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World Small Hydropower Development Report 2022

THEMATIC PUBLICATION:

SMALL HYDROPOWER AND CLIMATE CHANGE

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Introduction

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), published in early 2022, provided the most up-to-date physical understanding of climate change and brought together the latest information on climate change impacts, adaptation, vulnerability and mitigation opportunities.

On a global scale, some studies project an increase in hydropower production of between 2.4 per cent and 6.3 per cent under Representative Concentration Pathway (RCP) 4.5 and RCP 8.5, respectively, by the 2080s, while others are uncertain about the direction of change (from +5 per cent to -5 per cent). At the same time, all studies agree with high confidence that significant regional variations exist.

The largest increases in gross hydropower potential (more than 20 per cent) will happen in Middle Africa, India, Central Asia and northern high-latitude areas. Conversely, the most unfavourable regions with decreases of more than 20 per cent in gross hydropower potential are Southern Europe, Northern Africa, southern United States and parts of South America, Southern Africa and southern Australia. Regarding existing hydropower production, the Mediterranean region is projected to see up to 40 per cent reduction under the 3 °C warming scenario by 2080.

Depending on the scenario considered, the results can vary significantly. Behind any projection, it is important to understand the chosen emissions scenarios or any socioeconomic pathway or adaptation policy followed in the country that can influence those projections.

The methodology followed for the regional summaries outlined below is a synopsis of the information local and international experts have provided for the country chapters for the *World Small Hydropower Development Report (WSHPDR) 2022*. Experts refer to the scenario used for the reported change in most of the cases. As each one follows different scenarios, this paper does not allude to specific scenarios in the regional summaries. However, it acknowledges that the definition of climate change scenarios is crucial to understanding the potential impacts of the climate crisis on small hydropower (SHP) production and development. Country chapters in the *WSHPDR 2022* further expand on the data and scenarios for the projections on SHP production and potential.

Role of SHP in Mitigation and Adaptation

Hydropower has a dual relationship with climate change — it helps mitigate the impacts of changing climate but is also subject to vulnerability because of its dependence on the hydrological regime, which is affected by climatic conditions.

Adaptation and resilience

SHP projects provide climate change adaptation services to the communities they serve. They contribute to integrated water management, which is particularly important in water-scarce regions, and play their part in overcoming threats related to energy security induced or exacerbated by climate change.

Hydropower size influences the project's role in mitigation and adaptation to climate change. SHP plants are mostly run-of-river (RoR) projects (in the stream or off the stream with a diversion), which restricts their capacity to store water and control floods. This limitation increases the vulnerability of SHP plants to changing hydrological patterns and heightens the uncertainty of electricity generation forecasts. Mini- and micro-scale hydropower projects are even more sensitive to climate change impacts, but the effects are site-specific. However, other factors, such as land use changes in the catchment upstream or efficiency issues, have a more significant influence on SHP plant operations. In its turn, climate change acts as a multiplier of these more decisive issues.

Various measures to increase SHP resilience to climate change have been suggested, although very few countries have progressed with adaptation programmes for SHP plants. Measures for reducing vulnerability range from infrastructure improvements to monitoring and forecast tools and even insurance policies. Climate change-resilient SHP design should account for changes in extreme precipitation events and cope with flooding events of the infrastructure and operate even in low-flow conditions. Early warning systems for floods and landslides would reduce damage to SHP infrastructure and insurance could minimize the electricity generation loss.[1]

