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Will climate change undermine the potential for hydropower in Africa?

Energy Insight

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UKaid from the British people

Why the focus on hydropower?

Africa's demand for electricity is projected to grow exponentially in the coming decades, from the present level of 115 gigawatts (GW) to almost 700 GW in 2040 (PIDA, 2011, AFDB/OECD/UNDP, 2017). Hydropower is a critical component of African governments' plans to meet these growing energy needs. The Program for Infrastructure Development (PIDA), endorsed by African leaders in 2012, allocates nearly one-third (US$21 billion) of its priority budget allocation to hydropower. If implemented, hydroelectric power generation capacity would be expanded by more than 54 GW and water storage capacity by 20,000 cubic kilometres (Cervigni *et al.*, 2015).

Hydropower provides a flexible, sustainable, clean, and low-carbon source of energy – qualities that are especially important as countries seek to meet the carbon reduction goals set out in the Paris Agreement (International Hydropower Association (IHA), 2017a). Hydropower is also cost-efficient (International Renewable Energy Agency, (IRENA), 2012). Depending on the site-specific nature of the development, hydropower production can be the least-cost method of providing electricity in many developing countries.

The benefits of hydropower have propelled it to its current position of accounting for more than 70% of the world's installed renewable power generation capacity (World Energy Council, 2019), significantly reducing our global reliance on the fossil fuels responsible for climate change (World Bank, 2014).

Continent-wide, hydropower remains a largely untapped opportunity in Africa. Whilst Europe has developed 75% of its hydropower potential, Africa has developed only 7% of its potential, the lowest proportion of any of the world's regions (Cervigni *et al.*, 2015). In total, roughly 80 GW of future additional hydropower capacity is envisioned for Africa in the coming decades. 28 GW of potential hydropower is located on the Nile and 13 GW on the Zambezi alone (Conway D. Curran P. and Gannon K. E., 2018).

However, some African countries have long seen the benefits of hydropower and are already highly dependent upon it for the majority of their energy supply. Hydropower accounts for over 90% of electricity generation in the Democratic Republic of Congo (DRC), Ethiopia, Malawi, Mozambique, Namibia, and Zambia, and it provides 20% of energy generation across the entire Southern Africa region (Conway *et al.*, 2017). Three of the largest rivers in the world power the majority of this electrical generating capacity – the Congo, Zambezi, and Nile – with even more untapped potential in these rivers attracting much of the focus for future development.

Nevertheless, hydropower development frequently presents severe environment and social challenges – many of which are likely to be exacerbated by climate change. Opinions differ as to whether the development of hydropower dams should be prioritised by developing countries for investment (UN-Water, 2006).

Box 1: Benefits from hydropower

Water security and climate adaptation

Hydropower storage capabilities provide countries with additional water supplies and capacity to mitigate the impacts of extreme weather events, such as prolonged drought, and they can also mitigate the impacts of flood events.

Climate mitigation

Hydropower is mitigating climate change by reducing reliance on fossil fuels and helping countries to reduce CO_2 emissions in support of the Paris Agreement.

Instant power

Large-scale hydropower is flexible and reliable, providing an almost instantly available source of power, improving the capacity of energy suppliers to regulate and balance supply and demand, especially where intermittent sources of power, such as wind and solar, become more integrated into grids.

Cost-effective

The average levelised cost of US$0.02–0.19 per kWh for large hydropower projects and US$0.02–0.1 per kWh for small projects compares with an average levelised cost of US$0.05 kWh for onshore wind, US$0.07 kWh for solar PV, US$0.07 kWh for coal, and US$0.09 kWh for combined gas.

Enhancing regional cooperation

The development of hydropower plants on transboundary river systems can often improve regional coordination and enhance collaboration through the benefit-sharing and distribution of electricity and revenue. The Rusumo Falls hydropower project is a good example of how regional cooperation can lead to regional benefits, with shared electricity supplies for Burundi, Rwanda, and Tanzania.

Off-grid and mini-grid energy supplies

Small-scale, run-of-river hydropower can play an important role in providing sustainable, inexpensive energy access to remote areas where connection to a central grid is economically unfeasible.

