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URJA NEPAL
NEPAL POWER SECTOR RESILIENCE PLANNING GUIDELINES

For IRRP Committee, Government of Nepal

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ACRONYMS

AEPC	Alternative Energy Promotion Centre
DOED	Department of Electricity Development
DRR	Disaster Risk Reduction
EWS	Early Warning System
EV	Electric Vehicle
GLOF	Glacial Lake Outburst Flood
GoN	Government of Nepal
GRID	Green, Resilient and Inclusive Development
INPS	Integrated Nepal Power System
IPCC	Intergovernmental Panel on Climate Change
IPPAN	Independent Power Producers Association, Nepal
IRP	Integrated Resource Plan
IRRP	Integrated Resource and Resilience Plan
kW	Kilowatt
MW	Megawatt
NEA	Nepal Electricity Authority
RCP	Representative Concentration Pathway
ROR	Run-of-River
RPGCL	Rastriya Prasaran Grid Company Limited
SCADA	Supervisory Control and Data Acquisition System
T&D	Transmission and Distribution

1. INTRODUCTION

Power sector resilience refers to the robustness and recovery characteristics of utility infrastructure and operations that avoid or minimize interruptions of service during hazardous events.[1] Resilience matters because the Nepalese economy is dependent on a functional power sector and the probability of events requiring the consideration of resilience measures is growing each year. For that reason, resilience, which describes degrees of disruption over multiple dimensions, must be accounted for as part of a robust and modern power sector plan.[2] [3] The Government of Nepal (GoN) is no stranger to resilience planning, with programs such as Surakshit Sahar,[4] the GRID approach,[5] and strategy tools from the National Planning Commission.[6] However, the Integrated Resource and Resilience Plan (IRRP) Committee specifically must also be savvy about resilience concepts and the threats to Nepal's power sector. Globally, the net benefit of investing in more resilient infrastructure in low-income and middle-income countries would be United States Dollar (USD) 4.2 trillion, with USD 4 in benefit for each US Dollar invested on average.[7] In Nepal, 2,000 megawatts (MW) of electricity is currently under threat from floods, landslides, earthquakes, and other natural and man-made threats. Projects currently under construction or planned, representing billions of dollars' worth of investment and thousands of MW of capacity, will also be under threat if climate change and natural, and man-made disasters are not accounted for.[8]

Resilience concepts are important for power system planners to understand and incorporate into planning processes in order to enhance the quality of the system over the long-term. Planners can be proactive rather than reactive by incorporating resilience into power system planning. Resilience should account both for current and anticipated threats and for linkages and dependencies within the sector. This report will explain this process further and describe how to conduct a vulnerability assessment. Ultimately, these recommendations about how to develop a framework to include resilience in the planning process and develop a resilience action plan will help the IRRP Committee realize the economic and social gains that can come with resilience.

VULNERABILITY ASSESSMENT PROCESS

One of the leading practices for identifying threats, impacts, and power sector vulnerabilities is conducting a vulnerability assessment and developing a resilience action plan based on the output.[9] A vulnerability assessment brings together stakeholders to:

1. *Engage stakeholders:* the responsibility for incorporating resilience will fall to the Generation Expansion Planning Sub-Committee, the Transmission and Distribution Planning Assessment Sub-Committee, with frequent collaboration and data gathering from the Renewable Energy and Energy Efficiency Planning Sub-Committee with oversight from the IRRP Committee
2. *Identify threats and their impacts:* Section 2 will discuss what constitutes a power sector threat, what the primary threats to the integrated Nepal power sector (INPS) are, and what the impact of each threat is on various power sector components

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[1] https://pubs.naruc.org/pub/536f07e4-2354-d714-5153-7a80198a436d

[2] https://www.protectourpower.org/resources/vls-iee-pop.pdf?_ga=2.102106241.1642671334.1634570257-1866929240.1634570257

[3] https://www.rand.org/pubs/research_reports/RR883.html

[4] http://isetnepal.org.np/project/surakshit-sahar-safer-cities/

[5] https://www.worldbank.org/en/events/2021/09/15/nepal-s-transition-to-green-resilient-and-inclusive-development-grid-for-sustainable-recovery-growth-and-jobs

[6] https://www.npc.gov.np/images/category/climate_resilent_planning.pdf

[7] https://www.worldbank.org/en/news/press-release/2019/06/19/42-trillion-can-be-saved-by-investing-in-more-resilient-infrastructure-new-world-bank-report-finds

[8] RPGCL Transmission System Master Plan, 2018

[9] https://www.nrel.gov/docs/fy20osti/73069.pdf

3. *Identify power sector vulnerabilities:* Section 3 will discuss the nature of vulnerabilities and how each power sector vulnerability is susceptible to each threat
4. *Score threat likelihood and severity based on available data:* decision-makers should qualitatively and quantitively assess how likely each threat is to have a detrimental impact on the power sector and what the scale of that impact is
5. *Qualitatively score severity of vulnerabilities:* decision-makers should assign a severity score to each vulnerability, based on the damage caused should that vulnerability occur
6. *Score risk and create a risk matrix by associating threats with vulnerabilities:* Section 4 provides the scoring of threats and vulnerabilities and proposes a matrix that aligns the two. A risk score is calculated by multiplying the threat severity score by the vulnerability severity score. Decision-makers can easily see the direst threats this way
7. *Identify resilience solutions:* Section 5 describes how planners should evaluate the most pressing threats to the power sector and identify solutions to mitigate the risk. This section also provides an overview of the solutions based on threats and vulnerabilities identified in this report
8. *Develop a resilience action plan to address highest risks:* finally, Section 6 describes how planners should score and prioritize the solutions developed in the previous step, and consolidate them into one Resilience Action Plan

The IRRP Committee should also understand how to incorporate the resilience action plan into the IRRP process. Section 7 of this report will describe the considerations for including resilience concepts into the IRRP.

DATA REQUIREMENTS

Having up-to-date and accurate information about threats to the power sector and the sector's ability to adapt is key for guiding power sector decisions. Data required to understand threats includes:

- Forecasted temperature changes disaggregated by season and region
- Hydrologic data to estimate river flow and glacial melt
- Forecasted precipitation data
- Information on Nepal Electricity Authority (NEA) and Independent Power Producer (IPP) generation output and plans
- Transmission network data
- Seismologic data to better understand the probability and size of an earthquake

2. IDENTIFY THREATS AND IMPACTS

DEFINING THREATS TO NEPAL

Threats represent hazards which are beyond the control of power sector planners. Threats, sometimes called hazards, can be categorized as being natural, technological, or human-caused.[10] Understanding threats is essential for building power sector resilience. Power sector planners need to understand how conditions may change and impede the system's ability to reliably deliver power. These impediments can be thought of as the "impact" of a threat, or the effect that threats have on power system infrastructure, systems, or processes.[11] Most of the threats discussed in this paper are natural threats with some discussion of human-caused threats. Understanding natural threats provides a sufficient baseline for incorporating resilience into power sector planning, but additional threats can be evaluated and incorporated into planning procedures as time progresses.

Some of the principal threats that the Integrated Nepal Power System (INPS) should build resilience to are temperature increases; drought; sedimentation; landslides; floods and glacial lake outburst floods (GLOFs); wildfires; earthquakes; and human-caused accidents or attacks. Understanding these threats and their impacts is crucial for future scenario planning and resilience building. The cost of these events is estimated to be 1.5 - 2% of Gross Domestic Product (GDP) each year.[12] Many of these threats will directly impact the ability of hydropower installations to produce electricity and the ability of the transmission network to move the electricity to load. The "rule of thumb" estimate for the cost of constructing a power generating installation >10 MW is $1,500 - $2,000/kilowatt (kW). This is borne out in the data sampled from eight operational and planned installations for which data was available.[13] With an estimated 7,932MW of licenses outstanding, these threats place nearly $16 Billion worth of hydropower installations at risk.[14] [15] The remainder of this section will provide an explanation of how each threat affects the INPS.

NATURAL THREATS

TEMPERATURE INCREASES

Climate change is already beginning to increase the average temperature in Nepal. The average annual minimum and maximum temperatures have increased by 0.02°C and 0.56°C, respectively, per decade.[16] The average annual temperature is expected to increase by 1.6 – 2.2°C by 2050.[17] In some regions, the effects are particularly stark. Warming in the Nepal Himalayas increased by 0.15°C to 0.6°C every 10 years during last 30 years.[18]

The Intergovernmental Panel on Climate Change (IPCC) has selected four Representative Concentration Pathways (RCPs) to model climate futures under different emissions scenarios. Each scenario is based on the volume of greenhouse gases emitted over the time periods described.[19] Table

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[10] https://www.nrel.gov/docs/fy19osti/73489.pdf
[11] https://www.nrel.gov/docs/fy19osti/73489.pdf
[12] https://www.intechopen.com/chapters/53350
[13] Platts, Elsevier. Kaligandaki-A, Middle Marsyangdi, Sunkoshi-II, Sunkoshi-III, Uttar Ganga, Dudh Koshi, Bharbhung, and Budhi Gandaki
[14] https://www.nepalitimes.com/opinion/climate-risk-to-hydropower-investment/
[15] https://www.irena.org/costs/Power-Generation-Costs/Hydropower
[16] https://reliefweb.int/report/nepal/vulnerability-and-risk-assessment-and-identifying-adaptation-options-summary-policy
[17] https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID%20CCIS_Climate%20Risk%20Profile_Nepal.pdf
[18] https://www.adb.org/sites/default/files/publication/29889/climate-risks-adaptation-power-sector.pdf
[19] https://www.ipcc.ch/assessment-report/ar5/

1, adapted from World Bank Group Data, shows the average daily temperature increases relative to the reference period of 1986 – 2005 under the four most commonly used RCP scenarios for Nepal.[20]

Table 1: RCP Temperature Increases

	Average Daily Temperature Increase (°C)	
Scenario	**2040 – 2059**	**2080 – 2099**
RCP2.6	1.4	1.4
RCP4.5	1.7	2.5
RCP6.0	1.6	3.1
RCP8.5	2.3	4.8

Other sources project that the 1.4°C increase will take place as early as the mid-2030s.[21] Furthermore, the projected 1.4°C increase is just the mean. Extremely hot days, those defined as being in the upper 5% of temperatures, are expected to increase by 55% by mid-century.[22] These rising temperatures can have devastating effects on the power sector. These negative effects include stimulating demand for additional electricity; stimulating glacial melt which can shift power supply patterns and trigger GLOFs; increasing competition for water resources; damaging transmission and distribution equipment, including substations; and outpacing the rate at which standards and response plans are updated, leading to sectoral problems.

