Adaptation to Climate Change in the Hydroelectricity Sector in Nepal

POLICY BRIEF

May 2017

Key messages

- Current climate and hydrological variability is a major challenge for Nepal's hydropower sector.
- The impacts of climate change on hydropower are uncertain, due to the lack of reliable long-term hydro-meteorological data and the high uncertainty associated with future climate change in Nepal.
- The greatest impacts of climate change are likely to be increased climate-induced hazards, such as sediment load, 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, and institutional and regulatory issues).
- Adaptation pathways can help address the challenges associated with 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, hydro 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 for mainstreaming climate change into future sector development plans and policies.

Authors

Divas B. Basnyat and Paul Watkiss

Assessing the future impacts of climate change on the hydroelectricity sector in Nepal is a challenge because of the country's complex climate and hydrology, as well as the large changes in elevation that occur from low plains up to the high mountains. Projections of future climate change show high uncertainty, with large differences across future scenarios and between climate models.

To address these challenges, this study used a climate risk assessment (CRA) methodology (Figure 1) based on a bottom-up decision-scaling approach. The process began by assessing the sensitivity and performance of Nepal's present hydropower plants in response to the current climate, followed by an investigation of how future climate change could affect them.

The method identified key performance indicators of significance to hydro-energy generation that may be sensitive to climate and thus put the initial emphasis on understanding how the present meteorological and hydrological variability affect current operations and planned investments. The method has the advantage of focusing the analysis on what matters. It can then look at future climate change, including uncertainty, assessing the importance of future changes and how the key performance indicators could be affected. The CRA has been linked to an iterative adaptation pathway approach to use this risk information to build possible adaptation responses under uncertainty.

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

The method 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. The three types of adaptation are:

1. Immediate actions that address the current risks of weather and climate extremes (the adaptation deficit) and build resilience to future climate change. These include 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 hydropower plants.

2. The integration of adaptation into immediate decisions or investments with long lifetimes (climate smart planning), focusing on the new (planned or candidate) hydroelectric plants that will be built over the next decade or so. These plants will be exposed to uncertain future climate change. There will therefore be 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 investing in information and learning to help future decisions.

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

To capture uncertainty, the CRA focused on identifying the response of a water resources (hydropower) system to climate change (vulnerability domain) and subsequently used climate information from a multi-model ensemble of climate projections. The CRA therefore considered preparedness for a range of possible futures and provided information including uncertainty. This information was fed into the adaptation analysis, which considered possible options that could address the current and future risks (and the impact on performance indicators), and then prioritised these on the basis of costs, benefits and other key criteria.

As the focus of the study was on providing information to enable adaptation action by policy-makers and the private sector, the study also built an extensive understanding of the current policy landscape using institutional mapping. This institutional mapping has been complemented with extensive stakeholder engagement, including the government, the regulator, developers and the private sector.

Climate risk assessment

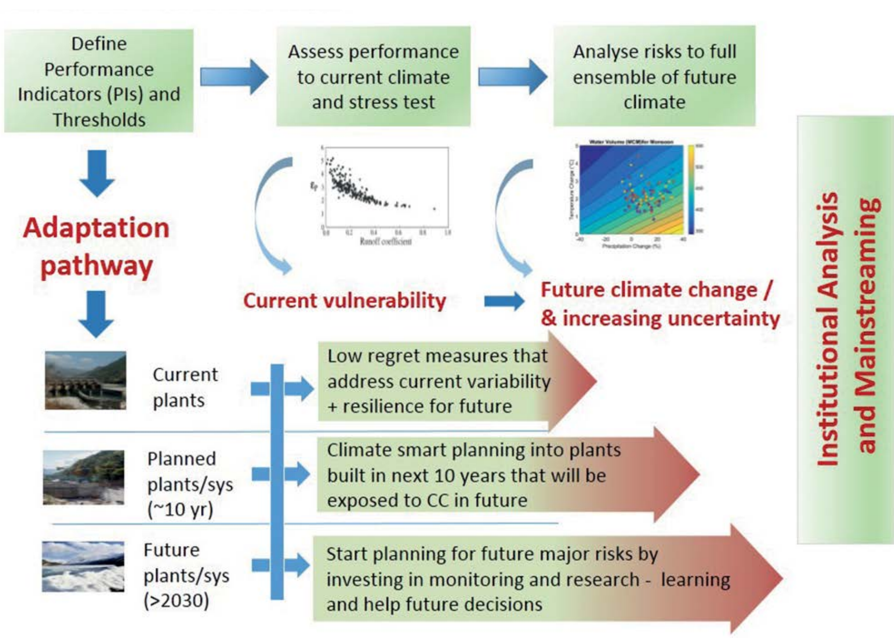
Review and discussion with stakeholders

The study first conducted a review and discussions with stakeholders to identify the following key performance indicators:

- total annual energy production (GWh/year)
- 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 load and geo-hazards, including glacial lake outburst floods (GLOFs) and landslide-induced dam outburst floods (LDOFs)
- economic performance indicators, including internal rate of return (IRR) and net present value (NPV) of planned investments.

