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PAANI PROGRAM | पानी परियोजना

SYSTEM-SCALE PLANNING TO SUPPORT SUSTAINABLE ENERGY SYSTEMS AND CONSERVATION OF FRESHWATER RESOURCES FOR PEOPLE AND NATURE

Executive Summary

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OVERVIEW OF THE PROJECT

BACKGROUND TO THE PROJECT

Nepal has significant water resources and, as a result, infrastructure projects, including hydropower and irrigation, are being proposed for nearly every river in Nepal. If all these projects were to be built, the ecological functions and aquatic biodiversity of Nepal's rivers would decline greatly. Rivers also support a wide variety of ecosystem services and human cultural and economic activities. The risk of significant tradeoffs - between infrastructure on the one hand and social and environmental values on the other hand - is especially significant with several large-scale projects proposed for the main channel of the Karnali River and its tributaries. Many nations have learned the hard lesson that restoration of degraded ecosystems is extremely costly. Furthermore, research in Nepal has shown that the climate risks of hydropower development (especially since dams are large, expensive, and immobile), are significant, with alternative energy options including solar or wind providing more risk adjusted opportunities.[1] Nepal's opportunity lies in incorporating these lessons learned now, while strategic decisions can be made to achieve development with broad benefits.

While developing its hydropower potential can help Nepal develop economically and meet its low-carbon energy goals, it also carries significant financial, natural and social risks. Choosing the sites with the lowest costs and impacts is therefore imperative. By quantifying and comparing impacts and benefits at large scales (e.g., river basins or even all of Nepal), a system-scale approach to planning and management can inform decision makers in Nepal so they can identify development opportunities that strike the best balance between energy development and maintaining natural and social resources.

Carrying out system-scale planning for power system development at an early stage can achieve more sustainable hydropower deployment. This would include avoiding or minimizing impacts on rivers that support multiple values across environmental, social, cultural and economic dimensions such as fisheries, tourism and trekking, rafting, water provision, heritage or religious uses and freshwater biodiversity. It would also increase resilience of the power system, for example with respect to climate change, through greater diversification of generation sources. One of the keys to achieving this potential is for the planning of hydropower to move beyond single projects. In this project, we developed information at a range of scales, including assessing energy options and river conservation priorities at the national scale. We also developed a decision support tool, primarily focused at the scale of the Karnali River basin (Figure 1).

OVERVIEW OF THE COMPONENTS

There are three major components to this project, with each component providing insights and contributions for different policy and planning processes in Nepal. However, the greatest utility to decision makers arises through integration of the components.

1 https://www.sciencedirect.com/science/article/abs/pii/S0959378016307002?via%3Dihub

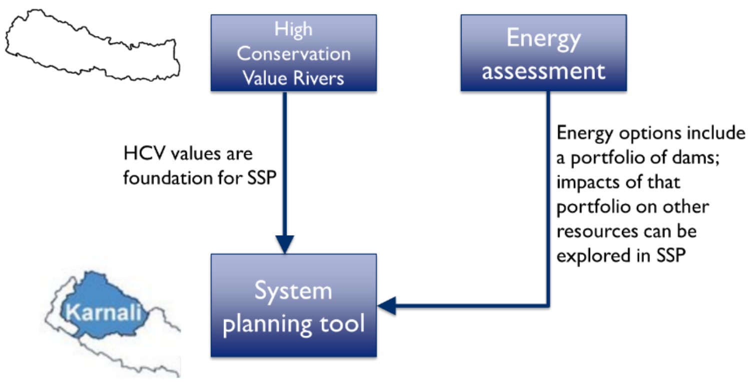

Figure 1: Three components of the project "System-scale planning to support sustainable energy systems and conservation of freshwater resources for people and nature"

HIGH CONSERVATION VALUE RIVERS

Nepal is blessed with remarkable rivers supporting aquatic and terrestrial biodiversity, ecosystem functions like groundwater recharge and flood abatement, and socio-economic benefits through livelihoods, recreation, tourism, natural beauty and cultural identity. However, despite the country's historic leadership in creating protected areas from the mountains to the Terai, there are no specific policies and legislation that offer protection for the nation's rivers. The purpose of this component was to complete a first national level map of High Conservation Value Rivers in order to:

- Highlight the increasing degradation of rivers in Nepal, and where restoration interventions could be directed to slow the loss of ecological, livelihood, cultural and other values
- Respond to the increasing calls to maintain portions of Nepal's river systems in a natural state and provide information on where rivers of high conservation value remain
- Provide information on the location of baseline rivers that could be monitored over time for comparison against rivers which are being developed
- Identify rivers or river stretches that are still relatively intact and that are providing critical ecosystem services to nature and people and, are thus candidates for protection
- Provide decision makers information needed on current state of rivers of Nepal in order to conserve or restore the integrity of these rivers and river stretches for current and future generations

ENERGY OPTIONS ASSESSMENT

The Energy Options Assessment (EOA) for Nepal produced least-cost pathways for the Nepal power system over the next 20 years to compare system cost implications of different policy options and other assumptions. These include different costs or incentives for technologies (e.g., solar PV, wind, and battery storage), different cross-border strategies, and policy prescriptions and targets. Model results provide insights into potential investments in generation, storage and transmission capacity and operations. A comprehensive portfolio-based scenario analysis has not yet been explored for Nepal, since previous planning studies focused on a single pathway with little sensitivity analyses. With falling costs of wind, solar PV, and battery storage globally, the results of this model provide valuable information for long-term energy planning for Nepal. The impacts on river resources from specific combinations of hydropower projects selected by the energy model can be explored within the system planning framework for a comprehensive cost and risk assessment of power system expansion.

SYSTEM SCALE PLANNING

The System Scale Planning (SSP) component explored the tradeoffs associated with hydropower development. A very high number of development options (different combinations of projects) can be compared in terms of their performance across a range of quantitative criteria (economic, social and environmental). The tradeoffs are clearly visualized through a series of parallel plots and other graphics. Ultimately, the model can be used to identify investment options (defined in terms of location, design and operation) that perform well across a range of economic, social and environmental objectives. It can be used to identify options for planning purposes, or to calculate and compare the cumulative impacts of pre-defined combinations of projects. Some of the inputs to this model come from the High Conservation Value Rivers (HCVR) analysis, while the EOA analysis provides the overall required scale of hydropower.

HIGH CONSERVATION VALUE RIVERS (HCVR)

BACKGROUND

To catalyze changes in policy and management, the values of rivers need to be framed in terms that are compelling for those making decisions. Rivers have traditionally been valued as providers of water supply or hydroelectric power. But the full value of rivers is far larger and includes a set of benefits that are often invisible to decision makers. These hidden values are generally not measured or prioritized until crises arise. The persistent failure to proactively manage to maintain these broader river values – such as the delivery of sediment to sustain downstream channels and deltas, freshwater fish stocks and flood mitigation – has resulted in dramatic and widespread social, environmental and economic losses. Nepal has already experienced this, since the Bagmati River in the Kathmandu Valley is considered a “dead river” and the Kulekhani River - once renowned for Asla (Snow trout) – has lost most of its trout after construction of dams.

The purpose of the HCVR component was to identify and document the diverse values of the rivers of Nepal, marking the first time that rivers of different conservation values have been identified and categorized in Nepal. Understanding where areas of high conservation value - i.e., those that support high levels of biodiversity, recreation, fisheries, or other socio-cultural values - occur within the country allows for more scientifically grounded decisions on river management and planning. **The HCVR definition within the Nepalese context is as follows:** A *High Conservation Value River* is a **clean, highly connected** or **free-flowing** river or stretch that acts as **a lifeline**, maintaining **ecosystem services** for present and future generations, providing **refuge** and **habitat** for high levels of **aquatic biodiversity**, and supporting important **socio-cultural values.**

APPROACH AND RESULTS

The HCVR assessment combines evaluations of the freshwater status (river and floodplain health) and freshwater values (ecosystem services) of the rivers of Nepal followed by an assessment of ecosystem representation to ensure that all river types are represented in the HCVR results. The evaluation of freshwater status assesses two components related to river health: (1) river and floodplain connectivity and; (2) water quality pressures on rivers and floodplains. Freshwater values include the biodiversity, recreational, livelihood and socio-cultural components and services of the rivers of Nepal (). Ecosystem representation is an important aspect of this assessment as this assures representation of important riverine and aquatic ecosystem in high conservation value rivers of Nepal.

