Security, Affordability, and Sustainability in Nepal’s Electricity Mix

The Case for Complementing Hydropower with Utility-Scale Solar Electricity

जर्मन सहयोग
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CONTENTS

Acronyms

AC	Alternating current
ADB	Asian Development Bank
AEPC	Alternative Energy Promotion Centre
BAU	Business as usual
CCGT	Combined cycle gas turbine
CFA	Central Financial Assistance
EUR	Euro
EVs	Electric vehicles
FY	Fiscal Year
GDP	Gross domestic product
GW	Gigawatt
GWh	Gigawatt hour
IDCOL	Infrastructure Development Company Limited
IEX	Indian Energy Exchange Limited
IPCC	Intergovernmental Panel on Climate Change
IPPs	Independent power producers
IREDA	Indian Renewable Energy Development Agency
IRENA	International Renewable Energy Agency
IRR	Internal rate of return
ISA	International Solar Alliance
kV	Kilovolt
kWh	Kilowatt hour
kWP	Kilowatt peak
LCOE	Levelized cost of energy
LPG	Liquefied petroleum gas
MoEWRI	Ministry of Energy, Water Resources and Irrigation
MW	Megawatt
MWh	Megawatt hour
NDC	Nationally Determined Contribution
NEA	Nepal Electricity Authority
NPR	Nepalese Rupee
PPA	Power purchase agreement
PROR	Pondage-run-of-river
PV	Photovoltaic
ROR	Run-of-the-river
SADC	South African Development Community
TJ	Terajoules
TOD	Time of day
TWh	Terawatt hours
USD	United States Dollar
WAM	With additional measures
WECS	Water and Energy Commission Secretariat
WEM	With existing measures

Summary for Policymakers

Nepal's energy sector is facing the challenge of seasonal variability in hydropower production. While there is an abundance of electricity during the wet season, a significant deficit exists in the dry season. Solar electricity is emerging as a cost-effective solution to mitigate these seasonal fluctuations and reduce overall energy costs.

The electricity generation mix in Nepal is dominated by hydropower, comprising 95% of installed capacity. The generating capacity of independent power producers (IPPs) comprises more than half (55%) of Nepal's total capacity, the vast majority of which are run-of-the-river (ROR) hydropower projects. This is followed by NEA-owned hydropower projects (22%) and NEA subsidiary hydro companies (18%) such as the Upper Tamakoshi Hydropower Limited. Hydropower is and will remain the major method of electricity generation in Nepal. The potential for solar power is considerable while the potential for other renewable energy sources for electricity generation, such as biomass and wind power, is limited. By nature, solar output is greatest during the dry season when hydropower generation is low. If integrated with hydropower projects, solar can produce electricity that would allow hydropower operators to meet required output with less water flow, preserving water behind the dam for when it is most needed. Scaled up solar can increase the value of hydropower reservoirs by stretching electricity storage capacity into the dry season and reducing the need to import expensive electricity from India during dry-season.

Climate change is increasingly impacting hydropower generation, with the variability in river flows due to climate change exacerbating dry-season shortfalls. This underscores the need for diversifying the electricity mix, particularly focusing on renewable energy-based forms of electricity production like solar photovoltaics (PV), which can reduce reliance on hydropower and mitigate climate change impacts.

Nepal's electricity trade with India is currently imbalanced, with Nepal purchasing more electricity at higher prices (NPR 10.48 per kWh on average with price peaks as high as NPR 32 per kWh in 2022/23) than it sells (NPR 7.02 per kWh on average in 2022/23). Expanding Nepal's own generation capacity, including solar PV, can help rectify this imbalance. Recent agreements promise increased power trade, including a significant commitment by India to purchase 10,000 MW of electricity from Nepal, offering an opportunity for Nepal to become a significant net exporter of electricity.

NEA's annual reports chronicle the high costs of relying on the Indian power market for imports, especially during drier winters. Nepal has the intention of building its way out of dry-season deficits through a substantial pipeline of hydropower projects, including large additions particularly in the years 2024 and 2025, with 1,716 MW and 2,294 MW of run-of-river projects planned to come online and smaller additions of pondage-run-of-river (PROR) projects. At the same time, electricity consumption in the country is expected to more than triple by 2030 compared to 2021 in a low-growth scenario, and nearly quadruple in more ambitious scenarios. If the pipeline of the planned additions and current installed capacity of 2,684 MW are derated based on historic dry-season production – and optimistically assuming that all are commissioned on schedule – then the country should reach a slight dry-season surplus by 2025 before dropping again to deficits between 377 to 749 MW by 2027. Keeping the lights on under these scenarios will require continued electricity imports from India unless the pipeline expands.

Solar PV-based electricity, particularly when combined with storage solutions, can quickly and affordably reduce the need for dry season electricity imports from India. Storage options include existing daily pondage in PROR hydropower, seasonal hydropower reservoirs, pumped storage hydro, and batteries. The addition of solar PV to existing hydropower generation sites can reduce the capital cost – making use of existing transmission facilities. Floating solar, agrivoltaics, and canal-top solar can reduce the competition for land needed for PV installations. Further benefits from deployment of

solar PV can be realized with the implementation of the time of day (TOD) tariffs. By introducing lower tariffs during sun-rich hours, consumers would be encouraged to shift their energy usage to periods when solar power generation is at its peak, lowering needs for storage.

Solar PV costs are rapidly declining and reached USD 0.12 to 0.125 per installed watt peak by the end of 2023. Historically, prices have been consistently declining by more than 20% for every doubling in global cumulative production. Installation is quick, taking months compared to years for hydropower.

Emphasizing non-hydro renewable sources is also vital for Nepal's commitment to the Paris Agreement, aiming for net zero emissions by 2045. Nepal's 15th National Plan envisages the share of renewable resources reaching 20% of total energy consumption in 2030. The Second Nationally Determined Contribution (2020) report sets 5,000 MW as an unconditional target for renewable electricity (e.g., solar, mini and micro-hydro, biomass, and wind) by 2030. With the recent COP 28 resolutions, it emerges that Nepal would also have a part to play in reducing the consumption of fossil fuels and toe the line of increasing non-hydro renewable energy investments. With the review of the current 15th National Plan, addressing implementation shortfalls may call for a more progressive focus on non-hydro renewables in the forthcoming 16th National Plan.

Nepal's solar power sector faces several hurdles, including low tariff ceilings, power evacuation capacity problems, reliability issues of the transmission system, and inconsistencies in policy implementation. These challenges need to be addressed to enable the widespread deployment of solar electricity.

Nepal's current renewable energy policies have primarily focused on small-scale development. Besides, only large-scale grid-connected hydropower has been the focus, with less attention to a diversification of renewable electricity generation. To harness solar PV's full potential, Nepal needs consistent policies and practices that encourage investment in solar technology and address the challenges of the energy sector. This report recommends the following to achieve that:

- **Stable and Fair Tariffs:** Raise tariffs above the most recent solar PV bid cap of NPR 5.94. This tariff is too low to motivate sustainable investments. Some solar companies, while participating in recent bids, are understood to be soliciting international donors to seek viability gap funding because of concerns that projects will not be financially viable at the assigned tariffs. One option for this would be to offer solar IPPs the same tariffs as those paid to ROR hydropower: NPR 4.8 in the wet season and NPR 8.4 in the dry season. Synchronizing tariff this way is based on NEA's acceptance of fairness in terms of funds paid for electricity. Solar PV-based electricity could be an important contributor to reliability of supply and diversity of generation sources in the context of Nepal.

  Considering that solar PV-based electricity generation is during the daytime, it is recommended to revise the TOD tariff to incentivize daytime electricity use to reduce the need for storage.

- **Remove Renewable Energy Cap:** Lift or raise the cap on non-hydro renewable-based electricity, currently ceiled at 10%, to unlock the economic potential and encourage investment in technically and financially feasible solar PV projects.

- **Promote Integration of Solar PV in Pumped-Hydro Energy Storage Facilities:** Solar PV-based electricity can be utilized for daytime pumping of water to the upper reservoir in pumped-hydro storage units. Water can be utilized for electricity generation during the peak demand hours in the evening. NEA is also moving towards PROR-based IPPs. Therefore, allowing solar PV integration in these systems would help in balancing electricity generation, and bring about the stability and reliability of electricity supply.

- **Expand IPP Licenses:** Allow current hydro PPA holders to develop solar PV within hydropower project sites to encourage a more balanced and increased electricity generation.

- **Promote Floating Solar on Reservoirs:** Pursue floating solar on suitable hydropower reservoirs can maximize land utilization and energy production.

- **Promote Agrivoltaics and Canal Top Solar:** Promote agrivoltaics, preferably on uncultivated agricultural land, supporting new economic opportunities. Similarly, allowing developers to use canal top for installing solar PV would avoid land use competition and save water losses through evapotranspiration.
- **Develop Mechanisms for Concessionary Financing:** Access to lower-than-market interest, national and international, is critical for the development of utility scale solar PV.
- **Facilitate Cross-Border Trade:** Expanding electricity trade with India and other countries in the region can increase the viability of solar PV in Nepal.
- **Utilize Solar PV for Grid Stabilization:** Utilizing geospatial mapping to identify suitable locations for solar PV installations will address power evacuation capacity issues.

Nepal's strained and rapidly growing electricity system, is heavily dependent on hydropower that is insufficiently available in the dry season. This can be made significantly more robust through well-planned additions of solar power capacities, particularly when matched with storage e.g., daily pondage and seasonal storage afforded by some of Nepal's hydropower plants. Recent and ongoing declines in solar panel prices, together with innovative approaches like agrivoltaics and floating PV that minimize land use impacts, open the door to a clean, sustainable, and robust electricity sector in Nepal. But the sector will only thrive if policies are fair and provide a stable investment climate for the private sector.

1. Introduction and Context

Over the past five years, Nepal has made substantial progress in improving electricity generation, expanding electricity access, reducing supply outages and reducing the consumption of petroleum products for captive back up power generation in industries and the commercial sector. This positive development is mainly the outcome of concerted long-term efforts of the Nepal Electricity Authority (NEA) to expand hydropower generation. NEA succeeded in attracting substantial private sector investment in this sector and has additionally invested in the development of its own hydropower portfolio. At the same time, electricity imports from India have been stepped up to address the remaining shortfalls. These changes have almost eliminated routine load shedding which was all too common previously. Additionally, Nepal was able to progressively raise the level of exporting excess electricity to India during the monsoon season. Data from NEA shows that in the fiscal year (FY) 2022-2023, Nepal's export revenue from electricity increased by about 165% compared to the previous year while imports have increased by only about 25% for the same period[1].

However, challenges remain. Even with increased power generation capacities, the supply of electricity during the dry season is insufficient as Nepal's hydropower plants are of the run-of-river (ROR) type and subject to seasonal variations in the river flows. NEA reports that in FY 2022-2023, an unexpected reduction in river discharge during the dry season led to about 10% decrease in electricity supply[2]. The vulnerability of the ROR hydropower plants to dry-season shortfalls is expected to be exacerbated by climate change which drives the continued retreat of glaciers[3] and which may progressively lead to shorter wet seasons with higher intensity precipitation and longer dry seasons.

Climate change impacts the availability of water and consequently, hydropower generation as confirmed by hydrological studies in Europe and various parts of Asia including Nepal. A study on the Dudh Koshi catchment based on 2012-2014 data shows that 55% of annual stream flow is contributed by ice melting (19% of which is from snow)[4]. The modelling indicates that flows will increase during the monsoon while annual flows will decrease by about 4% on average for 2045-2054, and by 2100, the reduction could be a staggering 26%. There is high confidence that the accelerated changes due to global warming will have a detrimental impact on hydropower generation[5].

As an example, Brazil relies heavily on hydropower; however, climate change is leading to altered rainfall patterns, including prolonged droughts in some regions. This reduces water availability in reservoirs used for hydropower generation, leading to decreased electricity production[6]. Brazil's hydropower generation share slid from 61% of the total electricity generation in 2020 to 53% in 2021[7]. Brazil committed to increase the share of renewables other than hydropower by 23% by 2030

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[1] Nepal Electricity Authority (NEA), 2023. "Nepal Electricity Authority: A year in review – Fiscal Year 2022/2023." (link)
[2] Ibid.
[3] Intergovernmental Panel on Climate Change (IPCC), 2023. "Climate change synthesis report contribution of working groups I, II and III to the sixth assessment report." (link)
[4] Soncini, Andrea, D. Bocchiola, G. Confortola, U. Minora, E. Vuillermoz, F. Salerno, G. Viviano, D. Shrestha, A. Senese, C. Smiraglia, and G. Diolaiuti, 2016. "Future hydrological regimes and glacier cover in the Everest region: The case study of the Upper Dudh Koshi Basin." *Science of the total environment* 565: 1084–1101. (link)
[5] Crootof, Arica, R. Shrestha, T. Albrecht, T. Ptak, and C. Scott, 2021. "Sacrificing the local to support the national: politics, sustainability, and governance in Nepal's hydropower paradox." *Energy Research & Social Science* 80. (link)
[6] Hunt, Julian, D. Stilpen, and M.A. Vasconcelos de Freitas, 2018. "A review of the causes, impacts and solutions for electricity supply crises in Brazil." *Renewable and Sustainable Energy Reviews* 88: 208–22. (link)
[7] Wener, Deborah, and L.L.B. Lazari, 2023. "The policy dimension of energy transition: The Brazilian case in promoting renewable energies (2000-2022)." *Energy Policy* 175. (link)

for energy security and its commitment to the Paris Agreement that demands emission reductions of 43% below the level of 2005 by 2030[8].

Nepal's power sector would likewise benefit from the expanded deployment of complementary renewable energy sources. This study seeks to demonstrate the benefits that larger scale development of PV could bring for Nepal's power sector and the economy and suggests policy measures to strengthen the PV sector. Therefore, this report first describes the status of Nepal's energy context and the power sector specifically. It then discusses current challenges in the power sector, and how these can be alleviated, at least in part, by expanded deployment of solar PV. Next, barriers to increased solar deployment are examined and policy measures are recommended to chart a pragmatic pathway for increasing Nepal's energy security and sustainability. To better inform national policy, there is a pressing need for evidence-based research on the potential of grid-connected solar electricity in Nepal to enhance the security, reliability, and affordability of the country's power supply. This report aims to assist in meeting this need and seeks to foster informed, factual dialogue.

[8] Montoya, Marco Antonio, G. Allegretti, L.A.S. Bertussi, and E. Talamini, 2021. "Renewable and non-renewable in energy-emissions-climate nexus: Brazilian contributions to climate change via international trade." *Journal of cleaner production* 312: 127700. (link)

2. Energy in Nepal

2.1 Energy consumption

In 2022, biomass accounted for more than 64% of total energy consumption in Nepal[9] (Figure 1), a change from 2000 when biomass met more than 70% of the total energy consumption. The reduction in the share of biomass is due to higher import of petroleum products and energy ladder progression for household energy consumption from fuelwood to kerosene to liquid petroleum gas (LPG). Among petroleum products, diesel accounts for the highest consumption, followed by LPG which accounts for about 20%. Coal is primarily used in industries such as brick, steel and cement[10].

Electricity only contributed about 5% to Nepal's energy mix in 2022, equivalent to about 9,358 GWh[11] (Chapter 2.2 below). The low share of grid-based electricity can be attributed in part to the unreliability or inaccessibility of electricity. In many industries, backup generation is used to safeguard operations during power cuts. A report from the Water and Energy Commission Secretariat (WECS) estimates that the petroleum-based captive generation in the industry and commercial sector is in the range of 600 MW, with a capacity utilization of less than 20%[12].

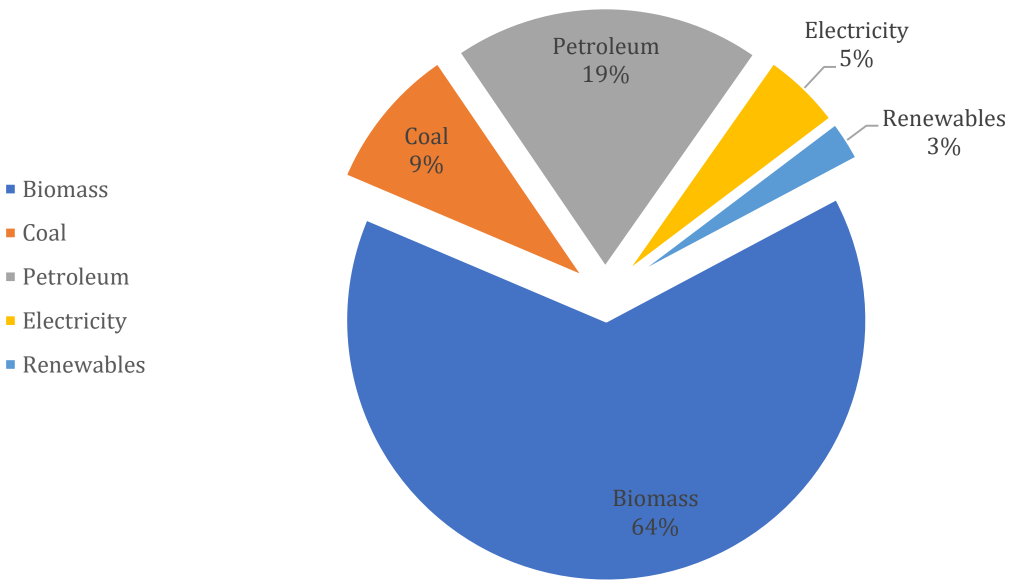

Figure 1: Nepal's energy mix 2022[13]

The share of what WECS terms as "modern renewable energy" sources – micro and pico hydro, solar, wind and biogas – is increasing in Nepal. It rose from under 1% in the early 2000s to 2.5% in 2022. Solar energy contributes about 32% compared to about 65% from biogas.

[9] Water and Energy Commission Secretariat (WECS), 2023. "Energy synopsis report 2023 FY 2078/79." (link)
[10] Energypedia, accessed Nov. 16, 2023. "Nepal – Energy efficiency in industry." (link)
[11] NEA, 2023. "Nepal Electricity Authority: A year in review – Fiscal Year 2022/2023." (link)
[12] WECS, 2013. "Preparation of long-term vision of Nepal's water resources and energy sectors: Nepal's energy sector vision 2050 AD." Nov. 2013. (link)
[13] WECS, 2023. "Energy synopsis report 2023 FY 2078/79." (link)

2.2 Electricity mix

The electricity generation mix in Nepal is dominated by hydropower, comprising 95% of installed capacity (Figure 2). The generating capacity of independent power producers (IPPs) comprises more than half (55%) of the total capacity in Nepal, the vast majority of which is ROR hydropower projects. This is followed by NEA-owned (22%) and NEA subsidiary companies-owned generation (18%) like the Upper Arun Hydro-Electric Limited and the Upper Tamakoshi Hydropower Limited. Solar electricity generation capacity is split between IPPs (62 MW installed capacity) and NEA (25 MW), comprising less than 3% of the total electricity generation capacity in Nepal. As of June 2022, about 2,265 MW of solar PV projects were at different development stages being e.g., "survey license awarded" (about 1,000 MW), "construction license awarded" (125 MW), and "projects under study by the Office of Investment Board Nepal" (550 MW)[14]. In December 2022, NEA invited bids for an additional 100 MW of solar PV-based electricity, with financial bids from six firms representing 90 MW opened in June 2023[15].