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

Figure 1. Climate risk assessment



> "Current climate and hydrological variability is a major challenge for Nepal's hydro sector"

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

- Smaller catchments exhibit higher relative variability than larger ones.
- Seasonal and inter-annual variations are higher in rain-dominated catchments than in snow-fed ones.
- Run-of-river (RoR) projects are affected more than storage-type projects due to flow variability.
- Base flow is dominant in the dry winter season (December–February), whereas snow melt becomes important in the pre-monsoon season (March–May).
- Glacier melt currently starts from May/June onwards but the share of glacier melt (in river flow) in these months is low in relative terms, once the monsoon begins.

There is additional vulnerability from a number of specific geographical risks:

- Sediment levels are generally high in Nepal, particularly so in some catchments.
- Power plants in certain upper catchments downstream of potentially dangerous glacial lakes are vulnerable to GLOF risks, especially those located within 50–100 km downstream of such lakes.
- Very high and intense rainfall during the monsoon can lead to high peak flows, and these pose a significant risk to hydropower projects.

> "The impacts of future climate change on hydroelectric plants and the sector are uncertain; the study approach addressed and adjusted for this"

Scenarios on the potential impacts of climate change

The CRA 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. 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 (from the plains close to sea-level up to the top of Mount Everest), leading to high heterogeneity.

Rather than ignore this uncertainty, the CRA approach addressed it directly. A range of scenario and climate models (using multi-model ensembles) from the Coupled Model Intercomparison Project Phase 5 (CMIP5), as used in the latest Intergovernmental Panel on Climate Change report, were used 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 of different levels of warming across different scenarios and models.

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

Based on average projection of 23 models in 2040–2059, a temperature increase in monsoon months (June–September) of around 2°C is predicted in the RCP 4.5 scenario and 2.6°C in RCP 8.5. The models indicate that the temperature rise in winter months (December–March) will be higher than that in other months, with the 23-model average estimated at 2.7°C and 3.4°C in the 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 3,000 m, after which precipitation decreases with increased elevation (though data for elevations above 3,000 m are limited). Recent observations also indicate changes in precipitation, but these are complex and vary across the country; there are therefore no clear trends.

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 averages across six different regions of Nepal project an increase in monsoon precipitation of 7–11% in the RCP 4.5 scenario and 10–15% in the RCP 8.5 scenario by the middle of the century (2040–2059). The change in monsoon precipitation is projected to be in the range of –5.6% to +32.7% in the RCP 4.5 scenario and –8.9% to +31.8% in the RCP 8.5 scenario for the same time period. Four of the 23 models show a decrease in precipitation during the monsoon, while 19 (around 80%) show an increase.

In winter months, 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 the middle of the century. More than half of the models show a decrease in winter precipitation. Hence, in general, the models indicate that a warmer and wetter monsoon, and a warmer and possibly drier winter (though with higher uncertainty) may arise in Nepal.

The models generally agree on the likelihood of an increase in extreme events, with higher-intensity precipitation occurring more frequently. Analysis of the maximum five-day precipitation (Rx5) from 17 General Circulation Models showed a model-average increase in magnitude of 9.1% in the RCP 4.5 scenario and 11.7% in the RCP 8.5 scenario by 2040–2059 in the upper regions of Nepal. In the RCP 4.5 scenario, nine models out of 17 showed an increase of more than 10% in the Rx5 magnitude, even though the range was –5.9% to +37%. Likewise, in the RCP 8.5 scenario, nine models showed an increase greater than 10%, while the range of change was –8.2% to +52.2%. Only one model showed a negative change across all regions for both scenarios.

Impacts of climate change on energy generation

Since the majority of climate models project increased annual 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 about the size and sign of winter precipitation change, which is important for the reliability of generation in the dry season.

From projections of water availability, average annual hydropower generation – especially for medium-sized and large projects – will be fairly resilient to future climate scenarios (2040–2059). Vulnerability to projected climate change varies for hydro projects, depending on their location, size, type, hydrological design parameters, installed capacity and live storage (i.e. capacity to store water that can be released when required). Smaller projects are likely to be affected more greatly by climate change; since their design is based on limited hydrological data, they are affected more by variable flow conditions and they can suffer from the adverse impacts of upstream interventions (e.g. irrigation diversions).