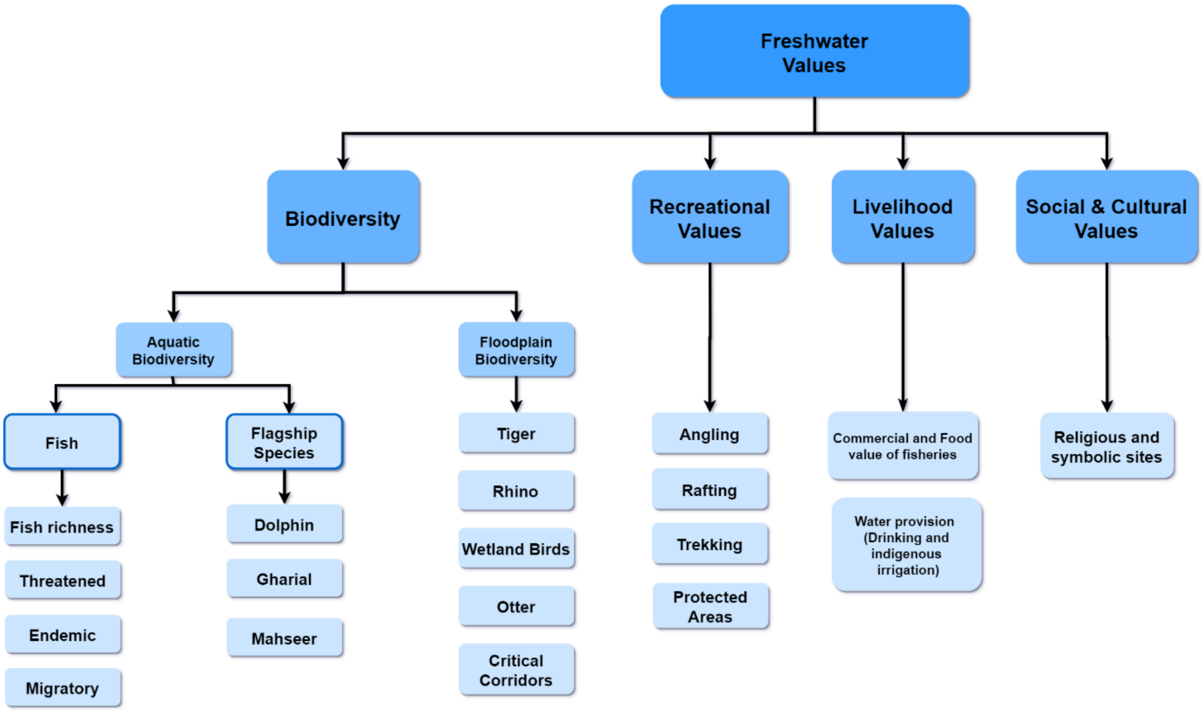

Figure 2: Tree-diagram identifying freshwater values

The process of determining a first map of High Conservation Value Rivers of Nepal took 18 months and was highly participatory. One of the first steps was to convene two workshops in Kathmandu and Surkhet in July 2019 with representation from the Government of Nepal, non-governmental organizations, and academic institutions. During discussions in these workshops, the participants agreed on the definition for a High Conservation Value river, freshwater values were identified, and a framework for the methods was developed.

A volunteer Advisory Group composed of Nepali experts across multiple disciplines played a crucial role in supporting the process with provision of data, expert knowledge and review, and guidance on methodology development. Beyond the in-person workshops, an additional set of six Advisory Group meetings and two additional virtual workshops were held during the 18-month long project to provide updates and receive feedback and guidance to improve results. A team of local and international hydrology and GIS experts conducted in-depth data collection and GIS mapping which resulted in more than 20 layers of novel data. These data layers represent freshwater values for aquatic and floodplain-related biodiversity, recreation, livelihoods, and the social-cultural uses of rivers in Nepal. Data sources and importance of these values can be found in more detail in the HCV Technical Report.

An index-based multi-criteria model was developed, and a stakeholder-driven approach was used to agree on a weighting scheme for integrating these layers into an HCV value score used to rank individual rivers and river stretches. The values were then integrated to create a single index (Figure 3). More information regarding the outputs of the HCV mapping can be found in the HCV Technical Report.

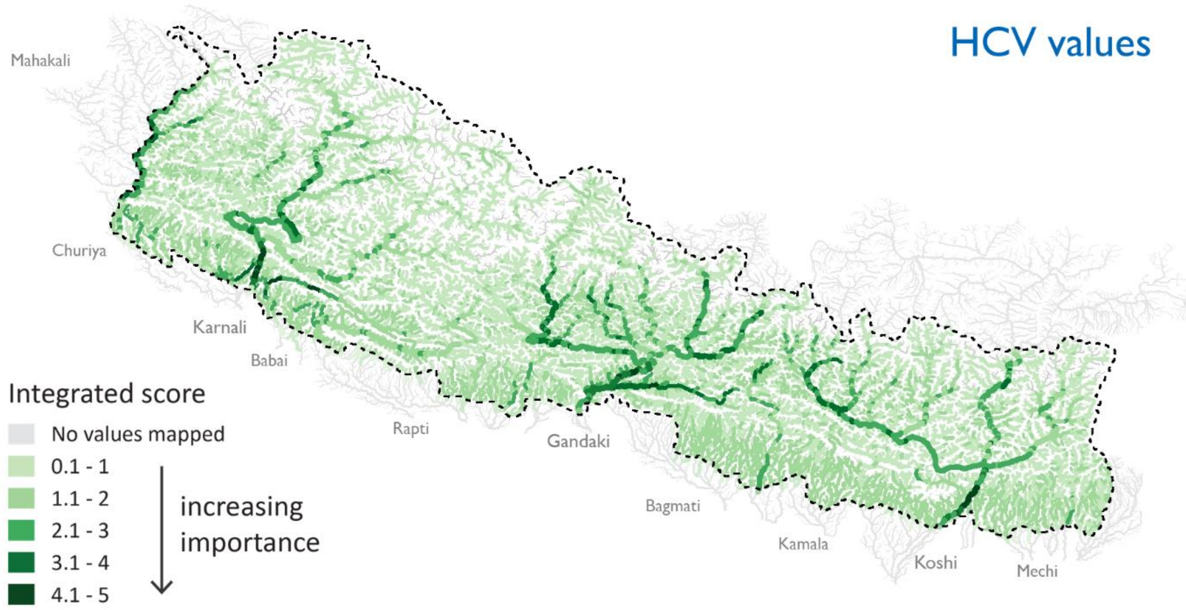

Figure 3: HCV integrated values

Then, the freshwater status was combined with the freshwater values assessment, and rivers were categorized into four HCVR types (Figure 4). Each HCV type aligns with specific recommendations for protection, management, or restoration. The HCVR typology includes the following categories:

HCVR Type 1: High Value + High connectivity + High Water Quality (WQ): these rivers or river reaches have one or more freshwater values, remain free-flowing and have been classified as having high water quality. They are rivers of the highest conservation value and their status should be maintained.

HCVR Type 2: High Value + High WQ: These rivers or river reaches have one or more important freshwater values and have been classified as high WQ, but where river connectivity is reduced, i.e., the river is no longer classified as free-flowing. The recommended management action for these rivers is to increase connectivity, for example by removing dysfunctional or unused barriers, by implementing environmental flows (increasing minimum flows of creating a release schedule that mimics the natural flow regime better), or by improving passability through bypass reaches or by increasing the effectiveness of fish ladders.

HCVR Type 3: High Value + High connectivity: These rivers or river reaches host one or more important freshwater values, are classified as free-flowing, but have a high level of water quality pressures. Recommended management interventions include those focused on the sources of water quality degradation including water treatment or buffers.

HCVR 4: High Value: These rivers or river reaches show one or more important freshwater values, but they are neither classified as free-flowing, or as high water-quality rivers. While these rivers contain important freshwater values, they are at risk due to pressures from loss of water quality and loss of connectivity and would need interventions to address both.