DROUGHT

Water resources are essential for Nepal's hydropower-driven power sector. Prolonged drought related to climate change will continue to exacerbate the disparity between wet and dry season power generation and increase competition for water resources across sectors.[23] Periods of drought in 2020 – 2021 were among the most severe in history, affecting Western Nepal in particular and reducing precipitation by 60% to 80% during the winter. The number of consecutive "dry" days projected to increase by 3% to 7%[24] and rainfall could decrease by 7% during the winter by the 2030s,[25] implying that this problem will persist as climate change becomes more severe. Overall, drought leads to vulnerabilities in the INPS, including dry season generation far below peak capacity and inter-annual and seasonal shifts in hydropower generation capacity, increased competition for water

Box 1: Drought and Hydro Production

Nepal would not be the first country to have its power sector crippled by drought-related impacts. Drought in the Philippines during El Nino caused shortages at Angat dam, which led to water rationing of about four hours in some areas and drastically reduced electricity production. An even starker examples comes from China. Yunnan province in China reduced hydropower production by almost 30% in early 2020 due to low water levels. Nepal's hydropower facilities are also at risk for reduced output, particularly during the dry season. These examples show the problems the INPS will face if drought is not accounted for in power system expansion planning.

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[20] https://climateknowledgeportal.worldbank.org/sites/default/files/2021-05/15720-WB_Nepal%20Country%20Profile-WEB.pdf
[21] https://www.climatelinks.org/sites/default/files/asset/document/2021-07/2021_USAID_CDCS-Annex-Nepal.pdf
[22] https://www.wri.org/our-work/project/world-resources-report/climate-change-nepal-impacts-and-adaptive-strategies
[23] https://winrock.org/wp-content/uploads/2021/08/Nepal_Country_Profile_Final.pdf
[24] https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID%20CCIS_Climate%20Risk%20Profile_Nepal.pdf
[25] https://www.adb.org/sites/default/files/publication/29889/climate-risks-adaptation-power-sector.pdf

resources, and unpredictable circumstances leading to incorrect demand forecasting and planning. Box 1 describes how drought can affect hydropower production.[26] [27]

SILTATION/SEDIMENTATION

Siltation can reduce hydropower production capacity and cause damage to both storage and Run-off River (ROR) hydro projects through wear and tear on turbines.[28] Siltation and sedimentation are heavily influenced by precipitation and flooding. The Kulekhani dam's capacity was reduced significantly by just one storm.[29] The increasing frequency of storms will continue to erode the reliability of MW available for generation by damage resulting from siltation both for ROR projects and future dam-based projects. The highest rates of sedimentation occur during the monsoon season as this when peak flows take place. This can occur outside of monsoon as well, as explained in Box 2. [30] Flooding exacerbates the issues related to siltation. In an even starker example, Kali Gandaki's generation capacity was reduced from 144 MW to 100 MW due to debris being carried downriver and reducing the flow of water into turbines after a storm. Kaligandaki A also faces regular downtime to sedimentation: during the rainy season, desander flushing is conducted every 2 – 3 days, alternating between the two desander flushing events, meaning 72 MW of plant capacity is down during this process.[31] Smaller plants also face this problem but often have even fewer resources to find solutions. For example, in 2021 the 5 MW Devighat plant faced frequent shutdowns from large silt depositions.[32]

Box 2: Sediment Damage at Jhimruk

Sediment damages hydropower infrastructure by causing wear and tear on turbines and lowers performance. This could be seen at the 12 MW Jhimruk installation in 2003, which was exposed to a total sediment load of 6,900 tons of sediment in a 2-month period. Efficiency losses were as high as 25% during the period of observation, which did not even take place during the peak of monsoon season.

PRECIPITATION, FLOODS AND GLACIAL LAKE OUTBURST FLOODS

Precipitation patterns are likely to change due to climactic factors. Multiple research institutions forecast that precipitation in the Gandaki Basin is going to increase, though exact patterns are difficult to forecast accurately. Estimates of the Gandaki Basin suggest that precipitation will increase by 7% – 32% between 2021 and 2046 and by 18% - 45% by 2100.[33] Other estimates are more focused, predicting increases of 10 -13% and 24% - 52% in similar time periods.[34] Additionally, this increase is stratified by seasons in a significant way. Pre-monsoon and monsoon seasons will get wetter with more extreme rainfall events, and post-monsoon and winter seasons may get slightly drier.[35] This pattern of

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[26] https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID_Screening%20Hydropower%20Facilities%20for%20Climate%20Change%20Risks%20to%20Business%20Performance.pdf

[27] https://www.reuters.com/business/sustainable-business/inconvenient-truth-droughts-shrink-hydropower-pose-risk-global-push-clean-energy-2021-08-13/

[28] https://www.researchgate.net/publication/334466363_River_sedimentation_challenges_for_hydropower_development_in_Nepal_A_perspective_review

[29] NEA Annual Report

[30] https://www.un.org/esa/sustdev/sdissues/energy/op/hydro_pratik_pradhan.pdf

[31] https://www.nea.org.np/admin/assets/uploads/annual_publications/Generation_2020.pdf

[32] https://www.nea.org.np/admin/assets/uploads/annual_publications/Generation_2020.pdf

[33] https://www.researchgate.net/publication/359002266_Assessing_Future_Precipitation_in_Gandaki_River_Basin_based_on_CMIP6_Projections

[34] https://www.tandfonline.com/doi/full/10.1080/07900627.2020.1826292

[35] https://www.researchgate.net/publication/359002266_Assessing_Future_Precipitation_in_Gandaki_River_Basin_based_on_CMIP6_Projections

results can reasonably be extrapolated to the Karnali Basin[36] and the Koshi Basin as well.[37] These new rainfall patterns will impact seasonal generation due to changes in river flows and water availability and can contribute to flooding as well.

Floods and GLOFs are a major threat to the INPS. There is expected to be a 3.9 – 5.1% increase in annual precipitation in Nepal by 2050 and a 35% to 52% increase in extreme rainfall events by 2050, mostly during monsoon season.[38] The World Resource Institute's AQUEDUCT model estimates annual impact of heavy rainfall to GDP of $218M.[39] Climate change is likely to lead to even more severe storms, likely increasing the risk to dam infrastructure of other power sector components due to flooding.[40] Another risk associated with flooding is the overproduction of electricity. While forecasts indicate that dry season generation is likely to decrease over time, wet season generation may increase. Excess energy on the grid can be problematic as well, as it can damage equipment or increase grid frequency. Furthermore, generating this excess electricity can be wasteful, especially as Nepal is a net power importer.[41]

Floods caused by glacial lake outbursts are also likely to increase. Climate change is contributing to significant snow and glacier melt which weakens the barriers holding back the water stored in glacial lakes and increases the chance that these walls break and release floods on the people and infrastructure below.[42] Of the thousands of glacial lakes mapped and analyzed, 47 were identified as potentially dangerous, with a concentration in the Koshi basin. Nepal hosts 21 of these lakes, while China and India host the other 26 that impact river basins in Nepal. In addition to direct damage, flooding leads to increased sedimentation and damage to intake structures. Box 3 describes past mitigation strategies.[43] [44] [45]

Box 3: Successful GLOF Mitigation

Recent examples of GLOF damage include the Dhauliganga dam, a 280MW dam in India, collapsing due to a GLOF.[1] However, successful planning to mitigate the risk of GLOFs is not uncharted territory. A success story includes the lowering of the Imja lake, where the United Nations provided $3M in funding to drain 4M cubic meters of water from the lake and protect the downstream communities and hydropower projects.[1] Tsho Rolpa was lowered by 3 meters, which cost $9M in 2000.[1] It did not burst in the May 2015 earthquake aftershock, providing a net positive return (Tsho Rolpa does remain one of the riskiest lakes in Nepal, however).[1]

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[36] https://link.springer.com/article/10.1007/s10584-021-03216-8

[37] https://www.academia.edu/13795465/Analysis_of_future_precipitation_in_the_Koshi_river_basin_Nepal

[38] https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID%20CCIS_Climate%20Risk%20Profile_Nepal.pdf

[39] https://climateknowledgeportal.worldbank.org/sites/default/files/2021-05/15720-WB_Nepal%20Country%20Profile-WEB.pdf

[40] http://aphrodite.st.hirosaki-u.ac.jp/scope.html#:~:text=APHRODITE's%20daily%20gridded%20precipitation%20and,areas%20in%20the%20Middle%20East.

[41] https://kathmandupost.com/national/2022/03/16/high-prices-of-imported-electricity-could-affect-power-utility-s-finances#:~:text=Nepal's%20peak%20demand%20for%20power,during%20the%20evening%20is%20expensive.

[42] https://ui.adsabs.harvard.edu/abs/2017AGUFM.C33A1165G/abstract

[43] https://www.nepalitimes.com/editorial/more-himalayan-tsunamis/

[44] https://www.bbc.com/news/world-asia-37797559

[45] https://www.sciencedirect.com/science/article/pii/S2666916121000189

Table 2 shows Nepal's potentially dangerous glacial lakes.[46]

Table 2: Potentially Dangerous Glacial Lakes

River Basin	Sub-basin	Potentially Dangerous Glacial Lakes
Karnali	Humla	1
Gandaki/Narayani	Trishuli	1
	Marsyangdi	1
Koshi	Tamor	4
	Arun	4
	Dudh Koshi	9
	Tamakoshi	1

EARTHQUAKES

Nepal is situated on a fault line in the Himalayas and has had devastating earthquakes in the past, most notably the 2015 Gorkha earthquakes. Estimates suggest that Nepal has a 10% chance of a potentially damaging earthquake in the next 50 years, indicating that earthquake resilience considerations should be taken into account when planning major infrastructure projects such as hydroelectric dams.[47] Box 4 provides an overview of the damage to infrastructure caused by the 2015 earthquake.[48] Earthquakes can damage hydropower, electrical equipment, generators, water pumps, and other key assets of the power sector. The main types of damage to hydropower projects related to the 2015 Gorkha earthquake are damage to pipes, cracks in intake, and damage or bursting of penstock and pipes.

Box 4: Hydropower Projects Damaged by the 2015 Gorkha Earthquakes

The 2015 Gorkha Earthquakes were devastating to Nepal. In addition to the tragic loss of life of home, a significant amount of hydropower was damaged. 31 hydropower projects, representing 1098MW of installed capacity, were damaged as a result of the quake or resulting aftershocks. 59.8MW of this was temporarily taken out of commission, and 702MW of this total was not in operation for a significant period of time.