> “Future climate change will have the greatest impact by increasing the incidence of climate-induced hazards, like higher sediment load and flooding, including outbursts from glacial lakes and landslide-induced dams”

Rising temperatures will affect snow hydrology and glacier melt, and may affect hydro plants with substantial catchments above the snow line (i.e. the approximate winter snow line of > 3,000 m elevation and the year-round snow line of > 5,000 m elevation), but the effects of snow hydrology and glacier melt will have 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 3,000 m; 17% are in medium-elevation (M) catchments (60–80% above 3,000 m); 19% are in low-elevation (L) catchments (only 40–60% above 3,000 m); and 20% are in rain-dominated (R) catchments (less than 40% above 3,000 m).

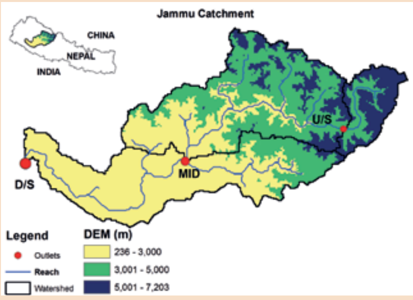
Of 20 current and planned storage projects, the majority (13 or 65%) are in rain-dominated catchments, with one (5%), two (10%) and four (20%) in the H, M and L catchments, respectively. The study assessed the impacts of climate change on these different types of plants. It took account of the complex interaction of hydrological elements like snowfall, snowmelt and evapotranspiration (ET) from precipitation and temperature changes. The study assessed a range of temperature and precipitation scenarios to understand how performance varies across the uncertainty envelope.

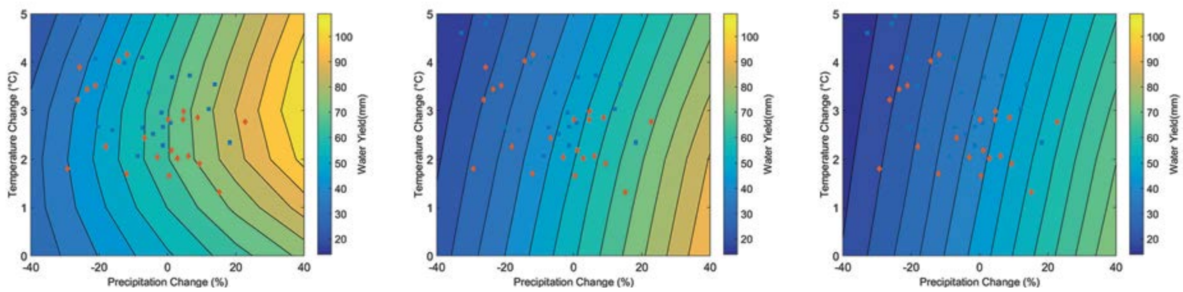
For an adverse climate change scenario (20% reduction in precipitation and +3°C rise in temperature by the 2050s), run-off decreases for all types of catchment, but the magnitude is greater in lower catchments. This is because ET losses increase in hotter, lower catchments. In the pre-monsoon season, 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 above 3,000 m and 5,000 m see increased snow and glacier melt, but ET also increases. All of these changes are more significant in smaller catchments.

RoR projects that are designed for higher dependable flows are less vulnerable to flow reductions than those designed for higher discharge but lower dependable flows. This is because higher design flows lead to more significant energy variations with flow variations. Out of the 69

Box 1. Climate change and hydrological modelling results

The future projections of 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 Soil and Water Assessment Tool hydrological model was used in this study to assess the changes in run-off with changes in P and T. The run-off response (for pre-monsoon period – April and May) 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 were more critical in a rainfed catchment (downstream location) than in a snow-fed catchment (upstream location) (see figures below).





Upstream Mid-stream Downstream

Run-off response to temperature and precipitation changes

Legend: ◆ RCP 4.5 ■ RCP 8.5

Notes: DEM, digital elevation model; RCP 4.5, Representative Concentration Pathway 4.5 scenario; RCP 8.5, Representative Concentration Pathway 8.5 scenario.

existing and planned RoR projects, 7% are designed for flows that are equal to 90% of the dependable flow (flow 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. Reservoir projects with greater live storage lead to better regulation, but they can be affected more by flow reductions due to climate change during the monsoon period.