Mitigation

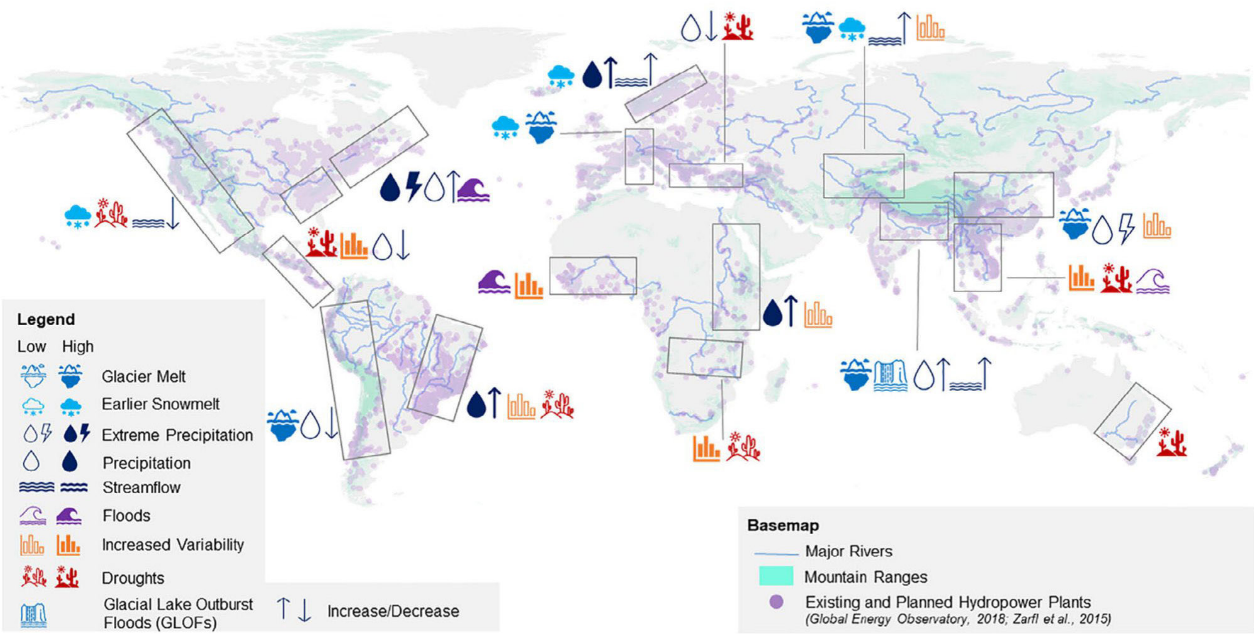
Hydropower projects help displace fossil fuel energy sources and limit global warming while satisfying the electricity demand and the flexibility required by the grid. SHP plants often help decarbonize decentralized systems reliant on oil-based generators or coal and biomass burning. Considering that hydropower has low median lifecycle emissions of 23 gCO2e/kWh and biomass cofiring emits 740 gCO2e/kWh, the existing SHP capacity avoids 248 million tonnes of carbon emissions annually (Considering the 2022 global SHP installed capacity of 79 GW and global capacity factor of 0.5).[2] The remaining SHP potential, if fully exploited, could help avoid an additional 448 million tonnes of carbon emissions per year. Although hydropower generation has low emissions, comparable to other renewable energy sources, site-specific conditions make some projects with reservoirs sinks of emissions or high emitters per unit of generation. Increasingly, financiers use the emissions intensity unit to screen out projects to help decarbonize the grid.

Present and Future Climate Change Impacts

Future hydropower forecasts are unrealistic based on business-as-usual (BAU) scenarios that do not consider global climate change. Small changes in climate conditions can lead to relatively significant percentage changes in electricity generation. SHP relies on runoff availability, which is directly influenced by temperature and precipitation patterns. Because of the small storage capacity of SHP plants, the change in runoff in the river flow can significantly influence the generation of electricity. Changes in runoff due to climate change can have an effect in the short term (days, months) and in the long run with significant implications for the productive uses of SHP plants.

Climate change also induces effects in other sectors that can cascade to SHP plant operations. With increasing temperatures, irrigated agriculture will require more water, electricity patterns will shift and electricity demand will rise in the hot months due to the use of air conditioning, for example. Competing water uses and different requirements from the grid will ultimately affect the operations of SHP plants. Besides rising temperatures, changes in precipitation will prompt new water regulations, which can be a detriment to the operational sustainability of SHP plants.

Figure 1. **Dominant Effects of Climate Change on Global Hydropower**



Courtesy of Wasti et al.[3]

Climate change will impact hydropower generation in different ways depending on the region in the world. Figure 1 shows the dominant effects in the regions where most hydropower development exists or is planned, based on scientific articles that used more than one climate model and multiple emission scenarios to prevent bias towards a particular climate model. The figure also provides a rough indication of whether the impacts will be low or high. Three major categories emerge as global impacts for SHP based on a combination of the dominant effects:

Increased frequency and intensity of droughts and reduced runoff

Climate projections predict a continuous temperature increase that will lead to a rise in evaporation and evapotranspiration, which in turn may lead to lower runoff. The increased frequency and intensity of droughts may have severe impacts on the runoff available and, therefore, the efficiency and performance of SHP plants. While storage SHP could present an advantage compared to RoR SHP regarding mitigation of the changes in runoff due to climate change, the water loss through evaporation could also significantly impact SHP performance.

