Climate & Development Knowledge Network

Policy Brief

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PRACTICAL ACTION Consulting

Global Climate Adaptation Partnership

Key Messages

- Current climate and hydrological variability is a major challenge for Nepal's hydro sector.
- The impacts of climate change on hydropower are uncertain, due to lack of reliable long term hydro-meteorological data and by high uncertainty with future climate change in Nepal.
- The greatest impacts of climate change is from increased climate induced hazards- sediment, extreme floods and geo-hazards (glacial lake outburst floods.
- The current power system suffers from an inefficient power mix leading to high economic costs at the system (national) level.
- Climate change impacts are additional to other factors and uncertainties (i.e. additional to current climate variability, institutional and regulatory issues).
- Adaption pathways can help address the challenges of adapting the hydro-sector. A suite of options is needed, i.e. it is not a case of one size fits all.
- Adaptation needs to be designed to the specific context, plant and vulnerability.
- There are low regret options to adapt the hydro-sector in Nepal, across the range of risks and climate induced hazards, for different types of plants.
- The institutional context is important to mainstreaming climate change into future sector development plans and policies.

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Adaptation to climate change in the hydro-electricity sector in Nepal

Assessing the future impacts of climate change on the hydro-electricity sector in Nepal is very challenging due to the complex climate and hydrology, as well as the very large changes in elevation that occur across the country. Projections of future climate change show very high uncertainty, with large differences across future scenarios and between climate models.

To address this problem, the study has used a Climate Risk Assessment (CRA) methodology based on a "bottom up" decision-scaling approach. This starts by assessing the sensitivity of Nepal's present hydropower systems – and their performance - to the current climate and then assesses how future climate change could affect this.

The method identifies key performance indicators (PI) significant for hydro-energy generation that may be sensitive to climate and thus puts the initial emphasis on understanding how the present meteorological and hydrological variability affect current operations and planned investments. This has the advantage of focusing the analysis on what matters! It can then look at future climate change, including uncertainty, and see how important future changes could be and how these key PIs are affected.
The CRA has been linked to an iterative adaptation pathways approach, to use this risk information to build up possible adaptation responses under uncertainty.

Critically this has adopted a policy centred approach, which aims to provide information for policy makers and the private sector to implement near-term adaptation. It has also included a strong consideration of the economic justification for adaptation, noting the challenges of uncertainty and discounting..

The method has identified three types of adaptation where decisions (or policy) will be important over the next five to ten years, and provides information to help address both current climate variability and long-term climate change. These are

1. Immediate actions that address the current risks of weather and climate extremes (the adaptation deficit) and build resilience to future climate change. This includes early low- and no-regret actions, which provide immediate economic benefits as well as future benefits under a changing climate. These activities are focused on current hydro-power plants.

2. The integration of adaptation into immediate decisions or investments with long life-times (climate smart planning), focusing on the new (planned or candidate) hydro-electric plants that will be built over the next decade or so. These plants will be exposed to future climate change but these changes are in the future and uncertain. This therefore involves a greater emphasis on low cost design or flexible or robust options that perform well under uncertainty.

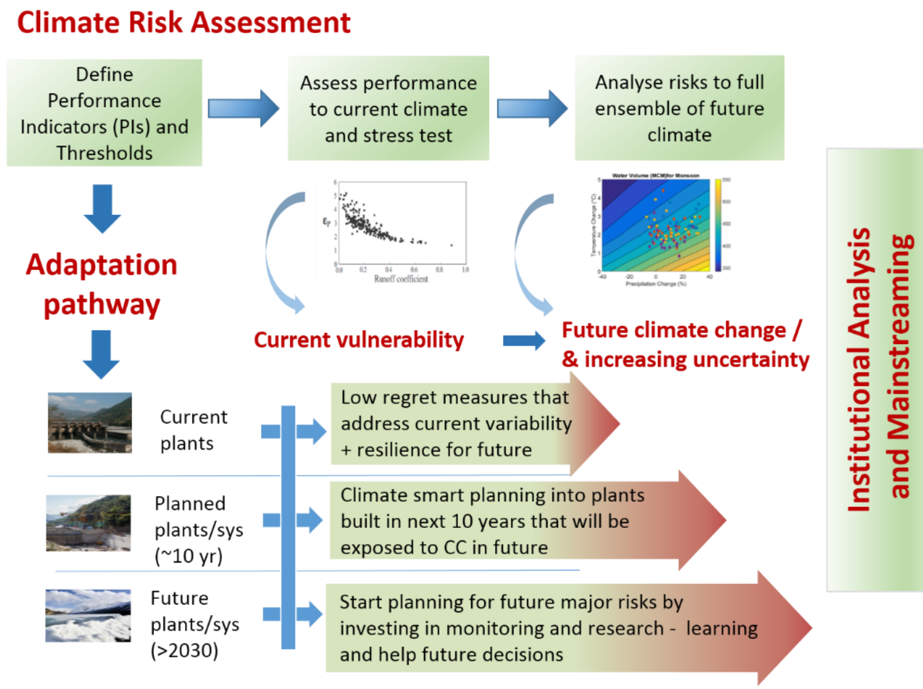
3. Early monitoring, research and learning to start planning for the future impacts of climate change. This includes the investing in information and learning, to help future decisions (through the value of information and option values and learning).

The three interventions can be considered together in an integrated adaptation strategy, often termed an adaptation pathway or portfolio.

To capture uncertainty, the CRA focuses on identifying the response of a water resources (hydropower) system to climate change (vulnerability domain) and subsequently using climate information from a multi-model ensemble of climate projections. It can therefore consider preparedness for a range of possible futures, and provide information that includes uncertainty.

This is fed into the adaptation analysis, which considers the possible options to address the current and future risks (and the impact on PIs), and then prioritises these based on the costs, benefits and other key criteria.

As the focus of the study, is on providing information to enable adaptation action amongst policy makers and the private sector, the study has also built up an extensive understanding of the current policy landscape with institutional mapping.



This has been complemented with extensive stakeholder engagement, with government, the regulator, developers and the private sector.