LANDSLIDES

Landslides, often triggered by large amounts of rain, pose an increasingly serious risk to Nepal's power sector infrastructure. There were multiple cases of landslide-induced damming and impounding of a large volume of water behind these dams in the early decades of the 2000s. See Box 5 for an example of how this can affect the power sector.[49] There are many examples of landslides damaging

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[46] https://www.undp.org/sites/g/files/zskgke326/files/migration/np/Inventory_Glacial_Lakes_2020_Full2.pdf

[47] https://thinkhazard.org/en/report/175-nepal/EQ#:~:text=In%20the%20area%20you%20have,in%20the%20next%2050%20years.

[48] [48] https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018GL079173

[49] https://myrepublica.nagariknetwork.com/news/floods-and-landslides-damages-26-hydropower-projects-multiple-road-sections/

infrastructure over the past decades, as hydropower projects are not often built with this consideration in mind. A quarter of planned and operational hydropower projects in Nepal, India, and Bhutan are "likely" to face severe damage from earthquake-triggered landslides during their lifetimes meaning the problem will not be resolved any time soon.[50] Non-earthquake related landslide frequency is also likely to rise. Warmer air leads to drier conditions that weaken soil, interrupted by periods of intense rain that leads to landslides.[51]

Box 5: 2014 Jure Landslide

The Jure landslide in Sun Koshi River in August 2014 impacted hydro plants downstream. Nearly 10% of the Nepal's hydropower capacity, some 67 MW at the time, was severed by the landslide, submerging a 5 MW power plant and disconnection of the power supply with Bhotekoshi hydropower (45 MW) and Sunkoshi hydropower (10 MW) and washed out over 400 houses, killing over 200 people. The Independent Power Producers' Association reported that floods in June of 2021 damaged 16 hydropower projects that were under construction and 10 projects already operating were damaged.

WILDFIRES

Forest fires, prominent especially during the dry season, threaten the transmission and distribution elements of Nepal's power sector. There were 2,087 forest fires reported between November 2020 and March 2021 alone, and wildfires are becoming more frequent in Nepal.[52] 100,000 hectares of forest area is affected annually.[53] Rising temperatures and drought, together with other threats exacerbated by global warming, indicate that the incidence of wildfires is also likely to increase. Wildfires pose a threat to the INPS as they often cause damage or destroy infrastructure such as power lines and substations.[54] Wildfires also pose a threat to reliable electricity delivery in other nations due to preventative power shutoffs in at-risk areas. Finally, and unlike most other threats, electric equipment can be the cause of wildfires, highlighting the need for an understanding and plan to accommodate for any incidents related to wildfires.

TECHNOLOGICAL THREATS

Technological threats refer to system compromise due to equipment or infrastructure failures or disruptions to processes. Aging equipment, poorly designed equipment, and unpredictable loads are all examples of the technological threats to the power sector. Specific examples might include a failure of an early warning system due to aging or unreliable load forecasting not accounting for rapid glacial melt and subsequent overwhelming of the system. See Box 6 for an example of how serious threats due to technological implementation can be.[55] [56] [57]

Box 6: Dams on Fault Lines

Technological threats may be particularly acute in Nepal due to the rapid expansion of electricity generation. Dams are being built at great scale in an active earthquake zone: without incorporating proper standards and fail safes into this construction the INPS could face another catastrophe. Furthermore, water behind a dam can also trigger earthquakes by the massive weight behind a dam combined with water seeping into fissures. This was suspected of the 760MW Zipingu Dam in China, whose reservoir is located nearby the epicenter of the 2008 earthquake.

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[50] https://www.nature.com/articles/d41586-018-06212-8
[51] https://www.recordnepal.com/landslides-are-at-the-heart-of-nepals-climate-vulnerability
[52] https://www.cnn.com/2021/03/30/asia/nepal-wildfires-air-quality-intl-hnk/index.html
[53] https://www.researchgate.net/publication/331138250_Wildfire_Dynamics_in_Nepal_from_2000-2016
[54] https://www.energypolicy.columbia.edu/research/testimony/out-control-impact-wildfires-our-power-sector-and-environment
[55] https://www.newyorker.com/news/news-desk/nepals-dangerous-dams
[56] https://www.newyorker.com/news/news-desk/nepals-dangerous-dams
[57] https://www.telegraph.co.uk/news/worldnews/asia/china/4434400/Chinese-earthquake-may-have-been-man-made-say-scientists.html

These technological threats can hinder efforts at power sector resilience-building. Another type of technological threat relevant for Nepal is the seasonality of hydroelectricity production and that seasonality's impact on supply forecasting and the ability of hydropower stations actually to produce power. Nepal already is managing a power surplus during the rainy season and a power deficit during the winter months.[58] Glacial melt and precipitation patterns are going to continue to exacerbate this disparity, making it difficult for planners to smooth generation. Table 3 shows the projected flow rates for the Koshi River under RCP 4.5 and RCP 8.5. Relative changes are relative to the reference period of 1981 – 2010.[59]

Table 3: Projected Seasonal Flows in the Koshi River Basin

	2016 – 2045				2036 – 2065				2071 - 2100			
	RCP4.5		RCP8.5		RCP4.5		RCP8.5		RCP4.5		RCP8.5	
Average annual/ seasonal flow	Absol-ute (m3/s)	Rela-tive %	Absol-ute (m3/s)	Rela-tive %	Absol-ute (m3/s)	Rela-tive %	Absol-ute (m3/s)	Rela-tive %	Absol-ute (m3/s)	Rela-tive %	Absol-ute (m3/s)	Rela-tive %
Annual	404	16	452	18	567	22	785	31	720	28	1449	57
Winter	98	17	72	13	113	20	121	21	132	23	223	39
Pre-monsoon	-44	-6	-2	0	79	11	68	9	115	15	154	21
Monsoon	818	13	1001	15	1183	18	1682	26	1585	24	3362	52
Post-monsoon	906	54	828	50	1030	62	1451	87	1139	68	2131	128

The 54%, 62%, and 68% increases in the short, medium, and long-term post-monsoon flows under the comparatively conservative RCP 4.5 make a strong case for the continued differential seasonal hydroelectricity production.

HUMAN-CAUSED THREATS

Human-caused threats can be broadly categorized into three categories: accidents, incompetence, and bad actors.[60] Accidents are just that: damage to power system equipment with no ill-intent. This could include illegal connections to the grid, a truck driver crashing into a transmission pole and disabling it, or a utility worker accidentally causing an incident. Incompetence refers to incidents caused by a lack of training, a lack of proper system management, or the failure to implement an emergency plan.[61]

Bad actors pose the most significant risk to the INPS. Bad actors can include disgruntled employees who intentionally sabotage processes or systems in order to disrupt service. Terrorism, direct, violent attacks on infrastructure, pose another threat to Nepal. The disruptions caused by a third kind of bad actor is beginning to become an increasingly severe problem across power systems worldwide: cyberattacks. Ever since late 2015, when hackers successfully infiltrated supervisory control and data acquisition (SCADA) systems of a Ukrainian power distribution company and shut down 30 substations for hours, power sector planners have had to worry about the physical consequences of

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[58] https://reader.elsevier.com/reader/sd/pii/S1364032119305969?token=2ED7443560C723A8A510F77CA0EBEFFFD193A93C169FF90DDB0CB9B5749D8DA143AA2D5D7D87724DC812EB3B5E9BD271&originRegion=us-east-1&originCreation=20220727135410

[59] https://www.tandfonline.com/doi/full/10.1080/07900627.2020.1826292

[60] https://www.nrel.gov/docs/fy19osti/73489.pdf

[61] https://www.nrel.gov/docs/fy19osti/73489.pdf

a cyberattack.[62] Nepal is situated near multiple cyber-savvy states, including India, China, and Pakistan. Cyberattacks have already happened in Nepal, including the hacking of 19 government websites and the data breach of Foodmandu.[63] Globally, the power sector is under a constant barrage of attacks: 56% of utility security professionals in the U.S. reported a shutdown or operation data loss due to a cyber incident in 2019.[64] New technologies including solar panels and smart grids provide a larger attack surface for bad actors, and so Nepali planners must factor cybersecurity plans into their governance processes as the system becomes increasingly digitized and advanced.[65]

SCOPE OF THREAT LANDSCAPE

All of these threats can and likely will transpire to expose the vulnerabilities of the INPS. Table 4 below shows the scope of the generation and transmission infrastructure that may be impacted. Table 4 shows the total constructed, under construction, planned, and proposed hydropower projects and transmission lines, delineated by the five zones used in the Rastriya Prasaran Grid Company Limited (RPGCL) Master Plan from 2018.[66] The total MW capacity constructed, under construction, planned, and proposed is approximately 34,084MW and the total transmission line length of combined voltage level lines is 6,741 km representing an estimated investment of $1517.17M according to the RPGCL report. The Department of Electricity Development (DoED) statistics report 750 hydropower projects representing more than 38,000MW of installed capacity are in different stages of development.[67] Table 4 reflects RPGCL data and Table 5 reflects DoED data. All of these projects are exposed to the threats described above to some degree. The scale of this investment and economic benefit underscores the importance of protecting the vulnerable aspects of each project from landsides, GLOFs, floods, and other threats described above.

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[62] https://www.globalsign.com/en/blog/cyber-autopsy-series-ukranian-power-grid-attack-makes-history#:~:text=Regional%20electricity%20distribution%20company%20Ukrainian,intrusion%20on%20December%2023%2C%202015.