Depletion of glaciers, ice storage and seasonal snow cover

Melt from retreating glaciers results in increased streamflow in the short term, presenting an opportunity for SHP within the next decades. In high emission scenarios (RCP 4.5 and 8.5), projections predict more than 20 per cent increases in gross hydropower potential by 2080.[4] At the same time, it also leads to increased flows and floods that could damage hydropower plants. The flood severity may worsen in regions where the glacier melt and the monsoon precipitation coincide. In the longer term, runoff from glaciers is projected to start declining. As glacier mass disappears, streamflow will also decline, reducing the potential for future SHP development during the second half of the 21st century.

Increased precipitation variability and precipitation extremes

Global warming is altering weather patterns. A recent study has found that climate change could shift the tropical rain belt of the planet.[5] The projections indicate a northward shift over Eastern Africa and a southward shift in the Eastern Pacific, which could amplify flooding in southern India and increase drought stress in South-Eastern Africa and Central America. The repercussions could be significant for SHP plants, including a direct impact on the generation capacity and the potential ability of SHP plants to adapt to climate change in the future. Moreover, changes in weather patterns could also have indirect impacts on energy consumption and electricity tariffs.

Regional Summaries

Africa

Eastern Africa

Almost half of the SHP installed capacity of Africa has been developed in Eastern Africa, with over 55 per cent being located in the Nile River basin. Climate change impacts appear to vary significantly depending on the models used. The variations in rainfall patterns and temperature changes threaten water storage and water supply. However, the expected increase in precipitation and runoff in certain regions can present an opportunity for SHP. For example, some watersheds in Tanzania could see an increase in runoff of 160 per cent. At the same time, in contrast to global trends, there could be a decrease in precipitation in the wet season. The variation in rainfall patterns poses a challenge to electricity generation in countries highly reliable on hydropower.

Western Africa

Precipitation and runoff in the region have been highly variable over the last century. However, despite the high uncertainty, countries such as Guinea project a decrease in the runoff, whilst Gabon and Sierra Leone project increased runoff. While expanding hydropower potential is essential to reaching a clean energy mix and universal energy access, increasing the share of hydropower without assessing the potential impacts of climate change may increase the countries' and regions' exposure to climate hazards and put their energy security at risk. Nevertheless, studies in the Upper Niger and Bani River basins highlight opportunities to reduce the high streamflow variability in the region. The studies suggest that operating hydropower facilities as RoR projects could reduce evaporation by 20 per cent.[6]

Middle and Southern Africa

Several countries in the region have uneven impacts, including areas with decreased rainfall and risk of low water levels and areas with more frequent floods. Malawi predicts a 40 per cent increase in rainfall in the wet season and a decrease of 75 per cent in the dry season. In South Africa, the Western Cape region is expected to see a 13 per cent decline in the average annual runoff, while the eastern coast will experience an increased risk of flooding.

Countries in the Zambezi River basin have already experienced climate change, especially rainfall variability. The projected continuous rise in evaporation and evapotranspiration due to the increased temperatures could spur higher water stress in the region. However, the impacts on runoff are yet uncertain.

Americas

Central America and the Caribbean

The region has already experienced increased winter precipitation and decreased summer precipitation during the El Niño Southern Oscillation (ENSO) phase, and it is projected to worsen. Moreover, the increase in frequency and intensity of extreme events exposes SHP infrastructure to damage. These effects have already been experienced in the Dominican Republic during the El Niño event in 2019.

Western South America

The glacial stability of the mountainous regions in the western region is affected by climate change. In the short term (next 10 to 20 years), the runoff could increase capacity plant factors of SHP in the Andean region but risks making hydropower less viable in the long term until the end of the century.