Climate Risk Assessment

The study first identified key performance indicators (PIs) through review and discussion with stakeholders. This identified key PIs linked to hydro-energy production, including:

- Total annual energy production (GWh/yr);
- Guaranteed production (MW) and total energy production (GWh) during the winter season (when demand is high and generation is reduced);
- System performance indicators;
- Floods, sediment and geo-hazards including Glacial Lake Outburst Floods (GLOFs); and Landslide-induced Dam Outburst Floods (LDOFs); and
- Economic performance indicators (Economic Internal Rate of Return (EIRR) and Net Present Value (NPV) of planned investments).

The first key finding is that the performance of Nepal's existing hydro-electric plants – and especially smaller run-of-river (RoR) projects - is heavily affected by current climate variability. This leads to a high current vulnerability for the overall hydropower system, and causes high economic impacts.

A key finding is that current climate and hydrological variability is a major challenge for Nepal's hydro- sector

However, there is a large variation in this vulnerability. It is influenced by catchment elevation, size of catchment and location, as well as the type of plant. To expand:

- Higher variability is observed in smaller catchments than larger catchments;
- Seasonal and inter-annual variations are higher in rain-dominated catchments than in snow-fed catchments;
- Run-of-river (RoR) projects are more affected than storage type projects due to flow variability.
- Base flow is more dominant in the dry winter season (Dec – Feb) whereas snow melt becomes important in the pre-monsoon season (Mar – May) season.
- Glacier melt currently starts from May/June onwards and the share of glacier melt (in river flow) in these months are reduced due to the onset of monsoon.

Furthermore, there is additional vulnerability from a number of geographical-specific risks:

- Sediment levels are high generally in Nepal, but particularly high in some catchments;
- Power plants in certain upper catchments downstream of potentially dangerous glacial lakes are vulnerable to Glacial Lake Outburst Floods (GLOF) risks, especially those within 50 to 100 km
- Very high and intense rainfall during the monsoon can lead to high peak flows, and these are a high risk to hydropower projects.

The impacts of future climate change on hydro-electric plants and the sector are uncertain: the study approach incorporates and adjusts for this

The climate risk assessment then assessed the potential impact of future climate change: a key finding is that these impacts are uncertain.

The lack of reliable and long-term hydro-meteorological data in Nepal is a key limitation to hydrological analysis and modelling work. There is insufficient coverage across different catchments, and a particular lack of data for higher elevations.

This is compounded by the high uncertainty when modelling future climate change in Nepal. There is inherent uncertainty in modelling climate change due to the range of possible future scenarios and the variation in climate model outputs. However, this is exacerbated in Nepal due to the complex climate and hydrology, as well as the very large changes in elevation that occur across the country, leading to high heterogeneity.

Rather than ignore this uncertainty, the climate risk assessment approach addresses it directly. It is informed by the range of scenario and climate models (using multi-model ensembles) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) that were used in the latest IPCC report, to assess how the envelope of future climate change will affect the key performance indicators.

Observational trends show that the climate of Nepal is already warming. Future climate projections show temperature will increase further and this is a robust finding across all the models. However, there is a wide range in the level of warming across different scenarios and models.

In the Representative Concentration Pathway (RCP) 4.5 scenario, which reflects a medium warming scenario, the 23 models from CMIP5 project a temperature rise from about 1.2˚C to 4.4˚C for upper catchments of Nepal by the middle of the century (2040-2059). In the RCP 8.5 scenario, which is a high warming scenario, the models project temperature increase from 1.6˚C to 5.2˚C for the same time period.

Based on average projection of 23 models in 2040-2059, a temperature increase in monsoon months (JJAS) around 2˚C is projected in the RCP 4.5 scenario and 2.6˚C in RCP 8.5. The models do indicate that the temperature rise in winter months (DJFM) will be higher than in other months, with the 23-model average about 2.7˚C and 3.4˚C in RCP 4.5 and RCP 8.5 scenarios, respectively.

At present, the observational data show that precipitation in Nepal increases up to an elevation of about 3000 m, after which, precipitation decreases with increased elevation (though data for elevations above 3000 m are very limited which limits understanding). Recent trends indicate changes in precipitation as well, but these are complex and vary across the country: there are therefore not clear trends as for temperature.

The projections of future precipitation – in terms of average, seasonal, inter- and intra-annual variability – are much more uncertain. The models mostly project that there will be an increase in monsoon precipitation, but the change in winter precipitation is uncertain, even in terms of the sign (+/-).

The CMIP5 23-model average projects an increase in monsoon precipitation of 7 to 11% in the RCP 4.5 scenario and from 10% to 15% in the RCP 8.5 scenario by the middle of the century (2040-2059). The change in monsoon precipitation (JJAS) is projected from -5.6% to +32.7% in the RCP 4.5 scenario and from -8.9% to +31.8% in the RCP 8.5 scenario for the same time period. Around 4 of 23 models show a decrease in precipitation in monsoon while 19 (around 80%) show an increase.

In winter months (DJFM), the projected precipitation change ranges from -40% to +66% in the RCP 4.5 scenario and from -37% to +24% in the RCP 8.5 scenario by mid century. More than half of the models show a decrease in winter precipitation. Hence, in general, the models indicate a warmer and wetter monsoon, and a warmer and possibly a drier winter (though with higher uncertainty) may arise in Nepal.

The models generally agree on an increase of extreme events with higher intensity precipitation occurring more frequently. Analysis of the maximum five day precipitation (RX5) from 17 GCM models show a model-average increase in magnitude of 9.1% in RCP 4.5 scenario and 11.7% in RCP 8.5 scenario by 2040-2059 in the upper regions of Nepal. In the RCP 4.5 scenario, 9 models out of 17 models show an increase of more than 10% in RX5 magnitude even though the range is from -5.9% to +37%. Likewise, in the RCP 8.5 scenario, 9 models show an increase greater than 10% while the range of change is from -8.2% to +52.2%. Only 1 model shows a negative change across all regions for both scenarios.

As the majority of climate models project increased average precipitation, this implies a positive gain might be expected in overall energy generation. However, this is driven by the increase in monsoon precipitation: the models are uncertain on the size and sign of winter precipitation change, which is important for the reliability of generation in the dry season.