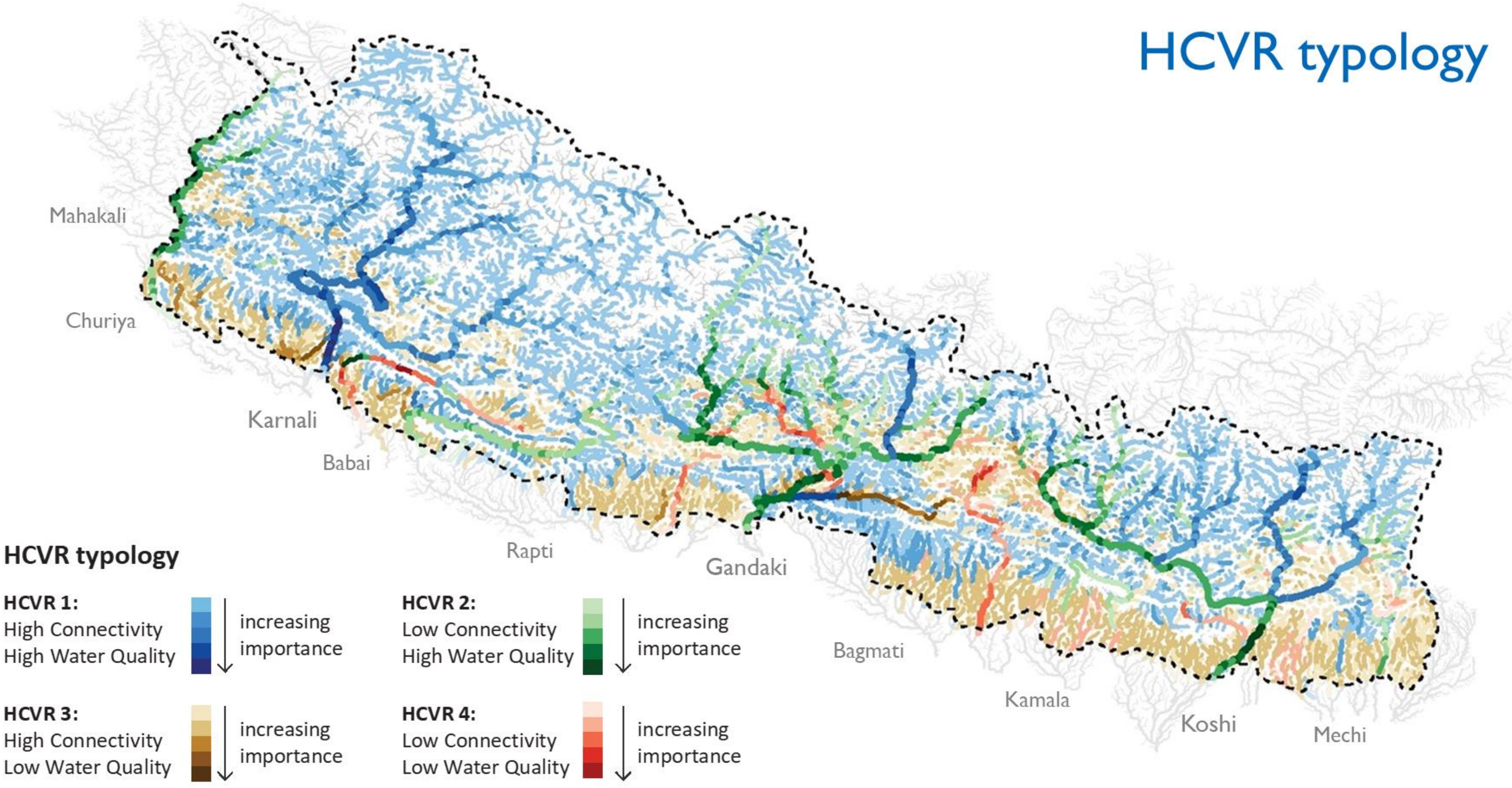

Figure 4: High Conservation River Typology for Nepal. The saturation of the colors represents how many values are represented in a particular river stretch.

Across Nepal, 50,500 km of rivers were evaluated in the HCV Rivers assessment (Figure 5). Out of these, most rivers — 31,300 km or close to 62% — are classified as HCVR Type 1, meaning they have at least one conservation value and are both free-flowing and of high water quality. The Karnali River Basin stands out as the basin with the highest number of HCVR type 1 rivers, followed by the Gandaki, Koshi, Mahakali, and the West Rapti basins, which all show more HCVR type 1 rivers than other types. The second largest category are HCVR type 3 rivers that make up 27.8% (14,000 km) of the total river length in Nepal. These river stretches are under high water quality pressure from both domestic and agricultural pollutants. HCVR type 2 rivers make up 7% (3,500 km) of rivers of Nepal and are rivers with compromised connectivity (i.e., they cannot be classified as free-flowing), primarily due to river fragmentation impacts from dams and barriers. The fourth category, HCVR type 4 are rivers where both losses of connectivity and reduced water quality are observed, with about 3.4% (1,700km) of rivers belonging to this category. It should be noted that any HCVR river type can harbor important and extensive freshwater values, which is indicated by the increasing saturation of the colors in the map.

At the river scale, the results of this assessment highlight the following rivers (among others) in Nepal with high freshwater values: the Karnali, East Rapti, Sunkoshi, Seti and Narayani. These rivers provide high biodiversity values, recreation opportunities, livelihood values, and socio-cultural services along most of their watercourses through Nepal.

Identification of HCVRs provides critical information for planning at different levels through quantitative evaluation and spatial mapping of the values that rivers provide to society. Natural resources managers and others involved with conservation efforts benefit from the identification of freshwater conservation priorities, which can guide decisions on where to focus their limited resources. Identification of HCVR can also guide hydropower development decisions. For instance, under concepts of sustainable hydropower, the high social and environmental values of a free-flowing Karnali River should be balanced against the benefits of hydropower development. Developing projects in other locations may have lower impacts.

Identification and ranking of Nepal's HCVRs can also help the country in meeting its national and international commitments. Nepal's National Biodiversity Strategy and Action Plan (2014-2020) and National Strategic Framework for Sustainable Development (2015-2030) prioritized maintaining north-south biological connectivity in at least three rivers. The HCVR results can be instrumental in supporting the identification of these rivers, preparation of the National Integrated River Basin Strategy and Action Plan, developed by the Ministry of Forestry and Environment (MOFE), and associated legislation.

Finally, HCVR maps can provide insights into opportunities for mitigation of development impacts. Avoidance, minimization, restoration and offsetting are options to mitigate the potential negative impacts of hydropower on river biodiversity and other values. Our results can provide quantitative assessment of rivers to avoid and rivers to protect or restore, to compensate for impacts.

ENERGY OPTIONS ASSESSMENT

BACKGROUND

As any other country, Nepal needs to ensure that its power demand is met in a reliable, affordable and sustainable way. Many different political objectives such as regional equity and carbon emissions can drive power sector planning. Most governments, even if they leave investments to the private sector, use modeling tools to develop medium- to long-term plans to understand how the power sector should expand and define the necessary frameworks and incentives. In the case of Nepal, one important question such models can answer is how much and where hydropower and other energy generation types are needed, and what costs are associated with river conservation and other policy objectives.

APPROACH AND RESULTS

The energy options assessment (EOA) component uses a model called SWITCH, which was developed by the Renewable and Appropriate Energy Laboratory at the University of California, Berkeley. SWITCH is a linear program that determines the least-cost investment decisions to expand a power system subject to meeting load forecasts and a host of operational constraints. The model concurrently optimizes installation and operation of generation units, transmission lines, and storage units. It employs a bottom-up load forecasting approach to estimate demand obligations for the planning horizon, which usually extends from 20 to 40 years into the future. In its application to Nepal, the model was set up to make investment decisions every five years in 2025, 2030, 2035 and 2040, meeting demand on each sampled hour in each one of these years. Other relevant input variables for the model are hourly capacity factors for wind and solar sites, hydrology, a portfolio of available hydropower sites, investments cost and fuel price forecasts, assumptions on power imports and exports, and a database of all existing generation plants and transmission lines to initialize the system. Models like SWITCH are best employed for scenario analysis to answer "What if …" types of questions that compare changes in a specific variable against a reference scenario. Understanding the impact of a variable, constraint, policy, or target can be a powerful tool for policy-making.

The model captures the main sources of cost in a power system. The results reflect the investment costs, including financing and return on investment, of building generation, transmission, and distribution infrastructure. In addition to investment costs, the model reflects typical operational costs such as variable fuel costs, variable non-fuel costs, and fixed annual costs for generation; operational and maintenance costs for planned transmission and distribution systems; and ancillary services costs to maintain spinning, non-spinning, and quickstart reserves.

The model includes a logic to define levels of imports and exports over the next 20 years. In conversations with stakeholders, we decided that the model would implement an "energy banking" strategy as a good compromise between (i) political sensitivities on cross-border power trade and (ii) lack of available data for economic decision making on imports or exports (e.g., on future costs of power in the Indian grid). An energy banking strategy constraints imports in the model to match exports, in every year of the simulation horizon.[2]

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2 Note that this strategy conditions imports and exports at the same time, preventing the power system from becoming a net exporter. We modify the energy banking logic in specific scenarios to examine the cost and benefits of Nepal becoming a net-exporter.

Limitations of the current SWITCH model, as applied in Nepal which could be corrected in future versions, include:

- Not representing the complexities of operating interdependent cascaded hydropower projects
- Not optimizing the medium-term dispatch of storage hydropower, which could contribute to mitigate dry season production declines
- Using an average or median hydrological year, which may not capture the challenges imposed on the power system during very dry years. This is partly mitigated by using a conservative 15% planning reserve margin
- The "energy banking" import strategy may, in some cases, not allow an optimal level of spills and curtailment (e.g., in case of very inexpensive wind and solar resources)
- The implementation of imports and exports are not based on economic decisions, but on testing different physical limitations due to possible policy decisions.

Table 1 below includes ten scenario groups (SG), including one base case or reference scenario. Each SG is composed of several individual scenarios or versions that implement a specific condition or assumption to be tested. In this context, each scenario corresponds to a specific model simulation. The table also reports the expected policy application for each scenario group, linking the simulation outcomes to policy relevant issues for the Nepali power system. Each scenario group is described in more detail within the energy options technical brief. In this Executive Summary, we provide a review of the results for the reference case and a few of the scenario groups, and then a set of key overall findings. Please refer to the technical report for more in-depth results.