So, what's the problem?

Site selection of hydropower infrastructure is relatively constrained. The geo-morphological and hydrological requirements for hydropower developments mean that projects can only be established in a certain number of river basins and only at a limited number of sites within these basins. Projects are also exposed to the vagaries of local governance structures, regional geo-politics along transboundary river courses, the need to connect the sites with transport links and services, and concerns over the impact on traditional land users and the local and downstream environment (International Finance Corporation (IFC), 2016).

In many cases, site-specific or regional concerns can be effectively mitigated. Joint benefit-sharing of energy production can enable regional collaboration. The promise of economic benefits from infrastructure development can help overcome local opposition. And the application of international best practice can help mitigate negative impacts on indigenous communities and the environment (IFC, 2016; Rudberg *et al.*, 2015).

Even where best practices are employed, however, negative consequences are often hard to avoid. Many major hydropower schemes remain associated with serious social and environmental concerns, especially where large infrastructure and associated water storage impacts livelihoods that are dependent upon the ecosystem services lost from the river.

What are even harder to predict and manage are the increasing constraints imposed by climate change. The long life-span of hydropower infrastructure exposes their operations to decades of climatic variability at a time when our capacity to accurately forecast climatic conditions is getting harder.

The potential impacts imposed on developments at any particular site are estimated through scenarios projected across the expected lifespan of the hydropower dam, which generally ranges from 50 to 100 years. Up until now, the storage capacity and operational flexibility of most hydropower systems in Africa have been designed to account for historical patterns of hydrological variability. Contingency measures enable mitigation of dry periods without disrupting power generation or resorting to load shedding (Conway *et al.*, 2017).

Future climatic conditions will likely be more variable than current or recent ones, and this increased variability is not being adequately considered in the design of many hydropower

schemes. Lumbroso *et al.* (2015) suppose that this oversight may be because climate-driven changes in river flows are only predicted to emerge after 2050 and the natural variability of the existing hydrological regime is within the 30- to 50-year planning horizons of most current hydropower projects. Sub-Saharan African countries are therefore responding to the immediacy of core development needs. In other words, policymakers are focusing on short-term energy requirements, rather than accounting for the potential longer-term implications of climate change.

The exposure and vulnerability of hydropower supplies to climate change, however, are already being felt. In 2015 and 2016, Zambia, a country dependent upon hydropower for around 90% of its electricity supply, was severely affected by hydropower shortages that impacted productivity in its copper mining sector. In May 2015, the national power utility warned that it would be forced to cut power supplies by one-third due to low water levels at the Kariba Dam on the Zambezi River, where 40% of Zambia's energy supplies are produced. In anticipation of power rationing, the Finance Minister reduced the forecast for national GDP growth from 7% to 5.8% (Conway *et al.*, 2017). The severe droughts from 2015 continued through 2016 and reduced power generation at Kariba by 75%. In 2016, Glencore's Zambian copper mines had to suspend operations as the country's electricity deficit rose to 1 GW (Reuters, 2018). In the same year, water levels in Mozambique's Cahora Bassa dam (also located on the Zambezi River) declined to 34% capacity, affecting electricity supplies across the Southern Africa region.

These recent events highlight the threat to hydropower generation from the impacts of climate variability. Africa's economies risk becoming more exposed if hydroelectric production is expanded. In countries with significant dependence on hydropower, Lara (2018) predicts that climate change could effectively shut down entire economic functions if droughts extend beyond the historical patterns and planned profiles. Recent analysis by Conway *et al.* (2017 and 2018) on the exposure of hydropower in East Africa and Southern Africa to the impacts of climate change suggests that the observations of 2016 could be part of an ongoing trend, undermining the infrastructure investments in both regions.

Proposed hydropower developments are geographically concentrated, with 82% of capacity in Eastern Africa to be concentrated within the Blue Nile and 89% of capacity in Southern Africa to be concentrated in the Zambezi (Conway D. Curran P. and Gannon K. E., 2018).