[63] https://kathmandupost.com/valley/2017/11/04/19-govt-sites-breached-in-latest-cyberattack

[64] https://dailyenergyinsider.com/infrastructure/22281-survey-56-percent-of-utilities-have-faced-a-cyberattack-in-the-last-year/

[65] https://asian-power.com/regulation/news/cybersecurity-risks-heighten-asia-power-plants-digitise

[66] https://www.rpgcl.com/pages/technical-documents

[67] www.doed.gov.np, accessed on 9/28/2022

Table 4: Hydropower Stations and Transmission Lines by River Basin (2018, RPGCL)[68]

Transmission Line Corridors	**Major Substations**	**MW of Plants Connecting/Intended to Connect within Transmission Line Corridor**	**Major Hydropower Stations Constructed, Planned, and Proposed**	**Length of Constructed, Planned, and Proposed Transmission Line (excludes cross-border lines)**	**Estimated Cost of Transmission Line**
Karnali, West Seti, Mahakali	Attariya	416.42	None	713km 400kV, 361km 132kV	$688.12M
	West Seti	1139	West Seti (750MW), Chainpur Seti HEP (210MW)		
	Dododhara	4890	Betan Karnali, Mugu Karnali, Tila HPPs, Phukot Karnali, Karnali St-1		
Bheri Corridor	Maintada	982.3	Bheri 4, Bheri 3 Storage	471km 400kV, 344km 132kV	$450M
	Nalgad	2306.4	Bheri 1, Bheri 2, Chera 1, Dadagau Khalanga Behri, Jagadulla Kohola, Thuli Bheri		
	Bafikot	680.69	Uttarganga Storage		
	Phulbari	501.48	Upper Jhimruk Storage		
	Burtibang	98.97	None		$909.58M

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[68] https://www.rpgcl.com/pages/technical-documents

Transmission Line Corridors	Major Substations	MW of Plants Connecting/Intended to Connect within Transmission Line Corridor	Major Hydropower Stations Constructed, Planned, and Proposed	Length of Constructed, Planned, and Proposed Transmission Line (excludes cross-border lines)	Estimated Cost of Transmission Line
Gandaki/Narayani, Marsyangdi	Kushma	1738.6	Kaligandak-Kowan, Kaligandaki Gorge, Upper Myagdi, Modi Cluster, Dana Cluster 1 and 2	394km 400kV, 626km 220kV, 728km 132kV	
	New Butwal	376.47	Kali Gandaki A, Andhi Kola Storage		
	New Damauli	776.16	Tanahu Seti, Begnas-Rupa, Mada Siti		
	New Marsyangdi	4328.56	Upper Budhigandaki, Budhi Gandaki Prok Khola, Manang Marsyangdi, Lower Marsyangdi, Uppers Marsyangdi 1 and 2, Super Trishuli, Lower Seti, others		
	Bharatpur	49.5	None		
Trishuli-Chilime, Khimti, Tamakoshi	Ratmate	1305.67	Budhi Gandaki Storage HPP	589km 400kV, 323km 220kV, 454km 132kV	$761.43M
	New Hetauda	81.04	None		
	Trishuli 3B	1569.91	Upper Trishuli-1 and II, Rasuwagadhi, Rasuwa Bhotekoshi, Langtang Khola, Chilime Cluster		
	Syuchatar	89.71	Kulekhani-I		
	Lapsiphedi	22.9	None		

Transmission Line Corridors	Major Substations	MW of Plants Connecting/Intended to Connect within Transmission Line Corridor	Major Hydropower Stations Constructed, Planned, and Proposed	Length of Constructed, Planned, and Proposed Transmission Line (excludes cross-border lines)	Estimated Cost of Transmission Line
	Barhabise	1018.49	Madya Bhotekoshi, Bhotekoshi Cluster, Tamakoshi-V		
	New Khimti	2226.67	Tamakoshi-3, Upper Tamakoshi, Lapche Khola, Likhu 1, 2, and 4		
	Dhalkebar	1709.5	Sunkoshi 2 and 3		
Koshi, Arun, Kabeli	Mirchaiya	341.48	Dudhkoshi Storage	637km 400kV, 210km 220kV, 627km 132kV	$755.74M
	Tingla	1444.94	Dudhkoshi 6, 9, V, 2		
	Arun 3	3031.37	Arun 3, Isuwa Khola, Upper Arun, Arun 4, Kimathanka Arun, Lower Arun		
	Inaruwa	561.16	Ilam Cluster, Kabeli Cluster		
	New Basantapur	843.43	Tamor Storage		
	Hangpang	1562.89	Upper Tamor, Ghunsa Khola		

Table 5: Status of Hydropower Projects (2022,o)

Category	**Number of Projects**	**Total Installed Capacity (MW)**
Operating Plants		
>1MW	119	2075.26
<1MW	17	13
Construction Licenses Issued by DoED		
>1MW	24	8184.5
<1MW	221	18.64
Survey Licenses Applied to DoED		
>1MW	169	13789.4
<1MW	15	10.7
GoN Project Bank		
Studied Projects	16	1494.32
Projects Under Study	48	9851.95
License Cancelled (Revoked)	150	2604.18

3. IDENTIFY VULNERABILITIES

DEFINING INPS VULNERABILITIES

Vulnerabilities in the power sector are weaknesses or deficiencies within the infrastructure, processes, and systems that various threats can impact. Vulnerabilities are features of the power sector which, if a threat does take place to expose them, will lead to economic or physical damage and reduce the INPS' ability to deliver power. Understanding vulnerabilities is the next step in designing a resilience action plan after defining threats. Identifying specifically how each threat could damage the power sector allows decision-makers to plan accordingly to prioritize and shore up any weaknesses within processes or infrastructure.

This report disaggregates vulnerabilities by each power sector segment to allow stakeholders to easily identify which vulnerabilities they have the opportunity to address. These segments are demand side; generation; transmission and distribution; and governance. The vulnerabilities discussed in this section are by no means exhaustive but are meant to provide representative examples and a starting point for system planners to think about how each hazard could damage power sector infrastructure.

DEMAND-SIDE VULNERABILITIES

Peak electricity demand exceeds domestic electricity supplied in Nepal. This leads to power shortages that will be further exacerbated by factors increasing the quantity of power demanded and increasing disparities in seasonal generation. Additionally, Nepal has suppressed demand due to 10% of its populace still not being connected to the grid and a lack of power availability to the manufacturing and industrial sectors.[69] The INPS is already limited by its demand forecasting capabilities that may not dynamically capture these future increases in demand. Understanding the factors that will lead to further demand on the system, from both the residential and commercial sectors, on an already stressed grid will help planners introduce demand side management measures that will reduce electricity demand without inhibiting economic growth and better understand how much generation and transmission capacity need be added.

INCREASED DEMAND FOR ELECTRICITY IN THE RESIDENTIAL SECTOR

Increased demand for power due to air conditioning and cooling, cookstoves, charging stations for electric vehicles (EVs), and other home appliances will further strain the INPS. The INPS often faces power deficits, especially during dry season, and relies on imports to close the gap. This is costly and blackouts are not infrequent anyway. Recently, peak demand increased by 28.7% from December 2021 compared to December 2020, and while this increase is largely a benefit due to investments in transmission and distribution (T&D) by the Nepal Electricity Authority (NEA), climate change could exacerbate the effects of this increasing demand in unexpected ways.[70]

Inadequate standards for energy efficiency and demand side management exacerbate the problem. While it is clear that standards for consumer products would help reduce electricity usage, Nepal does not have the capacity to develop them. A legal framework created by the Alternative Energy Promotion Center (AEPC) and prioritized by the government, drafted with international leading standards, could help mitigate residential electricity demand.[71]

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[69] https://www.macrotrends.net/countries/NPL/nepal/electricity-access-statistics
[70] https://www.nepalitimes.com/latest/nepal-electricity-demand-soars/
[71] Urja Nepal. 2021. Report on Energy Efficiency.

Temperature increases are likely to play a minor role in the quantity of electricity demanded. The general guidance from the U.S. Energy Information Administration is that temperature causes a greater change in peak demand than overall demand, largely due to air conditioning and heating.[72] There are many more factors than temperature, such as technology advancements, population growth, and space conditioning growth, that have a more notable increase on peak power demanded.[73] For example, in the United States, demand increases associated with rising temperatures are associated with the increased demand for cooling and fans. However, in Nepal, Fans comprise 4% of total residential sector electricity consumption and air conditioning comprised 2%.[74] The compound annual growth rate in air conditioning use in Nepal is 6.2% between 2021 and 2027.[75] So, as temperatures rise, annual demand is anticipated to increase from 16 GWh to 17 GWh which is a marginal increase in demand. Future increases in peak demand are more likely to come from the promotion of electricity use and release of suppressed demand rather than temperature increases.[76] Industrial demand alone was 3000 MW in 2018.[77] However, an estimate has been conducted with the result that demand variation per degree of temperature is 0.07 MW/°C increase during cold months and 0.02 MW/°C increase during warm months.[78] This effect is more pronounced during cold months than warm months as more Nepali homes have electric heating appliances than homes that have air conditioning.[79]

INCREASED DEMAND FOR ELECTRICITY IN THE INDUSTRIAL SECTOR

Increased demand for electricity in the cement industry, iron and steel industries, and fertilizer industries may increase the quantity of electricity demanded. One source reported that industrial companies have reported experiencing up to 8.8 hours of power outages every week.[80] This forces many of these factories to use diesel generators which can add nearly 5% to monthly expenditures.[81] This demand is poised to increase as Nepal's economy continues to grow, and so government initiatives to power the industries would be cost-effective to the industry while also reducing power wastage. Some industries stand out as clear consumers of additional power. The iron and steel industries are likely to increase production due to additional tariffs on Indian products. There are also between six and eight new steel and iron facilities coming online, and that kind of increase puts more demand and more stress on the grid. Examples of the costs of this suppressed demand include a cement factory in West Nawalparasi forced to reduce working and install generators to make up for the 8 MW of electricity supplied relative to the 20 MW required to operate at full capacity.[82] Reliable electricity too, is key. At the macro level, economic losses in the industrial sector resulting from unplanned outages are estimated to be nearly USD 25 million annually.[83]

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[72] https://www.aceee.org/files/proceedings/2014/data/papers/3-736.pdf
[73] https://www.nrel.gov/docs/fy15osti/64297.pdf
[74] Gokul report
[75] https://www.6wresearch.com/industry-report/nepal-air-conditioner-ac-market-2021-2027
[76] https://www.spotlightnepal.com/2021/12/19/peak-demand-electricity-has-increased-265-percent-md-ghising/
[77] https://www.sciencedirect.com/science/article/abs/pii/S0959652620335289
[78] https://www.mdpi.com/2571-5577/4/3/43/htm
[79] https://www.mdpi.com/2571-5577/4/3/43/htm
[80] https://www.nepalitimes.com/latest/nepal-electricity-demand-soars/
[81] https://www.nepalitimes.com/review/post-lockdown-comeback-for-nepals-industries/
[82] https://www.nepalitimes.com/banner/nepals-precious-electricity-going-waste/
[83] https://reader.elsevier.com/reader/sd/pii/S1364032119305969?token=187F0F4F0061944EFFE149B8D3478309DED4EBB7B066F65DA5399EA74A0E4C5419793EC13BED6C4D5E2D4D4C9B242CB1&originRegion=us-east-1&originCreation=20220712012251

GENERATION VULNERABILITIES

DAMAGE TO INFRASTRUCTURE FROM FLOODING AND GLOFS

Box 7: 2020 and 2021 Flooding Incidents

In 2020, hydropower plants had to halt the release of 490MW of power to the grid to avoid damage to infrastructure from flooding. This was equivalent to 40% of total electricity output at the time. In 2021, eight hydroelectric projects representing 208MW of generation were damaged due to floods and landslides triggered by them.