Eastern South America

In the eastern region, projections predict a decrease in rainfall and an increase in temperature during the peak rainfall season, combined with less precipitation during the dry season. The expected decreased runoff and an increase in seasonal flow variability threaten the viability of RoR hydropower projects.

Northern America

Runoff is anticipated to increase due to earlier snowmelt. With earlier snowmelt, lower summer flows are expected to diminish, which could reduce the hydropower generation in the summer months. Moreover, flood magnitude and frequency are increasing due to more frequent and more intense extreme precipitation events. This would require further investigations of potential impacts for seasonal and annual hydropower generation, as well as infrastructure risk assessment.

In the USA, the fleet is expected to absorb part of the runoff variability due to the relatively large storage capacity. However, the undertaken analyses do not consider any other changes that could affect the capability to mitigate the runoff variability, such as the ageing of the fleet, water use and environmental services.

Asia

Eastern Asia

The glaciers in the two river basins in the region with the highest degree of hydropower development (the Yellow and Yangtze River basins) have experienced significant melting with increased temperatures. However, the direction of future change in precipitation is unclear. In the Yellow River basin, other human economic activities, such as agriculture, have a significantly higher impact than climate change on seasonal changes and streamflow reduction.[7] Analysis of existing hydropower projects on the Yalong River suggests that modified reservoir operations could help manage the expected future variability in streamflow.[8] Rivers in Mongolia appear to be more sensitive to small changes in temperature and precipitation, affecting hydropower generation. An example is the Uvurkhangai SHP plant which was abandoned due to insufficient water levels. In Japan, heavy rainfall and suspended sediment in rivers are both projected to increase by up to 25 per cent by 2100, which is expected to increase the operation and maintenance costs of SHP plants.

South-Eastern Asia

The hydrological regime in the region is governed by monsoon precipitation that is influenced by the El Niño Southern Oscillation (ENSO) and countries such as the Philippines are some of the most vulnerable due to the high exposure to natural hazards. While different climate change scenarios project various changes in precipitation, flood damages and water supply deficit are projected to worsen. Countries such as Lao People's Democratic Republic (PDR) have already felt the impacts, with hydropower generation shortfalls of 13–22 per cent registered in 2020. Hydropower development policies in the region should prioritize dam safety and basin planning to mitigate risks associated with flash flooding events to

SHP. Moreover, reservoir-based SHP plants should be considered for future water infrastructure development to avoid the increased vulnerability of RoR plants.

Central Asia

The glacierized areas in this region show increased summer and winter runoff. Meanwhile, the areas with a lower fraction of glaciers present an increased interannual variation in streamflow. The magnitude of the projected runoff varies significantly across climate change scenarios. For example, Kazakhstan estimates that precipitation could increase up to 10 per cent by 2050. Kyrgyzstan forecasts that climate change will lead to a decrease in hydropower potential, even though SHP can be a great strategy to mitigate energy shortages in remote areas in the short term.

Southern Asia

The precipitation patterns in the region have already been affected by climate change, but not consistently. The Himalayan region is characterized by heavy monsoon precipitation during summers and dry winters and hydropower projects face risks due to Glacier Lake Outburst Floods (GLOFs). Most climate change models project a strengthened monsoon, resulting in an overall increase in runoff. Bhutan expects the most significant changes in streamflow after the mid-21st century due to increasing temperatures and higher glacier melt rates. The regions with low glacier coverage are expected to see reduced streamflow.

Moreover, the impact on SHP generation and development is expected to have wide seasonal variation. Adaptive measures will be required in these catchments for SHP plants to reduce the high dependence on seasonal flow variability. Moreover, floods and heavy sediment inflow should be considered in the operational and maintenance costs of SHP plants to avoid structural damage.

Western Asia

Several countries in the region have limited water resources and climate models indicate an increase in evaporation and a reduction in rainfall. The long-term effects are expected to have an impact on hydropower generation. For example, Lebanon is expecting a decline in annual generation of 540 GWh by 2090. In Iran, the reduction in hydropower generation is expected to reach 24 per cent by 2080, going as high as 36 per cent during springtime. Moreover, some hydropower plants in Afghanistan are expected to have zero production at least every 10–20 years. In the Caucasus region, impacts vary across river basins. In Armenia, annual river flow is projected to decline by 39 per cent by 2100, significantly impacting SHP as most plants are built on natural watercourses.