These geographical clusters of proposed dams are, unfortunately, exposed to the same climatic system. Inter-annual rainfall variability in both regions displays a strong influence from El Nino climate patterns, with the cluster of dams concentrating the risk of exposure to concurrent low rainfall periods and a greater potential for the disruption of electricity generation (Conway *et al.*, 2017). As occurred at Kariba and Cahor Bassa in 2016, these hydropower facilities will be exposed to the same wet and dry periods, leading to simultaneous impacts on the performance of multiple individual dams, with potentially major concurrent knock-on effects through domestic and regional power systems (Conway *et al.*, 2017) (see Figure 1).

The exposure of the Zambezi system to the impacts of climate change has been highlighted by the Intergovernmental Panel on Climate Change for almost a decade: the Panel stated that the basin exhibited the 'worst' potential effects of climate change among 11 major African basins (Beilfuss, 2012). What was not previously identified was the dual exposure of both hydropower developments in East Africa and those in Southern Africa.

Ignoring these recent warnings and the climate projections entails serious risks of designing infrastructure that is not suitable for the climate of the future (Cervigni *et al.*, 2015).

Box 2: Additional concerns for hydropower development

Climate change

Climate change has the potential to impact the hydropower sector through regional changes in rainfall and water availability, protracted drought events, significant variation in temperature regimes, and more frequent and severe weather events.

Sedimentation and land use change

Extreme rainfall and erosion due to climate change will continue to increase the rate of sedimentation and continue to undermine the potential electrical generating capacity of hydropower schemes, with hydropower energy production already being reduced by loss of reservoir storage capacity as a result of sedimentation occurring at an annual rate of 1% globally.

Environment and social concerns

Upstream of retention dams the flooding of natural habitats results in the loss of biodiversity, with involuntary displacement of people and loss of cultural property. Downstream of the dam, a reduction in the hydrological flow can undermine ecosystem services, cause the loss of biodiversity, negatively affect water quality, and impact water availability for other sectors.

Cost implications

There is significant cost inflation to development owing to hydrological or geological problems, which cause delays and potential safety risks.

Long life-span

The long life-span of hydropower infrastructure can make it vulnerable to future, uncertain changes in geo-politics and climatic conditions.

Geo-politics

Transboundary water resources constitute approximately 90% of Africa's freshwater resources, meaning that the majority of river basins where hydropower can be installed require international agreements, which can be time-consuming to obtain and politically fraught.

Cumulative impacts

Cumulative impacts can occur where multiple projects are developed on a single stretch of river.

So what needs to be done?

The following section outlines the key recommended steps and processes to mitigate the impacts of climate change for the hydropower sector in Africa, to ensure that it can deliver sustainable, clean energy supplies for a growing and divergent African economy.

Climate projections

The impacts of climate change on temperature, rainfall patterns and hydrological cycles are complex and poorly understood (Lumbroso *et al.*, 2015). Mixed messages from climate projections make it increasingly difficult for decision makers to plan and adapt appropriately, with a severe risk of adapting to climate change in the 'wrong' way. For example, under the driest climate scenarios, hydropower generation could decline by more than 60% in the Zambezi Basin, but under the wettest scenarios hydropower production could increase by up to 25% (Cervigni *et al.*, 2015).

To ensure the most valid messages are passed to decision makers, evidence should be drawn from studies that use downscaled analysis of individual river basins, and not those that rely upon the coarse scale of global climate models (Lumbroso *et al.*, 2015).

River basins display a range of sensitivities to climate change. The alignment of river basins north–south or east–west, the altitude and location of their water towers, (the source of these rivers), and their exposure to regional climate patterns, are all critical factors. Across all of the scenarios and climate projections the most consistent message for policymakers is that rainfall is less likely to be variable around the equator. Thus, the Congo basin is far less sensitive to climate change than more poleward rivers (Cervigni *et al.*, 2015).

Incorporating future climate change scenarios at the basin scale should become standard procedure for all proposed hydropower schemes, to ensure that they perform well under a wide range of future scenarios and help to avoid over- or under-designed infrastructure (Lumbroso *et al.*, 2015).

Case study: The love affair with Grand Inga

The DRC has more than 100 GW of hydropower potential, roughly five times the current installed capacity of all of Africa. This energy source is less exposed to the potential impacts of climate change and the seasonality of rainfall in Africa because the Congo basin straddles the equator, covering both the northern and southern hemispheres, and is aligned with areas projected to be less impacted by declines in rainfall.