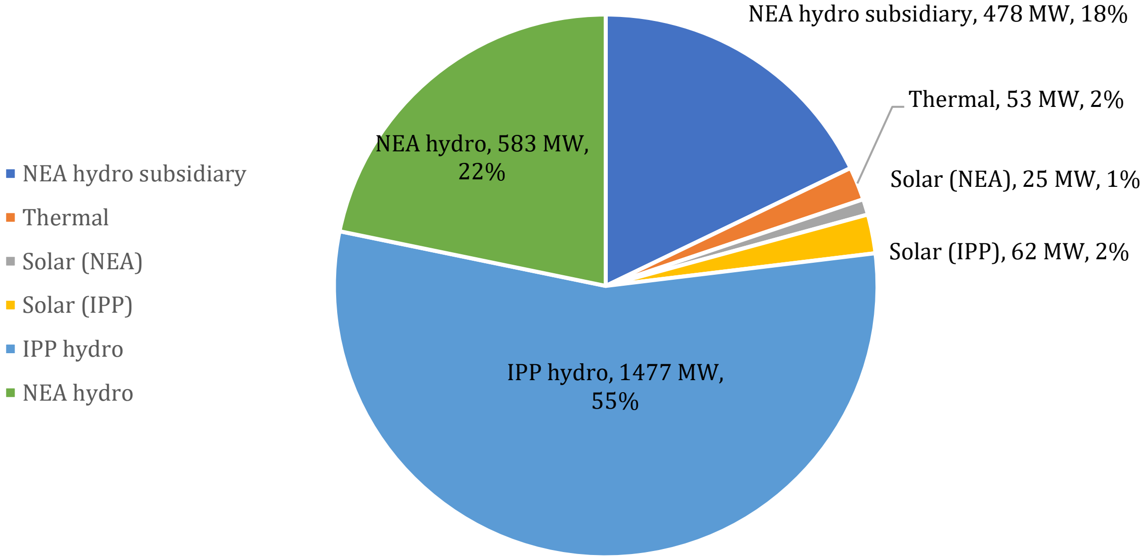

Figure 2: Grid-connected electricity generation mix, 2023[16]

From 2014 to 2023, the share of electricity generated and imported annually more than doubled from 4,687 GWh to 12,369 GWh (Figure 3). More than half of the growth in annual generation was attributed to IPPs, which increased by almost 460%, from 919 GWh in 2014 to 4,199 GWh in 2023. IPP generation as a portion of the total has risen from about 20% in 2014 to over 40% in 2023 (Figure 4). The second largest contributor was NEA subsidiary projects, which rose rapidly from 148 GWh in 2021 to 2,337 GWh in 2023 including the addition of the Upper Tamakoshi Hydropower plant (456 MW). In FY 2022-2023, NEA subsidiaries accounted for over 20% of total generation. Though growing 28% in absolute generation from 2,298 GWh to 2,930 GWh, NEA's contribution to electricity supply has decreased as a percentage of the total from 49% in 2014 to under 24% in 2023. Power purchase from India has been growing slowly, increasing 39% from 1,319 GWh in 2014 to 1,833 GWh in 2023, but with considerable year-to-year variation. Because of the even higher growth of other sources, as a portion of total electric energy, imports from India decreased from 28% in 2014 to 15% in 2023.

[14] Urja Nepal, 2022. "Tariff based competitive procurement of solar power in Nepal for Nepal Electricity Authority." Jun. 2022. (link)
[15] Shrestha, Prithvi Man, 2023. "Six firms to be chosen to supply solar power to grid." *The Kathmandu Post*, Jul. 13, 2023. (link)
[16] NEA, 2023. "Nepal Electricity Authority: A year in review – Fiscal Year 2022/2023." (link)

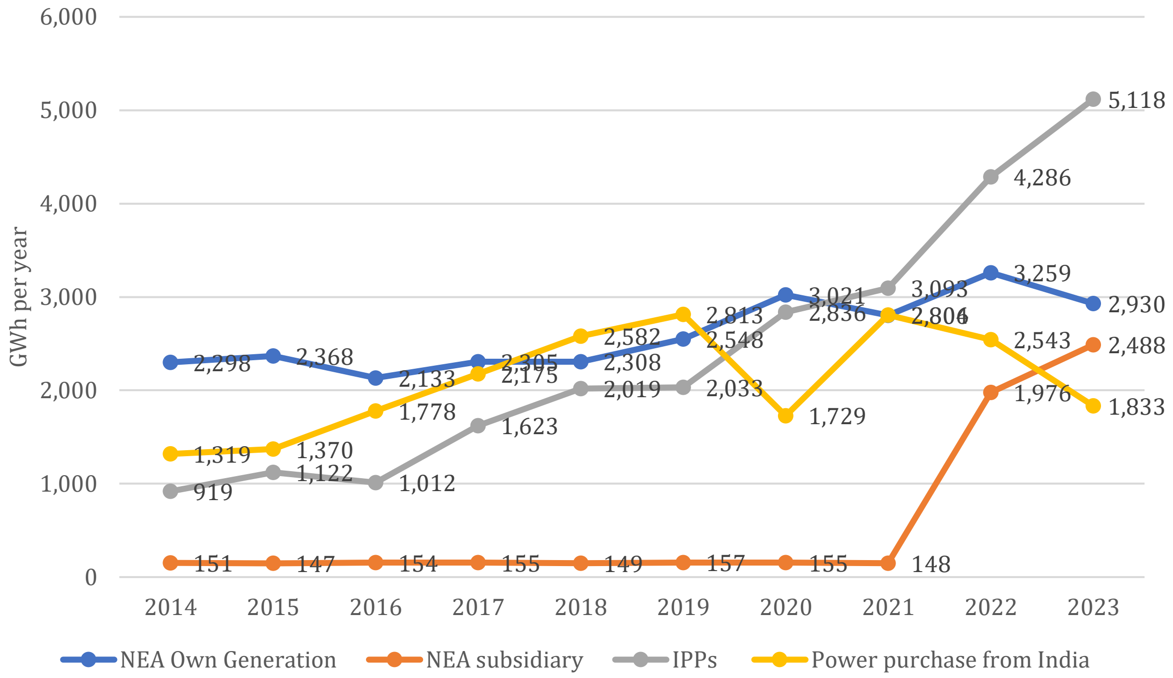

Figure 3: Electricity generation and import from 2014 to 2023 in GWh

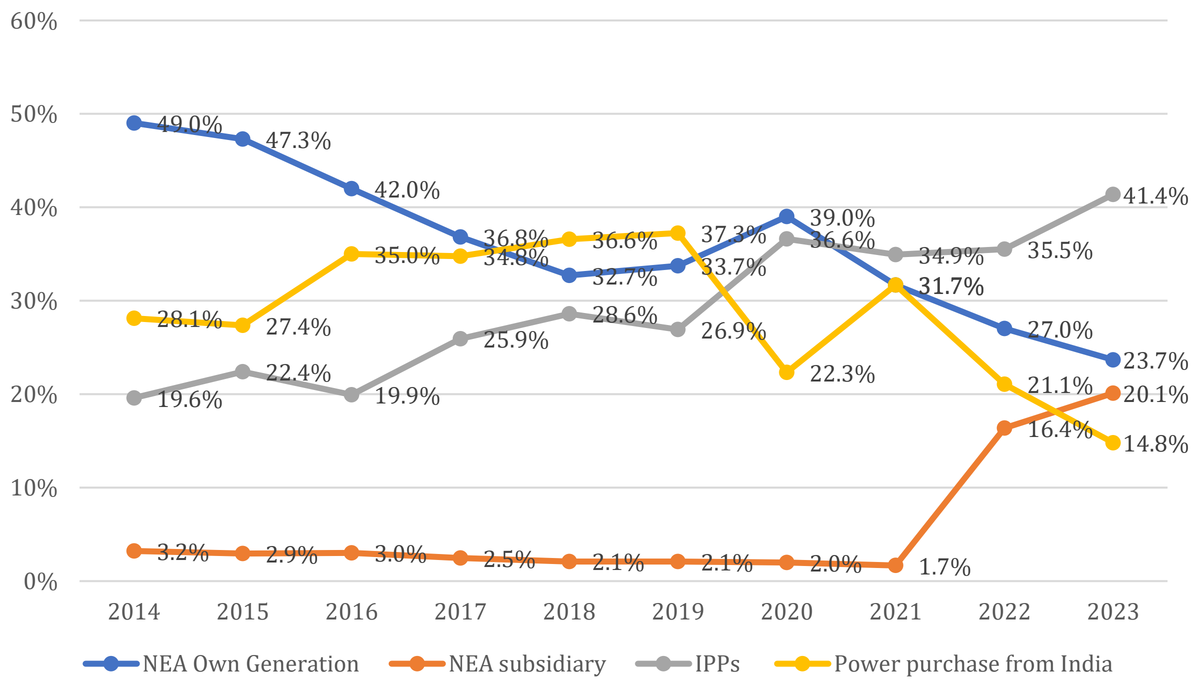

Figure 4: Electricity generation from 2014 to 2023 by source as a percentage of the total

Variation in precipitation drives significant month-by-month variation in supply from different sources – shown in Figure 5 from April 2022 to mid-May 2023. Since hydro IPPs (yellow line) are ROR type and sized to take advantage of monsoon season flows, generation is significantly higher during the monsoon season (June to November), dropping off with the onset of dry season (December to May). The electricity needed to keep the lights on during the dry season is imported from India – which is mostly coal generation.

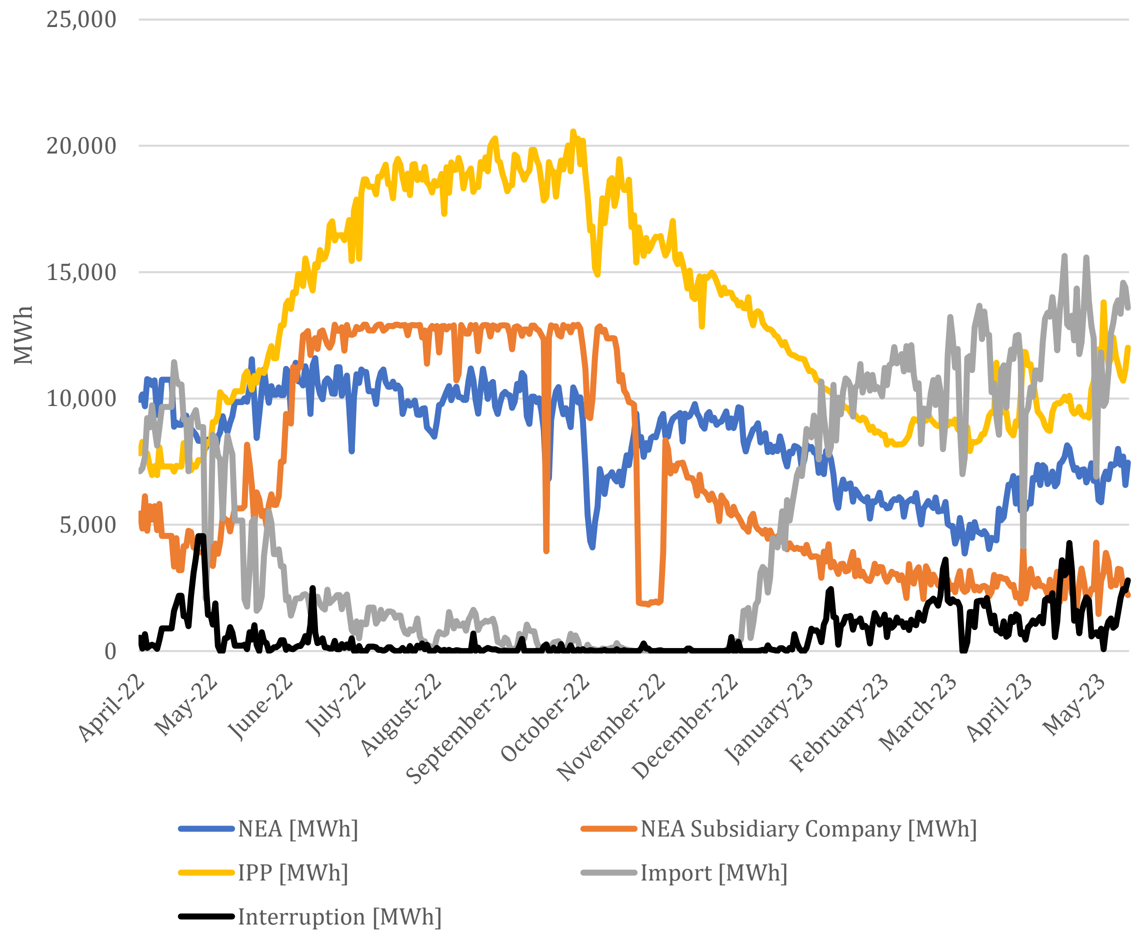

Figure 5: Generation of electricity from different sources between April 2022 and mid-May 2023

The ratio of minimum (a day in dry season) to maximum (a day in wet season) production from hydropower is 0.33 for NEA's plants, and about 0.34 for IPPs. NEA is obligated to purchase the electricity generated by these ROR IPP plants, and reselling to India provides an opportunity to evacuate excess wet season power. NEA subsidiaries have an even lower ratio of 0.12 of minimum to maximum daily output, but this is mainly a consequence of the role of the biggest NEA subsidiary, Upper Tamakoshi (456 MW), as a peaking plant with a reservoir. In this light, the 0.12 ratio should be interpreted not as an issue of dry-season vs. wet-season ability to produce, but rather as a reflection of Tamakoshi's role to ramp down when there is an energy surplus and ramp up, drawing on stored water in its reservoir, when electricity is most needed.

Plant factor, defined as the ratio of the average power load of a plant to its rated capacity, is another metric that indicates how much a plant is utilized. The average factor for NEA's hydropower plants was about 55% in 2022-2023[17] which is comparable to projects in Brazil[18]. However, it varies widely between individual plants in Nepal, ranging from 12% to 90%[19].

[17] NEA, 2023. "Nepal Electricity Authority: A year in review – Fiscal Year 2022/2023." (link)
[18] Prado Jr., Fernando Almeida and S.V. Berg, undated. "Capacity factors of Brazilian hydroelectric power plants: Implications for cost effectiveness." (link)
[19] NEA, 2023. "Nepal Electricity Authority: A year in review – Fiscal Year 2022/2023." (link)

2.3 Electricity demand trends

2.3.1 Year by year demand trends

The Nepal Electricity Authority's (NEA) has adopted a multifaceted approach to reduce load shedding. NEA's strategy includes boosting its own generation capacity, either internally or through its subsidiary companies, establishing power purchase agreements (PPA) with independent power producers (IPPs), and fostering electricity imports from India. These strategies have provided better electricity reliability which, in turn, has helped spur electricity demand together with the expansion of the number of customers served. According to electricity sales data in NEA annual reports, between 2001 and 2022, the average annual growth in electricity consumption was approximately 9.1%. The growth rate increased to 12% annually between 2014 and 2022. In FY 2022-2023, electricity consumption across major energy-consuming sectors rose by approximately 5.5% (reaching 9,358 GWh) compared to the previous year (July 2021 to June 2022)[20]. Because of a 10.1% decrease in NEA's generation during this period due to reduced water flow in dry months, demand was met through a 19.4% increase of generation by NEA's subsidiaries, a 25.9% rise in IPP generation, and a 18.8% increase in electricity imports.

The WECS (2023) study *Electricity demand creation in different sectors* projects electricity demand based on varying economic growth scenarios, ranging from 5% GDP growth (low) to 12% GDP growth (high) between 2025 and 2050[21]. The electricity demand estimated by this newest WECS study exceeds that of a 2020 WECS demand forecast[22]. Forecasts revised upwards suggest that electricity demand has been growing faster than expected previously. The study expects a cumulative annual electricity growth of 8% in the low GDP growth scenario and 12.8% in the high GDP growth scenario until the year 2050 (Table 1)[23]. The demand projection also includes an "Electrification" scenario that includes a target of 25% electrification of residential cooking by 2030 and 100% by 2050, along with a 100% electrification of industrial and commercial sectors.

Table 1: Electricity demand forecast[24]

Year	Demand forecast (GWh)			
	BAU	High	Low	Electrification
2021	7,313			
2025	15,118	15,670	14,501	14,616
2030	25,493	28,654	22,667	28,201
2035	40,994	53,459	32,868	49,122
2040	59,498	88,603	41,787	82,225
2045	86,758	147,007	53,153	133,265
2050	126,218	241,937	67,756	210,773

The 3.6-fold difference in electricity demand between the low (67,756 GWh) and high forecasts (241,937 GWh) by the year 2050 reflects the vast range of development possibilities in Nepal's electricity future. The WECS forecast does not explicitly include a "high GDP + electrification" scenario, but the combination could push electricity demand well above 300,000 GWh per year. A number of circumstances point to the possibility of further growth of demand and a shift from imported fossil

[20] Ibid.
[21] WECS, 2023. "Electricity demand in different sectors." (link)
[22] WECS, 2020. "Electricity demand forecast report 2014-2040." Jan. 2017. (link)
[23] WECS, 2023. "Electricity demand in different sectors." (link)
[24] Ibid.

fuels to domestically produced clean electricity. These include the continued high prices of petroleum products in the wake of wars in Ukraine and the Middle East, unfavourable exchange rates, anticipated economic growth fuelled by the internal economic activities and remittance earnings, switching of cooking from LPG/kerosene to electricity, faster adoption of electric vehicles (see box), and increasing pressure from international agreements to decarbonize the economy at a faster rate.

The rapid rise of Nepal's market for electric vehicles

In FY 2022/23 electric vehicles (EVs) accounted for a whopping 50% of passenger vehicle sales. Growth in the market has been staggering in the last two years. FY 2022/23 saw the import of 4,050 EVs, valued at NPR 11.8 billion, a dramatic increase from the 1,807 units imported in FY 2021/22 and just 200 units in FY 2020/21. This marks an astonishing 124% growth in EV imports in the most recent fiscal year compared to the previous one.

The popularity of EVs, particularly in urban Nepal, is based on the following:

- For FY 2022/23, the government announced a waiver of excise and customs on EVs up to 100 kW capacity. 99.5% of the EVs imported in FY 2022/23 fell under this category.
- Low fuel costs: a typical passenger EV costs NPR 1-4 per driven kilometre, compared to petrol cars typically exceeding NPR 10[25].
- EVs are basically emissions free during operation, thereby not contributing to air pollution.
- Intra-city and short inter-city distances favour EVs, reducing the need for high-range vehicles and alleviating range anxiety.

With the ratification of the Paris Agreement, Nepal committed to the reduction of emissions in the transport sector. Transportation currently accounts for 36% of Nepal's climate emissions. The Nationally Determined Contributions to the Paris Agreement specify that by 2025 at least 20% of public four wheeled vehicles sold should be electric, increasing to 60% by 2030[26, 27]. Nepal has already taken significant steps: Electric Safa Tempos pioneered public transportation starting in the late 1990s with over 600 deployed by the year 2000[28]. Currently, at least 3,500 public mini- and microbuses are being introduced in Nepal through the Mitigation Action Facility[29]. The WECS electricity demand study (Table 1) assumes that the electricity requirement for the transportation sector could increase annually as much as 28% in the scenario with higher electrification growth.

If increased adoption of EVs reduces petroleum imports by 25%, it would reduce imports by about 55 million litres annually, saving more than NPR 10 billion in fuel imports. The savings would be larger if the losses associated with transportation, storage, management, and delivery of diesel and petroleum fuel are included. Large scale adoption of EVs could help mitigate the risks of petroleum blockades and the rising fuel cost. Special time-of-day (TOD) rates incentivizing the charging of EVs during sunny daytime hours, can help making use of solar electricity and reducing the need for system-wide energy storage and balancing.