Europe

Northern Europe

An increase in winter discharges with earlier snowmelt has already been observed in Norway and Finland. Most of the increased inflow has been utilized for hydropower production and the inflow is expected to increase further. However, the interannual variability is expected to increase. The difference between the driest and wettest winters will double by 2090. On the other hand, the precipitation in the Baltic countries has decreased, although the effects on hydropower are varied. SHP plants in Latvia and Lithuania have already experienced negative consequences, with the water storage mode being banned during low-water periods or operations ceased due to the lack of water.

Southern Europe

The Mediterranean region has already experienced a much drier climate and studies suggest that hydropower generation will drop by 22 per cent in Italy by 2070. The decrease in generation from SHP plants has already been experienced in Greece since 2018. Moreover, studies show that hydropower generation may drop an additional 5–43 per cent in specific river basins in Spain by 2070.[9]

Eastern Europe

Annual precipitation is projected to have no change in Hungary and the Czech Republic or decrease in most of the southern basins in Eastern Europe. A recent study undertaken in Poland concluded that both positive and negative outcomes in the future are possible depending on the climate change scenarios considered. The major concern is the uneven precipitation distribution with wetter winters and more frequent droughts in summer, which can negatively affect the viability of SHP plant operations and make it harder to plan and develop SHP. Moreover, additional river runoff regulations in favour of irrigated lands will pose a competing use for hydropower in Ukraine and Moldova. The SHP potential of Russia will likely benefit from climate change, however, heavier precipitation risks dam erosion and catastrophic floods to the infrastructure.

Western Europe

The changes in the runoff pattern from Alpine rivers will be advantageous for SHP plants due to the snow and glacial melt in the next decades. However, natural hazards, such as floods, GLOFs and landslides, are likely to increase and hamper SHP plant operation and development. Additionally, without seasonal storage capacity, the downtimes due to extended droughts may halt electricity generation if adaptation measures are not taken. For example, France expects periods of extreme droughts due to an increase in evaporation of between 30 and 50 per cent by the end of the century. On the contrary, SHP plants in Belgium and Germany might benefit from increased precipitation in winter and spring and more spread precipitation in summer, respectively. Austria shows a tendency towards decreased annual production overall.

Oceania

Australia concentrates hydropower generation in the south-eastern region and Tasmania. These regions have experienced a 25 per cent decrease in rainfall since 1970. However, the net summer rainfall has increased across the country, increasing the regional and seasonal differences. Similarly, New Zealand expects to experience increased variability in precipitation and inflow. The higher variability could challenge SHP plants' performance and lead to generation shortfalls in the summer months, while still meeting the electricity demand in winter.

Quantifying Climate Change Risks and Adaptation Measures

SHP plants have a short life span (30–40 years depending on the source) and, therefore, physical climate change risks might not feature in short-term risk analysis as greater impacts are expected by the end of the century. Although projections still show uncertainty and sometimes even contradictions regarding the changes in runoff, there is evidence of increased runoff in high mountainous regions due to glacial and snow cover melt. In this shorter timeframe, catchment uses and land use changes (i.e., upstream agriculture, deforestation, increasing sediment yield, etc.) can be more influential for SHP design and operations in non-glacier basins.

Moreover, there is a relationship between the ownership-operation scheme and climate adaptation strategies. The shorter the period that the hydropower plant can be owned and operated by private developers, the smaller the incentive to design and build the plants for a higher return period. The impact on SHP development is more prominent as private developers can be more prone to own and operate plants than larger-scale projects that may require higher public entities' involvement.

Even if the project shows low risks with regard to climate change impacts, it should undertake a climate risk assessment as climate change can augment the effects of other more significant factors in the catchment. The International Hydropower Association's Hydropower Sector Climate Resilience Guide provides alternative approaches for projects with low climate change risks.[10] Nonetheless, it recommends that the analysis should always use at least two climate scenarios (i.e., one more optimistic and one more pessimistic). Whenever there is insufficient data to set up hydrological models, the Guide proposes simplified methods such as regression models, Budyko-type water balance models and historical climate analogies to assess the project performance under future climate scenarios. A combination of several techniques can provide better information about the expected hydrological changes (e.g., mean annual runoff, seasonal changes, etc.).