The DRC already receives more than 1.7 GW from the Inga 1 and Inga 2 hydropower dams, both situated at the Inga Falls on the Congo River. PIDA includes funding for Inga 3, a 4.5 GW hydroelectric dam, with construction planned to start soon. PIDA also outlines proposals for the Grand Inga (Cervigni *et al.*, 2015), the holy grail for hydropower in Africa. The Grand Inga has the potential to be the largest power plant in the world, producing 45 GW (IHA, 2017). The first phase of the Grand Inga is the completion of the Inga 3 Dam, to be followed by Inga 4 (7.1 GW), Inga 5 (6.9 GW), Inga 6 (6.6 GW), Inga 7 (6.7 GW), and Inga 8 (6.7 GW) (IHA, 2017b).

The Grand Inga would be so large it could supply the whole of Africa with power. The DRC has already signed a treaty with South Africa to export 2.5 GW from Inga 3 via future transmission lines throughout Southern Africa, including through Zambia, Zimbabwe, and Botswana. Nigeria and Egypt have also reportedly expressed interest in importing power from Inga (IHA, 2017a). The DRC Minister for the Agency for the Development and Promotion of Grand Inga, Bruno Kapandii, stated that Inga could act as a catalyst for the development of transmission lines and interconnectors to link the various sub-Saharan power pools (IHA, 2017a). However, concerns over financial transparency resulted in the World Bank pulling back its support of Inga 3, with no fixed date for its development at present.

Resilience planning

The Hydropower Sustainability Assessment Protocol – launched in 2011 by the IHA and the World Bank – is broadly recognised as the primary tool for evaluating the sustainability of hydropower schemes and balancing the multiple demands of different water users. The Protocol was developed by comparing the performance of hydropower projects using a set of globally applicable sustainability criteria. Almost 30 official assessments have already been carried out of hydropower projects across all regions of the world, with capacities ranging from 0.003 GW to 14 GW (World Bank, 2018).

Application of the Protocol requires support from both public and private sector stakeholders, including financial institutions, national and international authorities and electrical power supply companies. The Protocol measures the sustainability of hydropower projects across a range of more than 20 environmental, social, technical, and business topics, with four separate assessment tools applied according to the stage of project development: (i) early stage, (ii) preparation stage, (iii) implementation stage, and (iv) operation stage.

Each tool is made up of a set of sustainability topics of most relevance to that stage of the project. The early-stage tool, for example, includes assessments of the political risks to the development, the institutional capacity to develop and manage the scheme, the technical risks to development and operation, the social and environmental risks to development and operation, and financial risks. The technical assessment looks at the viability of the hydrological resource, including its availability and reliability in the short and long term, and takes into account future trends (including climate change) that could affect the project.

In the most recently completed Protocol for the Zambezi Basin, the assessors determined that 'the studies and hydrological simulations for the reservoir were adequate but that they should be enhanced with the consideration of climate change being carried out for the whole basin to understand and mitigate the risk of cascade failure' (World Bank, 2018).

Whilst the potential impacts of climate change are considered in early-stage technical assessment, their relative weighting and level of importance needs to be improved. Further resources should be allocated to better defining climate change impacts before a scheme moves beyond the preliminary stages of planning.

At a recent IHA international conference, the potential risks imposed by climate change were discussed at length, along with various mitigation measures that have been implemented around the world to reduce the vulnerability of hydropower schemes. The UN Commission for Africa presented a series of resilience measures being implemented in the Sanaga Basin in Cameroon, which generates 6 GW of hydropower (50% of the country's total), These included enhancing the effects of existing storage, developing additional storage, and regulating generation through additional capacity (IHA, 2017a).

The conference also highlighted a number of issues to consider when thinking about climate resilience (IHA, 2017a):

- Shared technology and access to information was a current theme discussed by participants, with suggestions to develop regional climate models, shared weather information systems, and climate monitoring networks.
- A portfolio of adaptation projects need to be implemented that increase the reliability of existing systems through grid integration and enhanced cooperation measures, such as between power pools in Africa.
- Climate change considerations undertaken at the design stage should recommend flexible, diversified energy systems that integrate alternative renewable options that reduce water consumption and maximise water efficiency.