Future climate change will have most impact by increasing climate induced hazards, i.e. sediment, floods, and GLOFs and LDOFs, rather than average generation

Based on projections of water availability, average annual hydropower generation - especially for medium and large projects– will be fairly robust to future climate scenarios (2040-2059)

Vulnerability to projected climate change varies for hydro projects, depending on location, size, type, hydrological design parameters, installed capacity and live storage (for storage projects). Smaller projects are likely to be more affected by climate change as their design is based on limited data, they are affected more by variable flow conditions, and can suffer from adverse impacts of upstream interventions (e.g. irrigation diversions).

Rising temperatures will affect snow hydrology and glacier melt and may impact hydro plants with substantial catchments above the snow line (i.e. the approximate winter snow line of > 3000m elevation and the year-round snow line > 5000m elevation) but will have little or negligible impact on plants at lower elevations.

In terms of the national level, 44% of the 69 current and planned ROR projects are in snow-dominated, higher elevation (H) catchments (with more than 80% of the catchment area above 3000m, 17% are in medium elevation (M) catchments (60-80% above 3000m), 19% are in low elevation (L) catchments (only 40-60% above 3000m) and 20% are in rain-dominated (R) catchments (less than 40% above 3000m).

In the case of 20 current and planned storage projects, the majority (65% or 13 of the 20), are in more rain dominated catchments, with one (5%), two (10%) and 4 (20%) in the H, M and L catchments, respectively.

The study has assessed the impacts of climate change on these different types of plants. This takes account of the complex interaction of hydrological elements like snowfall, snowmelt and evapo-transpiration (ET) from Precipitation (P) and Temperature (T) changes. The study has assessed a range of temperature and precipitation scenarios, to understand how performance varies across the uncertainty envelope.

For an adverse climate change scenario (20% reduction in P and +3^{o} rise in T by the 2050s), runoff decreases for all types of catchment, but the magnitude is greater in lower catchments. This is because evapo-transpiration (ET) losses increase more in hotter, lower catchments. In the pre-monsoon, higher catchments actually gain due to the complex interplay between ET and snowmelt (though the effect varies with the catchment area at higher elevation). Catchments with higher areas above 3000m and 5000m see increased snow and glacier melt but also ET increases. All of these changes are more significant in smaller catchments.

Run-of-river projects that are designed for higher dependable flows are less vulnerable to flow reductions than those designed for higher design discharge but lower dependable flows. This is because higher design flows leads to more energy variations with flow variations. Out of the 69 existing and planned ROR projects. 7% are designed for flows that are equal to 90% dependable flow (flows available 90% of the time), 10% are designed for flows that are between 60% and 90% dependable, 62% are designed for flows that are between 40% and 60% dependable, and 21% are designed for flows that are 40% or less dependable.

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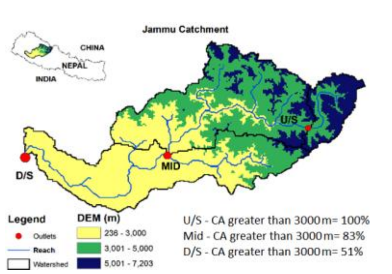
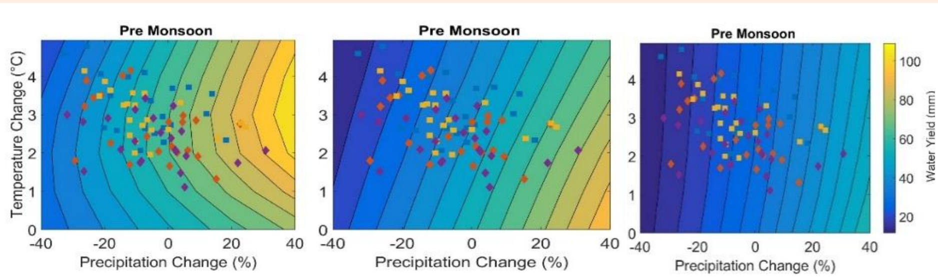
Reservoir projects with more live storage lead to better regulation, but they can be more impacted by flow reductions due to climate change during the monsoon period.

Box 1: Climate change and hydrological modelling results

The future projections in temperature (T) and precipitation (P) will influence changes in the hydrological regime by affecting key hydrological processes of evapotranspiration (ET), snow-rainfall ratio, melting time and the amount of snowmelt. The semi-distributed, physical based SWAT hydrological model was used in this study to assess the changes in runoff with changes in P and T. The runoff-response to changes in average P and T for three outlet locations (from upstream to downstream parts of the catchment) of Jammu sub-basin in the Karnali River Basin is shown below. The response along the river varied mainly due to the elevation differences directly affecting the hydrological processes. The adverse impacts of rise in T and any reduction in P is found to be more critical in more rainfed catchment (downstream location) than in more snow fed catchment (upstream location (see figures below).





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Runoff response to temperature and precipitation changes

Sediment load is higher in the river basins like Kali Gandaki and Marsyangdi in Gandaki Basin, and Thulo Bheri in Karnali Basin (in the Tibetan Sedimentary Zone). These areas can see annual sediment yields of more of than 7000 tonne/sq.km/year. Sediment loads in high glacierized area as in Arun sub-basin and Tama Koshi sub-basin in Koshi Basin are less than 1500 tonne/sq.km/year. Areas in the middle mountains, rain-fed catchments, such as Kulekhani and Khokhajor also have high yield of around 5000 tonne/sq.km/year.

The impact of climate change on sediment levels will vary with catchment location, type and size and also the project parameters. Case studies on the Khimti II project (low sediment and high Head) and the Jhimruk project ((high sediment and low head), estimated the loss of energy due to higher sediment flows associated with higher monsoon flows (for an increase of 20%) at 5.6% to 12 %.

Another major risk is from Glacial Lake Outburst Floods (GLOFs). These can have major impacts on hydro-electric plants. Peak discharge generated by potential GLOF events can be higher than the (hydrological) flood design capacity of the hydro plants, especially those located within 50-100 km downstream of such glacier lakes (see Box 2). However, the heavy sediments and debris flows from GLOFs can create problems in projects further downstream than that.