Adaptation measures

After quantifying the risks and opportunities (i.e., the potential for gains in generation), measures need to be taken to improve the resilience for changing hydrological conditions derived from climate or land use changes. The actions can range from structural design changes or modified operations at the asset level. Policy measures at the catchment or country level can be very effective in favouring and ensuring the resilience and adaptation to climate change of existing and new SHP plants.

The refurbishment of the civil works and the modernization of SHP plants considering climate risks and opportunities is an effective way to increase resilience and adapt the hydraulic infrastructure and operations for the variation of the hydrological regime. Otherwise, existing SHP plants could suffer overflow and flooding due to flash floods in scenarios of increased extreme precipitation events. Furthermore, increased sediment yields can cause more floating debris and sediment-laden flows that hamper plant structures, shut off operations and, overall, cause operation and maintenance costs to rise. On the other hand, SHP plant upgrades can optimize the water supply from glacier melt in high-mountain regions.

Significant alterations of rainfall and runoff patterns can suggest additional regulating reservoirs or reservoir-based designs to even the water inflow and maintain hydropower reliability. In this way, SHP plants can better cope with low and high flows and decrease the downtimes even under drought conditions. Also, attaching storage technologies such as lithium-ion batteries adds flexibility to SHP, providing some hours of energy storage.

Additional adaptation measures should include **careful site selection for SHP plants in locations less vulnerable to extreme weather impacts, better insurance policies and the development of early warning systems for floods and landslides** to reduce damage to SHP structures. Besides the powerhouse, these structures also include roads, weirs, desilting tanks, transmission lines, etc.

Watershed protection is the top priority to conserve water resources and mitigate water availability issues for SHP. Catchment authorities have a critical role in ensuring controlling practices (i.e., agricultural activities or deforestation in the basin) that help quantify and mitigate land use change risks to SHP. SHP plants have little or no control to reduce those risks derived from upstream economic activities. Adaptation measures should have an integrated approach to water resources and systems management and strengthen cross-sectoral planning.

Moreover, even without land use changes or significant drops in the runoff, increasing temperatures and drought frequency will drive water demand for agriculture, as has been the case in Eastern Europe and the Mediterranean countries, and might restrict hydropower generation. Basin authorities should consider the water-food-energy nexus to optimize water resources and not exacerbate the competition over the different uses of, and negative attention to, hydropower.

National policies can ensure consideration of climate change for the construction of new SHP plants and the operations of existing ones. National planning can take a holistic approach to the energy sector and water resources and plan those as low-carbon projects with minimum risk at the asset level and bring resilience to both energy and water systems. Policies can support the development of hydrological models for various climate scenarios relevant to local conditions, foster basin-wide planning, require climate risk assessments, promote robust structural designs to prioritize dam safety and improve licencing, including monitoring programmes. Capacity building on climate change risks in governmental bodies may be essential for implementing the policies mentioned and developing sectoral adaptation responses.

Need for Further Research

A changing climate can change the technical potential for SHP development worldwide. Higher temperatures, decreases or increases in precipitation until the end of the century and changes in the hydrological pattern will alter small rivers. Streams can dry up or change course because of shifting precipitation patterns, but new streams can also appear if glaciers melt. **Reassessing the hydropower potential** provides valuable information for national energy and water planning. The better the hydrological information at the basin level, the better the estimations of runoff and, therefore, the more feasible the potential. Increasing the number of hydrological and climatic gauges in each country is crucial for a high-density monitoring grid that will enhance weather and runoff analysis.

Climate change exacerbates **natural hazards**, such as flash floods, GLOFs, landslides, etc. Further research on how climate change might aggravate natural hazards is necessary.

Climate change will also alter **electricity demand patterns**. For example, temperature increases can decrease the need for heating in the cold season. Assessments of how much electricity will not be generated due to demand changes are necessary for long-term planning and adaptation measures.