System planners and power developers must be aware of the risk flooding in Nepal. Recent examples highlight the urgency of accounting for flooding possibilities, explained in Box 7.[84] [85] Flooding will increase as climate change increases monsoon season river flows and both hydroelectricity and irrigation projects are designed without basin-level planning or climate change considerations.[86] Hydroelectricity production will continue to be in a perpetual state of jeopardy during the wet season without building resilience into the system. The Koshi basin, for example, has an estimated 10,000MW of economically viable hydropower potential. While development is taking the place the upstream-downstream linkages are not well understood, which puts these projects at risk.[87] The economic stress will continue to worsen as well absent resilience measures, as the Independent Power Producers Association, Nepal (IPPAN) has begun to demand compensation for damage caused by floods and landslides, putting additional financial stress on the government. Temperature increases will further contribute to the likelihood of flooding. However, dry season precipitation changes are still an under-studied topic and estimates diverge.[88] Flooding itself does not always threaten larger hydroelectric installations, but the sediment and debris associated with them can cause severe damage.[89]

GLOFs in particular pose a risk to generation. One of the most comprehensive studies conducted on glacial lakes indicates that even in the absence of climate change, GLOFs threaten many hydropower projects across the Himalayan region. Despite the often-inadequate design features and the lack of spillways and diversion structures, planners across the region tend to favor the construction of hydropower installations at higher elevations to expand generation.[90] Another study showed the dangers of continued generation expansion without resilience considerations. Observing the Dudhkoshi, Tamakoshi, Marsyangdi, and Bhotekoshi/Sunkoshi River systems, the study revealed that ten major hydropower installations were at risk from a GLOF and the model showed that USD 573 million of existing generation assets are directly at risk, and that is discounting the >13 billion USD in capital planned for additional development in the Dudhkoshi, Tamakoshi, and Marsyangdi basins and the ten major transmission lines associated with the generating infrastructure.[91] [92] Box 8 shows how

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[84] https://kathmandupost.com/money/2020/07/10/hydropower-plants-temporarily-halt-output-as-floods-wreak-havoc-across-nepal
[85] https://www.spotlightnepal.com/2021/07/18/flood-and-landslide-damaged-eight-hydro-power-projects/
[86] https://dtm.iom.int/reports/nepal-%E2%80%93-landslides-and-floods-displacement-%E2%80%93-site-assessment-report-september-2020
[87] https://www.preventionweb.net/news/flooding-and-hydropower-missed-opportunities-koshi-basin
[88] https://en.unesco.org/sites/default/files/climate_resilient_water_management_webinar5_hydropower-nepal_divas-basnyat_dibesh-shrestha.pdf
[89] https://archive.nepalitimes.com/article/nation/preparing-for-the-big-flood,3190
[90] https://iopscience.iop.org/article/10.1088/1748-9326/11/7/074005/pdf
[91] https://www.tandfonline.com/doi/full/10.1080/07900627.2014.994116
[92] https://www.sciencedirect.com/science/article/pii/S2666916121000189

the Tsho Rolpa and Imja Tsho lakes threatens the major plant, Upper Tamakoshi.[93] [94] [95] [96] In addition, the potentially dangerous glacial lakes threatening hydropower development on the Trishuli sub-basin put additional generation capacity at risk.[97] There are also 22 “Level 3” glacial lakes which are not yet potentially dangerous but do need to be monitored closely for changes in structure and size.[98]

Box 8: Tsho Rolpa and Imja Tsho

Upper Tamakoshi, a 456 MW plant, one of the largest in Nepal, does not face much risk from climate change related stream flow decreases, but the Tsho Rolpa glacial lake poses a serious threat. The lake needs to be lowered by 15-20m in order to not pose a threat. As such, it is “probable” that the lake will burst and damage Upper Tamakoshi, removing some portion of the 456MW of generation for a time. Another lake, Imja Tsho threatens Upper Tamakoshi, Bhote Koshi, Arun-III, Khimti, Sun Koshi, and others. In addition to GLOFs, flooding due to increased river flows during monsoon season is likely to increase, posing a risk to

DAMAGE TO INFRASTRUCTURE FROM LANDSLIDES AND EARTHQUAKES

The 2015 earthquake damaged more than a dozen hydropower plants, reducing production capabilities by up to 30%.[99] The damage to generation alone was problematic enough for the sector, but extensive damage to transmission and distribution infrastructure kept hundreds of thousands of Nepalis without power for extended periods of time during the 2015 Gorkha quakes as well. Damage to hydropower infrastructure from earthquakes can include landslides triggered by a quake, cracks in dams that lead to leakage, and even falling boulders destroying sites.[100] Developers and electricity system planners need to be aware of the risks inherent to hydropower construction in Nepal. Currently, despite earthquakes being factored into codes governing infrastructure standards, the 2015 earthquake still caused USD 200 million in damages due to the aftereffects of the quake.[101] Failure to enhance resilience to earthquakes can expose even more investment in hydropower to damage than in 2015.

One research team applied their model of findings from the 2015 earthquake to the 273 hydropower projects currently operational in the Himalayas (across Nepal, India, and Bhutan) and found that a quarter of them are likely to face severe damage from landslides triggered by earthquakes.[102] With the additional hydropower projects that have come online since 2015, and without additional resilience safeguards, a future earthquake of similar magnitude could remove hundreds of MW from the grid until hundreds of millions of dollars are spent to adequately make repairs. This estimate is based upon the 25% of currently constructed and planned hydropower projects and more than 10% of potential hydropower projects have high probabilities of moderate to severe damage from future earthquakes.[103] Landslides are a historically persistent threat to the power sector, especially to transmission infrastructure. It is difficult to create a comprehensive picture of the total MW of

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[93] https://reader.elsevier.com/reader/sd/pii/S2212096316300274?token=A36C0D6A24762BFEFFC55162C9BEC65B6D58E098F761FAAB691C0865DB1EC08A4B711B5AB13F5C949D458377F8971D0F&originRegion=us-east-1&originCreation=20220711130402

[94] https://www.tandfonline.com/doi/full/10.1080/17477891.2011.582310

[95] https://www.iwmi.cgiar.org/publications/iwmi-working-papers/iwmi-working-paper-187/

[96] https://www.icimod.org/event/the-koshi-river-basin-insights-into-biophysical-socioeconomic-and-governance-challenges-and-opportunities/

[97] https://www.ifc.org/wps/wcm/connect/d9ba169a-3642-4928-a2b5-a7d567583f9d/Report_CIATrishuli_May2020_ExecutiveSummary.pdf?MOD=AJPERES&CVID=ns6PHB7#:~:text=There%20are%20six%20operational%20hydropower,total%2081%20megawatts%20(MW).

[98] https://www.undp.org/sites/g/files/zskgke326/files/migration/np/Inventory_Glacial_Lakes_2020_Full2.pdf

[99] https://www.forbes.com/sites/tomzeller/2015/05/08/earthquake-strains-nepals-already-shaky-but-potentially-powerful-electricity-sector/?sh=2110476328cd

[100] https://spectrum.ieee.org/nepals-hydropowerbased-power-system-survived-its-m79-quake-

[101] https://www.nature.com/articles/d41586-018-06212-8

[102] https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018GL079173

[103] https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018GL079173

generation and transmission under threat, but year after year hydropower and transmission projects are taken out of commission due to landslides triggered by heavy rains and occasionally earthquakes.

SEASONAL AND INTER-ANNUAL SHIFTS IN GENERATION CAPACITY

In addition to the increase in year-over-year in demand or peak demand due to temperature increase is the seasonal shifts in electricity production. Nepal already suffers from differences in electricity production during dry and wet seasons, and this problem will be exacerbated by climate change over the long term. Table 6 shows the current disparity.[104] Low winter rainfall will affect the run-of-river (ROR) hydropower projects' generation in dry season, and ROR projects are a major contributor to the INPS, accounting for 90% of hydropower stations. These ROR plants already only operate at 30% capacity during dry months.[105]

Table 6: Disparity Between Wet Season and Dry Season Peak Demand and Supply

	FY	Demand	Supply	Balance
Wet Season	2018/19	1841	2283	441
	2019/20	2225	2857	631
	2020/21	2638	3584	946
	2021/22	3062	3963	901
	2022/23	3365	4046	670
Dry Season	2018/19	1841	1470	-372
	2019/20	2225	1686	-539
	2020/21	2638	1928	-709
	2021/22	3062	2055	-1007
	2022/23	3365	2079	-1283

As climate change increases glacier melt in the future, the disparity between wet and dry season generation will increase, as dry season flows are likely to decrease while wet season flow will increase. This will lead to a scenario where dry season generation is determined by river flows (which do not allow large stations to produce at capacity) whereas wet season generation is determined by installed capacity, as the volume of water flowing will exceed an installation's ability to harness it. So, increased flows during the wet season will not typically have an impact on those hydropower plants already

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[104] https://reader.elsevier.com/reader/sd/pii/S1364032119305969?token=8EBD96E765004F7E0990227A40B299EC71F0AEC27BF9D2DADAF9C3A43107276IFDFDEE07745A9BB0F7815415F4937260&originRegion=us-east-1&originCreation=20220727171801

[105] https://www.intechopen.com/chapters/53350

operating at capacity but will limit dry season generation.[106] Box 9 shows how seasonality will play a role at the Kulekhani Hydropower Project.[107] [108]

Box 9: Kulekhani Output Reduction

Kulekhani I (62MW), Kulekhani II (32MW), and Kulekhani III (14MW) – impounds on the Kulekhani river. Analysis shows that temperature increases, and other climactic impacts could reduce the output of Kulekhani I by 12.1% by the 2050s under RCP8.5. Extrapolating this to the other similarly sited Kulekhani stations, this represents a potential loss of 13MW. An earlier estimate suggested that the reduction may be as high as 30%, representing a removal of 32.4MW from the grid. Additionally, the time of peak discharge is anticipated to shift from July to August, which is also a factor to be considered by planners.