Landslide induced dam outbursts (LDOFs) are common in the high mountains and hills of Nepal. These pose a critical risk to hydro-plants located in weak geological, steep slope watersheds. More intense and frequent cloud bursts, projected to rise with climate change could increase the likelihood of such events.

The higher monsoon peak flows projected could also increase the risks of extreme flows and floods, leading to damage of hydro-electricity plants, with the costs of repair and lost revenues. As an example, there have been recent losses of micro- and small hydro plants due to floods.

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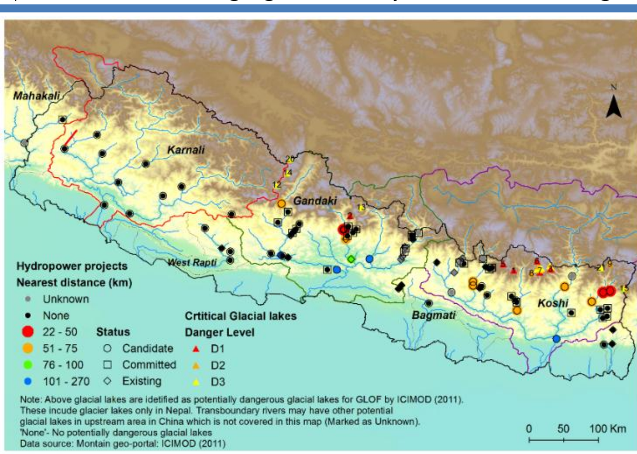
The expected rise in high flows due to climate change does have implications for the design of hydropower projects and flood design standards. Private developers for smaller/medium ROR projects are currently adopting design flood standards for shorter return periods (e.g. a flood with a probability of occurring once 1 in 100 years, or 1 in 1000 years) compared to NEA medium and large RoR projects which are designed for higher return periods (e.g. 1 in 10,000). Storage projects with substantial storage volume are however designed for 1 in 10,000 or probable maximum floods. The design of projects downstream of potential GLOFs and LDOFs should be based on the maximum potential peak discharges due to GLOFs and LDOFs events. For other other plants, there are a range of possible design standard for the estimated hydrological peak discharge. This involves a trade-off between the higher costs of greater protection versus the risks of damage. This study recommends that the minimum standards that might be appropriate for Nepal could be a minimum 1,000 year return period for smaller ROR projects without large pondage and of 1:10,000 year return period or probable maximum flood (PMF) for medium and larger ROR projects, and storage reservoir projects.



Mapping of critical glacial lakes and distance to nearest hydropower

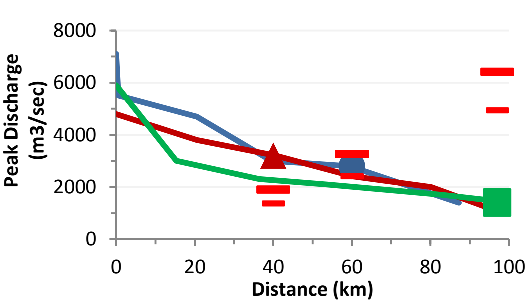
Box 2: Glacial Lake Outburst Flood

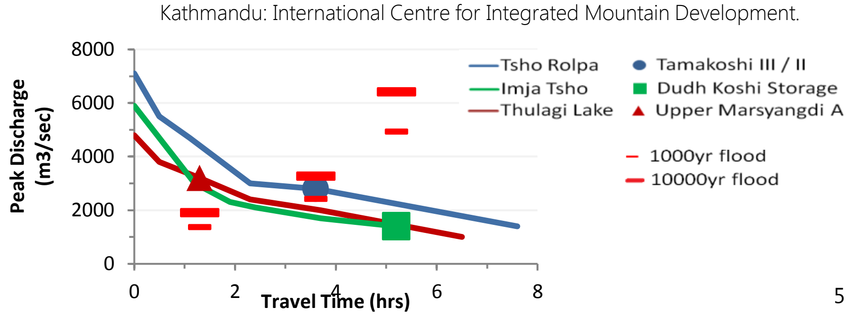
Temperature rise in the Himalayan watershed has contributed to the formation and expansion of glacial lakes and this is closely associated with an increased risk of glacial lake outburst flood (GLOF). These GLOF events are characterized by high peak discharge, high velocity, very high sediment and debris although they normally have very low frequency of occurrence. Only twenty four GLOFs in Nepal in the past have been documented (ICIMOD, 2011)..

ICIMOD (2011) has hydrodynamically assessed the risk of three critical glaciers, Tsho Rolpa, Thulagi Lake and Imja Lake. The study shows that in the event of a GLOF, the flood peak would attenuate by half the magnitude after around 50 km (over a period of about 3 hours); and by 80% after 100 km. This shows that the distance of hydropower projects to critical glacial lakes is important, with risks reducing with distance significantly.

Source:

- ICIMOD (2011): Glacial lakes and glacial lake outburst floods in Nepal. Kathmandu: International Centre for Integrated Mountain Development.





The impact of climate change on hydropower sector is additional to other factors and uncertainties

Nepal's power sector is affected by multiple issues and uncertainties. Climate change is therefore an additional emerging risk that the sector needs to adapt to.

In the short-term, for current plants, and for the new planned plants built in the next decade, the effects of current climate variability (baseline) and particularly the uncertainty regarding institutional and regulatory issues are likely to be more important, with issues related to tarrifs and pricing, export opportunities, construction costs (and the risks of delays and over-runs) and project financing.

There are some possible exceptions to this, when there is the potential for very large climate risks especially around safety or when risks lead to much larger economic costs and lead to major electricity supply disruption (this might apply to very large [storage] projects).

For plants built later (after 2030s), the impacts of climate change could be much more significant. However, the design of these plants does not have to be finalised now: there is the opportunity to learn more about emerging trends and changes, and adjust these investments. This does require some preparation and action today, nonetheless, to allow the learning to provide future information and reduce uncertainties, for example by enhancing hydro-met data with monitoring to gather information and investing in downscaled modelling.