2.3.2 Seasonal demand trends

Electricity demand in Nepal varies considerably on a day-to-day and month-on-month basis as Figure 6 illustrates[30]. In the period April 2022 to mid-May 2023 the demand peaked at 1,995 MW in August 2022, with a minimum of 1,263 MW in October 2022. Peak demand is higher during the wet season (June-August). However, it is conceivable that the actual dry-season demand may be above the wet

[25] Car Nepal. "Electric cars in Nepal" (link)
[26] United Nations Economic and Social Commission for Asia and the Pacific (UN ESCAP), 2023. "National strategy for electrification of public transport in Nepal." (link)
[27] The World Bank Group, 2019. "Nepal: Energy infrastructure sector assessment." Apr. 2019. (link)
[28] Bhattarai, Atul, 2019. "When Kathmandu was 'Shangri-La for electric vehicles'" *Bloomberg*, Aug. 27, 2019. (link)
[29] Mitigation Action Facility, 2023. "Nepal – Electric transportation approved by Mitigation Action Facility Board for the implementation phase." Sept. 19, 2023. (link)
[30] NEA, 2023. "Monthly operational reports." (link)

season demand if the unmet demand were included as well. This is impossible to assess because of current electricity curtailments.

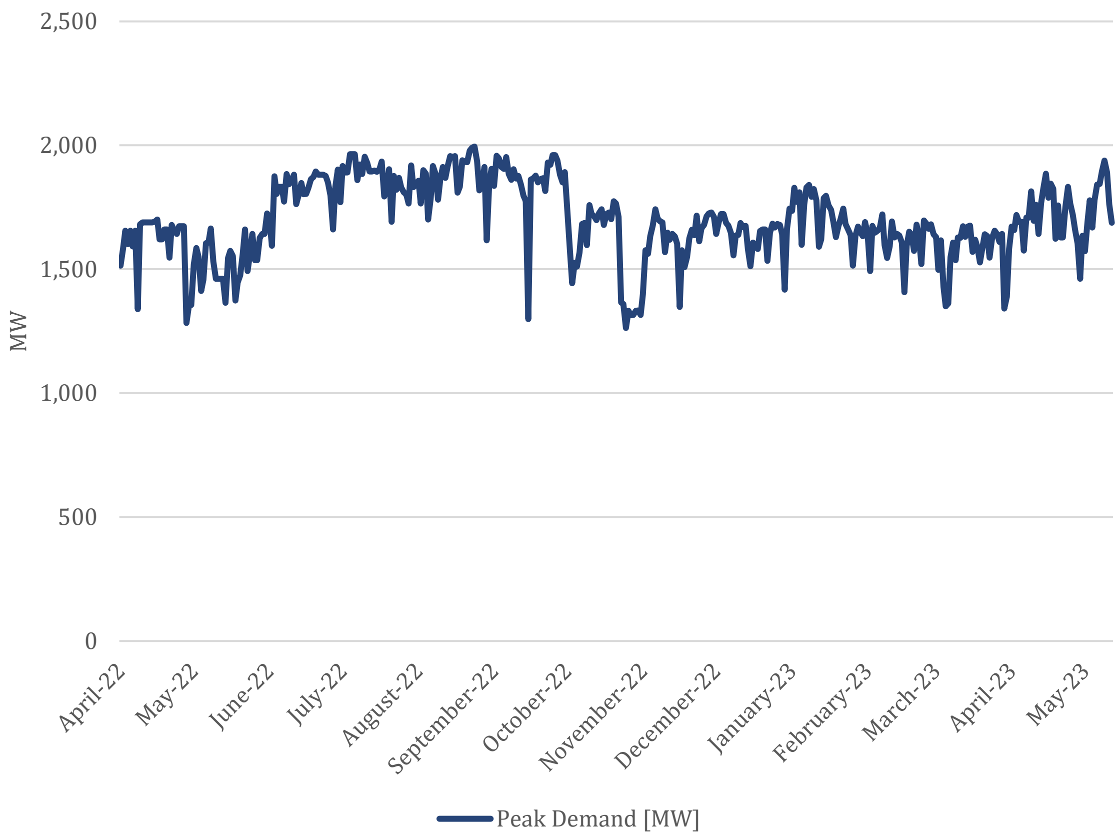

Figure 6: NEA electricity demand profile April 2022 through mid-May 2023

In summary, demand growth for electricity is uncertain but may increase up to 12.4% per annum through 2050 under the WECS high GDP growth scenario while further growth is conceivable in case Nepal pursues a more rapid adoption of electrification in transportation, cooking, and industry.

2.4 Water availability and hydropower generation

Climate change will likely decrease the efficacy of electricity generation from hydropower systems in Nepal and worldwide. Climate change impacts to hydropower include glacier melt, glacial lake outburst floods, earlier snowmelt, extreme and increased precipitation causing increased stream flows, floods, increased variability in flows, increased surface water evaporation from the storage or pondage, decreased precipitation and droughts[31].

Electricity generation from ROR projects is expected to be reduced due to longer, drier dry seasons in which waterflow falls well short of design values. This will not be made up during the shorter, more intense wet season because hydropower generators need to spill more water when the design capacity is exceeded. In NEA's FY 2022/23, the Generation Directorate reports that there has been a decrease in hydropower generation of 2,897 GWh or a decrease of nearly 11% compared to the previous year due to reduced river discharge caused by low precipitation (rain and snow) in the catchment area. The rainfall from December 2022 to February 2023 was only 21.5% of the normal

[31] Wasti, Asphota, P. Ray, S. Wi, C. Folch, M. Ubierna, and P. Karki, 2022. "Climate change and the hydropower sector: A global review." *WIREs Climate Change* 13, Issue 2: e757. (link)

rainfall. If this decrease persists, additional investments for hydropower generation or electricity import will be required to meet the demand.

According to the Intergovernmental Panel on Climate Change (IPCC), the long-term average electricity production from hydropower projects in the world has declined by 4-5% since the 1980s as a result of climate change[32]. A worldwide study of 24,515 hydropower plants (covering about 78% of installed hydropower capacity worldwide) predicts annual mean declines in usable capacity of 1.2% to 3.6%[33]. The same study finds that fuel switching (e.g., augmenting with solar electricity) or increasing the efficiency of hydropower stations could mitigate the reduced hydropower generation.

As water becomes scarcer, competition for water for crop irrigation, drinking, and fishing – already a problem in many countries – will also increase in Nepal, particularly during the dry season when evapotranspiration is high and agricultural demands coincide with high electricity demand[34].

2.5 Electricity trade with India

Though Nepal aims to be a net exporter of electricity to India, as long as Nepal has been engaged in power trade with India the balance is characterized by Nepal purchasing more GWh of electricity from India than it sells to its neighbour, while the purchasing also happens at higher per-unit prices (Figure 7). In FY 2022/23, Nepal spent NPR 19.44 billion to purchase 1,854 GWh, while it received only NPR 9.45 billion for the export of 1,346 GWh. Power exchange tariffs are based on a day-ahead schedule with prices generally higher during the dry season. The average purchase (import) price was NPR 10.48 with peaks as high as NPR 32 per kWh[35]. The average export tariff was NPR 7.02. Import tariffs on average are higher than most NEA retail tariffs which are typically between NPR 6 and 12 for different customer and usage categories[36], meaning that these units are generally resold to customers at a loss.

While Nepal's power imports from India have been relatively stable over the past four years, exports have been rising rapidly (Figure 7). From 2019/20 to 2021/22 exports nearly quintupled from 107 GWh/year to 493 GWh/year, and nearly tripled again from 2021/22 to 1,346 GWh in 2022/23. In 2022/23, though exports were 73% of imports the export revenue were only 49% of import costs because tariffs are lower for the wet season export of electricity.

[32] Almulla, Youssef, K. Zaimi, E. Fejzic, V. Sridharan, L. de Strasser, and F. Gardumi, 2023. "Hydropower and climate change, insights from the integrated water-energy modelling of the Drin Basin." *Energy Strategy Reviews* 48: 101098. (link)

[33] Vliet, Michelle T.H. van, D. Wiberg, S. Leduc, and K. Riahi, 2016. "Power-generation system vulnerability and adaptation to changes in climate and water resources." *Nature Climate Change* 6: 375–80. (link)

[34] Wasti, Asphota, P. Ray, S. Wi, C. Folch, M. Ubierna, and P. Karki, 2022. "Climate change and the hydropower sector: A global review." *WIREs Climate Change* 13, Issue 2: e757. (link)

[35] Shrestha, Prithvi Man, 2022. "High prices of imported electricity could affect power utility's finances." *The Kathmandu Post*, Mar. 16, 2022. (link)

[36] NEA, 2023. "Nepal electricity authority: A year in review – Fiscal Year 2022/2023." (link)

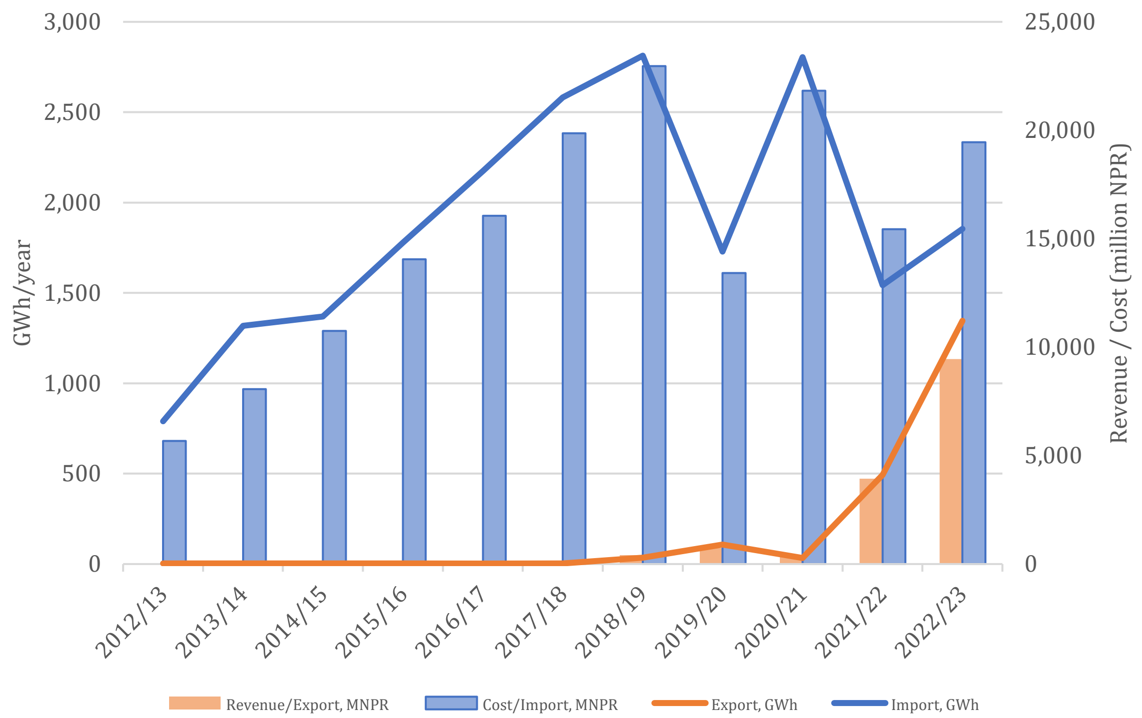

Figure 7: Electricity imports from and exports to India

The seasonal nature of the growth of Nepal's power exports is indicated in Figure 8, with exports largely occurring in the wet season from excess electricity generated by ROR IPPs and peaking in September and October.

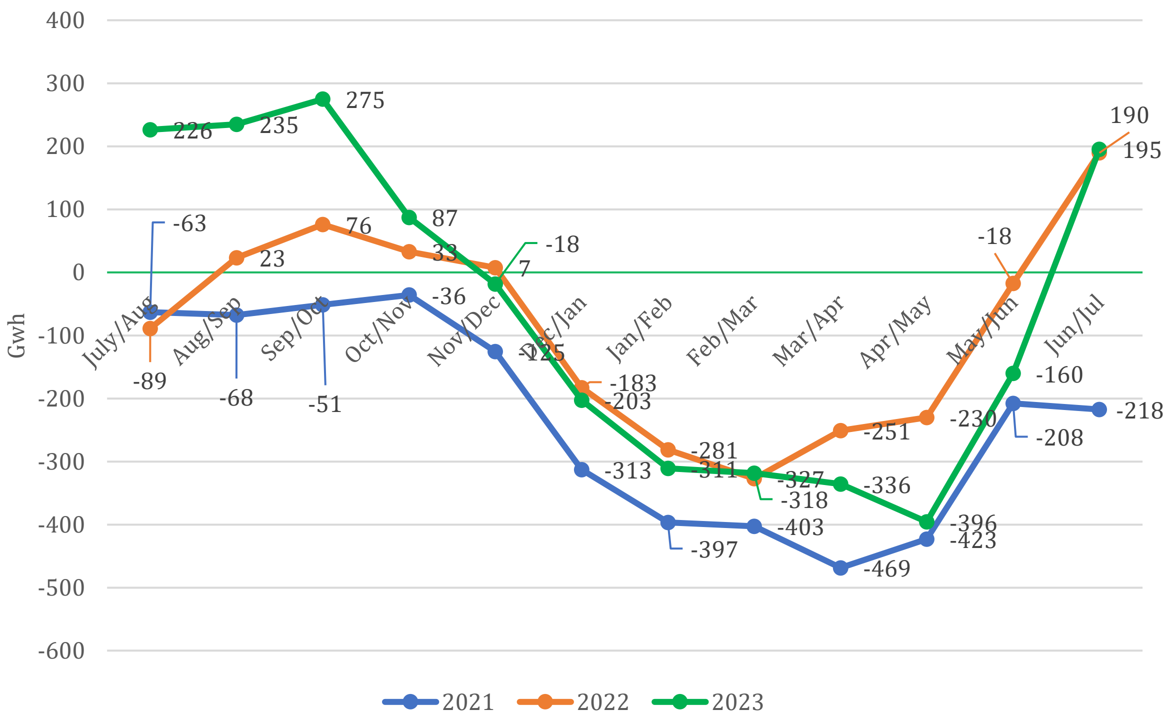

Figure 8: Net monthly electricity imports and exports of electricity from India 2021-23 – Note: Imports are shown as negative numbers, exports as positive

The quantity of electricity that India and Nepal have agreed to trade has risen quickly. As per the December 2022 agreement, NEA could export up to 453 MW of electricity to India[37] which increased to 600 MW in May 2023[38]. On June 1, 2023, prospects for vastly increased power trade were realized when the Prime Ministers of Nepal and India signed a 25-year Power Trade Agreement, with India promising to purchase 10,000 MW of electricity export from Nepal within 10 years as well as permitting Nepal to sell up to 50 MW of electricity to Bangladesh[39, 40]. However, the recent landmark agreement does not automatically result in the ability to export such large quantities of electricity overnight. On the one hand, transmission capacity is limited at present. On the other, Nepal requires approval from the Government of India on a project-by-project basis, and the terms of the *Procedure for approval and facilitating import/export (cross border) of electricity by designed authority*[41] include a provision that excludes projects that involve Chinese contractors, which affects significant projects such as the 456 MW Upper Tamakoshi. According to NEA's FY 2022/23 annual report, agreement had been secured for 10 projects to export about 452 MW to the day-ahead market of the Indian Energy Exchange Limited (IEX) in addition to the 200 MW to India's Haryana state under a medium-term PPA and the 300 MW to Bihar state[42].

Expanded export of Nepal hydropower to India will help lower India's rapidly growing coal consumption[43], which in turn could reduce particulate pollution that hastens the melting of glaciers in Nepal, as well as reduce the need for India to invest in new power plants[44]. For Nepal, expanded trade provides opportunities to de-risk profitable investment in its own hydropower or solar PV development by providing a market for surplus electricity.

It is important to consider that notwithstanding the clear benefits, electricity trade with India also comes with risks. Reliance on electricity imports from India presents an energy security and sustainability risk. Despite plans to increase power generation through ROR projects, Nepal will have energy deficits in the dry seasons. While India has not withheld electricity supplies from Nepal, it has on two occasions restricted the flow of diesel, petrol, and LPG, most recently in the 2015 fuel blockade[45], crippling transportation and creating challenges for households that rely on LPG for cooking. If India curtailed or paused exports of electricity to Nepal, it would cause a return to rotating load shedding with significant implications for Nepal's economy and the quality of life of electricity consumers. Also, it should be noted that import restrictions by India, especially in the wet season, could lead to significant financial consequences for NEA. Development of solar electricity in Nepal – especially in conjunction with storage such as ROR hydropower projects with pondage – will help mitigate this risk by reducing the amount of required dry-season electricity imports from India and the risk of India's import restrictions.

2.6 Pipeline projects vs demand: A dry-season analysis for the years 2023 to 2027

The Managing Director's report in the 2022/23 NEA annual report noted that: "NEA experienced difficult times in the previous FY while interacting with the Indian power market. As the last winter remained much drier than the previous years, there was an unprecedented fall in the domestic hydro generation, pushing NEA onto a higher dependence on power import from India to ensure reliable

[37] The Kathmandu Post, 2022. "Nepal allowed to export another 43.65 MW to India," Dec. 27, 2022. (link)
[38] The Economic Times, 2023. "Nepal starts exporting electricity to India." May 27, 2023. (link)
[39] Bhattacherjee, Kallol, 2023. "India to import 10,000 MW of electricity from Nepal: PM Modi." *The Hindu*, Jun. 1, 2023. (link)
[40] Shrestha, Prithvi Man, 2023. "How Nepal can sell 10,000MW Power." *Kathmandu Post*, Jun. 11, 2023. (link)
[41] Central Electricity Authority, Government of India, 2021. "Procedure for approval and facilitating import/export (Cross border) of electricity by the designed authority." Feb. 2021. (link)
[42] NEA, 2023. "Nepal Electricity Authority: A year in review – Fiscal Year 2022/2023." (link)
[43] Popovich, Nadja. 2023. "How electricity is changing around the world." *The New York Times*, Nov. 20, 2023. (link)
[44] Integrated Research and Action for Development (IRADe), 2017. "South Asia Regional Initiative for Energy Integration (SARI/EI) – Economic benefits from Nepal-India electricity trade." (link)
[45] Prasain, Krishana, 2022. "Electric vehicle imports see-saw as government policy fluctuates." *The Kathmandu Post*, Aug. 8, 2022. (link)

supply to our valued consumers. NEA eventually decided to procure power through bids from the Indian generators and traders ... Despite the certainty of losses due to higher purchase prices, NEA has provided uninterrupted supply to its consumers, affirming its strong commitment to serve the nation"[46].

Solar electricity is a tool that could help prevent this scenario from reoccurring. According to NEA data from FY 2022/23, on 18 April 2023, domestic electricity production generated 19,842 MWh. During the same period, 15,641 MWh were imported from India, but the system still suffered a supply disruption of 3,000 MWh. Taking into account domestic generation, imports, and curtailment, the system's 2,684 MW of installed capacity was able to supply about 51.6% of the required electricity on that dry-season day in which NEA recorded a peak load of 1,788 MW. In other words, the totality of Nepal's 2,684 MW of installed capacity had an effective installed dry season reliable generation of approximately 1,384 MW. Monthly NEA data (Figure 5, page 9) shows that ROR IPPs have an even lower ratio of dry-season power output to an installed capacity of 33.9%.