Basin level planning and watershed management

Basin-scale planning is critical for successful hydropower development. Beyond improving the climate resilience of a hydropower scheme, basin-scale planning can also improve broader economic, environmental, social, water, and energy supply outcomes (IHA, 2017b).

Applying a river basin perspective with a long-term outlook ensures that the variability of water available for energy production, water storage, and other purposes is accounted for during the planning phase of a new hydropower scheme (World Bank, 2014). The IHA (2017a) believes it is both feasible and practical for developers to implement basin-level planning. By addressing the broader-scale needs of basins, a diverse and more complete set of stakeholders can be included in the consultation phase, to consider the range of potential impacts, available options, and alternatives (World Bank, 2018). Integrating a basin-scale approach also allows for the inclusion of alternative strategies to hard infrastructure to adapt to the potential impacts of climate change.

Nature-based solutions can alleviate the need for high-cost hard infrastructural approaches. Nature-based solutions can improve water resource management throughout the basin and enhance the livelihoods of the people who are dependent upon the ecosystem services it provides. Sustainable, integrated land use planning and natural resource conservation can provide more resilient ecosystem services, which in turn can protect hard infrastructure, such as dams, from floods and increased sediment loads (IHA, 2017a). However, nature-based solutions have yet to gain political buy-in as viable alternatives to hard infrastructure measures (Oates and Marani, 2017).

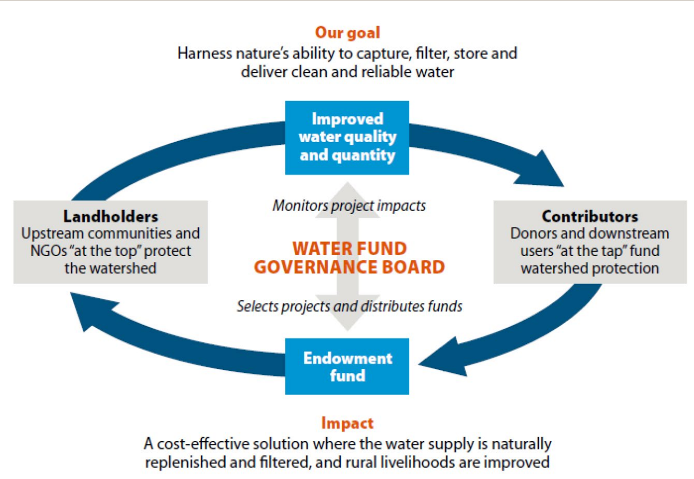
Case study: Using Water Funds to support integrated watershed management

The Upper Tana River Basin is of critical importance to the Kenyan economy. The river supplies 95% of Nairobi's drinking water, supports agricultural activities that feed millions of Kenyans, and provides half of the country's hydropower output. These ecosystem services are being undermined through land use degradation in the upper catchment, driven by a rapidly expanding population that has resulted in the conversion of forest to small-scale, subsistence cropland.

The unchecked degradation of land across the Upper Tana over the last 40 years has elevated sediment loads within the river system, reducing the efficiency and life-span of reservoirs. By 2001, the Masinga reservoir had lost an estimated 158 million cubic metres of storage volume due to siltation rates, twice as high as the reservoir was designed to accommodate, with reservoir function further compromised by reduced dry season flows resulting from increased demand for commercial agricultural irrigation and encroachment on natural wetlands that once stored runoff water and recharged aquifers (Abell ***et al.***, 2017).

The Upper Tana-Nairobi Water Fund, Africa's first Water Fund, was launched in 2015 by the Nature Conservancy, in collaboration with the Kenyan Government, to respond to these challenges. The Fund supports a holistic set of source water protection activities, with the objectives of increasing water yields, reducing sediment loads, and promoting sustainable food production and increased farming incomes in the basin.