Impact of climate change on sediment loads, GLOF and LDOF

Sediment load is higher in some river basins, e.g. the Kali Gandaki and Marsyangdi in the Gandaki basin, and Thulo Bheri in the Karnali basin in the Tibetan Sedimentary Zone. These areas can have annual sediment yields of more of than 7,000 tonnes per square kilometre. Sediment loads in high elevation areas with glaciers (e.g. Arun sub-basin and Tama Koshi sub-basin in the Koshi basin) are less than 1,500 t/km^2 per year. In the middle mountains, rain-fed catchments (e.g. Kulekhani and Khokhajor) also have a high yield of around 5,000 t/km^2 per year.

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

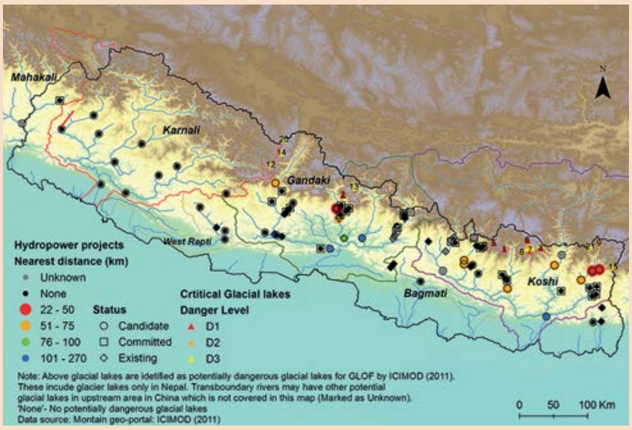
Another major risk is from glacial lake outburst floods. These can have major impacts on hydroelectric plants. Peak discharge generated by potential GLOF events can be greater than the (hydrological) flood design capacity of hydro plants, especially those located within 50–100 km downstream of such glacier lakes (see Box 2). However, the heavy sediments and debris flows from GLOFs can create problems in projects even further downstream.

Landslide-induced dam outburst floods (LDOF) 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 cloudbursts, which are projected to increase in frequency with climate change, could increase the likelihood of such events. The higher projected monsoon peak flows could also increase the risks of extreme flows and floods, causing damage to hydro plants, costly repairs and lost revenues. As an example, there have been recent losses of micro- and small-scale hydro plants due to floods.

Implications for the design of hydropower projects

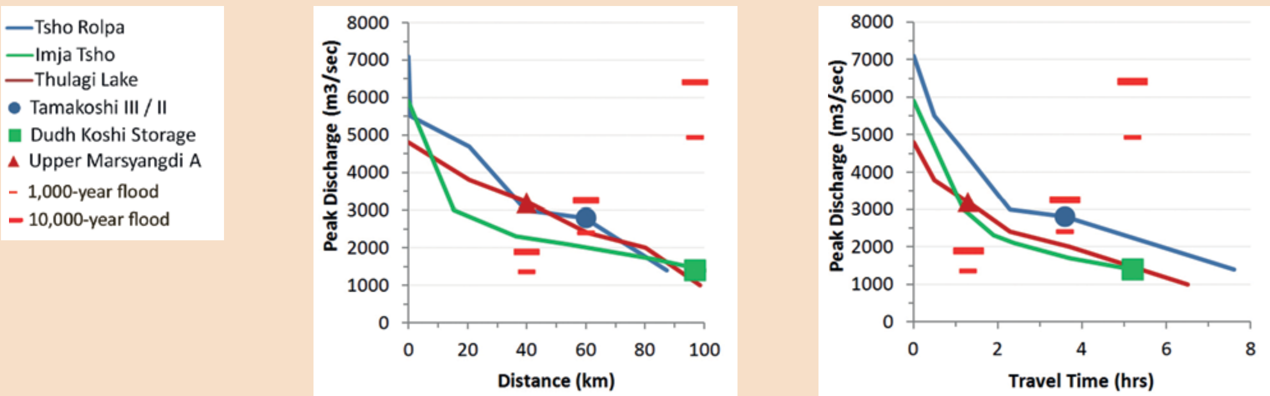
The expected rise in high flows due to climate change has implications for the design of hydropower projects and flood design standards. Private developers for small- and medium-sized RoR projects are currently adopting flood design standards for shorter return periods (e.g. a flood with a probability of occurring once in 100 years, or once in 1,000 years) compared with Nepal Electricity Authority (NEA) medium-sized and large RoR projects that are designed for higher return periods (e.g. once in 10,000 years). Storage projects with substantial storage volume are, however, designed for once in 10,000 years or probable maximum floods. The design of projects downstream of potential GLOFs

Box 2. Glacial lake outburst flood



Mapping of critical glacial lakes and distance to nearest hydropower plant

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 characterised by high peak discharge, high velocity, very high sediment and debris load, although they normally have a low frequency of occurrence. Twenty four GLOFs have been documented in Nepal since 1935. International Centre for Integrated Mountain Development (ICIMOD) (2011) undertook a hydrodynamic assessment of the risk associated with three critical glaciers: the TshoRolpa, Thulagi Lake and Imja Lake. The study findings showed that in the event of a GLOF, the peak flood would attenuate by half after around 50 km (over a period of about three hours), and by 80% after 100 km. This shows that the distance from hydropower projects to critical glacial lakes is important, with risks significantly reducing with distance.