There is a substantial pipeline of hydropower projects through 2027 (Table 2). The pipeline includes large additions, particularly in the year 2024 and 2025, with 1,716 MW and 2,294 MW of ROR projects coming online and smaller additions of PROR projects. At the same time, electricity demand is expected to grow within the scenarios developed by WECS (Table 1). If the installed capacity of 2,684 MW as of October 2023 is derated to dry-season amounts as discussed in the paragraph above, and the planned additions (all IPPs, 95% of capacity is ROR, 5% PROR) are derated to IPP's dry season record low, then the country should transition from a period of capacity shortfall in 2023 of 611 MW to a shortfall of 359 to 393 MW in 2024, depending on load growth scenario. The country should reach a surplus of between 22 and 90 MW by 2025, before dropping again to deficits that rise to 377 to 749 MW by 2027. Keeping the lights on under these scenarios in all years except 2025 may require electricity imports from India unless the pipeline expands.

Table 2: Expected additions of new hydropower projects assuming 100% build-out pipeline compared to dry-season load

Year	Expected new capacity in MW					Total capacity in MW		Peak demand in MW				Reserve in MW			
	ROR	PROR	Seasonal storage	Total addition	Dry season capacity thereof	Total installed capacity	Dry season effective capacity thereof	WECS BAU scenario	WECS High scenario	WECS low scenario	WECS electrification scenario	BAU scenario	High scenario	Low scenario	Electrification scenario
2023						2,684	1,384	1,995	1,995	1,995	1,995	-611	-611	-611	-611
2024	1,626	40	0	1,716	581	4,400	1,965	2,342	2,358	2,324	2,327	-377	-393	-359	-362
2025	2,154	140	0	2,294	777	6,694	2,742	2,689	2,720	2,652	2,659	53	22	90	83
2026	247	0	0	247	84	6,941	2,826	3,058	3,171	2,951	3,154	-232	-345	-125	-328
2027	94	38	0	140	47	7,081	2,873	3,427	3,622	3,250	3,648	-554	-749	-377	-775

Note: Three large seasonal storage hydropower projects – Dudh Koshi (635 MW, estimated 3,443 GWh annually), Budhi Gandaki (1,200 MW, estimated 3,590 GWh/a) and Nalsingh Gad (417 MW, estimated 1,406 GWh/a) are not included in the table as their development has not started as of October 2023, and are not expected to contribute materially to the power situation by 2027.

[46] NEA, 2023. "Nepal Electricity Authority: A year in review – Fiscal Year 2022/2023." (link)

The scenarios portrayed in Table 2 above assume 100% build-out of hydropower in the pipeline according to schedule. This is optimistic. Most of the hydropower projects developed in Nepal have suffered delays in commissioning[47]. Even the NEA-owned Chameliya (30 MW) project, which was started in 2008 with a three-year commissioning date was delayed to 2018 owning to reasons of delayed construction, payment disputes, and its cascaded effect on electromechanical works. The delay also increased the originally estimated cost of NPR 8 billion to 15 billion[48]. Challenges of underinvestment and weak implementation capacity are also cited as the reasons for delays[49]. There has been instances that NEA has terminated PPAs due to default by the IPPs[50].

The risk of delay in build-out is acknowledged in comments by NEA's Managing Director in 2023 mentioning that Nepal has "... to produce at least 15,000 MW in order to export 10,000 MW to India within the next 10 years as growing domestic consumption and possible export to Bangladesh should also be taken into account ... In order to produce at least 15,000 MW in a decade, we have to start projects for 20,000–25,000 MW right now, as all of them will not be completed on time."[51]

Similarly, the Minister of Energy, Water Resources and Irrigation, mentioned in 2023 that Nepal should "... aim to generate 20,000 MW of hydropower within the next 10 years, which looks realistic considering the amount of generation additions to the national grid every year. We shall continue to explore innovative avenues to minimize greenhouse effects and take encouraging steps for producing green hydrogen fuel, ammonia, chemical fertilizers and oxygen for industrial and medical purposes."[52]

Overall, Nepal has a number of hydropower projects (mostly ROR) projects in the pipeline. Even if all come online, they are insufficient to keep up with dry season load growth. And there is the uncertainty of when, or indeed if, all of them will come online. Solar electricity, when combined with storage facilitated by PROR or seasonal storage projects can reduce the amount of electricity that must be imported from India.

The risk of too little power is that Nepal will be forced to either expand its practice of expensive and price-volatile electricity imports from India or to face load shedding, especially during the dry season, thereby impacting the NEA balance sheet, with payments for electricity and increased cost of sales[53]. The risk of too much domestic power generation is much less thanks to the commitment by India to purchase up to 10,000 MW within 10 years under the long-term Power Trade Agreement. The complementarity of solar with hydropower can benefit from this agreement and can spin additional domestic consumption if assurance of reliable electricity can be provided.

2.7 Current policy

Till date, Nepal's renewable energy policies for electricity generation have mostly focused on small-scale development, diversification of the energy mix, and the funding gap for these projects. In 1992 and 1993, policy development focused on large-scale, grid-connected hydropower in the non-governmental sector and did not consider renewable electricity more broadly due to the high per-unit cost at the time. The Water Resources Act (1992), the Electricity Act (1992), and the Hydropower Development Policy (2001) were not focused on electricity generation *per se,* but on attracting foreign direct investment or domestic private investment in electricity generation through hydropower.

[47] Poudyal, Ramhari, S.K. Khaki, and P. Loskot, 2017. "Understanding energy crisis in Nepal – Assessment of the country's energy demand and supply in 2016." (link)
[48] Subedi, Bibek. "Chameliya hydro project finally comes online." *The Kathmandu Post*, Jan. 13, 2018. (link)
[49] The World Bank Group, 2019. "Nepal: Energy infrastructure sector assessment." Apr. 2019. (link)
[50] NEA, 2020. "A year in review – Fiscal Year 2018/2019." (link)
[51] Shrestha, Prithvi Man, 2023. "How Nepal can sell 10,000MW power." *The Kathmandu Post*, Jun. 11, 2023. (link)
[52] Ibid.
[53] The World Bank Group, 2019. "Nepal: Energy infrastructure sector assessment." (link)

Renewable energy generation, including hydropower, faced a variety of barriers:

- A lack of understanding of the financial investments required;
- A lack of access to electromechanical equipment;
- The need to involve foreign consultants and construction contractors;
- Lack of skilled personnel to manage project maintenance;
- Lack of business management for financial viability; and
- An insufficient policy framework for the governance of IPPs.

Electricity generation through a diverse mix of renewable energy sources is more easily attainable now. The cost of technology, particularly solar PV, has decreased dramatically. Several companies, operating through a subsidy scheme, have been able to install solar home systems. An AEPC project has helped broaden an understanding of the solar electricity potential across the country.

The government has established plans and targets to diversify the energy mix and increase the amount of renewable energy used for electricity generation. Among these, Nepal's Nationally Determined Contributions (NDCs) to the Paris Climate Agreement target net-zero carbon emission by 2045[54] can be considered. A study by the World Bank also provides some estimates on the investment requirements for hydropower development. The study estimates that investments averaging USD 1.3 to 2.1 billion annually are required from 2019 through 2040 to meet Nepal's growing demand and to develop the sector's export potential[55]. Notably, this estimate was developed before the 2023 agreement to export up to 10,000 MW to India.

The 15th National Plan of the National Planning Commission (2019/20-2023/24) aims to increase the share of renewable energy in the total energy mix by 12% by 2023/24 and 20% by 2029/30[56]. The plan calls specifically for 550 MW of solar PV electricity generation from the private sector by 2023/24. If the implementation of the target in the National Plan is realized, Nepal should have 4,000 MW of electricity generated from non-hydro renewables by 2029/30, in which solar would play a major role. Consistent with these levels, as part of the country's UNFCC climate commitments, Nepal's *Long-term strategy for net-zero emissions* targets 2,100 MW of grid-connected solar electricity by 2050 under both its "with existing measures" (WEM) and "with additional measures" (WAM) milestones[57]. While these targets and the plans show that the government consistently sets targets to have solar PV play a bigger role, the effort is not matched by consistent policy and utility practice.

A policy for grid-connected renewable electricity development was issued in 2018 with provisions for net-metering of electricity generated through solar rooftop systems (500 W_P to 10 kW_P), community and corporate systems (10 kW_P up to but not including 1 MW_P), and commercial entities (1 MW_P and larger)[58]. This pivotal policy set a tariff of NPR 7.30 per kWh, preparing the ground for the implementation of net-metering in Nepal. The regulation governing the implementation of the policy, however, limited the system size to a maximum of 500 kW_P and was initially valid for 5 years only until expiry in July 2022. Though it was eventually reinstated in February 2023, the halt caused uncertainty among consumers and potential investors, eroding confidence in the future of net-metering. The decline of confidence was further compounded by the reduction of the compensation to 5.94 NPR/kWh which is in effect as of the time of writing.

The second NDC under the Paris Agreement for the period 2021-2030, states that by 2030, 5-10% of Nepal's electricity generation will come from mini- and micro-hydro power, solar, wind and bio-energy[59]. It is noteworthy that the Ministry of Energy, Water Resources and Irrigation in *Grid-connected alternative energy working procedure* specifies "A power purchase agreement will be made

[54] Government of Nepal, 2021. "Nepal's long-term strategy for net-zero emissions." Oct. 2021. (link)
[55] The World Bank, 2019. "Nepal: energy infrastructure sector assessment" (link)
[56] National Planning Commission, 2020. "The Fifteenth Plan (Fiscal Year 2019/20 – 2023/24)." (link)
[57] Government of Nepal, 2021. "Nepal's long-term strategy for net-zero emissions." (link)
[58] Ministry of Energy, Water Resources and Irrigation (MoEWRI), 2017. "Grid-connected alternative energy working procedure 2074" (in Nepali, link)
[59] Government of Nepal, 2020. "Second Nationally Determined Contribution (NDC)" (link)

to connect alternative power up to 15% of the total connected capacity of the system (translated from (२) प्रणालीको कूल जडित क्षमताको १५% सम्म वैकल्पिक विद्युत जडान गर्न विद्युत खरिद सम्झौता गरिनेछ।)[60]. In interviews with private renewable energy developers, they expressed concern that the 10% from Nepal's second NDC is being interpreted as a cap on non-hydro renewable capacity which needlessly prevents the unlocking of the vast solar potential. Developers call for the country to expand the percentage of non-hydro renewable capacity to 20%, or even higher, or better still, to remove the defined cap.

Examples from other countries show success in much higher variable renewable energy penetration. For example, for a 24-hour period in 2017, Denmark generated more than 100% of its electricity requirements from wind[61]. In June 2022, California, USA met 103% of the state's electricity needs with renewables for a few hours[62]. However, the NEA and government officials express concern that levels of intermittent renewable energy above 10% could adversely affect the voltage and frequency stability. NEA simultaneously recognizes the importance of PV in helping raise and stabilize utility voltage. NEA set up bidding criteria for its 100 MW solar PV bid program in December 2022 for selected substations that have chronic low voltage issues knowing that PV at those substations would help support voltage stability.

[60] MoEWRI, 2017. "Grid-Connected Alternative Energy Working Procedure 2074" (in Nepali, link)
[61] Caughill, Patrick, 2017. "Denmark just ran their entire country on 100% wind energy." *Futurism*, Mar. 9, 2017. (link)
[62] Raskin, Evan, 2022. "California breaks record by achieving 100% renewable energy for the first time." *Earth Day*, Jun. 10, 2022. (link)

3. Opportunities for Non-Hydro Renewables

3.1 Electricity mix for energy security and long-term sustainability

Long-term sustainability in electricity supply deserves to be considered a priority in future government policies. Policy decisions should focus on three primary goals: the reduction of fossil fuel dependence and attendant emissions, increasing resilience of the electricity system, and enlarging the use of domestically available renewable energy sources in Nepal.

Nepal has not yet reached energy security. Nepal's current energy system is highly dependent on fossil fuels, especially in the heating and transport sector, and hence, highly dependent on energy imports. However, since energy use is shifting towards electricity due to efficiency reasons, the focus should be on electricity generation. But even the electricity supply in Nepal is not always reliable yet. Similar to other hydropower-dependent countries (e.g., Brazil, Bhutan, Norway, Kyrgyzstan, Tajikistan), there is a surplus of energy in the wet season and a deficit in the dry season. To become energy secure, in-country electricity generation must grow drastically. At the same time, the heavy dependence on hydropower must be reduced through a diversification of the electricity mix with complementary sustainable energy sources. Considering climate change and the need to end fossil fuel consumption, the only viable option to diversify the electricity mix is to ramp up generation from different renewable energy sources. Nepal can take inspiration from other countries that are already trying to follow that path:

- **India's** electricity generation capacities are 211 GW from coal and lignite, 24 GW from gas, and about 0.6 GW from diesel as of May 2023. Renewable energy sources, including solar, wind, and other renewable sources, comprise 132 GW[63]. India started diversifying the electricity mix to reduce fossil fuel emissions[64] and the social and economic costs of using diesel and coal[65]. Although new investments are still being made in fossil fuel-based energy, the emphasis has shifted to renewables: in FY 2021/22, the growth of coal-based power was only 0.06%, whereas that for non-hydro renewable sources was 16.4%[66]. With electricity from renewables, the country expects to reduce the current level of contribution from thermal power (coal, lignite, gas, and diesel) from 63% of installed capacity (share in the annual electricity mix is about 78%) to 36% (electricity mix: 54%) until 2030. At the same time, installed renewable energy capacities are planned to rise from about 23% (electricity mix: 9.2%) to about 53% (electricity mix: 31%)[67]. The report mentions that the total of solar installation in 2030 is estimated to be 35% (or 280 GW), contributing up to 19% (or 484,200 GWh, compared to 73,483 GWh in 2020/21) of total electricity generation.
- **Germany** introduced an *Electricity Feed-in Act* in 1991, followed by the *Renewable Energy Sources Act* in 2001, which specifies feed-in tariffs for different renewable energy sources and contains detailed regulations and procedures. The act stimulated the installation of

[63] Gupta, Uma, 2023. "India's installed solar power capacity expected to hit 104 GW by March 2025" *PV Magazine India*, Dec. 7, 2023. (link)
[64] IAS Parliament, accessed Sep. 10, 2022. "India's updated NDC." (link)
[65] Chakravarty, Shoibal, and E. Somanathan, 2021. "There is no economic case for new coal plants in India." *World Development Perspectives* 24: 100373. (link)
[66] Ministry of Statistics and Programme Implementation, Government of India, 2023. "Energy statistics 2023: Chapter 2 - Installed capacity and capacity utilization." (link)
[67] Central Electricity Authority, Government of India, 2020. "Report on optimal generation capacity mix for 2029-30." (link)

renewable energy systems leading to almost 70 GW of wind and 80 GW of solar capacities as of December 2023[68]. This growth in renewable energy capacities was made possible in particular by offering long-term planning security for developers and operators. As a result, renewable electricity is now covering almost 20% of the country's energy mix and over 50%[69] of the electricity mix. This has increased supply availability and security by reducing dependence on energy imports, diversifying energy sources, and decentralizing production as well as mitigating climate risk[70].

- In **Indonesia**, coal is the major contributor to the electricity mix. However, the country has started focusing on renewables – solar, wind, geothermal, hydropower, and biomass/biogas – to diversify the energy mix and reduce the emissions regardless of the greater variability these sources imply. The government plans to replace about 1,800 MW of coal-based electricity generation with renewable energy sources and has installed about 225 MW of renewable energy capacities by 2022[71]. Indonesia aims to increase the percentage of renewables in its energy mix to 23% by 2025[72], retire 8 GW of coal power plants by 2030, build no new coal power investments after 2030, and phase out coal-based electricity generation entirely by 2056[73]. That means diversification of the electricity mix with a focus on renewables is being actively pursued.

In Nepal, while hydropower must and will remain the backbone of electricity generation, the dry season limitations suggest that non-hydropower renewable energy will be beneficial and increasingly essential. Decreasing the dependence on hydropower also becomes necessary considering the risk of climate-change related impacts on the water cycle that reduce dry season flows, extended periods of drought, and risk flood damage during the rainy season. If the development and operation and management costs of non-hydro renewable energy sources are attractive, a diversification of the power generation portfolio can contribute to an affordable and secure energy supply in Nepal. In the following, the potentials of solar PV, wind power, and biomass are discussed as possible candidates to complement hydropower.

3.2 Solar electricity

Globally, due to technological advances coupled with large-scale deployment, solar electricity is among the most affordable sources of electricity. The cost of the technology has declined steeply over the past decades and will continue to decrease as expanded production drives industry efficiencies and manufacturing learning curves[74]. The cost per watt of solar panels declined by more than 99%, from USD 106 to 0.36, from 1976 to 2019. By the end of 2023, the price was projected to be around USD 0.12[75]. The manufacturing of solar PV, like most mass-manufactured items, followed a curve characterized by predictable reductions in cost with expanded production. In the case of solar panels, every doubling in cumulative production has brought about a decline in the cost per watt of about 20% (Figure 9)[76].

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[68] Bundesnetzagentur, Government of Germany, accessed Feb. 16, 2024. "Statistics of selected energy sources" (in German, link)
[69] Energy Charts, accessed Feb. 16, 2024. "Electricity generation in Germany in 2023." (link)
[70] Stiftung Wissenschaft und Politik, 2012. "Energy security in a sustainable world: An outlook from GIBSA countries." (link)
[71] International Trade Administration, U.S. Department of Commerce, accessed Feb. 16, 2024. "Indonesia energy – Country commercial guides." (link)
[72] Simanjuntak, Uliyasi, 2013. "Indonesia needs to overhaul strategy to pursue 23% renewable energy mix in 2025." (link)
[73] Indonesia Economic Prospects, 2021. "Energy transition in Indonesia." (link)
[74] International Renewable Energy Agency (IRENA), 2019. "Future of photovoltaic: Deployment, investment, technology, grid integration and socio-economic aspects – Executive summary." (link)
[75] Chase, Jenny, 2023. "Global PV market outlook, 4Q 2023." *BloombergNEF*, Nov. 29, 2023. (link)
[76] Roser, Max, 2023. "Learning curves: What does it mean for technology to follow Wright's law?" *Our World in Data*, Apr. 18, 2023. (link)

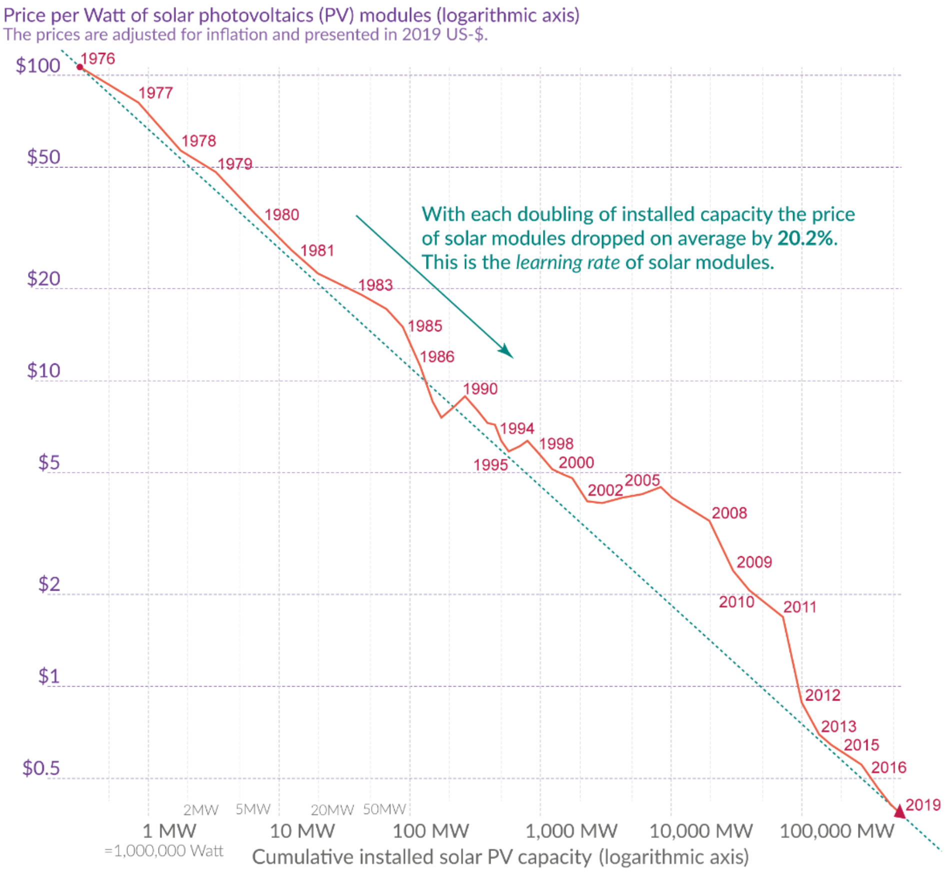

Figure 9: Relation between the technology cost and the cumulative capacity installed[77]

Nepal is in the initial stage of developing its solar industry, so costs are somewhat higher in Nepal. But just as global costs for solar decrease through learning curves, the country-level deployment also benefits from industry learning. Nepal's deployment costs will decrease substantially as developers learn country-specific methods to trim costs.