The underlying premise of Water Funds is that it is cheaper to invest in protecting water at the source (upstream) than it is to address water problems when they occur downstream. The objective is to shift from solely investing in grey infrastructure (water treatment plants and reservoirs) at the urban level to investing in green infrastructure in the upper catchment, so that the restored watershed yields enhanced water storage capacity and improved water quality through natural filtration and retention of sediment (International Water Association (IWA), 2016).



By recognising the multiple embedded values of a healthy watershed, and involving the key stakeholder groups, the Upper Tana-Nairobi Water Fund was able to design a collective action programme whereby investing together made the most financial sense (Abell ***et al.***, **2017). These activities** have resulted in measurable benefits to water quality and quantity. Scientists estimate that several million more litres of water are available for Nairobi each day as a result of on-farm activities to retain soil and to reduce water extraction from the river. Monitoring has identified a decrease in sedimentation of over 15%, with World Health Organization turbidity standards achieved for the first time since measurements began (IWA, 2016).

Transboundary governance

Planning at the basin scale in Africa usually requires transboundary collaboration: 90% of the fresh water resources in the continent feed 63 international river basins that cover 63% of the continent's surface area (Ashton and Turton, 2009; Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ), 2012). Notable benefits can be derived from transboundary collaboration.

However, issues of sovereignty, resource equity, and historical tensions, as well as differences in technical and financial capacity, can complicate transboundary water resources management (World Bank, 2019). The World Bank's Cooperation in International Waters in Africa (CIWA) programme recommends that these challenges be overcome through strategic and coordinated action that starts with inclusive dialogue through institutions such as transboundary river basin organisations (RBOs).

Transboundary RBOs can help lay the foundation of knowledge, trust, and confidence that is necessary for cooperative transboundary institutions and infrastructure (World Bank, 2019). To achieve this potential, RBOs frequently require the following types of technical support and decision support systems to be able to advise the riparian states on the most resilient development path:

- detailed downscaled information on climate projections;
- hydrological monitoring systems and flow models;
- integrated water resource management plans;
- investment opportunity assessments;
- ecosystem service maps and valuations;
- governance frameworks that can guide the decision-making processes;
- data-sharing agreements between governments and other stakeholders; and
- guidelines on the notification of planned developments between countries within the basin that respond to international law and improve transparency and shared decision-making.

Improving transboundary governance and a common understanding of climate risks for new hydropower developments can allow upstream and downstream states to jointly assess and mitigate the threats. However, Turton (2005) also highlights the complexities of geo-politics within shared river basins. Where unequal power relations exist within the basin, riparian states are sometimes unable to negotiate what they consider to be an equitable allocation of water. These dynamics can undermine the playing field upon which RBOs operate, and result in some RBOs functioning more effectively than others, depending upon the power play between member states. An example Turton (2005) cites is the pivotal status South Africa plays within the Limpopo River Basin, affecting the development options available to impacted countries, such as Mozambique.

Case study: Transboundary collaboration on the Zambezi River

The Zambezi Watercourse Commission (ZAMCOM), a river basin organisation consisting of eight riparian states within the Zambezi Basin, was established in 2014 to '*promote the equitable and reasonable utilization of the water resources of the Zambezi Watercourse as well as the efficient management and sustainable development thereof*' (ZAMCOM, 2016). A multi-sector investment opportunity analysis of the Zambezi River (ZAMCOM, 2010) showed that through the cooperative utilisation of existing infrastructure, the riparian states could benefit from an increase in energy production of 23%, without any additional investments, simply through added efficiencies in operation. RBOs, such as ZAMCOM, can allow countries to make these types of strategic regional decisions to manage and reduce shared water-related risks that stem from hydrological variability and long-term climate change (World Bank, 2019).

Regional connectivity

Africa's existing system of power pools is an ideal means to mitigate risks to hydropower supplies associated with rainfall variability and climate change. Power pools are electricity systems and markets shared across economic blocs within Africa. The first of these to be established, in 1995, was the Southern Africa Power Pool (SAPP), which is now the most advanced power pool on the continent (Kambanda, 2013). Subsequently, the Western Africa Power Pool (WAPP) was established in 2001 to promote energy trade between member countries, but it has yet to start trading power as bilateral and multi-lateral agreements are still being refined. The Central Africa Power Pool (CAPP) and the Eastern Africa Power Pool (EAPP) were established in 2003 and 2005, respectively. Of these, the EAPP is the most advanced, having initiated power sharing in 2017.