The current power system of Nepal is constrained by a severe deficit in supply compared to electricity demand. This leads to high imports of power from India and major load management by NEA to avoid load shedding. These problems arise from an inappropriate power mix and a lack of capacity during peak hours and throughout the dry season, but a surplus of power in non-peak hours and during the wet season. This balance is inefficient, leading to high costs in the form of imports and unmet demand.

The current power system suffers from an inefficient power mix and mismatch of supply and demand of electricity leading to high economic costs at the system (national) level

The study assessed the potential impacts of climate change at the system (national) level using a system wide model, WASP. One insight from the analysis is that existing and planned future projects are being designed at the project level under the current regime (pricing, market and regulatory policy) without fully considering the overall system requirements or possible changes in the regime. For example, more than 80% of the ROR projects are designed at discharges with 40% or lower dependability, which are "optimal" under the current pricing regime. Storage capacity of most reservoir projects are also limited, with only 20% storing more than 50% of the average monsoon runoff (June to Sep.) and only 45% generating more than 30% of the total annual energy in the 5 dry months from December to April.

Baseline investment planning (without climate change) that was carried out under the study shows that more storage type reservoir projects are required to meet the current and future power demand of the Integrated Nepal Power System (INPS). The optimal (i.e., cost minimizing) share of hydropower projects (in total installed generation capacity) is one in which storage projects increase over time. The analysis finds that the optimal share of capacity of both ROR and storage plants will be more or less equal to the order of 46 or 47% in the future (next 2-3 decades). Similarly, with the available type of candidate plants, the energy mix will stabilize at 72% for ROR plants and 18-22% for storage projects.

A limitation of the present investment planning analysis using WASP is that it cannot consider the differences between RoR and pRoR hydro plants explicitly. It would be important from the policy and investment planning perspective to determine the optimal mix of RoR, PRoR and storage power plant capacities as well as their energy generation mix. This limitation is an issue for future research

The investment planning exercise was also carried out for an adverse climate risk scenario. This included a 20% reduction in precipitation and a 3ºC rise in temperature. The probability of such an extremely dry, hot hydrological condition happening in the next 30 years has a very low likelihood. Such an analysis was made to "stress test" the investment planning with the objective of testing the sensitivity of key system-level performance indicators such as optimal capacity and energy mix requirement, levelized cost of energy as well as total investment cost.

Under this adverse climate scenario, thermal generation would increase under the adverse hydrological conditions compared to the base case.

The investment requirement, production cost and the levelized cost of energy generation was estimated to increase by 12 % (8% is attributed to lower energy and 4% to additional adaptation cost for climate-proofing from adverse extreme hazards). A note of caution is that such hydrological condition would gradually occur over the next 3 decades so the impact would not be as higher in the first one to two decades. On the other hand, the life of hydropower plants is much longer (50 to 60 years) as compared to the investment planning period of 30 years that was considered in the study. The optimal power mix ratio adopted for the baseline is however expected to perform satisfactorily in the case of the climate stress case as well. The above findings are based on the presently available projects, and a relatively high discount rate of 10-12%, which is used in Nepal.

Adaptation

Adaptation pathways can help the Adaptation pathways can help address the challenges of adapting the hydro- sector

There are options that can address the climate and future risks identified for the hydro-electricity sector in Nepal. However, the more difficult issue is to identify which adaptation options it makes sense to implement, given the balance of costs and benefits. This challenge arises because:

- Retrofitting options to reduce the risks of climate variability on current plants is often a very expensive option and is further complicated by existing power purchase agreements.
- It is possible to over-design new plants to mitigate against all possible risks, e.g. to design to cope with the most extreme climate scenarios, but this is unlikely to make sense in financial terms.

These decisions are complicated by the nature of climate change and the economics of investment decisions. Early adaptation to future climate change (such as with immediate retrofit or new plant over-design) has the potential to increase the costs of capital and operation of hydropower plants, and therefore affects the rate of return (and the cost of electricity produced). The benefits of these adaptation investments – in terms of reduced damages from climate change - however, will only arise in the longer-term, towards the end of the concessionary period of the project and may be very small when compared to the up-front costs in present value terms. Therefore, from the private perspective, they are unlikely to provide a payback on investment (unless somehow reflected in the performance contract).

Compounding this, future climate change is associated with high uncertainty, as highlighted in the earlier section. This makes it difficult to plan exactly what to do when. Even if early action is taken, it is likely it will under- or over-estimate the future risks that actually emerge.

To address these challenges, the project adopted the iterative climate risk management approach highlighted earlier. This has two critical aspects. First, it focuses on what action to take now over the next five to ten years to address current climate variability and future climate change.

Second, it identifies options that are economically attractive and make sense in terms of implementation, despite the challenges around timing and uncertainty above.

It is stressed that there are important differences in adaptation for current versus future plants, due to the lifetime and economics of different decisions. This means that at the individual and overall level, a set of complementary options is needed.

Adaptation needs to be designed to the specific context, plant and vulnerability

The adaptation assessment has taken on board a key finding from the climate risk assessment: vulnerability is location and plant specific. The vulnerability of different plants various with:

- Timing and type of decision, i.e. current plant, planned (next decade) or prospective long-term.
- Type of plant (small, medium, large, RoR vs pROR vs storage)
- Design parameters like design discharge dependability for RORs or live storage capacity for reservoir projects.
- Catchment (snow fed versus rain fed).
- Sediment loading.
- GLOF and LDOF risk.
- Policy, regulatory and financial agreements.

This means that the vulnerability of any individual plants, and the system as a whole, is very heterogeneous. This leads to an obvious but key finding: a suite of options is needed to adapt the hydro-power sector of Nepal, i.e. it is not a case of one size fits all.