Flood attenuation at various downstream locations

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

and LDOFs should be based on the maximum potential peak discharges likely due to GLOF and LDOF events. For other plants, there is a range of possible design standards for the estimated hydrological peak discharge. These involve a trade-off between the higher costs of greater protection versus the risks of damage. The study results indicate 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 storage, and 10,000-year return period for medium-sized and larger RoR projects and/or probable maximum flood for storage reservoir projects.

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

Nepal's power sector is affected by multiple issues and uncertainties. Climate change is an additional and emerging risk to which the sector needs to adapt. In the short term, for existing plants and those to be built during the coming 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 tariffs and pricing, export opportunities, construction costs (and the risks of delays and over-runs) and project financing. The one exception to this is when there is potential for very large climate risks, especially around safety, or when risks lead to larger economic costs and major electricity supply disruption (this might apply to very large storage projects).

For plants built later (after the 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 an opportunity to learn more about emerging trends and changes, and to adjust these investments. Some preparation and action is needed today to allow such learning, to provide future information and to reduce uncertainties; for example, by enhancing hydro-meteorological data with monitoring to gather information, and investing in down-scaled modelling.

Nepal's current electricity system is constrained by a severe deficit in supply compared with demand. This leads to large 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 with demand for electricity, leading to high economic costs at the system (national) level"

Impacts of climate change at the national level

The study assessed the potential impacts of climate change at the system (national) level using a system-wide model, WASP. The analysis highlighted that existing and planned 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 for discharges with 40% or lower dependability, which are 'optimal' under the current pricing regime. The storage capacity of most reservoir projects is also limited, with only 20% storing more than 50% of the average monsoon runoff (June–September) and only 45% generating more than 30% of the total annual energy in the five dry months (December–April).

Baseline investment planning (without climate change) carried out under the study showed 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-minimising) 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 two to three decades). Similarly, with the available type of candidate plants, the energy mix will stabilise 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 peak RoR (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 the 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 3°C rise in temperature. The probability of such an extremely dry, hot hydrological condition occurring within 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, levelised[2] cost of energy and total investment cost.

Under this adverse climate scenario, thermal generation would increase under the adverse hydrological conditions compared with the base case. The investment requirement, production cost and the levelised cost of energy generation were estimated to increase by 12% (8% is attributed to lower energy and 4% to the additional adaptation cost of climate-proofing in the face of extremely adverse hazards). A note of caution: such a hydrological condition would occur gradually over the next three decades, so the impact would be less in the first one to two decades. On the other hand, the life of hydropower plants is much longer (50–60 years) than the investment planning period considered in the study (30 years). The optimal power mix ratio adopted for the baseline, however, is also expected to perform satisfactorily in the case of the climate stress case. The above findings are based on the currently available projections and a relatively high discount rate of 10–12%, as used in Nepal.

Adaptation

> "Adaptation pathways can help address the challenges of adapting the hydro sector"

Which, what and when?

There are options that can address the future climate risks identified for the hydroelectricity sector in Nepal. However, the more difficult issue is to identify which adaptation options are sensible 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 complicated further by existing power purchase agreements.
- It is possible to over-design new plants to mitigate against all possible risks, e.g. 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 capital and operation costs 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 damage from climate change, however, will arise only in the longer term, towards the end of the concessionary period of the project, and may be very small compared with the upfront 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 earlier. 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 10 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 of timing and uncertainty (indicated 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 CRA: vulnerability is location and plant specific. The vulnerability of different plants varies with:

- timing and type of decision, i.e. current plant, planned (next decade) or prospective long-term
- type of plant (small, medium, large, RoR, pRoR, storage)
- design parameters, e.g. 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 plant, 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

2 This is the net present value of the unit-cost of electricity over the lifetime of a generating asset. It is often taken as a proxy for the average price that the generating asset must receive in a market to break even over its lifetime.