Furthermore, most Nepali developers are not prepared to cope with dwindling river hydrology and these developers are suffering due to poor hydrological analysis.[109] They are paying penalties due to their inability to deliver the committed quantum of electricity to the sole buyer, NEA. Furthermore, their revenues may lower than anticipated due to lower than accounted for dry season flows.[110] Not only does drought threaten existing generation but poses a problem for new projects as well. As early as 2015, developers began complaining that drought was impacting the financial viability of their projects due to a reduction in river runoff during the dry season.[111] A study conducted on ROR projects on the Budhigandaki river, which shares flow characteristics of many other rivers of Nepal,[112] indicated that dry season flow is less than anticipated by approximately 3%, meaning that dry season power production was lower than anticipated by 3% as well.[113] Though there is a high degree of variation in flow rates, drought, temperature increase, and the associated change in precipitation patterns could further decrease dry season flows.[114] Box 10 shows how decreasing flows may impact the three large dams on the Marsyangdi River.[115]

Box 10: $14M Loss in Flow

Middle Marsyangdi (70MW), Marsyangdi (69MW), and Upper Marsyangdi A (50MW) –Climate change under the RCP4.5 could cause flows to change by -3.93%, -2.49%, and -4.3%, respectively due to rising temperatures and drought. Flows are expected to drastically increase from glacial melt in the wet season, driving a disparity between wet and dry season generation. During dry season under RCP8.5, representing the greatest modeled loss, this would lead to a maximum decrease in electrical output of -5.26% for Middle, -2.36% for Lower, and -3.41% for Upper, representing 7MW taken offline. At an estimated $2M to construct 1MW, this is a $14M economic loss.

Eventually the de-glaciation of the Himalayas, past the year 2100 and the timeframe scope of the RCP forecasts, will lead to drastically reduced river flows as the amount of ice left to melt decreases.[116]

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[106] https://www.nepjol.info/index.php/JIST/article/view/37831
[107] https://climatenepal.org.np/sites/default/files/doc_resources/shrestha2020%2CElsevier.pdf
[108] https://link.springer.com/content/pdf/10.1007/s40710-014-0020-z.pdf
[109] https://www.thethirdpole.net/en/energy/nepals-hydropower-output-falling-due-to-climate-change-developers-claim/
[110] https://www.nepjol.info/index.php/JIST/article/view/37831
[111] https://www.thethirdpole.net/en/energy/nepals-hydropower-output-falling-due-to-climate-change-developers-claim/
[112] https://www.nepjol.info/index.php/JIST/article/view/37831
[113] Ibid
[114] https://www.nepjol.info/index.php/HN/article/view/4190
[115] https://www.irjet.net/archives/V8/i8/IRJET-V8I819.pdf
[116] https://www.researchgate.net/publication/264288015_Impact_of_Climate_Change_on_River_Flow_and_Hydropower_Production_in_Kulekhani_Hydropower_Project_of_Nepal

COMPETITION FOR WATER RESOURCES

Increased demand for irrigation from agriculture and other uses may reduce the amount of water available for power generation. Climate change is already exacerbating water shortages in some areas, as water is a necessity for farming and food security.[117] Population increases and economic growth will place more demand on water resources, and without proper planning, competition between hydropower, irrigation and other sectors to ensure demand is met. Additionally, water availability fluctuates seasonally and inter-annually which compounds planning challenges.

TRANSMISSION VULNERABILITIES

Nepal has 6,741 km of 400 kV, 220 kV, and 132 kV transmission line constructed, under construction, planned, or proposed throughout the country.[118] The transmission sector is highly vulnerable to climate change and natural disasters. To compound the issue of a 17.18% rate of T&D losses[119], climactic factors will continue to hamper the efficacy of the transmission system and poses a risk to new transmission under construction. These new lines are essential, as more than 50 hydropower projects representing thousands of MW of capacity are at risk of spilling power if not constructed.

Many of the hazards discussed in Section 2 can damage transmission and distribution infrastructure as well as generation infrastructure. Temperature increases can lead to equipment failure from high heat and reduce overall network efficiency. One study estimates that each 1°C increase in ambient air temperature reduces transmission efficiency by .7%.[120] Under RCP 8.5, by the 2080s, this could represent additional losses of 2.9% of electricity generated.[121] In 2017, almost half of Nepali citizens suffered from prolonged power outages due to heavy rain leading to flooding, a result of damage to electricity poles, substations, and transmission stations.[122] Due to increasing number of conflicts with locals in land acquisition and right of way, transmission line projects are being moved to more public/government land (forest lands) or landslide risk prone areas. In August of 2022 an 11 kV distribution line was damaged due to heavy rains and landslides, which is an increasingly common occurrence.[123] This also puts transmission infrastructure at risk of wildfires. There is currently no authority to track and manage fires which makes the extent of this problem uncertain.[124] Power lines themselves can cause wildfires, especially due the restoration of power following load-shedding.[125] The threat of wildfires is especially acute in the four westernmost provinces along the southern border of the country, Saptari, Sunsari, Morang, and Jhapa. These four provinces experienced more than 27 fire events annually on average between 1971 and 2011 and host five substations that are threatened by these fires.[126]

In addition to the existing transmission lines vulnerable to threats, there is an overall vulnerability in the transmission system due to the lack of redundancy. If a high voltage line is damaged, service disruptions can be disproportionately far-reaching. In addition to the threats discussed above, a vegetation management plan as part of a broader risk review strategy is important to protect these essential transmission lines.[127] While this issue is more prevalent in low-voltage transmission and distribution lines with lower criticality, this issue will continue to arise as more high-voltage

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[117] https://www.sciencedirect.com/science/article/pii/S1674237019300195
[118] RPGCL Transmission System Master Plan 2018
[119] NEA Annual Report 2020-2021
[120] https://www.researchgate.net/figure/Temperature-related-transmission-efficiency-through-the-TD_fig1_319161843
[121] https://www.adb.org/sites/default/files/publication/677231/climate-risk-country-profile-nepal.pdf
[122] https://www.aa.com.tr/en/asia-pacific/almost-half-of-nepal-left-without-power-after-floods/884774
[123] https://www.urjakhabar.com/news/0308486032
[124] https://www.wionews.com/south-asia/forest-fires-flare-up-in-nepal-air-quality-deteriorates-474115
[125] https://thehimalayantimes.com/kathmandu/short-circuit-biggest-cause-fire-valley
[126] https://www.researchgate.net/figure/Fire-Hazard-frequency-map-of-Nepal_fig7_282878978
[127] https://www.nea.org.np/admin/assets/uploads/annual_publications/Generation_2020.pdfder

transmission lines come online. Finally, from a policy perspective the lack of linkage between transmission and generation expansion planning can lead to a reduction in the INPS' effectiveness. Box 11 shows how service can disrupted.[128]

Box 11: 146 Hours of Downtime at Chameliya

In terms of the percentage of service disrupted, effects of natural phenomenon can already be seen in installed transmission. At Chameliya, 146h of downtime in 2021, representing 1.67% of the time in the year, the transmission line was down due to exposure to the elements through the high hills through which it is routed. The INPS will continue to have to manage through these extended periods of downtime absent resilience measures.

GOVERNANCE VULNERABILITIES

In addition to the vulnerabilities that can be "exploited" by natural phenomena, there are structural weaknesses within the institutions and processes that govern the power sector. Climate change can progress at a pace that renders extant legislation obsolete. Planners need to be aware of how quickly climactic impacts can take place and plan to legislate and regulate accordingly. This changing environment represents perhaps the greatest threat to INPS planners. Data limitations compound the issue. For example, creating an adequate demand forecast and understanding the location of high-risk glacial lakes form the sort of crucial data needed to build resilience into the power sector. At the end of any threat/vulnerability identification exercise, the data needed to inform the resilience measures that mitigate the vulnerability need to be identified as well.

Disaster risk reduction (DRR) strategies should be formalized and made operational at the installation level. Being prepared for outages will help to mitigate the impact of extended downtime due to a disaster. Implementing early warning systems as a part of the DRR strategy can help hydropower plants prepare themselves in the case of emergencies. Cybersecurity is also a rising threat to power systems globally. Developing cybersecurity governance plans, incident response plans, and good cyber hygiene can help protect ministries and utilities from exposing themselves to ransomware, malware, or other threats from malign actors.

Coordination across ministries is also important Stakeholders should work together and coordinate to develop strategies to address these vulnerabilities, including creating a robust repository of GLOF data, a consistent demand forecast, river flow forecast for major rivers, and incident response and recovery plans. Ministerial conflicts over jurisdiction can lead to project delays. Social and land use issues can also play a role in delaying transmission projects becoming completed on time. Procedural delays in clearances can affect completion times as well. Very few transmission projects meet the contract completion date, despite their criticality to the power system and generation expansion more broadly.[129]

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[128] https://www.nea.org.np/admin/assets/uploads/annual_publications/Generation_2020.pdf

[129] https://www.researchgate.net/publication/359652309_RISK_MANAGEMENT_OF_HIGH_VOLTAGE_TRANSMISSION_LINE_PROJECT_A_CASE_STUDY_OF_ADB_FUNDED_PROJECTS_IN_NEPAL

4. EVALUATE RISKS

ALIGNING THREATS AND VULNERABILITIES TO CREATE A RISK MATRIX

The next step in the vulnerability assessment is to understand the linkages between threats and vulnerabilities, and score each of them. Hazards are scored based on their likelihood of negatively impacting a power sector vulnerability. Vulnerability severity scores are selected based on the effect on power delivery and the extent of economic loss if that vulnerability is affected by a threat. A level of risk acceptance needs to be decided upon by decision-makers as well by selecting a threshold score, as limited resource prevent the risk from each vulnerability from being comprehensively mitigated.

Table 7 below shows a sample risk matrix for Nepal. This risk matrix aligns threats described in Section 2 with the Vulnerabilities described in Section 3. Each threat is assigned a likelihood of "Low," "Medium," and "High" based qualitatively on historical trends and future scenarios. Each vulnerability is a assigned a severity score of "Low," "Medium," and "High" based qualitatively of that vulnerabilities' impact on the INPS if affected by a threat. Not every threat can impact each vulnerability, so only shaded cells represent an area of concern. Cells are shaded:

- The darkest shade if both threat likelihood and vulnerability severity is High and the severity is High;
- The second darkest shade if threat likelihood is High and vulnerability severity is Medium or the converse;
- The second lightest shade if threat likelihood is High and vulnerability severity is Low or the converse; or if both threat likelihood and vulnerability severity are Medium
- The latest shade if threat likelihood is Medium and vulnerability severity is Low or the converse; or if both threat likelihood and vulnerability severity are Low
- White if the threat does not pertain to the vulnerability in a significant way

This framework serves as a convenient way for planners to understand which threat/vulnerability nexuses represent the greatest threat to the system and can help prioritize resilience actions.