TABLE 1: OVERVIEW OF SWITCH ENERGY MODEL SCENARIO GROUPS

ID #	SCENARIO GROUP NAME	SCENARIO GROUP DESCRIPTION	POLICY APPLICATIONS
1	Karnali	Eliminate or constrain future development of hydropower projects in the Karnali Basin	River conservation policy for the Karnali basin that uses a system approach to assess the cost and benefits of these conservation decisions.
2	Limited Hydro	Constrain hydropower expansion across Nepal to limit impacts on HCV rivers, with no basin-specific limits	River conservation policy for Nepal that uses a system approach to assess the cost and benefits of these conservation decisions. Impacts of potential exogenous (i.e. non-modeled) factors that would hinder hydropower development, such as access to financing, political stability, etc.
3	Expansive Hydropower	Remove alternative resource options for a hydropower-focused expansion	Understand the costs and risks of focusing on a single technology and not actively pursuing emerging technologies such as wind, solar PV, and battery storage, as well as existing imports. Note that the risk assessment would have to be an out-of-model calculation.
4	Non-Hydro Renewables	Produce scenarios that explore high future dependence on non-hydropower renewable resources	Produce an estimate of the costs and operational challenges of limiting hydropower resource development by requiring higher quotas for non-hydropower renewable resources.
5	Energy Independence	Constraint or eliminate imports from India, or modify financial conditions from those imports	Cost and operational impacts of reducing or eliminating imports and power system response to restrictions on imports. These may then be compared to the potential benefits of such strategy.
6	Export Strategy	Understand how the Nepal power system would look if it had to serve additional load for exports	Cost and operational impacts of pursuing an expansionary strategy to serve other markets beyond Nepal. These costs may be compared against out-of-model revenue calculations coming from export sales under different price scenarios.
7	Batteries vs PROR	Compare the cost-effectiveness and operational applications of both short-term storage methods	Identify the cost levels and timing at which battery storage may be a preferred resource adequacy solution compared to PROR. This may help prioritize hydropower project development to steer away from PROR projects.
8	High Hydro Costs	Hydropower development more expensive than the BAU, perhaps 50%	Measure the power system response to higher costs than anticipated on hydropower projects, due to project complexity, delays and cost overruns. This would help identify “borderline” projects that leave an optimal portfolio given cost increases, and focus development on projects that are robust to cost increases.
9	Regional Equity	Projects should be developed and benefit all regions in Nepal	Inform regional development targets and the potential costs of “forcing” projects to be developed in areas that have substandard resource quality and/or availability.
N/A	Futures	Possible expansion pathways described by a comprehensive set of future projections	Not intended for policy applications

The purpose of the reference scenario is to set a benchmark against which other scenario results can be assessed. The reference scenario expansion is mostly based on peaking run-of-river (PROR) and run-of-river (ROR) plants, and imports. Wind generation is profitable from the first period, with a small 3 MW installation, but growing to almost 1 GW by 2040. Flexibility to follow load is important in a power system, and the model deploys battery storage and diesel generators to provide peak power and intra-day balancing. Battery storage is deployed starting in 2025 with 80 MW, increasing to 300 MW by 2040, while diesel capacity increases from 170 MW to 900 MW in the same period.

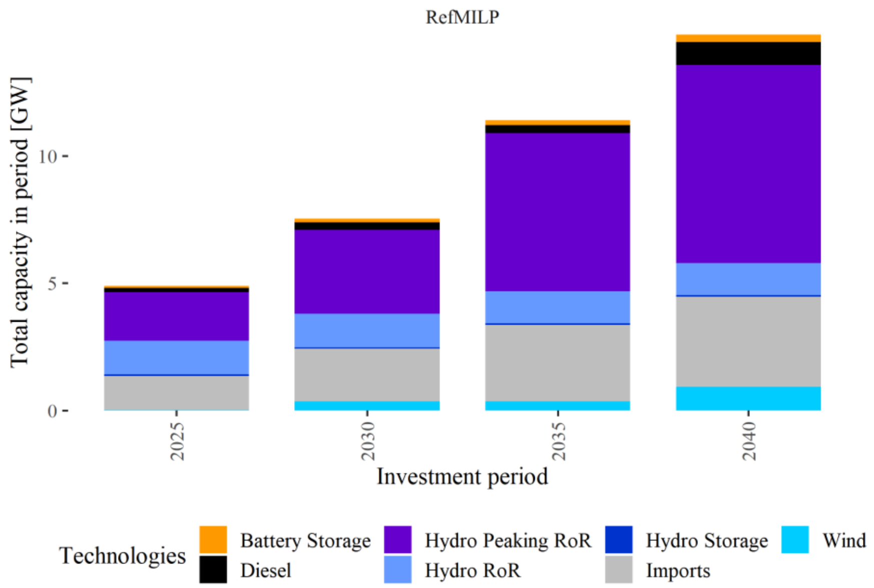

Figure 5: Capacity expansion for reference scenario

About 75%-80% of the annual energy is produced from hydropower, with the remaining 20%-25% supplied by a mix of imports and wind energy. As expected, the use of diesel plants is minimal, accruing less than 0.1% of energy in the year from their sporadic use as peaker units.

Imports from India provide a significant share of capacity and energy. The energy results show that the optimal level of imports under an energy banking logic are between 21% and 25% of energy needs per year. Imports play a fundamental role in balancing seasonal availability of hydropower and in reducing the costs of achieving this annual balance to meet demand at high levels of reliability. As described above, the model assumptions require that the same amount of energy is also exported, which in Nepal comes from surplus generation during the wet season.

The reference scenario is the least constrained scenario, with only least cost developments informing the choice of generation mix. There is an absence of storage hydropower projects in the reference scenario investment decisions. This is due to several factors. First, storage projects have a higher cost than ROR and PROR projects and are therefore not selected by the least-cost model. Second, these plants are much larger than ROR and PROR plants and in many cases the capacity of a single storage plant can be a substantial fraction of load. These capacity characteristics reduce the value of large projects such as storage hydropower that concentrate production on a single site and do not benefit from diversity across basins.

SG-1 Karnali River and basin conservation: Very low-cost impacts of effective Karnali river conservation policies

We tested eight scenarios for different Karnali basin conservation policies as part of this scenario group (SG–1). The policies impose different constraints on the plants available to the model by removing certain hydropower plants from the portfolio available to SWITCH for development. Scenario K01 (Karnali-all) is the most stringent, removing 189 projects (about 30%) from the portfolio. The remaining scenarios remove between 10 (2%) and 50 (8%) projects. Results show that the Karnali-all scenario has about 3.5% higher system costs than the reference scenario. Cost increases in all other conservation scenarios are lower than 1% compared to the reference scenario (Figure 6).

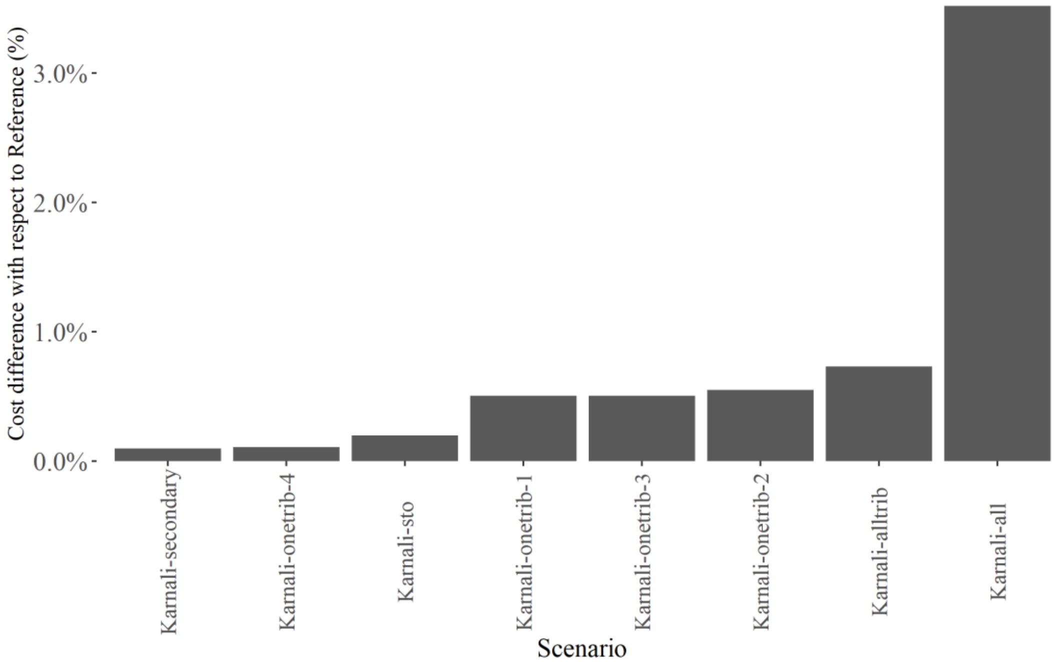

Figure 6: Cost difference between Karnali conservation scenarios and the reference scenario

The generation mix deployed across the scenarios is shown in Figure 7 below. Notice that storage hydropower becomes an option, because the unavailability of projects in the Karnali basin leads the model to develop storage and PROR hydropower mainly in the Gandaki (+100%) and Koshi (+60%) basins. Therefore, it is important to consider the system-wide scale of energy generation rather than focusing on a single basin as unexpected or unintended outcomes may result.