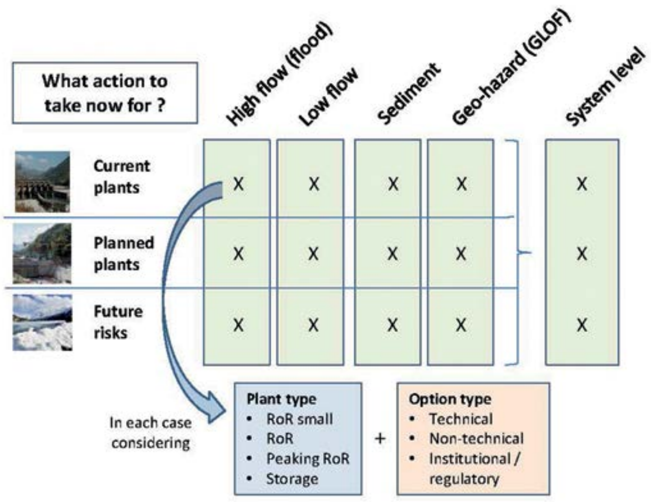
the hydropower sector of Nepal, i.e. it is not a case of 'one size fits all'.

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

- Technical options – These involve technical or engineering options (hard options) related to infrastructure, equipment, etc. 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 (though often complementary) 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 incentives). This list of options was mapped according to the decision criteria and risk using a matrix, as shown in Figure 2.

Figure 2. Adaptation option mapping



Note: GLOF, glacial lake outburst floods; RoR, run-of-river hydroelectricity.

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

Adaptation priorities

The assessment 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 assessment included an economic and financial analysis of options for both current and future or planned plants, assessing the costs of adaptation against the potential benefits, the latter being 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, the analysis also considered safety and wider economic effects. More details are provided in Box 3.

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 changes later when uncertainty becomes reduced but costs (of retrofit) may be greater. It also considered alternative options, for example building flexibility into the design to allow the upgrade of plants at a lower cost later or selecting more robust options that performed well over a wide range of future climate scenarios.

A number of general findings emerged from the overall analysis. First, it does not make sense to over-design the entire hydropower sector in Nepal today for all possible future climate risks. In many cases, the high cost of retrofitting existing plants or the high cost of over-design (future plant) did not provide sufficient benefits to justify the investment, or proved less cost-effective than alternative options (e.g. lower cost investment or alternative approaches to addressing risk, such as insurance). Second, from testing various 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 discussed on page 8). There is 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 hydropower 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 today, but also help address the early signals of 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-meteorological data, real-time sediment monitoring, early warning systems and information that helps manage or address risks, such as operational management, detailed flood risk assessments and insurance. There are also some retrofit options that are no- or low-regret, such as putting low-cost protective structures around key infrastructure, turbine recoating and some forms of sediment management.

In Nepal, many of these low-regret options are forms of good practice, but they have not been implemented due to existing barriers. They are particularly important for smaller plants, many of which have been designed based on 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), more expensive options may be justified (e.g. more advanced sedimentation management) because of the high current baseline costs. However, larger and costlier retrofit options that involved major infrastructure and works were not found to be low-regret. There may be cases where they are justified, but their application is highly context specific.

Planned plants

The integration of adaptation into new hydropower plants, i.e. planned and near-term candidate plants that will be designed over the next five to 10 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 requires a different approach to that taken with current plants, because planning must consider the timing of adaptation, i.e. the trade-off between additional upfront costs and long-term benefits under uncertainty. A number of aspects are recommended for these plants.

First, the low-regret options identified for current plants are also applicable to future design. Second, there is an opportunity to include additional low-regret options that address current climate variability more effectively in new design. As an example for rivers with high sediment load, advanced and efficient sediment equipment can actually lead to lower costs than the gravity settlement in use today, and provide extra resilience given climate change is likely to increase sediment loads in the future. Third, there are additional options that make more sense at the design phase for addressing future climate change. However, it is complex to assess the identification and applicability of these options. The key issue is that while these plants will come on stream in the next 10 years or so, the major changes projected from climate change will happen in the far future (2040–2060) and are uncertain.

Kali Gandaki Hydropower Project. Photo: www.nepalenergyforum.com

The question therefore concerns what additional options might be justified for inclusion in the design today, given that this will be cheaper than retrofitting later, but also that it incurs upfront costs to reduce uncertain benefits that will arise only in the far future. In general, four promising areas have 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 with general over-design (larger structure, additional spillways).
- There is potential to include flexibility in the design to allow later upgrades at lower cost. An example would be to include 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. These could include the choice of turbine(s), and selecting equipment that provides better performance over a range of flows (reflecting changes under climate change), rather than working best with a single flow regime.
- In many cases, however, the most economically efficient option is to wait and include a phased approach, but with the caveat that this should be adopted as part of an iterative risk management methodology at the plant level that enables learning and adaptive administration.