Table 7: Nepal Power Sector Risk Matrix

Vulnerability	**Severity Score**	**Temperature Increase**	**Drought**	**Landslides**	**Precipitation, Floods , GLOFs, and Sedimentatio**	**Wildfires**	**Earthquake**	**Technological Threats**	**Human-Caused Threats**	**Vulnerability Number**
Likelihood Score		High	Low	High	High	Medium	Medium	High	Medium	
Demand Side										
Increased demand for air conditioning and cooling, cookstoves, charging stations, and other home appliances strains the INPS	Low	▒						▒		1
Increased demand for industrial uses such as in the cement, iron and steel, and fertilizer industries	Medium							▓		2
Generation										
Wet season results in excess generation capacity	Medium	▓			▓					3
Dry season generation is below peak demand	High	█	░							4
Siltation can reduce reservoir capacity and cause damage	Medium				▓					5
Frequent and flash floods resulting in closures and outages	High			█	█					6
Peak generation and demand could undergo shifts in seasonality	Medium	▓	░							7

Vulnerability	**Severity Score**	**Temperature Increase**	**Drought**	**Landslides**	**Precipitation, Floods , GLOFs, and Sedimentatio**	**Wildfires**	**Earthquake**	**Technological Threats**	**Human-Caused Threats**	**Vulnerability Number**
Likelihood Score		High	Low	High	High	Mediu m	Medium	High	Mediu m	
Competition for water with other sectors such as irrigation; availability fluctuates seasonally and inter-annually	Low		░							8
Future dam projects are threatened by increasing discharge exceeding spillway capacity	Medium	▓			▓					9
Severe damage to generation infrastructure and removal of MW from the grid	High			█	█		▓	█	▓	10
Inter-basin water transfers	Low	▒	░		▒					11
Reservoir evaporation	Low	▒	░							12
Transmission and Distribution										
Severe damage to transmission equipment and removal of MW from the grid	High	█	▒	█	█	▒	▒		▒	13
Substation efficiency decreased	Medium	▒								14
Lack of redundancy in major transmission lines to load	Medium			▒	▒		▒	█		15
Governance										
Power system regulations and technical standards are inadequate for a changing environment	Medium	▓	░	▓	▓			▓	▒	16

Vulnerability	**Severity Score**	**Temperature Increase**	**Drought**	**Landslides**	**Precipitation, Floods , GLOFs, and Sedimentatio**	**Wildfires**	**Earthquake**	**Technological Threats**	**Human-Caused Threats**	**Vulnerability Number**
Likelihood Score		High	Low	High	High	Medium	Medium	High	Medium	
Lack of early warning systems (EWS) and response plans	Medium	■	░	■	■	▓	▓	■	▓	17
Inadequate data formalized for GLOFs	Medium				■					18
Demand forecasting is not responsive to changing conditions	Medium	■	░		■			■		19
Ministerial jurisdiction conflict can lead to project delays	Low							▓		20
Social and land use related issues affecting new TL projects, no single project has been completed on time	Medium							■		21
Procedural delays in clearances (environmental, forest, compensations) affecting timely completion of projects	Low							▓		22
Lack of cybersecurity governance plans and incident response and recovery plans	Low							▓		23

5. IDENTIFY RESILIENCE SOLUTIONS

Once the relationship between vulnerabilities and threats is understood, system planners can adopt regulations and policies, programs, capital projects, or long-term strategies to mitigate the impact of a threat exposing a vulnerability. This process begins by identifying resilience solutions. The criterion for creating solutions is explained in more depth in Section 6, but Table 8 provides some representative resilience solutions for Nepal and aligns them to vulnerabilities described in Section 5. The number of solutions is not defined or prescribed, planners must think through and evaluate solutions with this framework as guidance.

Table 8: Example Resilience Solutions

Resilience Solution #	Resilience Solution	Vulnerability Addressed
Demand Side		
1	Legislate minimum energy efficiency standards for appliances and Demand Side Management (DSM) activities	2
Generation		
2	Desilting basins (as was done at Jhimruk)	5
3	Trap sediment upstream of reservoirs	5
4	Provide support to local communities dependent on rivers with large hydro installations for agriculture	9
5	Build storage into new hydro projects to mitigate the impact of flow rates on production	3, 4, 8, 9
6	Glacial lake lowering for high-risk lakes	6
7	Construct storage projects with the opportunity to provide water for irrigation to mitigate the competition for water resources	3, 4, 8, 9
8	Shotcrete landslide-prone hills near critically important hydroelectric stations	10, 13
9	Support the construction and development of microgrids	7
10	Build spillways for dams under construction to meet or exceed maximum flows predicted by climactic models	10
11	Implement resilience strategies that account for basin-wide interconnections	11
12	Modify turbines, canals, tunnels, and other hydropower project components to account for changes in river flows	9, 10
13	Prepare developers for variable flow rates and the associated costs of dry season low-flow	7

Resilience Solution #	Resilience Solution	Vulnerability Addressed
Transmission and Distribution		
14	Build redundancy into the transmission network	13, 14, 15
15	Build awareness of wildfires and develop a wildfire management plan	13
16	Plan for redundancy by created a ring-like network to have multiple supply points to each node (avoiding the need to build additional lines that connect the same two nodes	15
17	Implement a vegetation management strategy	13
18	Plan for redundancy with multiple transmission lines from the same facility	15
19	Reduce technical and non-technical losses to ease the burden on the system/total amount of electricity needed to be generated	16
20	Implement more effective cooling systems for transformers	14
	Governance	
21	Develop detailed forecasts for flow rates of major rivers and basins	3, 4, 7, 11
22	NEA to mandate regular risk assessments for each installation	6, 10
23	Plan for proactive shutoff event in case of transmission lines causing wildfires	13
24	Conduct an assessment to understand the impact of flooding on rivers with major hydro installations	6, 9, 11
25	Implement an integrated disaster risk management framework for new projects to build resilience into permitting, with considerations such as ensuring equipment is aligned with leading standards (Iran example) and that climate change considerations have been accounted for	20, 22, 23
26	Create metrics such as average return intervals or annual exceedance probability to quantify the risks and measure quantitatively how much should be invested in resilience	10, 13
27	Include climate in existing activities: Risk screening in Design Guidelines, System Planning, Environmental Impact Assessment (EIA) process, Power Purchase Agreement (PPAs), Dam Safety, Risk Sharing Mechanism	10
28	Continue to invest in and deploy smart grid technology	16, 19

Resilience Solution #	Resilience Solution	Vulnerability Addressed
29	Equip the Generation Development Department with resilience objectives as part of the regular monitoring and inspection processes	16
30	Enhance GLOF data-sharing capabilities between Nepal, India, and China	16
31	Develop an organizational security to policy an incident response plans to prepare for cyberattacks that could compromise the ability to generate and distribute power	23
32	Develop and create early warning systems and response plans	16

6. RESILIENCE ACTION PLAN

AGGREGATE SOLUTIONS TO DEVELOP A RESILIENCE ACTION PLAN

Once the list of potential resilience solutions has been finalized, planners can grade each resilience solution based on feasibility, cost, and effectiveness. If two out of the three are rated "Good" with the third category not being "Poor," planners should prioritize that solution and plan to implement it. If the mean rating is "Fair," planners should keep the solution in mind but evaluate at a later date. If two or more categories are "Poor," planners should remove that proposed solution from consideration. Once this is accomplished, planners can aggregate solutions by sector and then have a draft of the resilience action plan. Table 9 provides a framework for evaluating solutions and Table 10 provides definitions for the criteria in Table 9.

Table 9: Example Resilience Solution Evaluation Matrix

Criteria	Timeframe	Feasibility	Cost	Effectiveness	Priority Level
Resilience Solution #					
1	1 – 5 years	Good	Good	Fair	Implement
2	1 – 5 years	Good	Fair	Fair	Evaluate
3	5 – 10 years	Good	Fair	Good	Implement
X	X	X	X	X	X

CRITERIA DEFINITION[130]

Table 10: Solution Evaluation Criteria

Criteria	Level		
	Good	Fair	Poor
Feasibility (technical and political)	-IRRP Committee and associated institutions have the technical capacity -Strategy is consistent with other long-terms planning documents	-IRRP Committee and associated institutions have some of the technical capacity, gap can be filled internationally -Strategy is mostly consistent with other long-terms planning documents	-Technically infeasible -Outside the scope of energy sector planning
Cost	-Low operations and maintenance cost -Financing available	-Significant operations and maintenance cost -Some financing available	-Prohibitive operations and maintenance cost -Limited financing available

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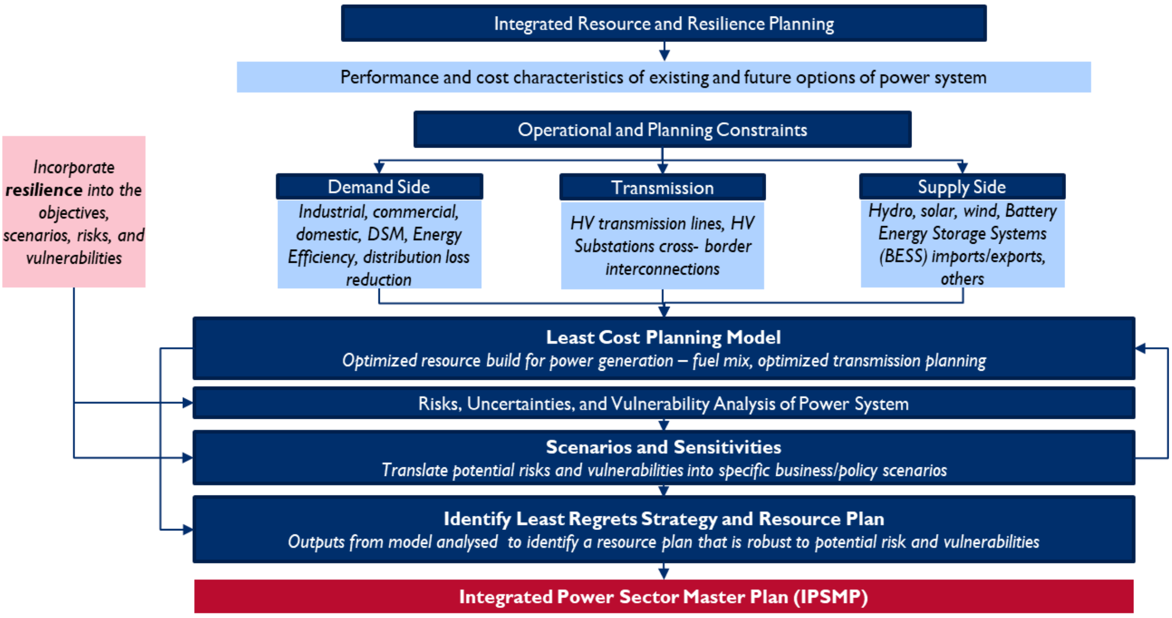
[130] https://www.nrel.gov/docs/fy19osti/73489.pdf