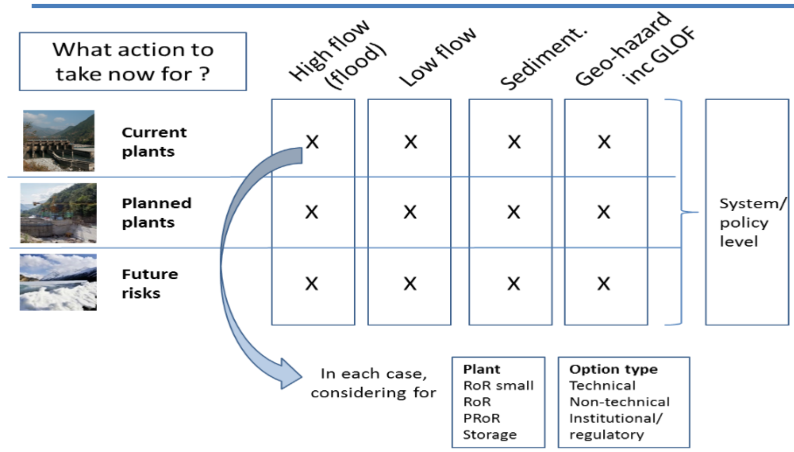
The study identified a long list of adaptation options to the various climate risks identified. The list of adaptation options considered included:

- Technical options. These involve technical or engineering options (hard options) related to infrastructure, equipment, etc. noting these options were assessed in terms of their applicability to the typology above (i.e. current, planned or future) for different climate risks.

- Non-technical options. These involve alternative approaches, such as capacity building, the provision of information or, changes in management (soft options).

The analysis also considered policy or regulatory options, which include the means to implement some of the options above (e.g. changing guidance or power purchase agreement (PPA) incentives).

This list of options was then mapped according to the decision criteria and risk using a matrix, as shown below.



There are low regret adaptation opportunities for the hydropower sector in Nepal

The assessment therefore then set out to prioritise adaptation, both for interventions in general, and the choice of individual options (specifically).

The adaptation pathways approach was used to help identify the timing and sequencing of adaptation, ensuring options were designed to fit the relevant decision context.

The analysis included an economic and financial analysis of options for both current and future planned plants, assessing the costs of adaptation against the potential benefits of adaptation, the latter quantified in terms of reduced revenues (from lower generation from changes in flow) or increased downtime (revenue loss) and damage from climate induced disasters. For major storage plants there was also the consideration of safety and wider economic effects. More details are provided in the box.

The analysis also used the case studies to test the timing of adaptation, especially for new plants, looking at the trade-off between including adaptation in design or implementing later when uncertainty is reduced, but costs (of retrofit) may be higher. This also considered alternative options, for example building flexibility into the design to allow the upgrade of plants at lower costs later or selecting more robust options that performed well over a wide range of future climate scenarios.

Based on the overall analysis, a number of general findings emerge.

First, it does not make sense to over-design the whole hydro-power sector in Nepal for all possible future climate risks today. In many cases, the high cost of retrofitting existing plants or the high costs of over-design (future plant) did not provide sufficient benefits to justify investment, or else proved to be less cost-effective compared to alternative options (e.g. lower cost investment or alternative approaches to addressing risk, such as insurance).

Second, from testing different options in different case studies, it is clear that the applicability, suitability and economic performance of adaptation options is highly plant and project specific (linked to the factors on the previous page). There is a danger in providing general recommendations on 'good' adaptation.

Nonetheless, it was possible to identify a set of interventions that look very promising, i.e. the third key finding is that there are a number of low regret adaptation options for the hydropower sector in Nepal, which have wide applicability. These are discussed below.

Current plants

For current hydro-power plants (and the current system), the key focus is to introduce no- and low-regret options that address the current risks of climate variability, i.e. that make sense to do anyway, but also help address the early signals from future climate change and thus help build resilience.

The most promising options provide immediate (net) economic benefits. These include an emphasis on options that have low costs, particularly non-technical options and capacity building. Examples include improved hydro-met data, real-time sediment monitoring, early warning systems, and information that helps manage or address risks, such as operational management, detailed flood risk assessments as well as insurance. There are also some retrofit options that are no- or low-regret, such as putting low-cost protective structure around key infrastructure, turbine recoating, and some forms of sediment management.

In Nepal, many of these various low-regret options are forms of good practice, and they have not been implemented due to existing barriers. They are particularly important for smaller plants, many of which have been designed with limited hydrological data. They also provide greater resilience to future climate change, notably the increase in climate induced hazards.

For plants that are exposed to high current impacts of variability (e.g. high sediment loads) there may also be more expensive options that can be justified (e.g. more advanced sedimentation management) because of the high current baseline costs. However, larger and more costly retrofit options that involved major infrastructure and works were not found to be low-regret: there maybe cases where they are justified, but application is highly context specific.

Planned plants

The integration of adaptation into new hydro-power plants, i.e. planned and near-term candidate plants that will be designed over the next five to ten years, involves different issues. As well as designing for current variability, these plants will be exposed to future climate change, especially towards the end of their economic lifetime.

The focus is therefore on making these new hydropower plants 'climate-smart'. This necessitates different thinking to current plants (above), because it must consider the timing of adaptation, i.e. the trade-off between additional up-front costs and long-term benefits, under uncertainty. A number of aspects are recommended for these plants.

Kali Gandaki Hydropower Project

First, the low regret-options identified for current plants are also applicable for future design.

Second, there is also the opportunity to include additional low-regret options that address current climate variability more effectively today in new design. As an example, for rivers with high sediment load, advanced and efficient sediment equipment can actually lead to lower costs than gravity settlement today, and provide extra resilience given climate change is likely to increase sediment loads in the future.

Third, there are additional options which make more sense at the design phase for addressing future climate change. However, the identification and applicability of these is more complex to assess. The key issue here is that while these plants will come on stream in the next ten years or so, the major changes projected from climate change will happen in the far future (2040 – 2060) and are uncertain.

The question is therefore around what additional options might be justified to include in the design today, given this will be cheaper than retrofitting later, but also that it incurs up-front costs to reduce uncertain benefits that will only arise in the far future. In general, four promising areas emerged.

- There are some very low-cost over-design options that can be incorporated to help build future resilience. An example is fuse-gates or fuse-plugs for storage projects. These contrast to a general over-design (larger structure, additional spillways).
- There is the potential to include flexibility in the design to allow later upgrades at lower cost. An example would be to include the space for adding additional spillways later (should these be needed).
- There are some options that are robust, i.e. that perform well under a range of future scenarios. This could include the choice of turbine/s, selecting equipment that provides better performance over a range of flows (reflecting changes under climate change), rather than optimally to one flow regime.
- In many cases, however, the most economically efficient option is to wait, with a phased approach, but with the caveat that this should be as adopted as part of an iterative risk management approach at the plant level that enables learning and adaptive management.