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

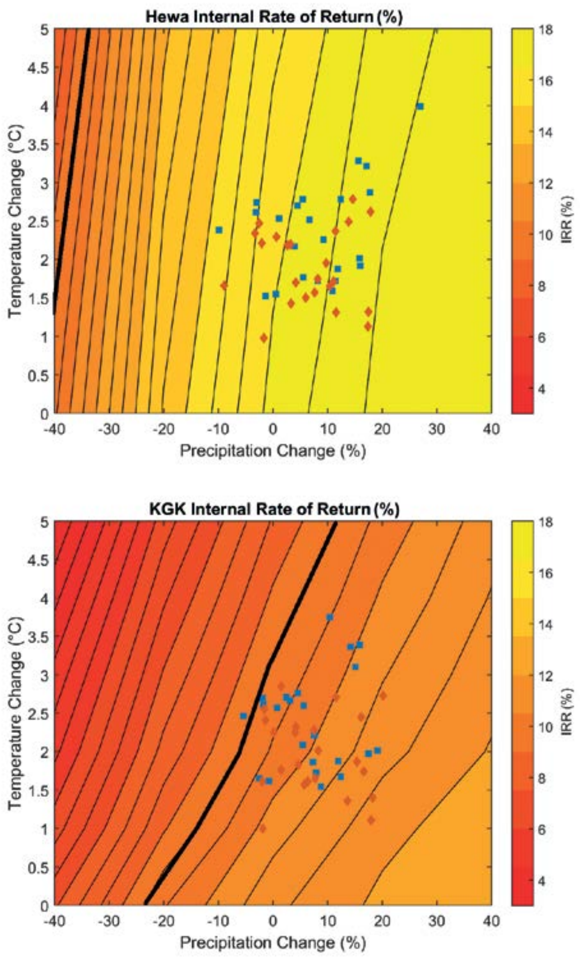
One caveat for this approach to work, however, is that there must be investment in monitoring and planning, which itself has a cost, albeit low. This can be seen as an investment in information (the value of information).

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 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, an RoR project in a rain-dominated catchment (14.9 MW) (top right) and an RoR project in a snow-dominated catchment (180 MW) (bottom right). The thick black line is the threshold IIR of 10%. The dots in the figures show the range of precipitation (P) and temperature (T) changes by 2040–2059. The figure highlights that IRR sensitivity to climate change varies between the two catchments, with a greater influence on the rain-dominated catchment.

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 included analysis of the trade-off 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. The method 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



Legend: ◆ RCP 4.5 ■ RCP 8.5
RCP: Representative Concentration Pathway

Future plants and risks (after 2025)

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

Existing glacial lake monitoring is a good example. It provides information that will help to identify emerging risks and could be extended to include other high flow risks. Research to inform improved modelling of climate change in Nepal is another priority, along with pilot and evaluation projects to

Early warning system siren at TshoRolpa glacier lake
Photo: www.mountainsoftravelphotos.com

test new adaptation options. One key priority is the need for general capacity-building (across the different actors in the sector) and institutional strengthening.

Overall, the analysis showed that, while the application of adaptation will need to be location and plant specific, and will 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. Table 1 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, with other factors 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.

Institutional analysis

The study considered how to mainstream 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 standalone activity. The focus is therefore to include climate in existing policy, regulations and planning, i.e. to make them climate smart.

Table 1. Example of promising adaptation options

			Technical	
		Non-technical	Current plant	Planned plant
High flow (flood)	If a vulnerable area	Enhanced hydro-met (including online/real-time monitoring) Detailed flood risk assessment Early warning systems Insurance Reservoir management (storage)	Modifying existing spillways to increase discharge capacity Fuse-gate/plugs Protect key infrastructure, e.g. intake structure, power house	As per 'Current plant', 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 cooperation (especially cascade) Reservoir management	Turbine upgrade during retrofit	As per 'Current plant', 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 per 'Current plant', plus: Enhanced trapping devices, e.g. centrifugal, hydro-cyclones, 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 per 'Current plant', plus: Set-back or raised structure (and potentially some key structures underground) Smart tailrace gates

> "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. These include government policy-makers and regulators, international finance institutions and development partners, the private sector, domestic and foreign developers, foreign regulators (for exports) and civil society. These stakeholders are involved at different stages of hydropower development (Table 2) and they have different roles in risk assessment, adaptation strategy and implementation.