Power pools allow electricity to be traded between countries across the pool, and potentially between pools, to help meet domestic demand or sell excess supply. The climate-related risks to a country's or region's electricity supply can therefore be mitigated by trading electricity from countries with available capacity to those where supply is curtailed due to climatic conditions (Conway D. Curran P. and Gannon K. E., 2018). When one basin is experiencing periods of low rainfall, another may not be.

Geo-political challenges and the lack of required infrastructure are undermining the potential of power pools. Whilst energy trade within Africa's power pools is currently limited to non-existent, financial investment through PIDA and institutional support through the African Union should start to see the pools become more active. The driving force behind this process may be the expansion of hydropower plans in the Congo, especially the potential capacity of the Grand Inga. The electrical supply from the Grand Inga could benefit the SAPP, CAPP, EAPP, and WAPP, but only if the proposed investment in infrastructure for new transmission capacity is realised (Cervigni *et al.*, 2015). Conway *et al.* (2017) also raise concerns about the capacity of the continent to realise this vision, highlighting that years of under-investment, poor service provision, low technological dynamism, and the failure of state monopolies to improve overall efficiency, are set to continue. These factors also inhibit private sector investment by undermining the potential returns on investment (Conway *et al.*, 2017). Ultimately, the greatest threat to this vision may be sovereignty issues expressed through concerns over national energy security.