Criteria	Level		
	Good	Fair	Poor
Effectiveness	-Reduces the majority of the risk for a given vulnerability -Reduces the risk related to many other vulnerabilities -Addresses a sector priority	-Reduces a significant amount of the risk for a given vulnerability -Addressed a medium-priority vulnerability for the sector -Reduces the risk related to at least one other vulnerability	-Reduces a small amount of risk for a given vulnerability -Reduces the risk for only one vulnerability -Reduces the risk for a low-priority vulnerability

7. RESILIENCE PLANNING AND THE IRRP

Figure 1 describes the IRRP planning process. Resilience typically fits into the vulnerability analysis stage and the scenarios and sensitivities stage. Resilience can also factor significantly into the strategy selection process. Scenarios are defined as potential future states beyond the GoN's control, in which Nepal's electricity sector may be operating. Sensitivities are defined as future states where the reference case has one variable changed or one constraint added. Unlike the exogenously defined term scenario, a strategy is defined as a business decision or policy direction that the GoN can take in each scenario to accomplish a specific objective.

Figure 1: Resilience and the IRRP Planning Process



Planners should review the resilience action plan when considering the various scenarios to model. The risks and mitigation strategies contained in the resilience action plan are likely to have impact on model factors and present new considerations to be accounted for. Key elements of an integrated resource plan (IRP) include the demand assessment and forecast, supply-side resources, T&D analysis, and power systems analysis. As shown throughout this report, the hazards and the vulnerabilities these hazards expose have an impact on how each of these components is measured and evaluated. Planners must incorporate the data about hazards and vulnerabilities into each of these components to incorporate this resilience component, move from a "least cost" expansion plan into a "least regrets" expansion plan, and turn the IRP into and IRRP. As such, the Committee should develop scenarios based on the most impactful hazards that threaten Nepal's power sector. The scenarios the Committee may want to consider first are those pertaining to temperature increase, drought, sedimentation, earthquakes, and GLOFs. These scenarios and sensitivities need not be final and in fact should be iterated upon as more stakeholders provide insight and more data is gathered, but the Committee can begin incorporating resilience into the IRRP by beginning with these five scenarios.

Basin-level differences in the impact of hazards and the scale of vulnerabilities are another element of the IRRP process for the Committee to consider.

Table 11 below provides examples of how hazards affect different basins in different ways.

Table 11: Scenario Impacts by Basin

River Basin	**Impact of Scenario by Basin**				
	Temperature Increase	Drought	Sedimentation	Earthquakes, Landslides, and Floods	GLOFs
Karnali	**Medium:** temperature increase estimates vary	**Medium:** precipitation is decreasing by 4.91mm/year	**Unknown:** though likely higher as in other basins	**Medium**: <10% of structures at risk, 40% of roads at risk	**Low**: 1 potentially dangerous glacial lake
Gandaki/Narayani	**Medium**: maximum temperature increase between 1.1 and 1.5C by the 2080	**High:** dry season flow is decreasing in most rivers	**High:** storage becomes more valuable under this scenario	**Medium**: <10% of structures at risk, 40% of roads at risk	**Low**: 1 potentially dangerous glacial lake
Koshi	**High:** temperature increase between 2.5 and 5 degrees C by 2100 which can lead to a 20-40% decrease in snowfall by 2050.	**Low**; runoff is expected to increase (largely due to rising temperatures) in the medium term; consecutive dry days likely to increase, however	**High:** large-scale sediment aggregation has led to superelevated channels in several places, leading to flooding and instability	**Medium;** less frequent but more intense rains will cause more floods and trigger more landslides	**High**: 18 potentially dangerous glacial lake

The GLOF scenario, for example, is mainly relevant only to the Koshi Basin that contains 18 of 20 potentially dangerous glacial lakes in Nepal. Basin-level considerations must be kept in mind as model inputs are refined during the IRRP planning process.

Finally, to plan the scenarios, the IRRP should incorporate the impact of each scenario on demand and on supply. Then, mitigation strategies can be examined. Strategies to mitigate the damage from an exploited vulnerability can include capital investments, capacity augmentation, or changes to policies and laws. Table 12 presents some representative mitigation strategies for the five scenarios.

Table 12: Scenarios and Mitigation Strategies

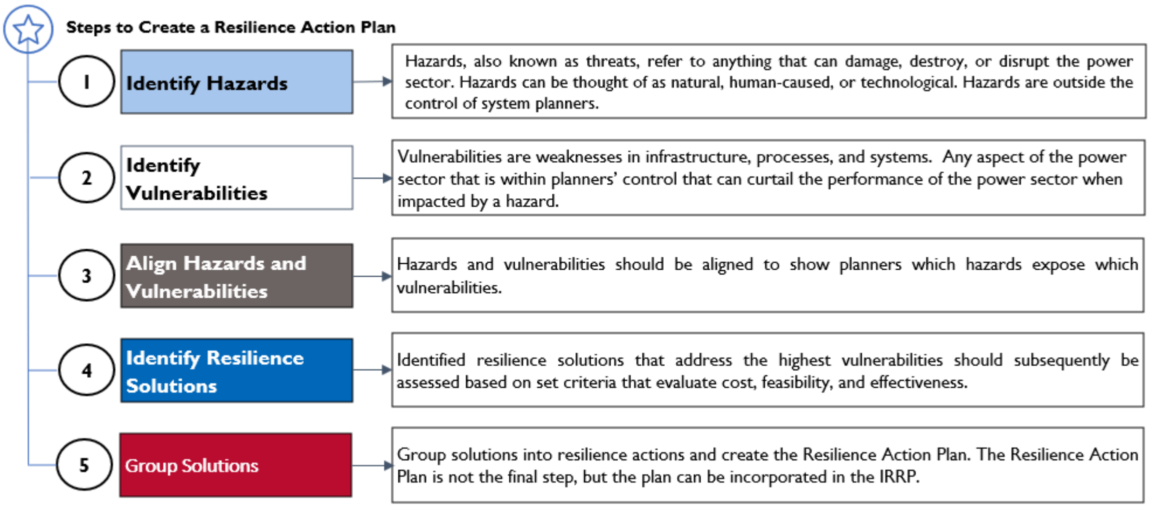
	Impact		**Example Mitigation Strategies**		
Scenario	**Demand Impact**	**Supply Impact**	**Capital Investment**	**Capacity Augmentation**	**Changes to Law, Policy, Process**
Temperature Increase	Slight increase in demand for home appliances	Evaporation in storage projects; reduced efficiency of transmission infrastructure; stimulating glacial melt	Implement more effective cooling systems for transformers	Design future storage-based projects with evaporation as a consideration	Monitor water in glaciers over the long-term
Drought	Increased demand for water from other sectors	Changes in inter-annual precipitation; decrease in RoR generation capacity during dry season	Revise designed discharge in alignment with changing river flows	Develop microgrids and other renewable energy technologies to reduce dependence on water	Coordinate across sectors to cover costs of management
Increased Sedimentation	N/A	Damage to hydropower plants; reduced capacity in storage projects	Construct storage projects with multiple uses (electricity, irrigation, drinking)	Modify desanders and other project components to account for increased sediment loads	Map and quantify sources of sediment
Earthquakes and Landslides	N/A	Damage to hydropower plants; damage to transmission infrastructure	Shotcrete landslide-prone hills near critical infrastructure	Calculate potential generating capacity at risk from an earthquake and plan generation expansion accordingly	Implement an integrated disaster risk management framework to build resilience into permitting

	Impact		Example Mitigation Strategies		
Scenario	**Demand Impact**	**Supply Impact**	**Capital Investment**	**Capacity Augmentation**	**Changes to Law, Policy, Process**
GLOF Events	N/A	Damage to generation and transmission infrastructure and supporting infrastructure	Lower high-risk glacial lakes	Calculate potential generating capacity at risk from a GLOF and plan generation expansion accordingly	Map and monitor glacial lakes and their moraines to continually track risk

8. CONCLUSION AND NEXT STEPS

Resilience is an essential, definitional component of the IRRP. The resilience action plan creation process is captured in Figure 2.

Figure 2: Steps to Create a Resilience Action Plan



1 **Identify Hazards**	Hazards, also known as threats, refer to anything that can damage, destroy, or disrupt the power sector. Hazards can be thought of as natural, human-caused, or technological. Hazards are outside the control of system planners.
2 **Identify Vulnerabilities**	Vulnerabilities are weaknesses in infrastructure, processes, and systems. Any aspect of the power sector that is within planners' control that can curtail the performance of the power sector when impacted by a hazard.
3 **Align Hazards and Vulnerabilities**	Hazards and vulnerabilities should be aligned to show planners which hazards expose which vulnerabilities.
4 **Identify Resilience Solutions**	Identified resilience solutions that address the highest vulnerabilities should subsequently be assessed based on set criteria that evaluate cost, feasibility, and effectiveness.
5 Group Solutions	Group solutions into resilience actions and create the Resilience Action Plan. The Resilience Action Plan is not the final step, but the plan can be incorporated in the IRRP.

Once the resilience action plan has been created, scenarios, sensitivities, and mitigation strategies can be drawn out to inform the least-regrets generation expansion plan. Resilience is a critical piece of the IRRP process. Power sector threats, especially those related to climate change, must be accounted for to develop a true least-regrets generation expansion plan. The IRRP committee needs to understand power sector hazards to prepare for and adapt to changing conditions along the entire generation-transmission-distribution chain. The IRRP committee's selection of scenarios and generation portfolios that are built to consider what steps need to be taken to account for climactic and other threats will lead to better long-term outcomes for the INPS.

About USAID Urja Nepal Program:

USAID Urja Nepal Program supports the efforts of the Government of Nepal in establishing effective policy, regulatory and operational changes to create a financially viable electricity sector, thereby enabling it to provide affordable, reliable, and secure electricity while encouraging private sector investment into Nepalese energy market. The Program is supported by the American people through the United States Agency for International Development (USAID) and is implemented by Deloitte Consulting LLP.

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