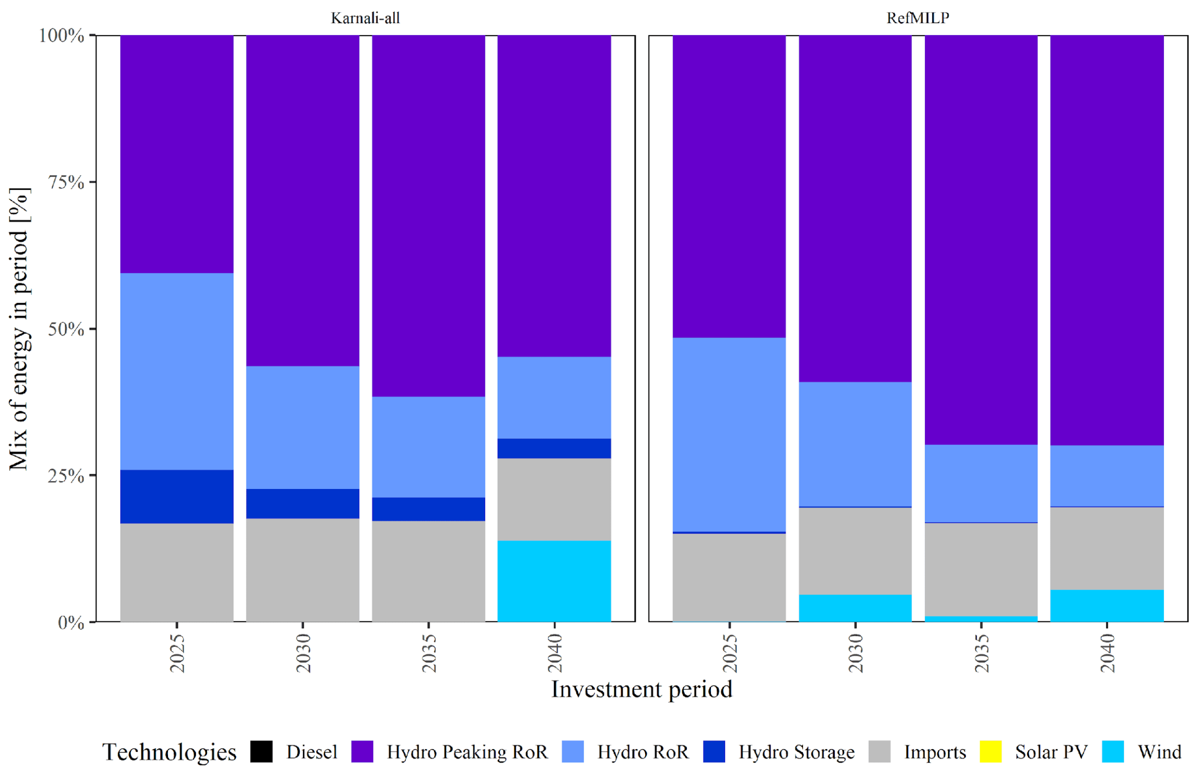

Figure 7: Energy mix for the reference scenario and the Karnali-all scenario, by period

SG-2 Nepal river conservation: Nepal can conserve protected and HCV rivers at relatively low costs

Eight hydropower-constrained scenarios for the entire country were tested for SG-2. Six of these represent actual conservation policy scenarios that Nepal could put in place to preserve rivers with certain properties. These scenarios include protecting all free-flowing rivers (FFR), preventing development in rivers classified as HCV levels 1or 2, and not developing selected benchmark rivers and rivers in protected areas.

In addition, there are two Nepal-wide limited hydropower growth scenarios. In one we limit hydropower development to capacity levels that equal a percent of peak load on each period. In the second we test a moratorium of all hydropower development in Nepal. The objective of these scenarios is to demonstrate that non-hydropower intensive pathways are feasible and to show how the system evolves with these limitations. These scenarios do not try to suggest Nepal should refrain from developing all of its hydropower resources, but to show that developing them, while cost-effective in many cases, is not the only pathway for power system growth.

Nepal-wide conservation scenario costs are 2% to 10% higher compared to the reference scenario, and hydropower-limited scenarios have much higher cost impacts of 20% to 34% (Figure 8). The lowest cost scenarios are the one that protects Nepal's benchmark rivers from being intervened (2.1% increase), and the one that prevents development in protected areas (1.5% increase). The Nepal-Protected scenario has about a third less hydropower projects than the Nepal-Benchmark scenario, yet has lower costs. This demonstrates that strategic selection of projects for conservation impacts, coupled with cost assessment tools like the SWITCH model, enhances decision making.

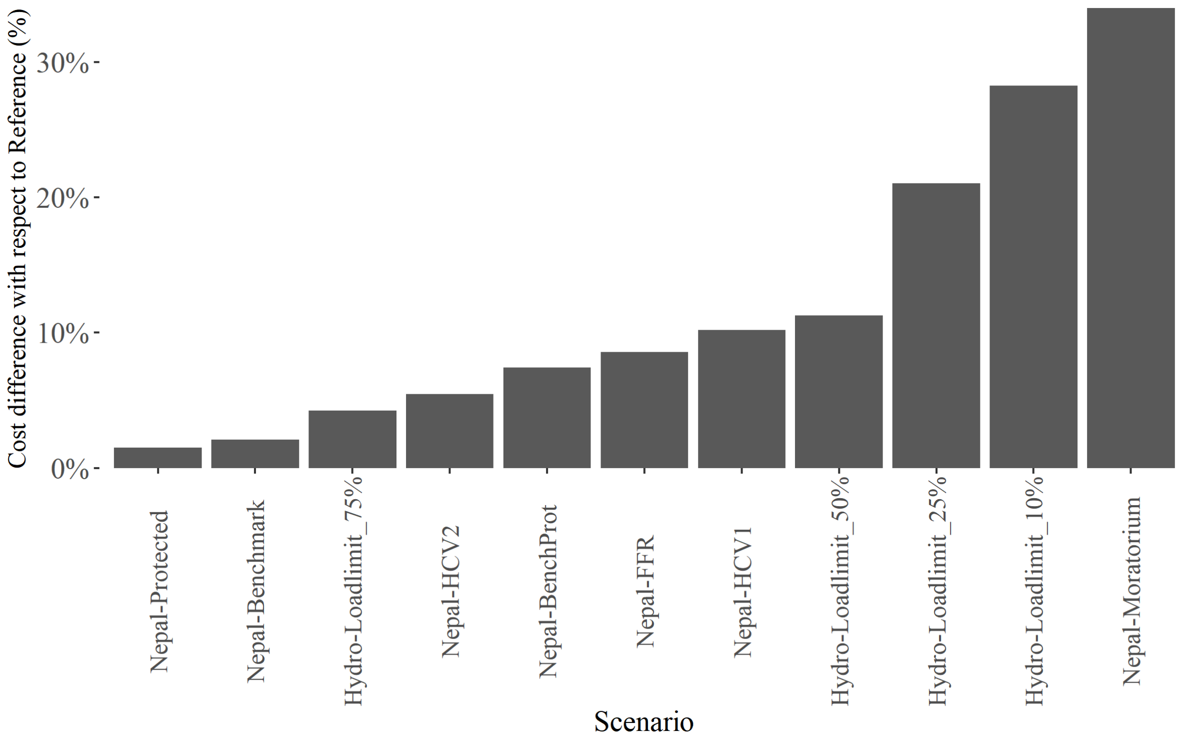

Figure 8: Cost difference between Nepal-wide conservation and hydropower constrained scenarios and the reference scenario

All conservation policy interventions produce a significant change in the resource mix (Figure 9). In some cases, like in the Nepal-HCV1, Nepal-Benchmark, and Nepal-Protected scenarios[3], the conservation constraints trigger higher adoption of other renewable resources such as wind and solar. Indeed, up to 3.5 GW of additional wind and 1.4 GW of additional solar PV are deployed by 2040 in the Nepal-HCV1 scenario compared to the reference scenario. In other cases, like in the Nepal-FFR, Nepal-HCV2 and Nepal Benchmark/Protected combination scenarios, the substitution takes place within hydropower technologies, with an increase in storage hydropower. These substitution pathways suggest that the consequences of certain conservation scenarios can be very different. For example, it is likely that scenarios that produce higher adoption of storage hydropower will have higher ecosystem impacts than scenarios that lead to more adoption of wind and solar power.

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3 Nepal HCV1 only allows 30%-40% of the projects in the portfolio to be developed (i.e. no development on HCV rivers with a value less than 1). Less stringent scenarios such as Nepal-Protected and Nepal-Benchmark allow for 60% and 90% of projects to be developed (i.e. no development on HCV rivers with a value less than 2).