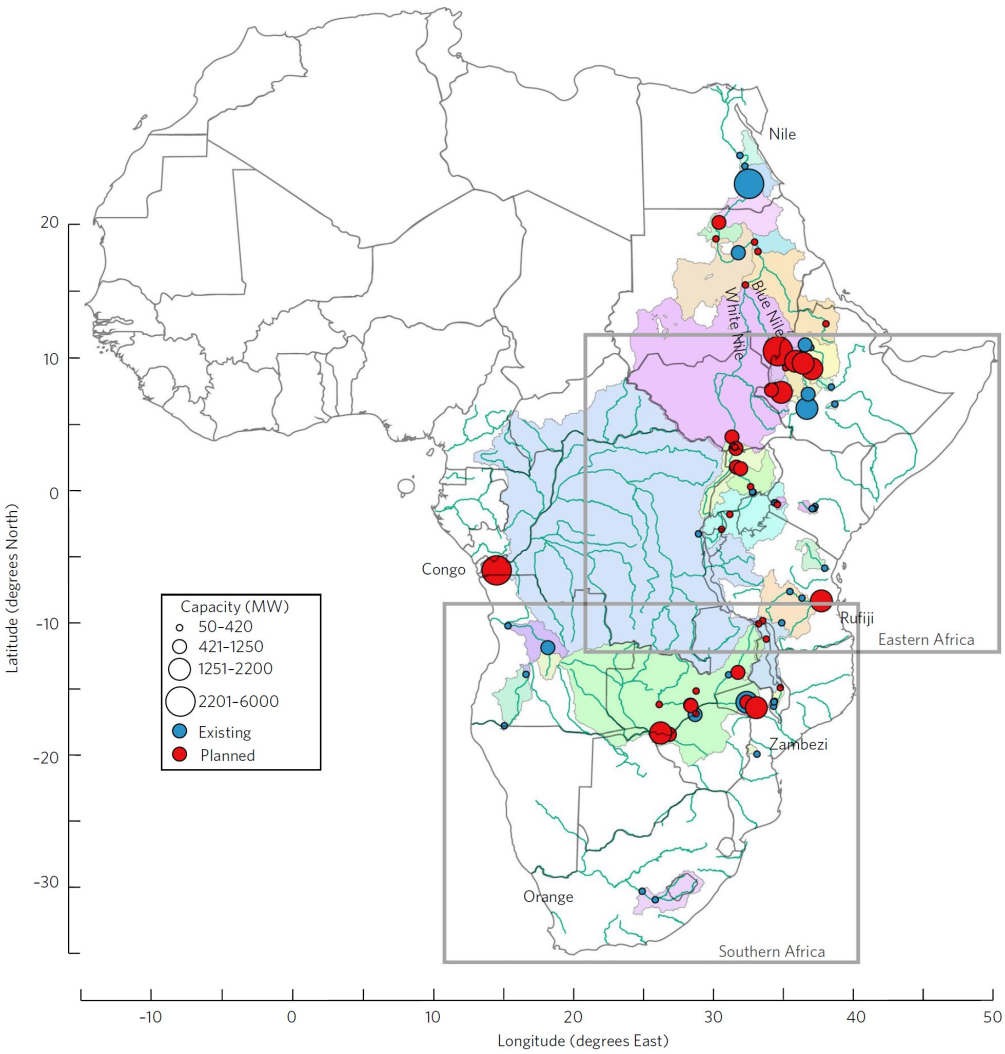


Figure 1: Existing and planned hydropower dams and their main river basins in Eastern and Southern Africa, extracted from Conway *et al.*, 2017.

Conclusion

To mitigate the impacts of climate change on African hydropower, investing in science and delivering clear and consistent messages to decision makers will be critical (Cervigni *et al.*, 2015). Improvements in our scientific ability to predict the downscaled impacts of climate change within river basins, as well as our technological ability to adapt hydropower production to extended drought conditions, will help make energy systems more resilient. The drive to integrate this information and the required technical designs into planning process should be accelerated with the growing awareness and recognition of the risks (Conway *et al.*, 2017).

To date, technical design modifications to increase the resilience of hydropower dams have generally been made on a case-by-case basis, with no structured guidelines for widespread adoption (Davies and Sveinsson, 2016). Most early-stage technical assessments of hydropower dams, including the World Bank's Hydropower Sustainability Assessment Protocol, continue to rely on historical hydro-meteorological records. The capacity to systematically generate, analyse, and integrate climate projections into longer-term planning and investment decision-making remains lacking (Lumbroso *et al.*, 2015).

Partnerships are needed between African governments, energy providers, and regional hydrological/ meteorological agencies so that climatic projections can be effectively integrated into decision-making processes for the planning, design, and operational management of hydropower schemes (Davies and Sveinsson, 2016). To reduce the cost of the analysis needed for each country and energy provider, Cervigni *et al.* (2015) recommend that a common data source be established to share climate scenarios and hydrological information. This data source could be hosted by African institutions, such as the African Climate Policy Center of the United Nations Economic Commission for Africa.

In pursuit of the Paris Agreement targets, countries must also look to integrate other renewable energy supplies, such as solar and wind. The hydro-photovoltaic-wind hybrid generation approach should be developed using micro-grids that can more efficiently provide energy supplies to rural areas with a sparse population without the need for extensive transmission infrastructure (IHA, 2017a).

Technological solutions to improve the effective generating capacity of hydropower in low-flow conditions are available and should be included in all system designs. For example, systems can be designed with seasonal storage capacity to compensate for flow reduction (IHA, 2017a), and greater operational flexibility and adjusted/adjustable turbine capacity to accommodate future climatic uncertainty.

The potential of the African power pools to mitigate the impact of climate change depends upon the capacity of African nations and financial institutions to shrink the growing infrastructural gap and invest in the underpinning transmission capacity. Along with improving the collaborative planning and transboundary agreements required to share the energy supplies, national governments and finance institutions must prioritise investment in transmission lines that link across rainfall clusters to support the diversification of risks posed by climate-related hydropower disruption (Conway D. Curran P. and Gannon K. E., 2018).

Financial institutions should be encouraged to invest in more integrated power grids that pull in electrical supplies from multiple sources and pools. By investing in power pools, financial institutions can reduce the climate exposure of their investments in any single high-capacity hydropower scheme. Power pools will only mitigate the impact of climate change, however, if the spatial interdependencies of rainfall are taken into consideration across the continent (Conway D. Curran P. and Gannon K. E., 2018).

Climate projections, therefore, must be integrated into system-wide domestic and regional energy planning processes that recognise the complementarity of a mix of energy sources, including, but not limited to, hydro power.

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