A study by IRENA compared the global renewable energy costs in 2010 and 2022 and their results are shown in Table 3[78]. The study shows that installation costs and levelized cost of energy (LCOE) for solar PV has the highest rate of decrease with a drop in LCOE per kWh from USD 0.445 in 2010 to **USD 0.049 in 2022** – down by 89%, while the LCOE per kWh of hydropower rose 47% over the same period, increasing from USD 0.042 to USD 0.061 due to rising construction costs. Crucially, the data shows that the LCOE for solar PV has fallen below that of hydropower.

[77] Ibid.
[78] International Renewable Energy Agency (IRENA), 2023. "Renewable power generation costs in 2022." (link, link)

Table 3: Global comparison of average installation costs and LCOE[78]

	Total installed costs (2022 USD/kW)			Capacity factor (%)			Levelised cost of electricity (2022 USD/kWh)		
	2010	2022	Percent change	2010	2022	Percent change	2010	2022	Percent change
Bioenergy	2 904	2 162	-26%	72	72	1%	0.082	0.061	-25%
Geothermal	2 904	3 478	20%	87	85	-2%	0.053	0.056	6%
Hydropower	1 407	2 881	105%	44	46	4%	0.042	0.061	47%
Solar PV	5 124	876	-83%	14	17	23%	0.445	0.049	-89%
CSP	10 082	4 274	-58%	30	36	19%	0.380	0.118	-69%
Onshore wind	2 179	1 274	-42%	27	37	35%	0.107	0.033	-69%
Offshore wind	5 217	3 461	-34%	38	42	10%	0.197	0.081	-59%

Another respected resource, the Lazard report which is updated regularly, pegs the LCOE of utility scale solar PV at **0.024-0.096 USD/kWh** in 2023 (24-96 USD per MWh) which includes the cost of capital, e.g. expected equity returns and debt interest (see Figure 10). For community-scale PV and commercial and industrial-scale solar rooftops, the report pegs the costs at 0.049 to 0.185 USD/kWh (49 to 185 USD/MWh). Solar plus battery storage at utility scale is 0.046 to 0.102 USD/kWh (46 to 102 USD/MWh), which is comparable to the LCOE of combined cycle gas turbine (CCGT) power plants (39 to 101 USD/MWh) and of coal power plants (68 to 166 USD/MWh)[79]. Newly built utility-scale solar projects (without storage) are cheaper than the *marginal cost* of operating fully depreciated gas, nuclear, coal, and CCGT. It should be noted that the LCOE cost analysis in Figure 10 is based on 60% debt (@8% interest) and 40% equity (@12% cost). Like hydropower, though solar has zero fuel cost, it is capital intensive, and the cost of capital has a huge bearing on how financially attractive this energy source is.

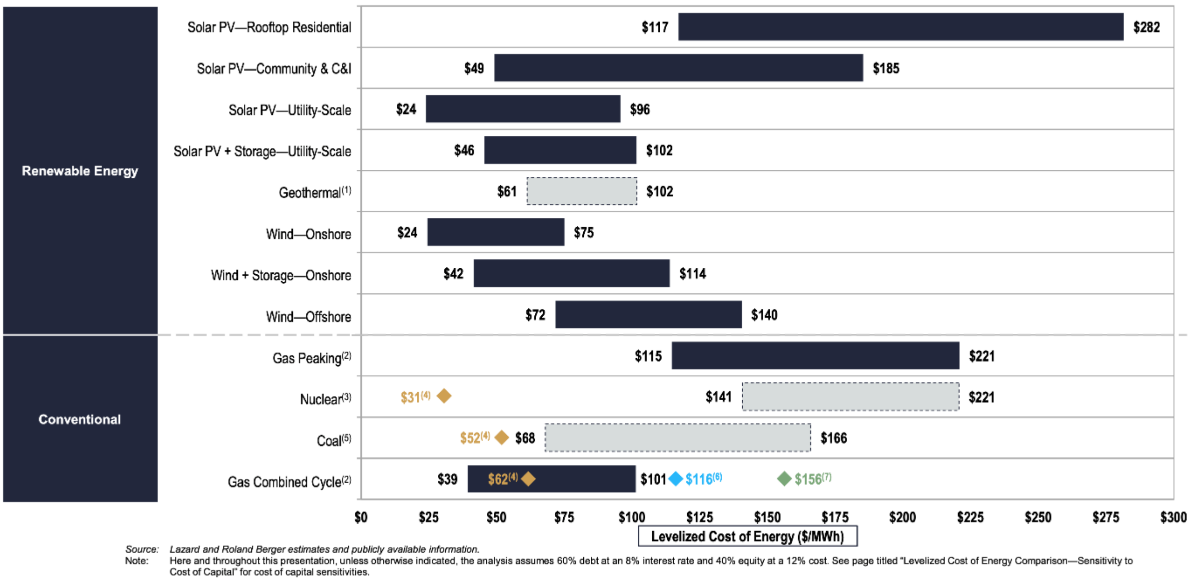

Figure 10: The levelized cost of energy (solar PV and conventional generation) in USD per MWh[80]

[79] Bilicic, George, and S. Scroggins, 2023. "2023 levelized cost of energy+." *Lazard*, Apr. 12, 2023. [(link)]
[80] Ibid

Solar irradiation in Nepal is fair to high, particularly in the north and west. Data shows that a 1 kW_P installed solar capacity generates between 1.85 MWh annually in Jomsom, 1.53 MWh in Kathmandu, and 1.45 MWh in Nepalgunj[81]. At 432 GW, the technical potential for solar PV is about 10 times larger than Nepal's technical hydroelectric potential of 42 GW[82].

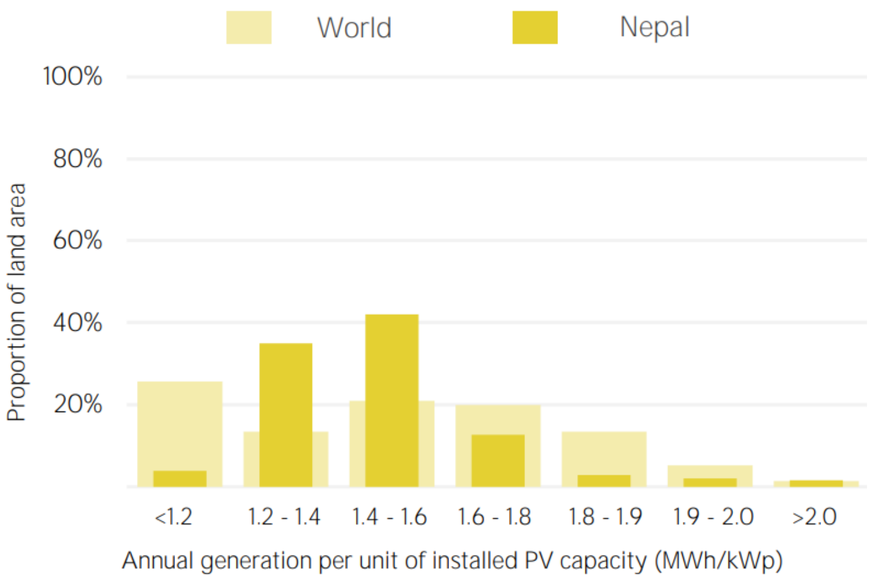

Figure 11: Comparison of Nepal's solar potential for its land mass[83]

The use of solar energy in Nepal started in the eighties, when the Government of France assisted with the construction of mini-grid PV plants in three remote locations (Tatopani/Kodari, Simikot, and Gamghadi). The total installed capacity was 130 kW. In the past, PV in Nepal was primarily seen as an option to electrify remote regions without access to the national electricity grid with solar or hybrid mini-grid systems. Other traditional use cases are solar home systems and PV charged backup systems. Installing larger grid-connected PV system is a recent development. At the moment, Nepal has 62 MW of IPP solar PV installation and 25 MW operated by NEA; an additional 29 MW of solar PV capacity is under construction.

The maps in Figure 12 compare the solar electricity potential of Nepal and Germany[84]. In 2022, about 10% of Germany's electricity was supplied by solar[85]. Germany's installed PV capacity stands above 80 GW_P at the end of 2023[86]. The installed PV capacity in Nepal is less than 100 MW despite having vastly superior solar power potential. The cost of solar PV technology in the 1990s, when Germany adopted its first feed-in tariff for PV, was about 14,000 EUR per kW_P – now it is only about 7% of that cost or less than 1,000 EUR per kW_P.

[81] The World Bank, 2017. "Solar resource and photovoltaic power potential of Nepal." Mar. 2017. (link)
[82] Teske, Sven, S. Niklas, and S. Miyake. 2023. "Technical scenario for 100% renewable energy in Nepal by 2050: Possible transition pathways for NDC & LTS implementation." Institute for Sustainable Futures. (link)
[83] International Renewable Energy Agency (IRENA), 2023. "Energy profile Nepal." (link)
[84] Solargis, accessed Nov. 16, 2023. *Global Solar Atlas* online application website. (link, link, link)
[85] Fraunhofer Institute for Solar Energy Systems (ISE), 2023. "Photovoltaics report." (link)
[86] Energy charts, accessed Feb. 16, 2024. (link)

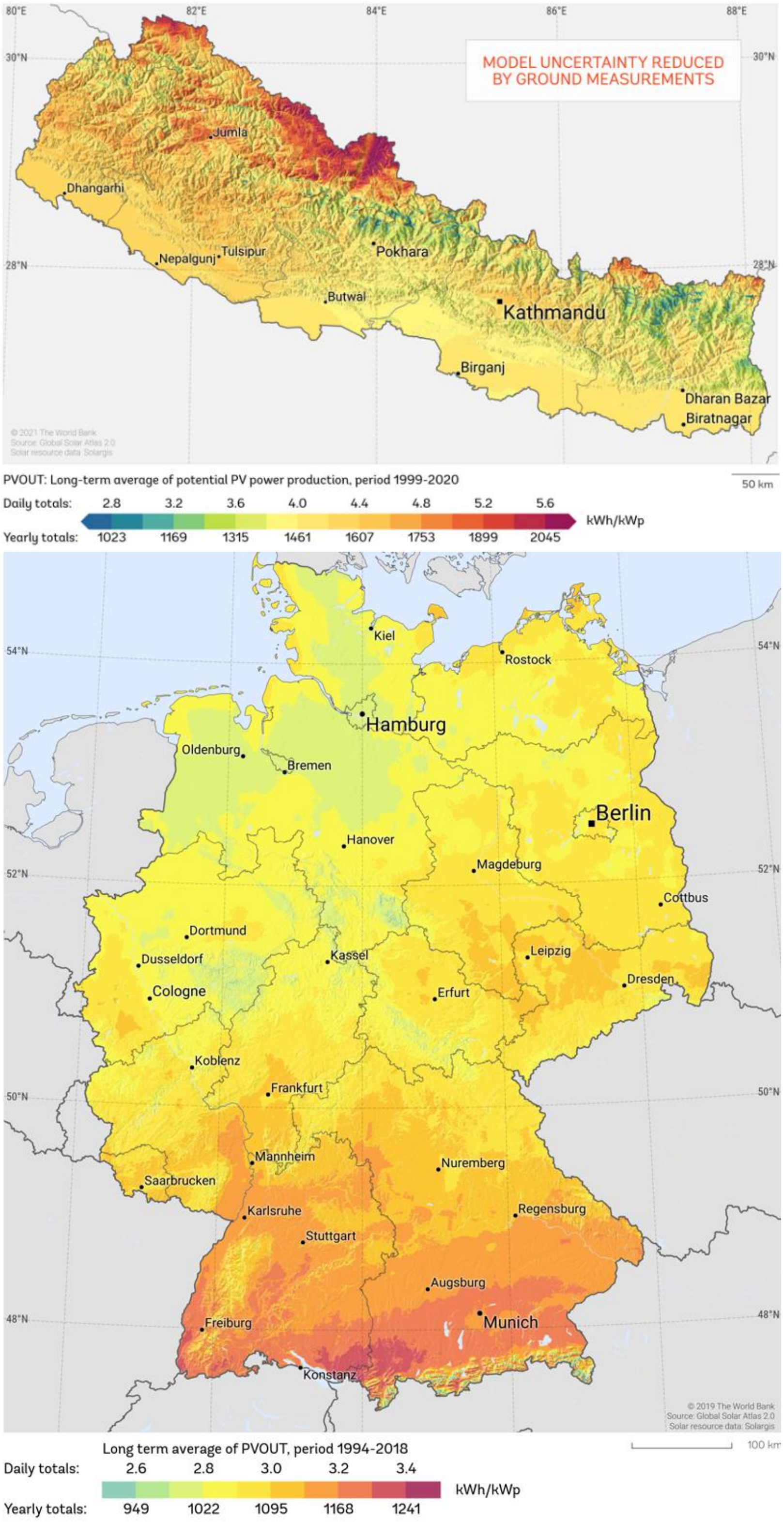

Figure 12: Comparison of annual solar power potential of Nepal and Germany[87]

[87] Solargis, accessed Nov. 16, 2023. *Global Solar Atlas* online application website. (link, link, link)

3.3 Wind

Globally, wind technology cost, both in terms of installation and levelized cost of energy (LCOE), has decreased significantly over the past 11 years. The cost per kW of installation has decreased from 2,179 USD to about 1,274 USD, and the LCOE per kWh decreased from about 0.107 USD to about 0.033 USD[88].

No comprehensive study on wind electricity potential has been carried out in Nepal but insights can be drawn from the Global Wind Atlas. It shows an average wind speed of about 7.4 meters per second and wind power density of 521 W/m^2 at a height of 100 metres from ground level in the top decile, that is the 10% of land area with the greatest wind resource in the country[89]. WECS cites a wind power potential of 3 GW in Nepal[90]. However, a recent study that examines the options for 100% renewable energy for Nepal[91] cites a potential of only about 250 MW.

The map at Figure 13 shows that the potential for large scale wind electricity is minimal in the south while there is potential in the mountainous north. However, areas with the best wind potential present severe challenges for the construction and maintenance of wind turbines and transmission lines thereby limiting the prospects of wind energy. To harness the potential, larger wind turbines would be needed, and they should be installed in the northern side of the country, where the road infrastructure is non-existent to carry huge turbine blades. At potential wind electricity generation sites, the collection of site data prior to the installation would also be required. Considering the low cost of solar and hydropower in Nepal and the challenges associated with installing wind power at scale in mountainous terrain, this energy source is unlikely to play a large role in the electricity mix.

Consequently, there is little or no research and development for wind technology in Nepal though the country has experimented with a couple of pilot projects. Nepal's first attempt to harness wind with two 10 kW turbines in 1989[92] failed when the turbines were swept away three months after installation[93].

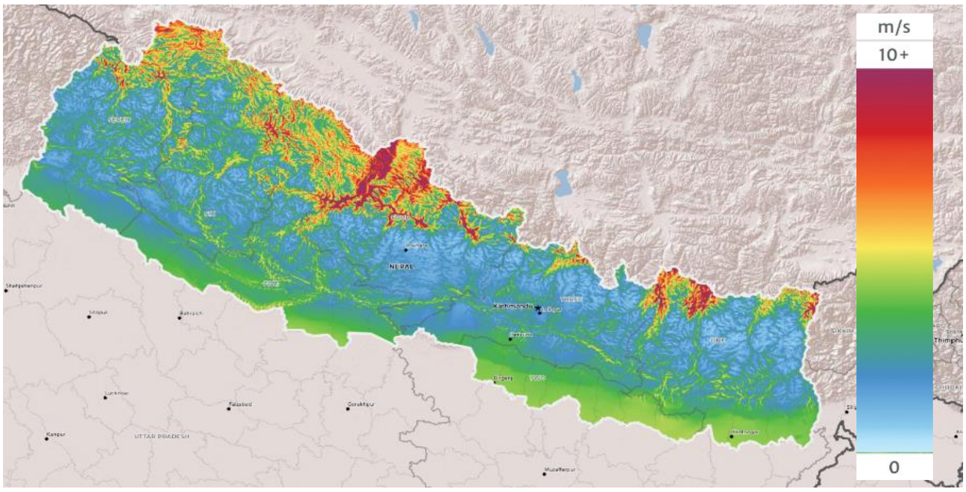

Figure 13: Mean wind speed at 100 metres in Nepal[94]

[88] International Renewable Energy Agency (IRENA), 2023. "Renewable power generation costs in 2022." (link)
[89] Global Wind Atlas, accessed Nov. 16, 2023. (link)
[90] WECS, 2023. "Energy synopsis report 2023 FY 2078/79." (link)
[91] Teske, Sven, S. Niklas, and S. Miyake. 2023. "Technical scenario for 100% renewable energy in Nepal by 2050: Possible transition pathways for NDC & LTS implementation." Institute for Sustainable Futures. (link)
[92] The Himalayan Times, 2008. "Nepal should harness wind power." Jan. 10, 2008. (link)
[93] Mahato, Rubeena, 2010. "Riding the wind". "*Nepali Times*, Issue 532, Dec. 17–23, 2010. (link)
[94] Global Wind Atlas, accessed Nov. 16, 2023. (link)

3.4 Biomass

Biomass is primarily used for heating purposes in Nepal – mainly cooking and heating – rather than for electricity generation. Nepal uses about 378,000 TJ of fuelwood energy, 19,000 TJ of agricultural residue energy, and 18,000 TJ of dried animal waste energy for cooking and heating annually. This is almost two thirds of Nepal's total energy consumption (refer also Figure 1 in Chapter 2.1). Animal manure is also used in biogas digesters to obtain gas for cooking stoves. Due to livestock husbandry as one of the major activities in rural areas, it is estimated that up to 250,000 biogas digesters have been installed for households. However, only 60% of them are estimated to be operational. While being commercially used e.g., in India[95] and Thailand[96], the use of biogas digesters for electricity generation in Nepal has always been limited to experimental scales.

One source of biomass, however, should be considered for electricity generation in Nepal: the utilization of bagasse in sugar mills which has good potential to generate captive electricity. About 35% by weight of sugarcane is usable for fuel, and about 5 tons of crushed bagasse is required to produce one MWh of electricity. Indu Shankar and Everest Sugar Mills have 3 MW of captive generation capacity each in operation. In addition to generating electricity to power the sugar mills, surplus electricity is supplied to the grid, based on PPAs with NEA[97, 98]. This approach could be extended to all 12 sugar mills of Nepal which, taken together, have an electricity generation potential of 100 MW[99].