Overall, while there is the opportunity to include some early climate smart elements, the main focus should be on a cycle of monitoring, evaluation and review over time, to bring in additional options if needed (or delay if not). This has the advantage that adaptation only takes place if needed, and furthermore, costs are borne later, and are closer to the stream of adaptation benefits (improving the economic return).

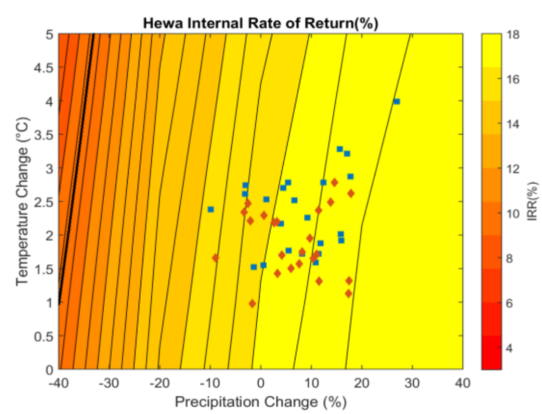
One caveat for this approach to work, however, is that there must be investment in monitoring and planning (which itself has a cost, albeit low). This can be seen as an investment in information (the value of information).

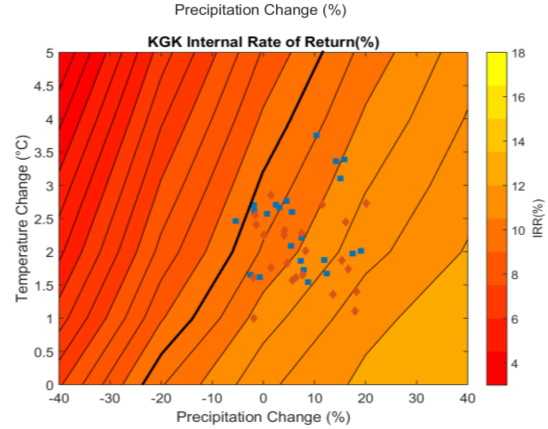
Box 3: Financial analysis of adaptation

The financial analysis was undertaken using real hydrological and cost data from a number of existing plants in Nepal. The analysis then introduced climate scenarios – looking at the envelope of change from the models - to see how climate change affected the net present value (NPV) and internal rate of return (IRR). The figures on the right show the vulnerability domain of the projects (IRR response to climate) for two projects, a ROR project in a rain-dominated catchment (14.9 MW) (top right) and a ROR project in a snow-dominated catchment (180 MW) (bottom right). The thick black line is the threshold internal rate of return (IIR) of 10%. The dots in the figures show the range of P and T changes by 2040 – 2059 (red dots for RCP 4.5 and blue dots for RCP 8.5). The figure highlights the IRR sensitivity to climate change varies between the two catchments, with a greater influence on the rain dominated catchment (left).

The next step was to use the information on the potential costs and benefits of adaptation options, for example to address increased sediment load or floods associated with these climate change scenarios, and to analyse how these options changed the financial performance. This analysed the tradeoff between revenue losses (before and after adaptation) against additional adaptation costs. Critically, the analysis was extended to consider the timing and phasing of options, to align to the iterative approach of the Climate Risk Assessment methodology. This therefore considered the introduction of options during design (upfront) or later (phased) in response to an increasing climate signal. The overall analysis was used to select the most promising adaptation options.

Financial performance response to climate change





Future plants and risks (>2025)

The final category involves different concepts again. It is focused on preparing for hydro-sector for the future major risks from climate change with the critical difference that it involves plants that will be built in the future. This would include, for example, the next generation of planned plants (that start to get planned after 2025). In this case, there is no need to make a firm decision now of any particular adaptation option and there is time to learn. This therefore involves a set of options that provide the information to help make better decisions and planning in the future.

The example of existing glacial lake monitoring is a good example of this, providing information that will help to identify emerging risks, and could be extended, including to include other high flow risks. Research to help the modelling of climate change in Nepal is also a priority, as well as pilot and evaluation projects to test new adaptation options. A key priority is also the need for general capacity building (across the different actors in the sector) and for institutional strengthening.

Overall, the analysis shows that while the application of adaptation will need to be location and plant specific, and does involve some challenging factors, this is not a reason for inaction. There are many early actions that can be taken in the short-term to address climate variability and build resilience. The table below includes some specific examples of low-regret options identified by the study.

Finally, one additional conclusion emerged that mirrors the vulnerability findings. Climate impacts generally have a relatively small impact on project finances in the short term, and other factors are likely to be more important, such as the tariff used (the electricity generation price) or the discount rate/rate of return threshold. This reinforces the point that adaptation should be integrated (or mainstreamed) into existing sector policy and planning – not the other way around.

Example of promising adaptation options

		Current plant		**Planned plant**
		Non-technical,	Technical	
High flow (flood)	IF a vulnerable area	Enhanced hydro-met (including on line /real time monitoring) Detailed flood risk assessment Early warning systems Insurance Reservoir management (storage)	Modifying existing spillways to increase discharge capacity. Fusegate/plugs Protect key infrastructure, e.g. intake structure, power house	As left plus, Siting assessment Space for future auxiliary spillway
Low Flow (dry, winter)	IF a vulnerable area	Enhanced hydro-met (see above) Improved use of climate information and plant management Plant co-operation (especially cascade) Reservoir management	Turbine upgrade during retrofit	As left plus, Choice of turbine (flow conditions) Space for future additional turbine or upgrade
Sediment	IF a high sediment laden river	Sediment monitoring (real-time) Slope stability monitoring	(Re) Coating of turbines Retrofit sediment management Sloping intakes	As left plus Enhanced trapping devices, e.g. centrifugal, hydrocyclones, vortex basins.
Geo-hazard (GlOFs, LDOFs)	IF in potentially risky river	Detailed risk assessment Early warning Insurance	Protect key infrastructure, e.g. intake structure, power house	As left plus, Set back or raised structure (and potentially some key structures underground), Smart tailrace gates

Institutional analysis

Understanding the institutional context and barriers is critical for effective adaptation

A wide range of stakeholders have an interest in the hydropower sector, and thus in adaptation.