Table 2. Stakeholders in each project cycle phase

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

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

There are a number of barriers to adaptation that make it difficult 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 developing hydropower. There are ways to reduce or overcome these barriers; however, this requires them to be considered from the start of the adaptation planning process.

Recommendations

Addressing current vulnerability. The priority is for Nepal's hydropower system to address current climate variability and geo-hazards, since 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 no- and low-regret options will improve financial performance and protect assets as well as offset the future risks of climate change. At the system level, looking at the balance of plants on the system currently operating nationally to help address current variability now will have a major benefit in strengthening the sector to address the risks of future climate change.

River basin disaster risk management and assessment. This is a priority to raise awareness and help plan for the impacts of climate change in terms of increased climate-induced hazards (floods, sediments, GLOFs, LDOFs), which are the most important risks to the hydro sector in Nepal.

Hydro-meteorology. While positive initiatives are happening, notably the Pilot Programme for Climate Resilience initiative, further strengthening of hydro-meteorological information is critical. The lack of information on catchments above 3,000 m is identified as a particular gap, but greater hydro-meteorological and sediment monitoring across the country should be made a priority. These investments in information will provide the foundation for current and future adaptation, i.e. they will improve current and future investment decisions and produce a 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, and financial and institutional barriers. These can be targeted to create an enabling environment for early adaptation by developers. To address this, it would be useful to use the vulnerability work and undertake climate risk assessments for existing plants. This would provide key information for operators on the current risks. It 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 project development cycle (the application, approval and financing arrangements). The priority would be to ensure that plants are addressing current climate variability effectively, but also to help operators consider any further 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 to provide 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 INPS. At present, the share of storage plant capacity is only about 10%, and the analysis indicated that is too low in the existing and planned INPS generation system (leading to an inefficient capacity mix). System planning is also constrained by an insufficient number of variations in project types and sizes. It is recommended that project feasibility studies and hydropower/river basin master plans should undertake a more detailed options assessment considering both current hydrology and future changes, and likely changes in the policy, regulatory and pricing regimes.

At present, system planning is being carried out for one future power demand scenario based on a particular level of gross domestic product (GDP) growth. Since there are uncertainties in predicting the growth of GDP and associated future power demand paths, the implications of climate change for system planning and costs are unlikely to be fully reflected in this single plan. It is recommended that future system planning should 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 the long term.

Invest to learn. There is a need to invest in 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 observation 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, putting greater focus on awareness-raising and information, along with support for 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 key recommendations above, and would help the hydropower 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 the Nepal Development Research Institute (NDRI), working with Practical Action Consulting Limited (PAC) in Nepal and the Global Climate Adaptation Partnership (GCAP) from the United Kingdom (UK).

The study team (in alphabetical order) consisted of: Rishesh Amatya, Divas B. Basnyat (Team Leader), Dipendra Bhattarai, Gopal Babu Bhattarai, Federica Cimato, Laxmi P. Devkota, Sindhu Devkota, Johan Grijsen, Jaya K. Gurung, Govind Nepal, Hari Pandit, Saurav Pradhananga, Dibesh Shrestha, Moushumi Shrestha, Ram M. Shrestha, Shiva G. Shrestha and Paul Watkiss.

This document is an output from a project funded by the UK Department for International Development (DFID) and the Netherlands Directorate-General for International Cooperation (DGIS) for the benefit of developing countries. However, the views expressed and information contained in it are not necessarily those of or endorsed by DFID, DGIS or the entities managing the delivery of the Climate and Development Knowledge Network (CDKN), which can accept no responsibility or liability for such views, completeness or accuracy of the information or for any reliance placed on them. CDKN is a project funded by DFID and DGIS and is led and administered by PricewaterhouseCoopers LLP. Management of the delivery of CDKN is undertaken by PricewaterhouseCoopers LLP, and an alliance of organisations including Fundación Futuro Latinoamericano, LEAD International, the Overseas Development Institute and SouthSouthNorth.

About this document: This policy brief synthesises key findings and recommendations for decision making under uncertainty in the hydropower sector in Nepal. It provides guidance to hydropower designers, developers and policy-level decision-makers on assessing climate risks at the project and the system level, and on mitigating the risks using the adaptation pathways approach.

More detailed descriptions of the climate risk assessment methodology used, vulnerability assessment of individual plants and the system as a whole, identification of the adaptation pathways, and institutional and policy mapping to identify barriers and entry points for adaptation are covered in the technical reports of the project.

Editing, design and layout: Green Ink (www.greenink.co.uk)

Funded by:

UKaid from the British people

Ministry of Foreign Affairs of the Netherlands