[95] Ministry of New and Renewable Energy, Government of India. "Biogas application portal." (link)
[96] Tonrangklang, Pennapa, A. Therdyothin, and I. Preechawuttipong, 2017. "Overview of biogas production potential from industry sector to produce compressed bio-methane gas in Thailand." *Energy Precidia* 138: 919-924 (link)
[97] NEA, 2023. "A year in review - Fiscal Year 2022/2023." (link)
[98] KTM2DAY.com, 2018. "Nepal electricity signs PPA with sugar mills." *Kathmandu Today,* Sep. 30, 2018 (link)
[99] Pokhrel, Sajjan, S. Bhattarai, S. Rajbamshi, and Y. Bhusal, 2014. "Prospects of bagasse cogeneration in sugar industries of Nepal." *Rentech Symposium Compendium* 4. (link)

4. Solar Electricity in the Nepal Context

The attributes of solar electricity, including its low cost, seasonal complementarity with hydropower, and opportunity for coupling with storage, encourage an expanded discussion for Nepal's unique context.

One of the benefits of solar electricity in Nepal is its seasonal complementarity with Nepal's hydropower. Solar irradiation in Nepal is highest between October and May (Figure 14), while Nepal's monsoon-driven hydropower season extends from June through November. A direct consequence of this, as mentioned before in this report, is the surplus of hydropower-based energy generation in the monsoon seasons and the energy deficit in the dry seasons. Electricity from PV would therefore be ideal to bridge the hydropower production gaps during dry seasons.

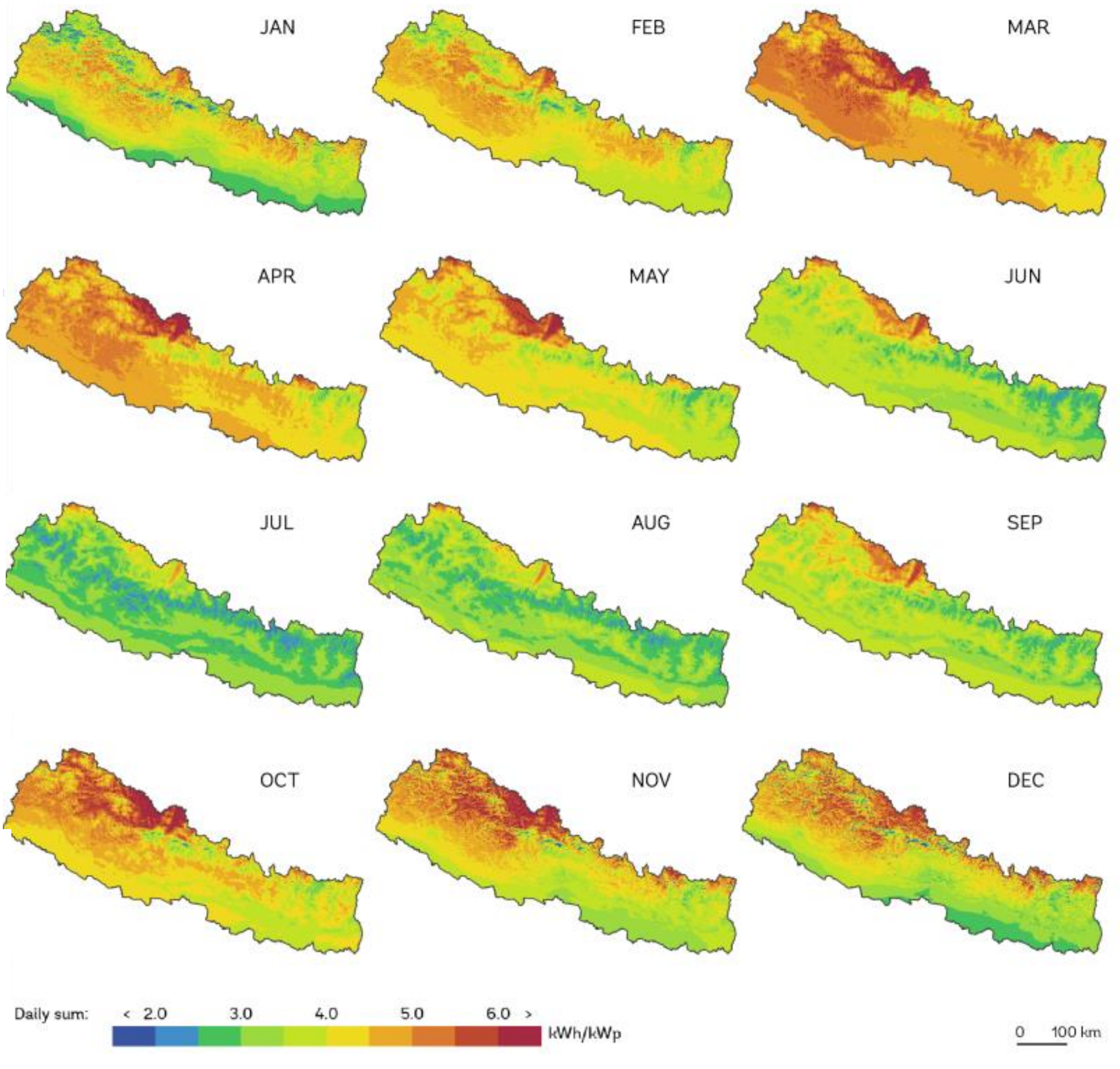

Figure 14: Month-by-month variations in PV power generation potential in Nepal[100]

[100] The World Bank, 2017. "Solar resource and photovoltaic power potential of Nepal." (link)

4.1 Complementarity of solar and seasonal storage hydropower

Hydropower reservoirs have the potential to store vast amounts of water seasonally, acting as a kind of battery – with oftentimes much less expensive storage capacity than electrochemical batteries – that can help balance the intermittency of volatile renewable energy sources such as solar power. By retaining water during periods of abundant rainfall or snowmelt (in the upstream of the rivers), water stored in reservoirs can be harnessed to generate electricity during times of higher energy demand or reduced energy production from PV.

The high solar output during the dry season, when seen in relation to hydropower, will allow the hydropower operator to meet the required output with less water flow, preserving water behind the dam for times of high electricity demand. Scaled up intermittent renewable energy sources such as solar can increase the value of hydropower reservoirs, stretching electricity storage capacity into the dry season and beyond, hence, reducing the need to import dry-season electricity from India.

4.2 Floating solar on existing hydropower reservoirs

An example of complementing a reservoir with solar PV can be considered for the Kulekhani cascade of dams generating a total of 104 MW as a seasonal storage plant. Floating solar installed on 15% of the 2.2 km^2 Kulekhani reservoir could generate about 100 GWh annually[101].

An advantage of floating solar on existing hydropower installations is that transmission infrastructure is already in place. Solar output is greatest during the dry season, producing electricity that allows the hydropower operator to meet the required output with less water flow, preserving water behind the dam when it is most precious. Floating solar also can help reduce evaporation from the reservoir, further reducing the loss of water, while the cooling effect on the solar panels at reservoirs mean that floating solar yields 5% to 7% higher output than ground-mounted solar[102]. Floating solar has shown to reduce reservoir temperatures, which can improve the habitat for aquatic species. After building a test project of 1 MW floating PV on a water reservoir, the Public Utilities Board, Singapore's National Water Agency found no negative impacts on water quality and flora and fauna in the reservoir and is now building a 60 MW project on the Tengeh Reservoir[103]. Nevertheless, it is recommended to consider environmental impacts for all new project sites and make respective pre-installation studies and continuing monitoring obligatory.

Modelling of floating solar in hydropower-rich Brazil found that adding solar PV to existing reservoirs could increase energy production by an estimated 53 TWh annually. This increase translates to an additional capacity factor of roughly 20% to the original 32 GW of installed hydropower capacity, or almost 10% of Brazil's total electricity demand in 2018[104]. A follow-up study found that floating solar on just 1% of Brazil's reservoir surface area could contribute almost 13% to the country's total electricity generation[105].

Switzerland has recently installed a floating PV system with a 2.2 MW capacity on the Muttsee dam[106, 107]. The panels also prevent[108] dust accumulation in the reservoir[109].

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101 15% of a 2.2 km^2 reservoir is 0.33 km^2, assuming 2,000 kWh per m^2 of solar horizontal radiation per year and a solar array efficiency of 15% yields 100 GWh.
102 Niyogi, Deepanwita Gita, 2021. "Do floating solar panels work better?" *Tehelka*, Sep. 25, 2021. (link)
103 Public Utilities Board: Singapore's National Water Agency, accessed Feb 19, 2024. "Floating solar systems." (link)
104 Maués, Jair Arone, 2019. "Floating solar PV—Hydroelectric power plants in Brazil: Energy storage solution with great application potential." *International Journal of Energy Production and Management* 4, Issue 1. (link)
105 Santos, Beatriz, 2023. "Study highlights Brazil's floating solar potential." *PV Magazine International*, Mar. 10, 2023. (link)
106 Lewis, Michelle, 2023. "Europe's highest dam is now covered in nearly 5000 solar panels." *Elektrek* Feb. 6, 2023. (link)
107 Dorenkamper, Maarten, A. Wahed, A. Kumar, M. de. Jong, J. Kroon, and T. Reindl, 2021. "The cooling effect of floating PC in two different climate zones: A comparison of field test data from the Netherlands and Singapore." *Solar Energy* 219, May 2021. (link)
108 Sahu, Alok, N. Yadav, and K. Sudhakar, 2016. "Floating photovoltaic power plant: A review." *Renewable and Sustainable Energy Reviews*, Volume 66, Dec. 2016. (link)
109 Cuce, Erdem, P.M. Cuce, S. Saboor, A. Ghosh, and Y. Sheikhnijad, 2022. "Floating PVs in terms of power generation, environmental aspects, market potential, and challenges." *Sustainability* 14(5): 2626. (link)

China leads the world in the deployment of floating solar with more than 1.3 GW installed as of 2021[110]. It is projected that China and 14 other countries are expected to have more than 500 MW of installed floating solar PV capacity each by 2031[111]. The cited examples are indicative of significant opportunities for Nepal to integrate floating solar in hydropower projects. However, a study would be required to assess the technical and economic potential at different hydropower sites.

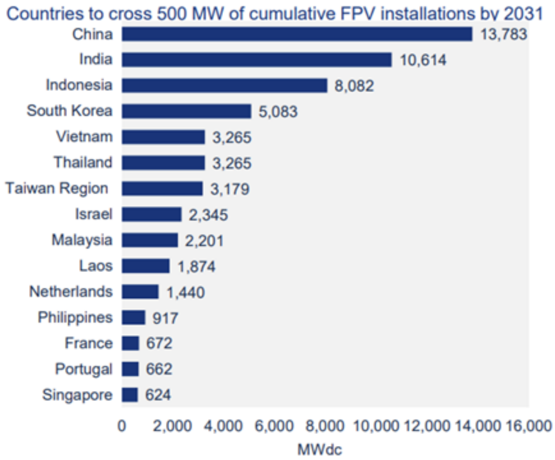

Figure 15: Total expected capacity (MW_P) of floating solar installed by country until 2023[112]

Figure 16: 45 MW floating solar at Sirindhorn Dam, Thailand[113]

4.3 Solar and daily pondage

In contrast to conventional hydropower with big reservoirs that are used to shift electricity production between weeks or months, daily pondage storage behind the weir or in the conveyance system of a run-of-river hydropower project only provides enough storage to shift electricity

[110] Iberdrola Group, accessed Feb. 20, 2024. "Do you know about floating photovoltaic energy?" (link)
[111] Wood Mackenzie, accessed Feb. 20, 2024. "Global floating solar to top 6GW threshold by 2031." (link)
[112] Ibid.
[113] Electricity Generating Authority of Thailand (EGAT), 2021. "The world's largest hydro-floating solar hybrid." (link)

production between hours, perhaps days. Daily pondage is therefore oftentimes used to shift electricity production within a day from low-demand (night-time) to high-demand times (morning and evening hours). Solar power can play a complementary role to hydropower facilities with daily pondage. Electricity generated by solar PV during the day reduces production demand for hydropower, allowing water to be retained behind the dam. This stored water can then be released to generate electricity when solar power is unavailable, such as during night-time hours or periods of reduced sunlight. This harmonious synergy between solar and hydropower technologies promotes a more stable, reliable, and continuous supply of electricity. NEA is currently planning and constructing pondage-run-of-river (PROR) projects with storage from 1 hour to 6 hours[114]. There are two PROR projects (Chamelia and Middle Marsyangdi) in operation. Four projects are under construction. A discussion of the authors with officials of the Ministry of Energy, Water Resources and Irrigation (MoEWRI) revealed that more PRORs are being identified for development in the future. Combining hydropower plants with solar power balances the electricity supply and increases the value of both types of power plants[115].

4.4 Solar and pumped hydro

If seasonal or pondage hydropower storage at existing or planned reservoirs is insufficient, dedicated pumped storage hydropower is an option to manage seasonal differences in production, support peak evening demand, limitations of power evacuation capacities, and variations in electricity prices.

Pumped storage hydropower is a form of "gravity battery" that stores potential energy in the form of water pumped to a height. The stored water at the elevated basin will be released and channelled through turbines to generate electricity when needed, typically during peak evening demand. This process can utilize solar power during the day for pumping water to the upper reservoir. As an example, a pair of 50-hectare reservoirs of 20 meters depth can store up to 9 million cubic meters of water. With a 600-meter height difference between them and 80% efficiency, the system can store 12 GWh of electricity.

Globally, pumped storage hydropower accounts for an energy storage potential equivalent to about 96% in terms of power (MW) and 99% in terms of capacity (MWh)[116, 117]. It is cost-effective, with costs ranging from 1.8 to 50 USD per MWh of energy stored depending on the storage capacity and the integration options with existing hydropower plants[118]. Combining pumped storage with renewable energy sources can reduce long-term costs. For instance, Nepal's Tamor multipurpose project plans to incorporate pumped storage for better energy management[119].

Pumped storage hydropower comes in two types: open-loop, connected to a natural water body, and closed-loop, where the same water is reused in a self-contained system. Closed-loop systems offer more location flexibility as they need not necessarily be located near natural water bodies. According to the Global Pumped Hydro Storage Atlas, Nepal has about 2,800 suitable sites with a combined potential storage capacity of 50 TWh[120]. Even a small fraction of this potential could significantly support Nepal's shift to renewable energy, aligning with its increasing demand and consumption patterns.

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114 NEA, 2023. "A year in review - Fiscal Year 2022/2023." (link)

115 Jurasz, Jakub, and B. Ciapała, 2018. "Solar-hydro hybrid power station as a way to smooth power output and increase water retention." *Solar Energy* 173, October 2018: 675–90. (link)

116 Blakers, Andrew, M. Stocks, B. Lu, and C. Cheng, 2021. "A review of pumped hydro energy storage." *Progress in Energy* 3: 022003. (link)

117 Sandia National Laboratories, accessed Mar. 26, 2023. "DOE global energy storage database." (link)

118 Hunt, Julian D., E. Byers, Y. Wada, S. Parkinson, D.E.H.J. Gernaat, S. Langan, D.P. van Vuuren, and K. Riahi, 2020. "Global resource potential of seasonal pumped hydropower storage for energy and water storage." *Nature Communications* 11: Article number 947. (link)

119 National Planning Commission, 2020. "The Fifteenth Plan (Fiscal Year 2019/20 – 2023/24)." (link).

120 Lohani, Sunil Prasad, and A. Blakers, 2021. "100% renewable energy with pumped-hydro-energy storage in Nepal." *Clean Energy,* Volume 5, Issue 2. (link)

4.5 Solar and batteries

Investment in utility-scale battery storage, particularly for solar PV and wind power, has become increasingly cost-effective worldwide. Battery technologies are advancing, with costs significantly decreasing. For example, from 2020 to 2023, lithium-ion battery storage costs dropped by about 80%, reaching around 137 USD per kWh, and are projected to fall to 50 USD kWh by 2030[121]. In the USA, utility-scale battery deployment is expected to reach 30 GW/111 GWh by 2025, particularly in regions like Texas and California, where natural resources for pumped hydropower are limited[122]. India also plans to develop battery-based energy storage with a total power output of 27 GW and a capacity of about 108 GWh by 2030[123].

However, compared with pumped storage hydropower, battery storage is more expensive, costing at this point roughly twice as much. This cost difference makes widespread application of battery storage in Nepal less likely at the moment, especially since pumped storage can integrate more cost-effectively with existing hydropower projects. Despite this, utility-scale batteries offer advantages such as rapid response and flexibility for shorter durations, which are vital for enhancing grid stability and reliability as the deployment of power generation from volatile renewable energy sources e.g., solar PV, increases. Also, batteries are less dependent on geographical conditions when compared to pumped storage hydropower. Moreover, batteries offer a higher round-trip efficiency (around 90% for lithium-ion, compared to approximately 80% for pumped storage hydropower) and can respond more quickly to load changes, providing enhanced frequency and voltage stability. In addition, with the scale of current research and mass-scale application of battery storage in electric vehicles, the prices are slated to decline further and may reach parity with pumped storage hydropower at some point in the future which may not be too far.

4.6 The role of solar in cross border trade with India

Nepal has multiple interconnection points with India through transmission lines of 400 kV, 220 kV, and 132 kV, as well as distribution level interconnections at 33 kV and 11 kV. At the moment, these lines can transmit approximately 700 MW of electricity. So far only 400 kV cross-border transmission line between Dhalkebar (Nepal) and Muzaffarpur (India) currently offers a power import and export capacity of 800 MW[124]. There are agreements for the further development of interconnections, including the 400 kV double circuit lines from Gorakhpur (India) to Butwal (Nepal) and from Dhalkebar (Nepal) to Sitamarhi (India). Other projects include the 132 kV double circuit transmission line from Nanpara in Uttar Pradesh (India) to Kohalpur (Nepal), the addition of a second circuit to the existing 132 kV line from Kataiya (India) to Kushaha (Nepal), and a 132 kV line from Raxaul (India) to Parwanipur (Nepal)[125, 126].