Governments may want to introduce policies to encourage a diverse electricity mix and not rely mainly upon one energy source that depends on certain climate risks. Thermal assets are also dependent on water, in this case, for cooling. Diversifying the energy mix with other renewable energy sources, such as wind and solar power, may reduce climate risks for a generation but increases the need for resilient power systems due to the variable type of energy generation of these technologies. Studies to **better understand the evolving energy market** are essential to inform policies and regulatory frameworks. Beyond sovereign borders, countries may look to expected disruptions to electricity imports due to climate change to build additional resilience into their mix.

The global performance of flow diversion practice for feeding SHP plants can be improved by engineering dynamic residual flow policies. Constant minimum flow release policies can affect the morphology and the ecosystem of the riverine area. Environmental releases that mimic the natural flow regime can help improve the resilience of the ecosystem. [11] The more flexible the redistribution rule is, the more efficient the use of water by the riverine ecosystem will be.[12] Further research can go into finding **more efficient redistribution rules**.

Research on **new technologies for the operations and maintenance** of SHP assets can make a significant contribution to their performance (i.e., optimization algorithms, predictive maintenance), safety (i.e., digitalization of the control to enable remote operation), flexibility (i.e., modern equipment) and storage (i.e., lithium-ion batteries).

It is also critical to conduct more in-depth, site-specific studies that explore how adjusting current operating rules may help reduce the climate variability impacts while also considering how changes in operation will affect biodiversity and ecological flows.

Climate Finance

Climate change impacts the future sustainability of SHP plants. High uncertainty and non-adequate information could discourage potential developers from investing in a business model where water availability is a significant barrier.

While SHP plays a crucial role in the clean energy transition and climate mitigation, information on climate risks is essential to making SHP projects feasible and financially attractive. Increasingly, financiers use the emissions intensity unit to screen out projects to help decarbonize the grid and require prior estimation and a posteriori monitoring of greenhouse gas (GHG) emissions from projects with reservoirs. SHP could be subject to climate finance for mitigation, resilience and adaptation if the projects provide adequate information. There are initiatives, such as the Net Zero Climate Resilient Hydropower initiative, that advance the availability and quality of climate-related disclosure at the project level to help the effective mobilization of climate investment to finance or refinance hydropower assets. The initiative launched the first of the Hydropower Reporting Guideline series on climate change mitigation to provide the much-needed clarity on report emissions, climate mitigation actions and analysis of mitigation risks and opportunities. [13]

Conclusions and Recommendations

SHP facilities could be deployed at the urgency rate needed to limit global warming to 1.5ºC and contribute to countries' net-zero strategies. Fast-tracking the provisions to tap into the exploitable potential could help avoid more than 475 million tonnes of carbon emissions per year by 2050 and provide adequate, reliable, affordable and sustainable power to mainly rural areas that foster socio-economic growth.

While tapping SHP potential is crucial to mitigating climate change, providing access to energy and increasing energy security in a changing climate, any development should consider climate impacts with different models and scenarios. Alterations in streamflow volume, seasonality and sediment load changes will affect hydropower production, and the effects will vary regionally.

The following points provide recommendations for national planning and regulatory institutions and for SHP developers, asset owners and operators to foster the development of SHP, considering their role in mitigation and adaptation and the impacts of climate change under different climate scenarios.

For the national planning and regulatory bodies:

- Introduce policies to ensure consideration of climate change for the construction of new SHP plants and the operations of existing ones.
- Foster the development of hydrological models for various climate scenarios relevant to local conditions and studies to reassess the SHP potential.
- Develop holistic climate change adaptation plans including sectoral adaptation responses for watersheds.

- Set up regulatory frameworks that provide incentives for SHP development and reward SHP projects adequately in the evolving energy markets.

For SHP developers, owners and operators:

- Even if the project shows low risks to climate change impacts, it should undertake a climate risk assessment. The Hydropower Sector Climate Resilience Guide is a reference in the sector to identify and assess risks.
- During the refurbishment of an SHP plant, consider measures to increase the resilience of the project's hydraulic infrastructure.
- Consider additional regulating reservoirs, reservoir-based SHP plants and other storage technologies such as lithium-ion batteries to add flexibility and energy storage.
- Consider SHP sites in locations less vulnerable to extreme weather impacts, better insurance policies and the development of early warning systems.
- Enhance climate-related information disclosure including GHG emissions and climate risks to access climate finance.

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