rates of overall power demand.
- We projected a 30% share of solar photovoltaic contribution to grid electricity mix by 2050. To achieve this, a total capacity of about 2.3 GW for Burkina Faso and 6.6 GW for Ghana would be required, which calls for reliable grid stability, control and improved weather forecasting for better daily/weekly/monthly dispatch planning.
- Integrating off-grid solutions, in view of the complexity of grid operations, would require a coevolution of centralised grid and small-scale decentralised grids and off-grid solutions.

Interlinkages of energy and water and – the need for co-managing these two resources

- Electricity generation requires large amounts of water, depending on the type of generation. Hydropower and biomass-based electricity generation, as well as cooling of thermal power plants, are most water-intensive. Thermal solar and PV are less water-intensive. Wind-powered electricity does not require significant amounts of water. Therefore, a reduction of fossil fuel-based electricity generation comes with the co-benefit of reducing the water demand for electricity generation (depending on the type of renewable by which it is replaced).
- Providing water for irrigation, households and other uses requires large amounts of energy, in particular for pumping, but also for other steps in water supply, e.g. desalination of saltwater, treating water and wastewater, heating of water etc. Fossil fuels (e.g. diesel for pumping) need to be replaced with renewables in order to mitigate climate change.
- The co-management of energy and water holds large potentials for sustainable and climate-smart improvements of energy and water security, electricity and clean water for all.
- CIREG has only just begun to address the interlinkages between energy and water (the "energy-water nexus"). Based on the science-stakeholder discussions at the upcoming workshop, we will implement critical issues and solutions (e.g. solar driven water pumping, energy recovery in wastewater treatment plants, co-generation of electricity and water etc.) in CIREG's planning tools which will be available for further use to all interested partners in Ghana and Burkina Faso.

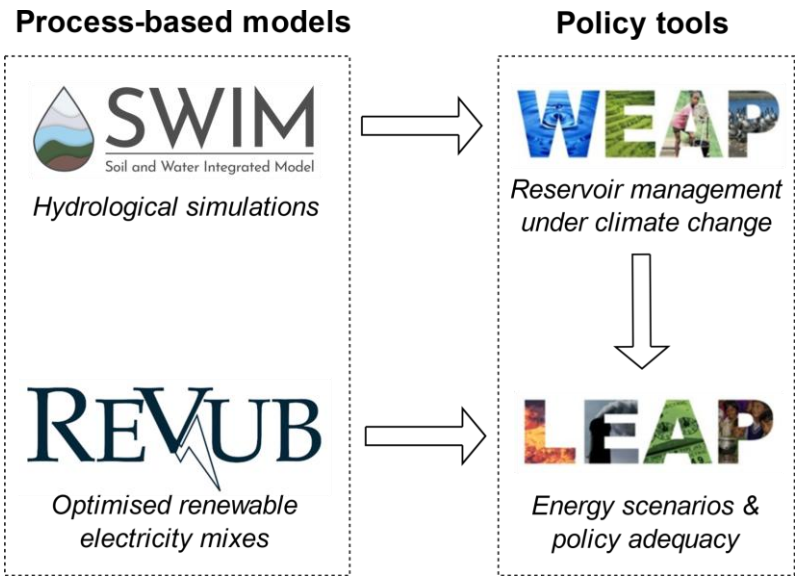
[3] https://www.lazard.com/media/450774/lazards-levelized-cost-of-storage-version-40-vfinal.pdf
[4] https://www.sciencedirect.com/science/article/pii/S0960148120304109

2 Open questions for discussion

- Pathways and strategies for a sustainable co-management of energy and water under climate change and economic development:
    - What are the water requirements for sustainably meeting electricity demands for all in different scenarios in Ghana and Burkina Faso, e.g. for hydropower, cooling water demands of fossil fuel power plants, water demands to clean PV panels, water demands for other renewables such as biomass? Can they be met sustainably in view of all other (growing) water demands and under climate change?
    - What are the energy/electricity requirements for sustainably meeting water demands for all, including energy demands for water pumping (e.g. for drinking water supply, irrigation and other uses),
    - What are possible synergies when coordinating water and energy management, what could water-smart energy solutions, energy-smart water solutions, and climate-smart integrated energy and water solutions look like, and what needs to change in the management and governance in the energy and water sectors to implement these solutions?
- What is the effect of rising temperatures on energy demand, such as the increased need for space cooling?
- Bui hydropower plant in Ghana has been operated below capacity. Is there the possibility to ramp-up its operation?

3 Models, approach and scenarios

Results of this brief were produced through aframework of four inter-linked models:



SWIM and REVUB are process-based models and the backbones of the modelling framework of the CIREG project. They provide inputs to the WEAP and LEAP planning tools, that are used for the co-development of realistic and science-based scenarios jointly by stakeholders and scientists.

The WEAP and LEAP tools have already been used by different water and energy managers in Ghana and Burkina Faso for some time.Several additional trainings were provided in both countries as part of the

CIREG project, to support water and energy planning by developing and analysing a set of WEAP- and LEAP-based scenarios.

4 CIREG project

The rationale for the CIREG (*Climate information for Integrated Renewable Electricity Generation*) project is that West African countries have a large potential to leapfrog on modern renewable energy technologies. It is a crucial transformation process that CIREG intends to support, by co-developing climate services and science-based solutions which provide stakeholders and decision-makers with relevant information on risks and opportunitiesunder climatechange and variability.

Activities of the CIREG project include a series of science-stakeholder dialogues to jointly identify information needs and develop relevant climate servicesincluding i) socio-economic scenarios which project future electricity demands and hotspots, ii) opportunities and complementaritiesbetween the different renewables as electricity sources, iii) scenarios which assess risks and opportunities for renewable electricity generationunder climate change, iv) solutions, technologies and businessmodels for decentralised mini-grid and standalone solutions which complement the existing electricity grid, and v) synthesis oflocal and traditional knowledge/perceptions which complement the science-based perspectives in five urban and peri-urban casestudies.

The project started on 1st February 2018 and will end in June 2021.

Consortium partners

National funding organizations