[121] Teske, Sven, S. Niklas, and S. Miyake. 2023. "Technical scenario for 100% renewable energy in Nepal by 2050: Possible transition pathways for NDC & LTS implementation." Institute for Sustainable Futures. (link)
[122] Schoeck, Michael, 2022. "U.S. to deploy 30 GW, 111 GWh of grid-scale energy storage in three years." *PV Magazine USA*, Dec. 8, 2022. (link)
[123] Central Electricity Authority, Government of India, 2020. "Report on optimal generation capacity mix for 2029-30. (link)
[124] Nepal Live Today, 2023. "Nepal, India agree to add 200 MW to Dhalkebar-Muzaffarpur transmission line." Feb. 19, 2023 (link)
[125] Ministry of Power, Government of India, accessed Dec. 4, 2023. "Interconnection with neighbouring countries". (link)
[126] International Hydropower Association, 2020. "Hydropower status report, sector trends and insights." (link)

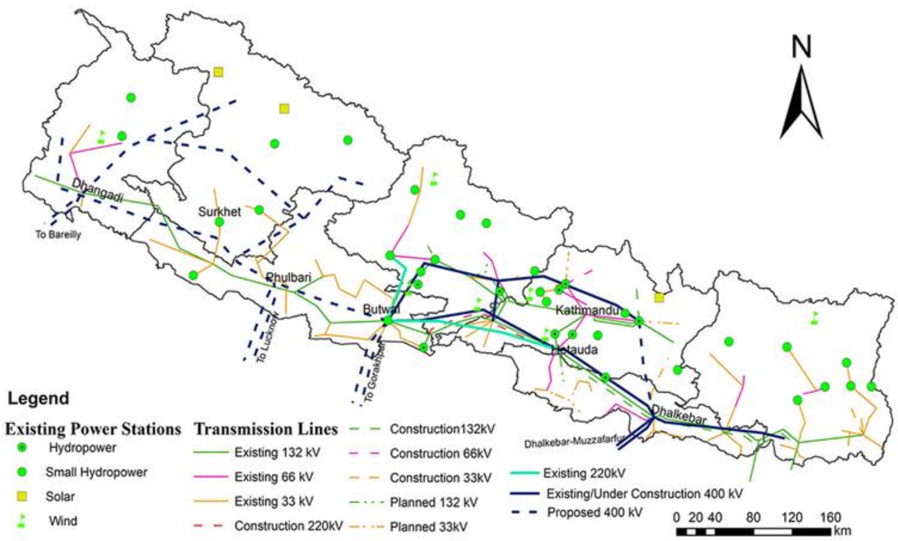

Figure 17: Nepal's transmission network including interconnections with India, planned and existing as of 2020[127]

As Nepal expands its solar PV capacity, cross-border trading can continue to facilitate the exchange of electricity during periods of surplus generation or high demand, fostering regional energy security and economic cooperation. Increased solar PV deployment in Nepal can lead to periods of excess electricity generation during the mid-day peak. By exporting this excess electricity, Nepal can generate revenue and support India's growing energy demand and reduce dependence on fossil fuels.

Conversely, India may also end up exporting solar electricity to Nepal. The Indian government is providing favourable terms for solar electricity development in the form of facilitated permitting, land acquisition, and long-term low-interest debt financing. If India goes ahead with its plan to develop 280 GW of solar[128], and Nepal remains purchasing dry-season electricity from India, a significant portion of this energy import may end up being solar. It is not difficult to imagine a scenario in which Nepal supplies surplus wet season hydropower and imports dry-season solar from India. Or Nepal exports wet-season hydropower and both countries supply dry-season solar to each other, depending on local conditions of load and sunlight availability. With a high level of solar PV, the regional differences in the sources of electricity can be balanced, providing opportunities for surpluses to find off-takers, enhancing grid reliability and resilience for both countries while promoting the integration of renewable energy sources. A good example where it is already highly relevant today is the synchronous grid of Continental Europe.

In general, however, it remains to be seen whether India will achieve its goals for the expansion of solar energy and whether the planned additional renewable energy capacities will be sufficient to meet the country's increasing energy demand. Either way, owning solar power capacities will help Nepal to increase its energy sovereignty and improve its bargaining position.

With Nepal being involved in the International Solar Alliance (ISA), a group of 105 countries, of which Bangladesh and India are also members, the exchange of information, technology, research and funding, and electricity trading among these three countries is expected to increase in the future. The presence of multilateral agencies like the World Bank and donations from other countries to the solar energy development fund will further spur the effort for regional development of solar PV.

[127] Bhattarai, Tek Narayan, S. Ghimire, B. Mainali, S. Gorjian, H. Treichel, and S. Paudel, 2022. "Applications of smart grid technology in Nepal: Status, challenges, and opportunities." *Environmental Science and Pollution Research* 30 (2023) 30:25452–25476. (link)
[128] Central Electricity Authority, Government of India, 2020. "Report on optimal generation capacity mix for 2029-30." (link)

4.7 PV can help increase voltage stability and grid reliability

Nepal still experiences blackouts and voltage dips. The majority of these blackouts and voltage dips, though much less frequent than in years past, occur during the dry season. Distributed grid-connected solar PV systems can play a significant role in enhancing the voltage stability and reliability of Nepal's electricity grid in several ways:

1) **Decentralized power generation**: Distributed PV systems generate electricity at or near the point of consumption, reducing the load on transmission and distribution systems. This decentralization can lessen the stress on grid infrastructure and improve voltage stability, especially in remote or rural areas where grid infrastructure may be less robust.
2) **Peak shaving**: Solar PV can help in managing peak load demands. By generating electricity during peak sunlight hours, which often coincide with peak demand periods, PV systems can reduce the need for additional power generation from other sources. This helps in maintaining a stable voltage level across the grid. In areas where peak hours occur during the evening, PV can help by reducing requested power output from hydropower stations during the daytime, whereby water can be stored in reservoirs to then meet evening and night-time loads.
3) **Reducing transmission losses**: Electricity losses during transmission and distribution are a significant issue, especially over long distances. Distributed PV systems reduce the need to transmit electricity over long distances, thereby decreasing these losses and maintaining better voltage quality.
4) **Voltage support**: Solar PV systems, when integrated with advanced inverters and control mechanisms, can provide voltage support. Modern inverters can be programmed to help regulate voltage levels within the grid, thus contributing to overall grid stability. Modern inverters are designed to help grids when they are struggling with low frequency and low voltage conditions. Industry standards (IEEE 1741 and IEEE 1547.1) that most PV inverters comply with, assure low-voltage ride-through and low-frequency ride-through[129]. This means that in the event of a low voltage or low frequency, inverters that are equipped with such will stay connected for a programmed period of time, contributing voltage and frequency support that the grid needs to avoid a cascading failure.
5) **Reactive power supply**: Solar PV systems, especially those equipped with smart inverters, can supply reactive power (a key component in voltage regulation) when needed. By providing or absorbing reactive power, these systems can help maintain the voltage within the desired range.
6) **Grid resilience during outages**: In cases of grid outages or disruptions, consumers who are equipped with an off-grid ready PV system and adequate battery storage can maintain power supply, operating independently from the main grid. This could potentially be interesting for consumer units that are dependent on a stable power supply e.g., hospitals or sensitive industries.

It would be a good idea to carry out load flow studies to evaluate and rank the potential for grid-connected solar PV at specific nodes in the NEA grid to improve voltage stability. There could be additional cost savings, taking into consideration that strategically located grid-connected PV could delay investments in substation upgrades, new transformers, or larger conductors. Such studies could be put to good use in the identification of priority locations for future tenders for grid-connected PV.

4.8 Barriers to PV scale up

The authors of this report conducted meetings with the relevant stakeholder groups in Nepal to understand their perspectives on upscaling solar PV. The perspectives of the three parties, the developers, the utility (NEA), and the government, are provided below.

[129] NH Research (NHR), accessed Feb. 4, 2023. "Low voltage ride through (LVRT) testing in solar PV inverters and grid-tied systems." (link)

4.8.1 Developer's perspective

There are multiple perspectives considered by the developers to scale-up solar PV. The most important among them was the feed-in tariff adopted by the government.

1) **Low feed-in tariffs:** Currently, NEA pays the developers a feed-in tariff of up to 5.94 NPR/kWh[130]. In earlier solar PPAs, the tariff was set at NPR 7.3 NPR/kWh and included a 3% annual escalation for 8 years – similar to the PPAs for hydropower. Based on the discussion with the developers, even though technology costs are decreasing, the material costs (such as mounting structure, cables and accessories, fuse box, AC combiner box, etc.) and human resource costs have increased. Therefore, the announced tariff is not attractive for the developers to focus on solar PV.

   In November 2022, NEA requested proposals from PV developers for up to 100 MW of solar PV in a competitive reverse-auction tariff bidding process with a maximum tariff of 5.94 NPR/kWh. Although developers held that the tariff was too low for a viable commercial gain, NEA received eligible bids and six solar companies were selected with bids of 5.93 NPR/kWh and below[131]. Bidders expressed their concern that if they did not bid, they would be shut out of the opportunity for further projects. Compared to winning bids in India, tariffs around 5.94 NPR/kWh do not appear excessively low. The auctioned tariff in the state of Gujarat in India fell to 1.99 Indian Rupees per unit (equivalent to 3.18 NPR/kWh), in December 2020, similar to INR 2.0 (NPR 3.20) in November and INR 2.81 (NPR 4.50) in August. In Punjab, one 25-year PPA was signed at INR 2.63 (NPR 4.21) for an 18 MW project[132]. However, solar developers in India enjoy various incentives such as subsidy on installation costs, long-term low-interest debt financing, and preparation of land provided by the government under various solar development schemes[133]. Also, geography, terrain, and infrastructure pre-conditions have to be considered when comparing solar PV projects.

2) **Financing barriers:** The developers share the perspective that the current interest on bank loans, which is 12% or higher, makes investments in solar PV projects challenging considering the current feed-in tariffs.

3) **Limited capacity of transmission lines/substations:** The lack of quality of electricity evacuation infrastructure causing e.g., voltage dips (mainly in the western Terai region), creates challenges and in many cases poses prohibitive barriers to PV installations in some areas.

4) **Limited training and education:** Developers expressed a need to establish professional certificate programmes for designing, installing, and maintaining solar PV systems.

5) **Current hydropower sites are not permitted for use by solar:** A number of hydropower developers would like to optimize and balance power generation by adding solar PV arrays at their hydropower sites. However, current policies do not allow solar PV installations on those sites. It should be considered to treat PV farms at these locations as the same kind of asset class as the hydropower hardware and include PV among the assets that are handed over to the government at the end of the license period (which is typically 25 years for most PPAs). This is a win-win arrangement: developers benefit now, and the government gets additional PV systems and power capacities later.

***Authors' notes:** In respect of **point (1),** above, the authors made an independent assessment of the financial performance with the prevailing feed-in tariff (see Annex). The results suggest that at prevailing lending rates, assumed here to be 13% because other marginal cost not having been considered, the equity internal rate of return (IRR) is consistently below the interest rate in case of full debt financing*

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130 MyRepublica, 2023. "NEA to purchase 100 MW of electricity from solar power through competitive bidding." Nov. 30, 2023. (link)

131 Shrestha, Prithvi Man, 2023. "Six firms to be chosen to supply solar power to grid." *The Kathmandu Post*, Jul. 13, 2023. (link)

132 Ranjan, Rakesh, 2023. "SJVN bags 18 MW solar projects in Himachal Pradesh, signs PPA." *Mercom Clean Energy Insights*, Sep. 11, 2023. (link)

133 Ministry of New and Renewable Energy, Government of India, 2024. "Schemes under Government's solar energy initiative – Rajya Sabha unstarred question no. 448." (link)

even at the most favourable tariff considered in this report (8.4 NPR/kWh). This suggests challenging conditions considering the currently offered tariff below 5.94 NPR/kWh. At the moment, investment in utility scale PV systems does not appear financially attractive. In respect of ***point (2)****, the authors note that even though solar has zero fuel cost, it is capital intensive and the cost of capital has a huge bearing on how financially attractive the investment is. If the lending rate could be reduced to, say, 8% through concessionary financing, the IRR and payback period would improve significantly.*

4.8.2 Utility (NEA) perspective

The discussion with the officials from NEA revealed a cautious welcome of solar PV-based electricity. NEA implements the government policy and aims at generating or buying electricity to a provide reliable power supply at the lowest possible price. NEA's experience with solar includes the installation and operation of a 25 MW solar PV plant at a cost of USD 37 million[134] in Trishuli, Nuwakot. Although the installation was delayed by about four years, the project meanwhile provides about 200 MWh of electricity per day. The most important points from the discussion with NEA are summarized in the following.

1) **Land use conflicts in the Terai**: Investors seem to focus on the Terai region, where most of the land is either agriculture, forest, or protected area. So, disputes over land use and acquisition are more likely. Instead of focusing on the Terai, investors should consider the supply situation in the northern part of the country, such as in Karnali province. There, the disputes over land acquisition would be minimal and land for a PV project would be cheaper.

2) **Grid capacity and spillage:** NEA's expertise is in the hydropower sector. It also has plans for signing more RORs and PRORs in the future based on its own generation plan. Besides, there is an ongoing discussion about electricity generation from water storage in Nepal[135]. If solar PV is added, NEA may not have the grid capacity or sufficient load to evacuate the solar PV based electricity. As NEA must pay for spilled energy due to take-or-pay PPAs, additional solar power generation are feared to intensify that problem.

3) **PV supply pattern mismatches demand:** In Nepal, the peak solar electricity supply is obtained around midday, but peak electricity demand occurs in the morning and the evening. This means that the maximum solar power supply and electricity demand are mismatched. If the solar PV system is combined with batteries, the LCOE will be significantly higher. As PPAs are for a specific purpose, combining solar with existing ROR will create administrative problems for its execution.

4) **Policy uncertainty:** The government policy for net-metering directs how NEA should manage rooftop and larger scale solar PV power generation. Many operational grid-connected solar PV systems to date benefit from the net-metering arrangement. Although it expired in July 2022 it got reinstated in February 2023 with a net-billing arrangement at 5.94 NPR/kWh. However, policy changes such as this create uncertainty in the market. Net-metering for solar PV is explicitly listed as a goal in the government's 15th National Plan (National Planning Commission 2020).

Authors' notes: *Regarding* ***point (2)****, the dry season analysis presented in this report suggests that the planned hydropower additions are largely insufficient to accommodate expected dry season load growth. Hence, substantial electricity imports from India or additional in-country generation capacities will have to be considered. In respect of* ***point (3)****, it is worth considering that different orientations and tilts of PV modules can help aligning electricity generation to the demand. East-west oriented solar systems, for example, will distribute the power generation more evenly over a day's sunlight hours and flatten the midday peak. Such generation pattern would offer a better fit for Nepal's demand curve.*

[134] Thapa, Krishna, 2022. "Nuwakot solar power station begins supplying electricity to Kathmandu." *The Kathmandu Post*, Sep. 14, 2022. (link)

[135] Pun, Surya Bahadur, 2017, "Storage projects in Nepal's electricity development decade 2016/2026: For whom Nepal's storage projects toll?" *Hydro Nepal,* Issue no. 20. (link)

4.8.3 Government perspective

The examination of the government's perspectives is obtained mainly from statements by MoEWRI, the National Planning Commission and AEPC.

1) **Land use conflicts:** The government considers the conservation of forest and agricultural land a matter of serious concern. It cannot provide licenses to developers who propose to develop solar projects in nature reserves, forest areas or on agricultural land.

2) **Land speculation concerns:** The government expressed concerns that the development of solar projects could increase land speculation. Concerns were raised that land purchased ostensibly for solar projects could be resold at a profit after dismantling the solar array prematurely.

3) **Land clearance, and waste management:** Another concern is that there is no provision to clear the site of the PV system, manage the PV waste and convert the land to its original condition once the project ends. It is to noted that this type of concern could be addressed by including responsibilities in policies or tender documents. Challenges and opportunities for PV waste management have been studied in India[136], Korea[137], Thailand[138], and globally[139,140].

***Authors' notes:** Regarding **point (1),** a geospatial study of land potentially suitable for solar development in Nepal, within 10 kilometres from existing transmission lines, found that 17,273 km^2 are suitable to develop a total of 432 GW of solar PV[141]. The identified areas exclude protected areas, closed forests, wetlands, moss and lichen, permanent water bodies, mountain areas with slopes exceeding 30%, and snow and ice. With reference to **point (2),** it is not clear whether this concern is justified. Explicit policies allow for government land to be leased (not sold) for solar project development which should address the concern. The Hydropower Development Policy (2001), Article 6.1.2, states that "… if the land is government owned, the Government of Nepal shall make it available on lease for a period up to the term of license in accordance with the prevailing laws." The same provision is made in Article 33 of the Electricity Act (1992). Thus, provisions for land lease for the development of electricity infrastructure exist, but they may not be deemed applicable for solar PV going by current interpretation.*

[136] Jain, Suresh, T. Sharma, and A.K. Gupta, 2022. "End-of-life management of solar PV waste in India: Situation analysis and proposed policy framework." *Renewable and Sustainable Energy Reviews* 153, 111774. (link)

[137] Kim, Hana, and H. Park, 2018. "PV waste management at the crossroads of circular economy and energy transition: The case of South Korea." *Sustainability* 10, 3565. (link)

[138] Faircloth, Cameron C., K.H. Wagner, K.E. Woodward, P. Rakkwansuk, and S.H. Gheewala, 2019. "The environmental and economic impacts of photovoltaic waste management in Thailand." *Resources, Conservation and Recycling,* 143. (link)

[139] Xu, Yan, J. Li, Q. Tan, A.L. Peters, and C. Yang, 2018. "Global status of recycling waste solar panels: A review." *Waste Management* 75. (link)

[140] Bogacka, M., K. Pikon, and M. Landrat, (2017). "Environmental impact of PV cell waste scenario." *Waste Management* 70. (link)

[141] Teske, Sven, S. Niklas, and S. Miyake. 2023. "Technical scenario for 100% renewable energy in Nepal by 2050: Possible transition pathways for NDC & LTS implementation." *Institute for Sustainable Futures.* (link)

5. Policy Changes Recommended to Unleash Grid-Connected PV

Currently, the economic and regulative environment in Nepal is impeding substantial investments and sustainable development of utility-scale solar PV systems. This chapter suggests nine key actions and policy changes that could help to overcome the main barriers to upscaling PV in Nepal.

5.1 Stable and fair tariffs

Developers argue that current tariffs for solar PV are too low for commercial viability considering the cost of capital in Nepal. Tariffs are also unstable in the sense, that it is not certain when and how they might change in future[142]. Unstable tariffs present a high risk for developers who oftentimes make significant investments even before they receive a PPA e.g., for site assessments, financial analysis, licensing, and environmental permits. Changing purchase tariffs during the development phase of a project can negatively influence a project's financial viability, in the worst case leading to a premature termination without any expectations that investments made up to that point will be returned.

Raise the IPP tariffs

The first and most important recommendation is that there is a need to raise the set tariff of 5.94 NPR per kWh (0.043 USD/kWh) for purchasing solar based PV electricity. Though NEA received proposals for its recent call for the development of 100 MW of grid-connected PV capacity with tariffs up to 5.94 NPR/kWh should not be misinterpreted as the tariff being viable. Several companies participated ostensibly to eliminate the risk of being excluded from future tenders while others sought to protect past investments in land and infrastructure while the tariff was at 7.3 NPR/kWh. Some of the awarded bidders have approached development partners and donors for viability gap funding[143] as they risk default on the PPA for financial reasons. This type of request is also unfair to the donor community, which has many competing priorities for limited aid funds. Raising the tariff is recommended to encourage private sector participation in supporting the electricity generation expansion and balancing.

Alternatively, NEA could offer the current PPA rates for hydropower projects based on the average tariff. NEA is already paying 8.4 NPR/kWh for dry-season power from domestic IPPs, and more than 10 NPR/kWh on average for dry-season imports from India. Even picking the simple average of 4.8 NPR/kWh (hydro ROR IPP wet season) and 8.4 NPR/kWh (dry season), with an average of 6.6 NPR/kWh, would offer an incentive. Offering solar PV, the same tariffs as hydropower would value electricity at amounts that NEA has already accepted as fair. Table 4, Table 5, and Table 6 show the posted tariffs that apply to hydropower since May 2017[144]. The tariffs for projects up to 100 MW include a 3% simple escalation rate for 8 years for the capacity.

[142] The tariff for solar PV was 5.21 NPR per kWh in 2012, rose to 7.40 in 2019, fell to 7.30 in 2020; there was a moratorium on solar projects, and purchases for up to 100 MW were re-instated by auction with a cap at 5.94 in 2022.

[143] Currently, viability gap funding is available under the Sustainable Energy Challenge Fund but only for projects under 1 MW.