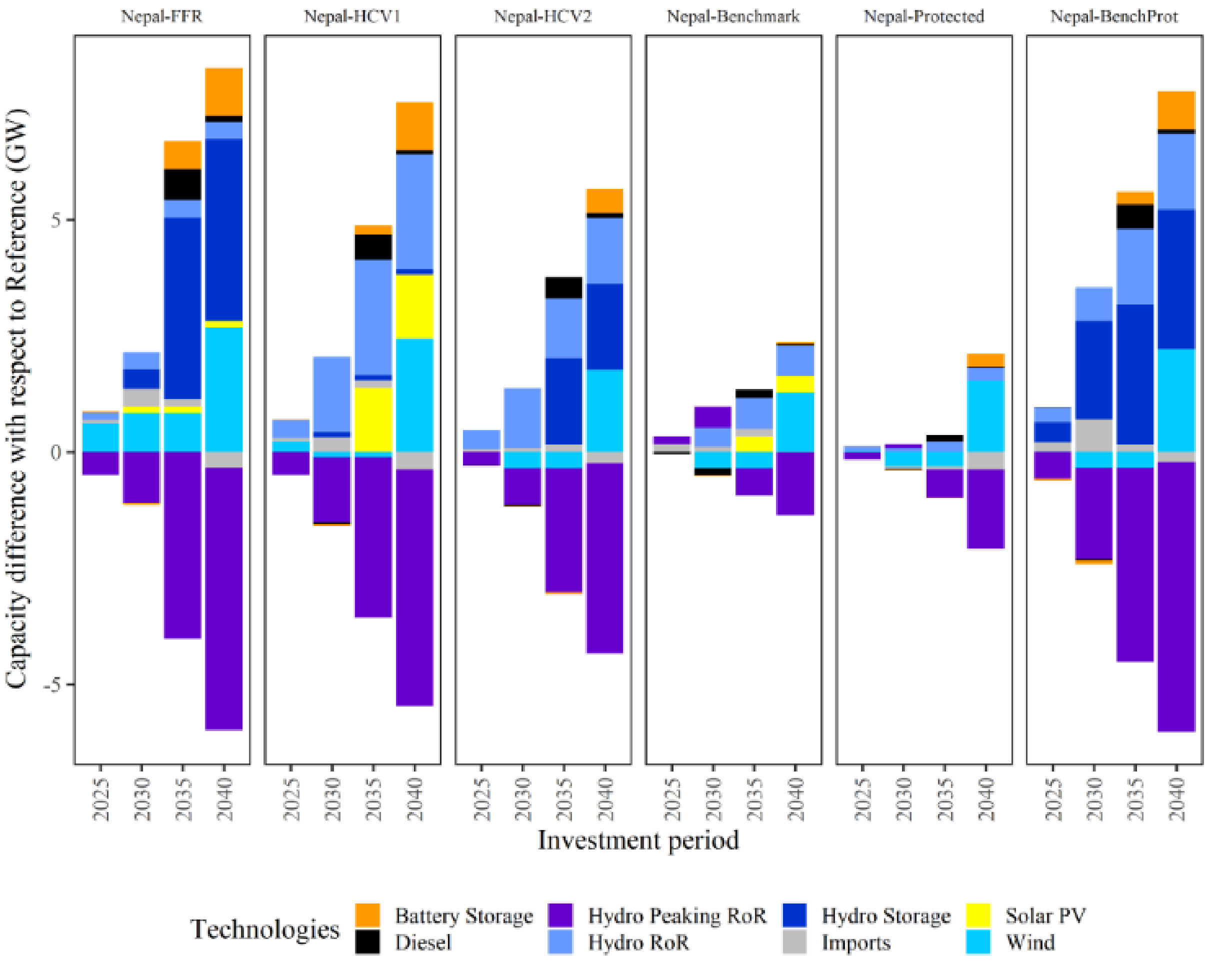

Figure 9. Capacity mix difference between Nepal-wide conservation policy scenarios and the reference scenario

KEY MESSAGES

Decisions about future hydropower development have to ensure that Nepal can meet its energy needs reliably, affordably, and sustainably.

Because today's investment decisions will determine the future mix of sources over decades, it is beneficial for countries to plan far ahead to ensure viable, low-cost and low-impact combinations of technologies over time. The outputs from the HCV assessment, EOA and SSP can all help contribute in making better decisions.

Hydropower development has suffered from extensive delays, and current generation is dependent on the seasonality and variability of rainfall. Relying exclusively on hydropower can be a short- and long-term risky strategy for Nepal.

Other power technologies including wind, solar and batteries are becoming increasingly viable globally and are growing at much faster rates than hydropower. Nepal can benefit from including these technologies in its mix.

In the Reference Scenario, by 2040 Nepal will rely heavily on peaking RoR plants in the wet season and on imports in the dry season. About 25% of annual energy needs should come from imports for an optimal balance of cross-border trading.

Model results suggest that Nepal can achieve considerable river conservation that will have minimal influence on power system cost by combining strategic siting of hydropower units, transmission expansion, and deployment of wind, solar PV, battery storage, and imports.

Battery storage can effectively fulfill the role of pondage in peaking RoR plants and storage hydropower to modulate production to meet varying demand. The ecosystem impacts of battery storage deployment should be negligible compared to those of hydropower units.

SYSTEM SCALE PLANNING

BACKGROUND

One of the major strategic lessons that Nepal can implement is that there are now tools available to assess multiple projects at a system level, rather than single projects. System scale planning (SSP) is a planning framework that is quantitative, multi criteria and multi project. Its purpose is to support decision makers in making proactive decisions on river basin development with an informed perspective of the tradeoffs between different future development solutions. The SSP process considers how multiple combinations of projects, or solutions, perform across a range of environmental, social, financial and energy metrics.

Rather than a single-project assessment of benefits and impacts, SSP can be run at a scale that is relevant for decision making. This may be the river basin scale, electrical grid scale or national scale. The data used in the modelling correspond with the scale of the analysis, and generally do not require detailed site-specific information (like that from a hydropower EIA) which is often not yet available. The outputs of the SSP analysis can be used to inform the selection of projects for which detailed studies (such as EIAs) should be undertaken. One of the benefits of carrying out SSP at an early stage is that this approach is more likely to identify development pathways with a better balance of energy outputs, costs and environmental and social impacts.

The intent of SSP is not to provide a single answer that identifies the "best" hydropower development solution but rather to quantify and make explicit the tradeoffs that are inevitable in any development solution. The decision support tool provides the opportunity to interactively explore and filter through development solutions. In the Karnali Basin for example, the list of potential projects can be combined in 4.9×10^{86} possible combinations of projects, i.e. future development solutions. It is impossible to individually evaluate each of the possible development solutions so, instead the model uses a multi-objective evolutionary algorithm (MOEA) to sift through them and narrow them down to a sub-set of options which can illustrate tradeoffs between solutions. For example, solutions with around 4,000 MW installed capacity there is a tradeoff between the impacts to rivers with recreation values and sediment capture. It is possible to minimize one of these impacts, but the solutions that have the lowest impacts for one metric have higher impacts for the other. By quantifying and making this tradeoff visible to decision makers, it can empower them to make the most informed decisions possible that balance the interests of various stakeholders.

APPROACH AND RESULTS

The MOEA component of the SSP model was run for 20,000 iterations. These iterations produced approximately 3,500 solutions that were identified as pareto-optimal solutions that is those solutions where no further improvements could be made to one dimension without further diminishing the performance of other dimensions. In addition to the solutions identified by the MOEA, another 20,000 solutions were generated by the pseudo-random process, which generates random solutions across a range of installed capacities (from solutions with very little total capacity to those with a lot of installed capacity).

The results of the SSP modelling outputs can be most effectively visualized using parallel axis plots. Parallel axis plots are a type of graph that can facilitate the exploration of multiple metrics for many solutions, by simultaneously plotting these metrics for all solutions. These can then be interactively explored by the user to identify solutions and inform discussions around which solutions have acceptable impacts across the multiple criteria. The samples below are static screen captures; within the actual tool, users can select "filters" around a set of objectives to greatly narrow the number of solutions to compare.