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The study has also considered how to mainstream (to integrate) adaptation into the institutional and policy landscape. Mainstreaming is the integration of climate change into existing policy and development, rather than implementing measures as a stand-alone activity. The focus is therefore to include climate in existing policy, regulations and planning, e.g. to make it climate-smart.

A wide range of stakeholders have an interest in the hydropower sector, and thus in adaptation

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This includes Government policy makers and regulators, International Financial Institutions (IFIs) and Development Partners (DPs), the private sector, domestic and foreign developers, foreign regulators (for exports) and others such as civil society.

Importantly, these stakeholders are involved at different stages of hydropower development and they have different roles in risk assessment, adaptation strategy and implementation.

The study has also considered how to mainstream (to integrate) adaptation into the institutional and policy landscape. Mainstreaming is the integration of climate change into existing policy and development, rather than implementing measures as a stand-alone activity. The focus is therefore to include climate in existing policy, regulations and planning, e.g. to make it climate-smart.

One of the first activities of mainstreaming is to identify relevant entry points, that is, to identify the existing framework and opportunities in the national, sector or programme plans and activities where climate adaptation can be integrated.

Finally, there are a number of barriers to adaptation that make it harder to plan and implement. These include a range of economic, social and institutional factors, including market failures, policy failures, governance failures and behavioural barriers.

Addressing these barriers is critical to successful adaptation, especially for medium to long-term decisions such as for hydro-power. There are ways to reduce or overcome these barriers; however, this requires their consideration from the start of the adaptation planning process.

Project cycle phase	Decision makers and relevant parties
Planning	Government, Planners, Regulators, Developers, Local communities
Design	Developers, Designers, Government, Financiers, Local communities
Construction	Developers, Owners, Financiers, Insurers, Local communities
Operation	Owners, Operators, Financiers, Insurers, Local communities

Recommendations

Addressing current vulnerability. The priority is for Nepal's hydropower system to address current climate variability and geo-hazards, as this would improve current performance and produce immediate benefits, while also building resilience to future climate change for the medium and long-term.

Individual plants are often not designed to cope with current risks, but addressing these risks with low-regret options will help financial performance, help to protect assets, and will help offset the future risks of climate change.

At the system level, looking at the balance of plants on the system to help address current variability now will have a major benefit in strengthening the sector to address the risks of future climate change in the future.

River Basin Disaster Risk Management . River basin disaster risk management and assessment is a priority to mitigate the impacts of climate change on increased climate induced hazards (floods, sediments, GLOFs, LDOFs), which are more important risks to the hydro-sector in Nepal.

Hydro-met. While positive initiatives are happening, notably the PPCR initiative, further strengthening of hydro-meteorological information is critical. The information on catchments above 3000 m is identified as a particular gap, but greater hydro-met and sediment monitoring across the country is a priority.

These investments in information provide the foundation for current and future adaptation, i.e. they will improve current and future investment decisions and produce a very high benefit from improving decisions (the value of information).

Risk assessment, best practice and awareness. There are barriers to plant operators adopting early low regret measures including information gaps, finance and institutional. These can be targeted to create the enabling environment for early adaptation for developers.

To address this, it would be useful to use the vulnerability work and undertake risk assessments for existing plants. This would provide key information for operators on the risk they face. This could be complemented with good practice examples (from Nepal) on the application of promising low regret options, with benefit and cost information, to raise awareness, highlighting financial benefits.

Climate risk screening and design standards. Following on from the analysis above, there is a need to mainstream climate risk assessment into the development project cycle (the application, approval and financing arrangements).

The priority gap would be to ensure that plants are addressing current climate variability effectively, but also help operators to consider if there are additional areas where climate change might justify additional investment, noting that this needs to consider the balance of costs and benefits.

The priority is again likely to be for smaller plants. A similar approach of providing support information and case study material for the development of new plants (good practice examples) would be particularly useful.

System Planning. The development of a more efficient capacity mix, with a greater share of storage type reservoir projects, is required to meet the current and future power demand of the Integrated Nepal Power System (INPS). At present, the share of storage plant capacity is about 10% only, and the analysis here indicates this is too low in the existing and planned future INPS generation system (leading to an inefficient capacity mix) inadequate. System planning is also constrained by insufficient number of variations in projects types and size.. It is recommended that project feasibility studies and hydropower/river basin master plans undertake a more detailed options assessment considering both current hydrology and future changes, and likely changes in policy, regulatory and pricing regime.

At present system planning is being carried out for one particular future power demand scenario (which is based on a particular GDP growth scenario). As there are uncertainties in future GDP growth and the associated future power demand growth paths, the implications of climate change for system planning and costs are unlikely to be fully reflected. It is recommended that future system planning also consider these issues for a more comprehensive assessment of the nature and scale of climate change adaptation involved in hydropower development in the country over a long run.

Invest to learn. There is a need to invest, with monitoring, research and pilots, to improve future decisions and planning (learning).

This could include further work to improve the modelling of climate change in Nepal, but also a greater focus on observations and monitoring (e.g. building on the existing monitoring of GLOF risks).

Institutional Strengthening and Capacity Building. The need to build capacity in the sector is paramount, with more focus on awareness raising and information, along with support of research. One important aspect is to develop the institutional research landscape and ensure information is disseminated.

Finally, there is a need for institutional strengthening on climate change in Government and across the major agencies involved in the hydro-sector, as well as for the private sector. A planned programme of technical assistance support would enable all the other key recommendations above, and would help the hydro-power sector to mainstream climate change and develop future sector development plans and policies to ensure they are climate smart.

Project Study Team: This project was led by Nepal Development Research Institute (NDRI), working with Practical Action Consulting Limited (PAC) in Nepal, the Global Climate Adaptation Partnership (GCAP) from the UK.

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