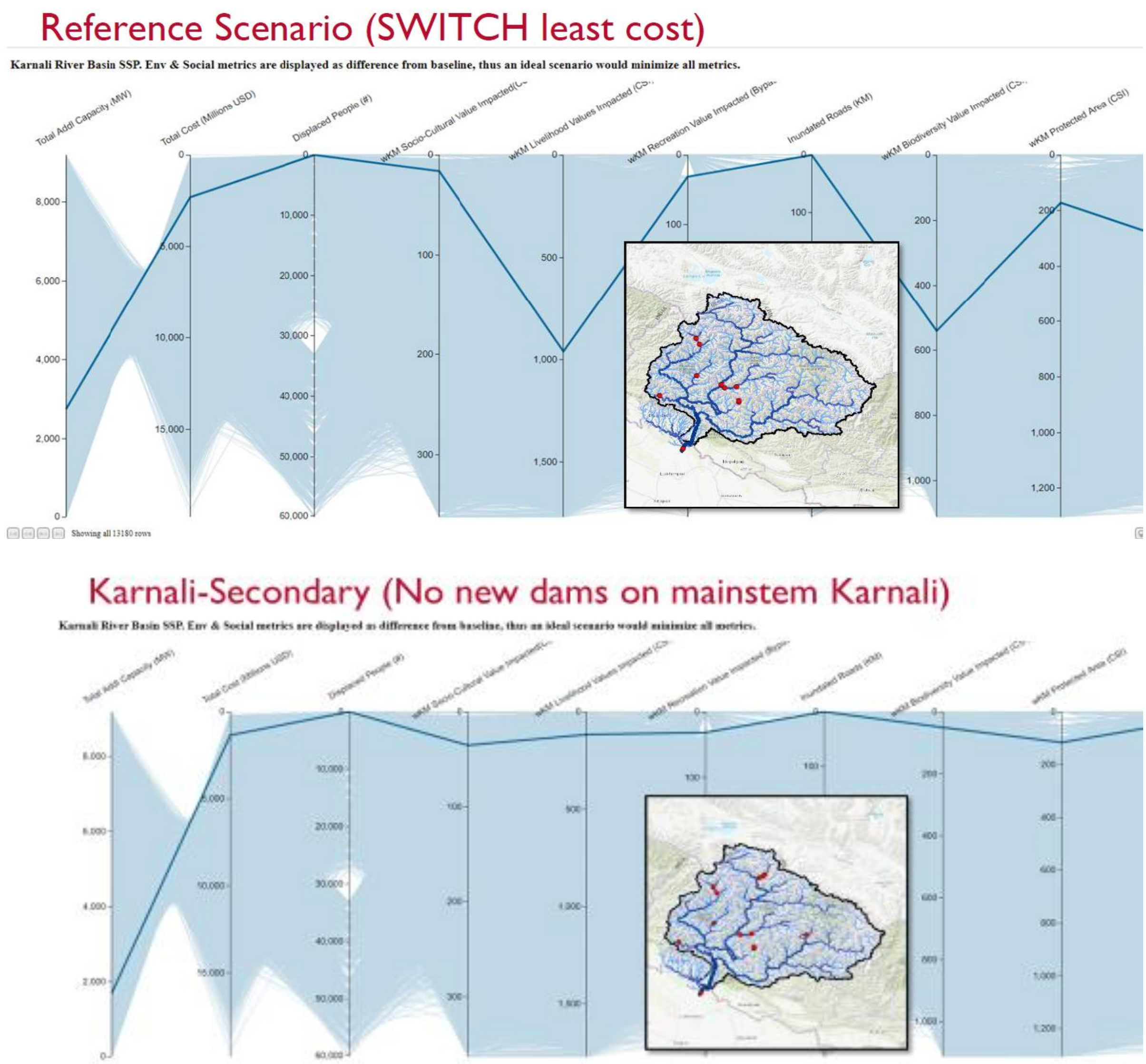

Figure 10. Parallel axis plots for two sample scenarios, with the underlying combinations of projects shown in map

The outputs from the SSP model can also be compared with the outputs from the energy planning SWITCH-Nepal model, to find solutions that are both least-cost and have limited environmental and social impacts, as shown in Figure 11. There will never be a perfect solution, but this method provides a way to identify solutions that strike an acceptable balance between energy production, society and the environment.

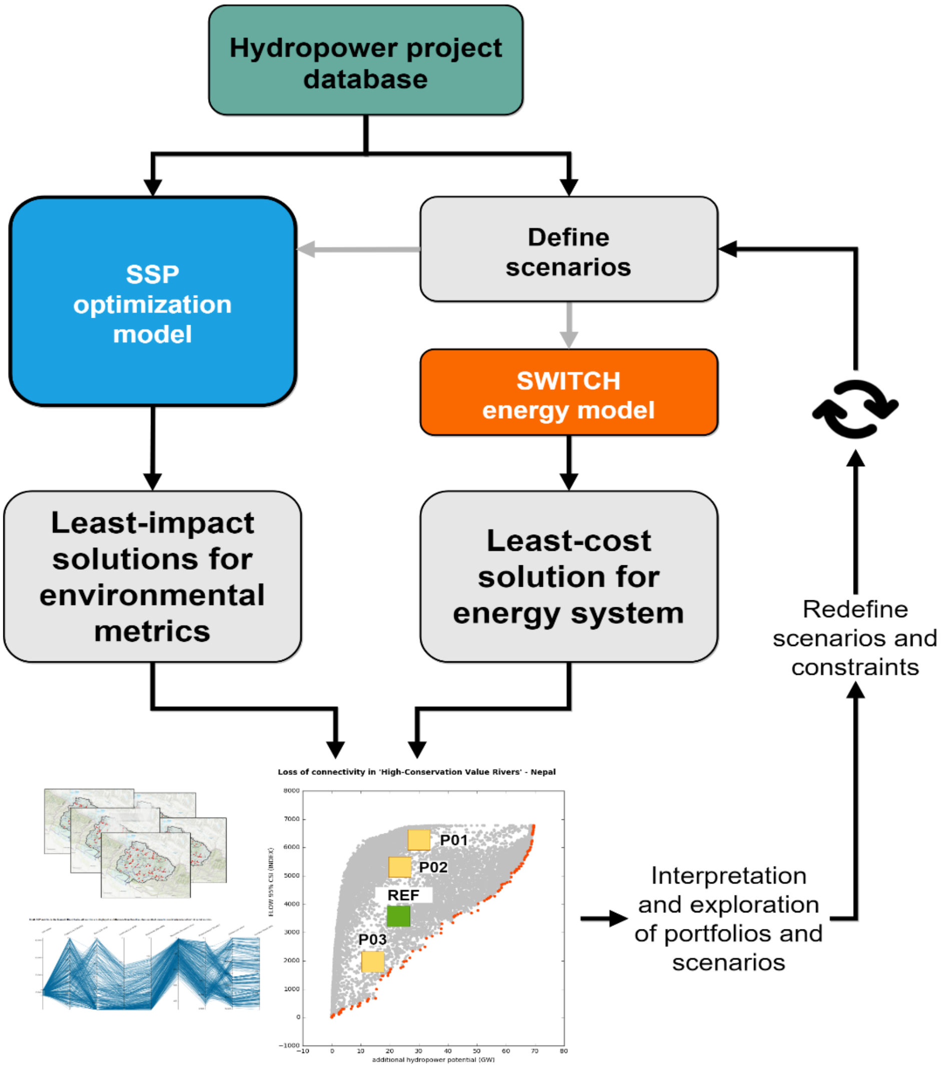

Figure 11: Schematic overview of the integration between SSP and Energy option modelling

The SWITCH model calculates a least-cost solution for each of a series of policy-driven scenarios. The SWITCH solution for scenario K03 (Karnali-Secondary) is thus the lowest cost combination of hydropower projects that conforms to the scenario: all projects in the basin are candidates for development *except* those on the Karnali mainstem. This least-cost solution from SWITCH is then assessed in the SSP model for the Karnali to evaluate environmental and social performance across the more comprehensive range of metrics (Figure 10).

To further examine the impacts of the SWITCH scenarios across the entire country (beyond just the Karnali), a simplified pairwise optimization was run for just two metrics: KM of HCV affected vs total installed capacity. The SWITCH solution for 2040 for the K03 scenario (Karnali-Secondary) includes almost 8 GW of hydropower nation-wide, with slightly more than 1,000 km of HCV rivers affected (Figure 12). While this is not the lowest HCVR impact solution for that amount of installed capacity, it does perform much better than many other solutions, some of which affect over 5,000 KM of HCV river.

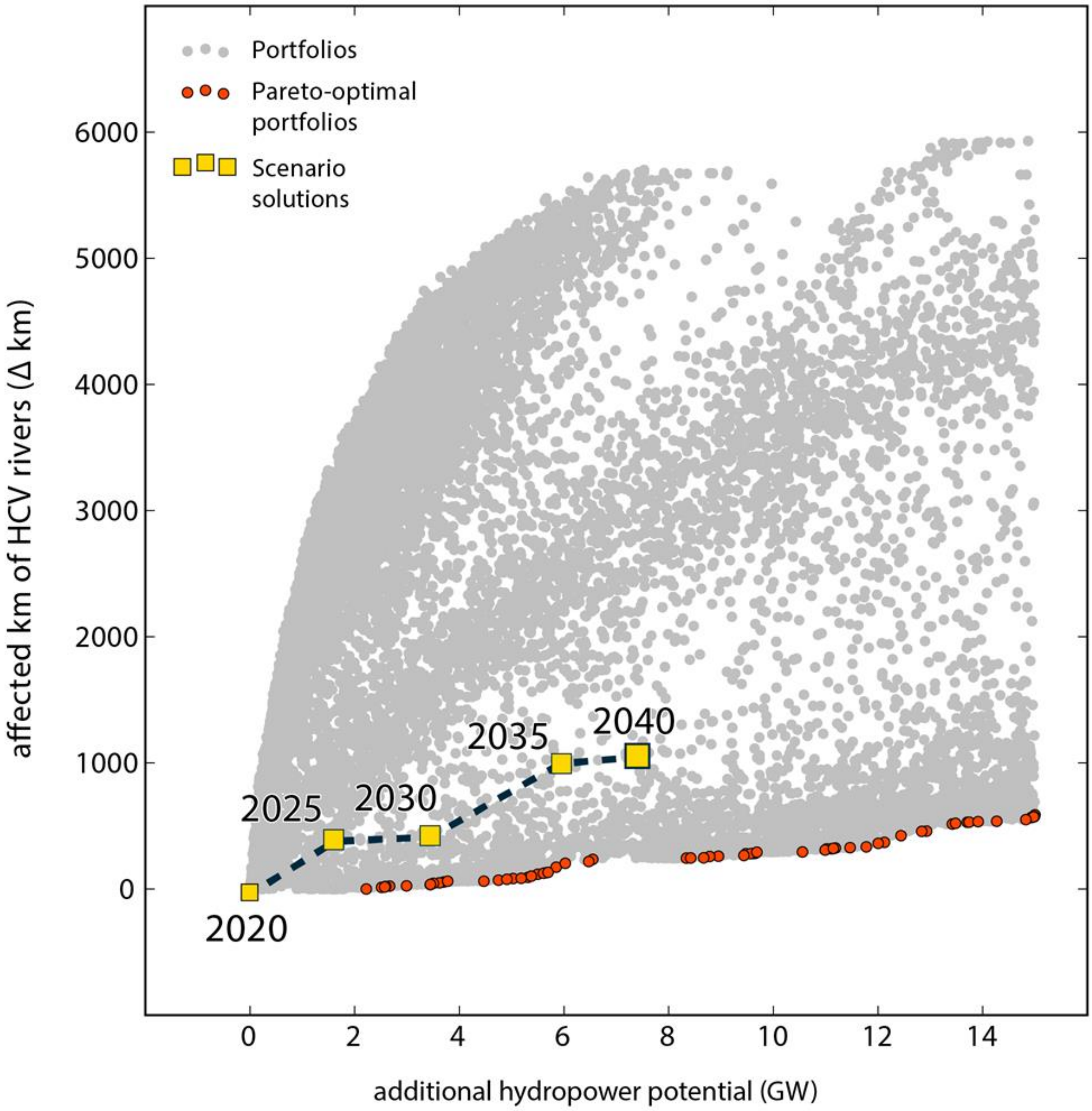

Figure 12: K03 scenario portfolios (grey) and pareto-optimal portfolios (red) that are limited to a capacity of up to 15 GW. The yellow portfolios represent the most cost-efficient energy system option at five-year intervals from today (2020) to 2040.

OBSERVATIONS AND WAY FORWARD

The integration of the components of this project demonstrates that the economic benefits created by early SSP and enhanced risk management are quantifiable and attainable, and the increased system costs from certain well-selected policy scenarios can be quite limited, compared to the socio-economic and environmental benefits that can be gained. The project also demonstrates that the majority of required data and methods are already available and can be further improved to serve the needs of Nepal.

The three distinct components of this project support each other, and each of them supports specific planning processes in Nepal and can inform the positions of stakeholders or decisions of government leaders. However, the utility of these components is greatest when they are integrated. For instance, while the HCVR assessment provides crucial information on Priority Rivers for protection, combining HCV with System Scale Planning (SSP) and Energy Options Analysis (EOA) can provide decision makers with a range of options for making protection consistent with cost-competitive energy development. By incorporating and integrating the outputs from this project, Nepalese stakeholders and decision makers will have a more complete understanding of future options for energy development and conservation.

Categorization of rivers with high conservation value can contribute to Nepal's commitments to the Convention on Biodiversity (CBD). Understanding which rivers have been identified as HCVRs is based on objective, quantifiable criteria such as riverine and aquatic biodiversity, and the cultural, social and economic value to communities. This is especially pertinent since, according to the review of Nepal's commitments to the CBD, "freshwater ecosystems have so far have remained disregarded despite their significantly rich biodiversity hotspots and resources that make critical contributions to the livelihood and life support systems of Nepalese people." Those rivers that are critical for conservation can then be legally protected. While such permanent protections are under preparation, options can be preserved through project-level decisions (e.g., on environmental licenses).

Understanding the lowest cost energy options for Nepal can support future energy generation development planning. The power system pathways component of our project quantifies the costs of a range of scenarios that can all satisfy Nepal's future power demand. These scenarios are characterized by different technologies (including new technologies such as solar PV, wind, battery storage), demand forecasts, assumptions on cost developments over time, and policy prescriptions and targets. By calculating the cost differences between alternative generation mixes, Nepal can carry out improved generation development forecasting and planning.

For any scale of hydropower development required, the system scale planning component can then help Nepal undertake more detailed analysis, to identify combinations of projects that have both low costs and low negative environmental or social impacts. The SSP process shows how outputs can be used to explore tradeoffs, make tradeoffs visually clear and understandable, and to search for a set of investment options (defined in terms of location, design and operation) that perform well across a range of economic, social and environmental objectives. Knowing which combinations of projects are attractive in terms of costs and impacts can help the Government of Nepal in prioritizing their power generation decisions. As a more detailed process, SSP also works well at the provincial and basin level.

The integrated outputs of our project can support the prioritization of future hydropower investments, and the most immediate opportunity is to inform the ongoing Water and Energy Commission Secretariat (WECS) planning processes. WECS is preparing a national hydropower masterplan and associated river basin plans, to revisit and prioritize all potential future hydropower projects, including those that already have licenses. In some cases, the masterplans will propose changing the location or the redesign of potential projects. The installation value and costs of all projects are estimated, which is a significant advance as there has previously not been any systematic information on comparative costs of these projects. The river basin plans also include other river-related developments, such as irrigation and flood control infrastructure, and will be subjected to Strategic Environmental and Social Assessments (SESA). The Paani-WWF initiative benefited greatly from the interim results of this process, allowing us to work with up-to-date project data. In turn, our initiative can inform the final formulation of the masterplan and the related reports.

A number of lessons have been learned from this initiative:

The utility of the SSP approach was improved by its integration with the other components. Basing an SSP analysis on detailed HCV assessments, and combining it with EOA analysis to demonstrate that preferred combinations of projects are viable and cost effective from an energy perspective, significantly increases the confidence in and the usefulness of the approach.

The SSP analysis can not only be used to identify future low-impact hydropower portfolios, it can also be used to assess the cumulative impacts of pre-defined portfolios. For example, it can inform the SESA assessments anticipated for WECS' river basin plans.

The licenses handed out to developers for the preparation of projects appear to add up to a larger capacity than can realistically be used, according to the EOA. Nepal could selectively cancel licenses or discourage developers of the least promising projects, in terms of costs and impacts. The SSP process could be used "in reverse" to identify projects that are not represented in any of the preferred combinations.

Generation portfolios that rely heavily on hydropower carry greater system costs than those with more balanced generation mixes. This suggests that government should remain open to a more diverse generation mix, especially if the costs of solar, wind and batteries should fall even faster than in our conservative assumptions.

Overall, the EOA shows that very substantial protection of high conservation value rivers can be achieved with small impacts on system cost, well within the typical cost uncertainties of hydropower. This is a surprisingly positive result for river conservation, and shows that with the right framework, Nepal can have a robust and low-cost power system and maintain the values of its river systems for future generations, at the same time. The framework that is needed requires some reforms (such as mitigation requirements for projects, and proactive river protection policies at local, provincial or national levels) but the payoff from such reforms will be substantial.

Fundamentally, the goal for this project was to contribute to the various planning processes funded by World Bank and led by WECS. Ideally, the data, results or methods from our process will be directly incorporated into the WECS processes including the development of the River Basin plans, and the sector specific (hydropower, irrigation) Master Plans as proposed by the National Water Resources Policy.

Ultimately, the outputs of this project can help the Government of Nepal identify a suite of projects that have lower impact (and perhaps price) for the same energy output. These projects could then receive preferential treatment in terms of licenses, purchase power agreements and development. One of the ways these outputs can be used is when Nepal introduces an auction or tender mechanism to select between the many projects offered by the private sector, the government will have the basis to decide which projects should be eligible in terms of location and technology. This will benefit both the people and nature of Nepal, as the financial investments in infrastructure will have lower costs together with lower negative environmental and social impacts.

USAID PAANI PROGRAM/WWF STUDIES

System-scale Planning to Support Sustainable Energy Systems and Conservation of Freshwater Resources for People and Nature.

USAID Paani Program, WWF/Nepal, and WWF/US. 2020. ***Energy Options Assessment (EOA)***.

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