[144] NEA, 2017. "NEA board decisions on the power purchase rates and associated rules for PPA of ROR/PROR/Storage projects effective from 2074/01/14 (April 27, 2017)." (link)

Table 4: PPA tariff for ROR projects

Option		Season	Rate NPR/kWh (up to 100 MW)	Min dry season energy required
1.	Dry and wet season of 6 months each	Wet season June to November	4.80	30%
		Dry season December to May	8.40	
2.	Dry 4 and wet 8 months	Wet April to December	4.80	15%
		Dry December to April	8.40	

Table 5: PPA tariff for PROR project

Option		Hours	Daily hours required to generate electricity at rated capacity	Rate NPR/kWh	Min dry season energy required
1.	Dry season (Dec-May)	Peak hours	1 hour or less	8.50	30%
			2 to less than 3 hours	8.80	
			3 to less than 4 hours	9.40	
			4 to 6 hours	10.55	
		Non-peak hours		8.40	
2.	Wet season (Jun-Nov)	All hours		4.80	

Table 6: PPA tariff for storage projects

Option		Rate NPR/kWh	Min dry season energy required
1.	Dry season (Dec-May)	12.40	35%
2.	Wet season (Jun-Nov)	7.10 (if wet season energy is more than 50%, this rate shall be decreased by the excess %)	

Solar irradiation in Nepal is highest from March to May and September to December, coinciding with the dry season in the 6-month dry/wet cycle. During this period increased yields from solar photovoltaic (PV) electricity production can be expected. Consequently, varying tariffs based on peak electricity provision hours would seem appropriate in Nepal and encourage innovations in combinations of PV and storage (through pondage or other means) to meet minimum peak hour provisions. This, in turn, increases the reliability of supply when it is most needed.

Incentivize daytime consumption through TOD

In February 2020, NEA introduced the tariff rate for charging electric vehicles. The differentiated rates of 11.20 NPR per unit during peak hours (5:00 pm to 11:00 pm), 4.45 NPR per unit for off-peak hours (11:00 pm to 5:00 am), and 10.10 NPR per unit for normal hours (5:00 am to 5:00 pm) during the wet season, with a slight variation for the dry season, help to balance the load on the power grid by incentivizing EV charging during off-peak hours.

Similar TOD tariffs could be used to balance electricity demand and solar PV output in Nepal. By introducing lower tariffs during peak-sun hours, consumers would be encouraged to shift their energy usage to periods when solar power generation is highest. This tariff could be lower than typical retail tariffs, yet higher than the IPP tariff paid to solar PV, guaranteeing a good distribution margin for NEA. Special solar TOD tariffs could potentially maximize the direct utilization of PV produced electricity and also decrease the load on the grid during high-demand periods since consumer are motivated to shift some of their electricity consumption away from the established peak-demand hours.

5.2 Revision of renewable energy cap for enhanced energy security and job creation

The current policy of the Government of Nepal, which sets a 10% cap on the percentage of electricity generated from renewable sources other than hydro, appears to lack a solid rationale. Many countries are increasingly adopting these renewable sources to bolster their energy security[145] and resilience[146]. Particularly, integrating solar PV with storage solutions such as pondage or batteries can significantly enhance the grid's capacity to meet fluctuating domestic and export demands.

There is a pressing need to either remove or significantly raise this cap if Nepal wants to diversify its renewable energy portfolio. The investors' response to NEA's tender for 100 MW solar PV at the end of 2022 suggests a growing interest in this sector. A policy shift akin to the one made for hydropower in the early nineties could pivot the market towards extensive solar PV utilization in Nepal.

Nepal's commitment to net-zero emissions in its energy mix by 2045 places solar PV in a pivotal role. A recent scenario analyses for 100% renewable energy in Nepal by 2050 suggest that already by 2030, the installed solar PV capacity should be nearly half to more than twice the hydropower capacity[147].

Globally, countries are harnessing the substantial economic potential of solar energy. Depending on their resource availability, nations are increasing their solar or combined solar and wind energy share, thereby enhancing grid flexibility. Examples include India (solar and wind at 8.2% on average with Karnataka province reaching the highest value of 29%[148]) and Brazil (17%[149] share from solar and wind electricity). Other examples include Chile with 17.5%, the Netherlands with 14.3%, Australia with 14.2%, and Spain with 11.5%.

The renewable energy sector, particularly solar PV, is expected to be a significant job creator. Globally, it is anticipated to generate over 30 million jobs by 2030[150] and 40 million jobs by 2050[151]. A supportive policy from Nepal's government could ensure that these job opportunities are available to Nepali citizens. Currently, most utility-scale installations in Nepal employ foreign workers on a contractual basis, but a policy change could help shift this towards local employment.

Removing the cap on non-hydro renewables i.e., solar power, from the government policy is essential to enhance Nepal's energy security, flexibility, and resilience, to align the policy with its net-zero emissions goal and to create better employment opportunities for Nepalese citizens.

5.3 Promote integration of solar PV for energy storage

Enhanced energy storage is regarded essential in strengthening Nepal's energy security. Expanding storage capacity is crucial for maximizing the benefits of solar power, particularly during the dry season when it can effectively complement the country's hydropower resources. To facilitate this scale-up of energy storage, several strategic steps are recommended:

1) **Promotion of pumped hydropower storage:** NEA should be encouraged to develop pumped hydropower storage systems. This technology essentially stores the electricity generated by solar PV (in the form of water) through pumping water during the day and storing it for electricity generation during periods of high demand.

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[145] Eid, Cherrelle, Y. Chen, Y. Perez, and R. Hakvoort, 2015. "Aggregation of demand side flexibility in a smart grid: A review for European market design." *Institute of Electrical and Electronics Engineers*: *12th International Conference on the European Energy Market*, 978-1-4673-6692-2. (link)

[146] International Energy Agency, 2021. "Net zero by 2050: A roadmap for the global energy sector." (link)

[147] Teske, Sven, S. Niklas, and S. Miyake, 2023. "Technical scenario for 100% renewable energy in Nepal by 2050: Possible transition pathways for NDC & LTS implementation." *Institute for Sustainable Futures*. (link)

[148] International Energy Agency, 2021. "Renewables Integration in India". (link)

[149] Government of Brazil, 2022. "Renewable energy in the Brazilian energy matrix: the share of solar energy reached 6.9% and wind energy, 10.9%." (link)

[150] International Energy Agency, 2021. "Net zero by 2050: A roadmap for the global energy sector." (link)

[151] International Renewable Energy Agency, 2020. "Energy transformation can create more than 40m jobs in renewable energy." (link)

2) **Leveraging NEA's commitment to PROR capacity:** NEA's recent initiative to sign PPAs for 1,000 MW of projected reservoir capacity is a commendable step. Increasing the scale of such provisions and allowing the integration of solar PV would help to meet peak electricity demands and balance the electricity output from a particular generation site.

3) **Addressing market dynamics and stability:** With increased energy trading, maintaining stability becomes critical, especially considering the severe penalties for failing to meet electricity supply commitments. In a spot price market, the higher the spot price and the shorter the bidding time, the greater the potential penalty, underscoring the need for reliable and responsive energy systems[152]. Therefore, in Nepal's case, the integration of solar in the energy system would help mitigate this vulnerability due to its complementarity with hydropower generation.

5.4 Allow existing IPP licensees to complement existing hydropower

Presently, IPP licenses are limited to hydropower. The policy should be revised to permit existing IPPs operating hydropower facilities to integrate solar-based electricity into their operations. Allowing the addition of solar power would enhance land utilization at these sites and bolster overall electricity output. Given that the necessary transmission infrastructure is already established, this integration is not only feasible but also beneficial in aiding IPPs in consistently meeting NEA requirements towards a balanced electricity production (NEA mandates IPPs to maintain their rated generation capacity for at least 40% of the year, equivalent to about 4.8 months).

A prime example of this integration's success is NEA's 25 MW solar power plant, co-located with the 14.1 MW Devighat hydropower project. Furthermore, the NEA, supported by the KfW, is planning another solar project at a hydropower site in Surkhet. Extending this model to other IPPs could significantly enhance the consistent power output of ROR plants. By amending policies to facilitate the co-location of solar and hydro facilities, Nepal can significantly improve the efficiency of its energy infrastructure and strengthen its energy security.

5.5 Pursue floating solar at hydropower sites with suitable reservoirs

Another example of co-location of solar and hydropower is the use of floating solar on existing and planned reservoirs. Floating solar provides efficient land use, reduces water evaporation, and cools the solar panels, leading to higher efficiency and synergistic benefits when combined with hydropower (see Chapter 4.2 above).

Interestingly, NEA's 2020/21 annual report includes the discussion of a *Feasibility and detailed study of a floating solar power project of up to 10 MW in Indrasharowar at Khulekhani*. The annual report concludes "After the careful analysis of advantages and disadvantages of floating PV system, the department has recommended carrying out the feasibility and detailed study for the construction of 'Floating solar PV power plant up to 10 MW' at Indrasharowar in Kulekhani owing to the merits such as easy installation and maintenance, increased power production, minimization of evaporation and water saving, and hassle free landmass acquisition quickly pays off the relatively higher cost of it as compared to that of terrestrial project. It is a reliable, environment-friendly, and cost-effective source of application of renewable energy in the areas where there is shortage of land and is seen as perfect amalgamation to reservoir-based projects."[153]

Subsequent NEA annual reports do not mention the floating solar power project. NEA should reassess the potential for floating solar on reservoirs of existing hydropower projects.

[152] Australian Energy Market Commission (AEMC), accessed Feb. 22, 2024. "Spot and contract markets". (link)
[153] NEA, 2021. "A year in review Fiscal Year 2020/2021.". (link)

5.6 Enhancing land utilization through agrivoltaics and canal top solar PV

In Nepal, land use competition between agriculture and solar PV might become a bigger issue once the benefits of utility-scale solar power for the energy system are recognized. Therefore, policies should support innovative land use strategies like agrivoltaics and canal top solar PV. As shown below, Nepal has more than 10,300 km^2 of uncultivated agricultural land[154], which can be potentially used for both, solar PV installations in the form of agrivoltaics and agriculture.

Potential for agrivoltaics in Nepal

Nepal has 30,910 square kilometres of cultivated and 10,300 square kilometres of uncultivated agricultural land. The average electricity output from solar PV can be considered as 4 kWh per kW$_P$ per day. A 500-W$_P$ panel requires about 3 square metres including structure and panel spacing. 6 square metres would be needed for 1 kW$_P$ capacity while each square metre would produce 0.67 kWh (4 kWh/6m^2) of electricity per day. If only 1% (103 km^2) of the uncultivated agricultural land surface would be used for solar PV installation, this land would produce about 69 GWh of electricity every day. At the same time, the land would still be used for crop production as a part of the licensing requirement for agrivoltaics.

Agrivoltaics (also AgriPV) is the integration of solar PV with agricultural activities (Figure 18) or livestock farming. It can support crop growth and energy production concurrently[155]. This dual-use approach can take various forms, such as mounting solar panels above crops, between crop rows, or on greenhouses (Figure 19). Such systems not only conserve land but also maintain soil moisture, benefiting crop growth.

To fully harvest the benefits of agrivoltaics, policies, standards, and regulations must be defined for project development (site evaluation, impact analysis, construction, PV-crop interaction, etc.), to set long-term targets (e.g., agrivoltaics capacity by 2030), and to offer economic incentives for investors. Projects that incorporate features like rainwater harvesting or optimal light spectrum management for crop growth could provide additional benefits. By adopting these strategies, Nepal can enhance its energy security while supporting agricultural productivity.

Figure 18: Tractor tilling under a 1.5 MW agrivoltaics power plant in Maharashtra, India[156]

[154] Ministry of Agriculture & Livestock Development, 2022. "Statistical information on Nepalese agriculture 2077/78 (2020/21)." (link)

[155] Fraunhofer Institute for Solar Energy Systems (ISE), 2022. "Agrivoltaics: Opportunities for agriculture and the energy transition." (link)

[156] National Solar Energy Federation of India, 2023. "Agrivoltaics in India: Overview of projects and relevant policies." (link)

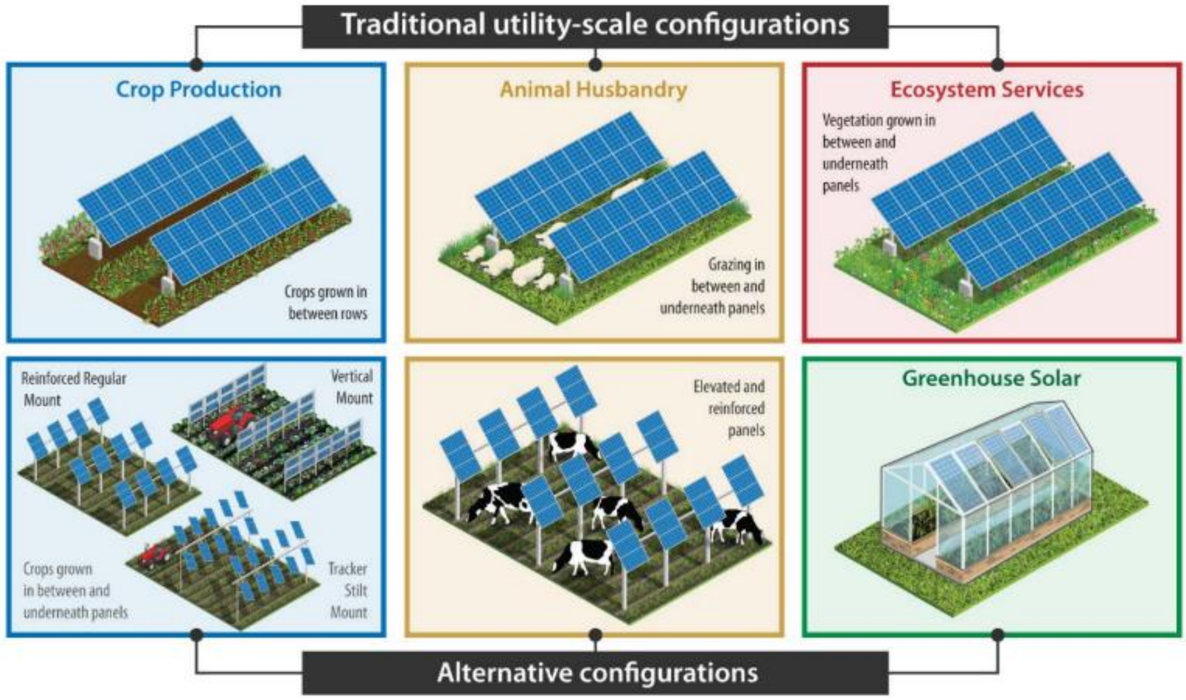

Figure 19: Different configurations of agrivoltaics[157]

Canal top solar: Utilizing existing concrete-lined irrigation canals for canal top solar PV installations (Figure 20) presents another opportunity. This not only efficiently uses land but also conserves water by reducing evapotranspiration[158] and algae growth[159]. India's successful implementation of 10 MW canal top PV, covering a 3.6-kilometre long canal in the Vadodara district of Gujarat, saves about 10 hectares of land requirement for solar installation[160]. Subsequently, several other projects have been commissioned in India, including a 100 MW canal top solar power project stretching for a distance of 40 km and covering branch canals off the Narmada river[161]. Such projects in neighbouring India demonstrate the potential for canal top solar PV in Nepal, as well. There are established concrete lined irrigation canals in the Terai region from east to west. As an example, the Kankai irrigation system in Jhapa has a main canal of 36 km providing a large potential for PV installation. A list of canals in the federally managed irrigation system is readily available from the Department of Water Resources and Irrigation[162].

[157] National Renewable Energy Laboratory (NREL), 2022. "The 5 Cs of agrivoltaic success factors in the United States: Lessons from the InSPIRE research study." Technical Report, NREL/TP-6A20-83566. (link)
[158] Lewis, Michelle. 2022. "In a US first, California will pilot solar-panel canopies over canals." *Electrek*, Aug. 26, 2022. (link)
[159] Water Research Commission, 2008. "Weeding out water wastage in irrigation canals." *Irrigation*, The Water Wheel. (link)
[160] Kumar, Manish, S.S. Chandel, and A. Kumar, 2020. "Performance analysis of a 10 MWp utility scale grid-connected canal-top photovoltaic power plant under Indian climatic conditions." *Energy,* 204, 117903. (link)
[161] Financial Express, 2019. "Renewable future: Gujarat govt to set up 100 MW solar power project atop Narmada canal." Feb. 22, 2019. (link)
[162] Department of Water Resources and Irrigation, accessed Feb. 17, 2024. "Agency managed irrigation systems." (link)

Figure 20: Canal-top solar in Gujarat[163]

For canal-top solar PV, it is recommended that the government categorizes suitable canals for utility-scale installations, considering factors such as the security of the operation of the canal, grid connectivity, and the sharing of responsibilities between the Department of Irrigation and investors. Financial support models, similar to those in India[164] could also be considered to offset installation costs.

5.7 Enhancing concessionary financing for grid-connected solar PV

In Nepal, the development of grid-connected solar PV is also impeded by high commercial lending rates (around 12% or higher) and collateral requirements, reflecting banks' limited understanding of the risk profile for solar projects compared to hydropower. The government could play a pivotal role in mitigating these challenges by covering a part of project costs, preparing land, or facilitating access to national and international financing, thus increasing bank confidence.

Learning from India's policy, which offers Central Financial Assistance (CFA) for solar parks and sets targets under various solar promotion schemes, Nepal could implement similar financial incentives. The Indian government's viability gap fund, for instance, provides substantial support for solar PV installations, boosting the sector's growth[165].

Examples from non-banking financial institutions in India and Bangladesh, such as the Indian Renewable Energy Development Agency (IREDA) and Bangladesh's Infrastructure Development Company Limited (IDCOL), offer valuable lessons for Nepal. These institutions provide long-term

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[163] Sunder, Kalpana, 2020. "The 'solar canals' making smart use of India's space." *BBC Future Planet*: *Renewable Energy*, Aug. 4, 2020. (link)

[164] Ministry of New and Renewable Energy, Government of India, 2017. "Schemes launched by the Government to promote solar energy in the country." (link)

[165] The ministry offers Central Financial Assistance (CFA) at INR 2.5 million per park for detailed project reports preparation of solar parks and conducting surveys, and INR 2.0 million/MW or 30% of the total project cost, including grid-connectivity costs, whichever is lower. The government has set targets under different solar promotion schemes and provides viability gap fund (VGF). In a scheme to promote 5,000 MW solar PV installations, the government of India provided VGF with an upper limit of INR 10 million/MW for open category and INR 12.5 million/MW for projects meeting domestic content requirement. The government has also provided incentives to increase the domestic manufacturing of solar PV within the country, so that it can be manufactured at lower cost than imported modules.

project financing and bridge loan assistance[166], which could be emulated in the Nepalese context. Nepal already has a viability gap fund programme for solar PV projects up to 1 MW, offering subsidies for bank loans, installation costs, and tariffs; the extension of such programmes can also support the viability of utility scale PV plants.

Multilateral development banks such as the World Bank or Asian Development Bank (ADB) could offer low-interest loans. A notable initiative by ADB, which provided USD 20 million to support 25 MW of solar PV capacity in Nepal in 2018[167], helped to bridge the gap between private sector costs and NEA's feed-in tariff. Similarly, Scatec ASA's project in Brazil, financed through international banks and the Inter-American Development Bank[168], showcases the potential for access to multilateral funding for its 531 MW solar PV plant.

To further upscale solar PV installations, it is recommended that Nepal

- considers the possibility of creating a dedicated non-banking financial institution,
- extends viability gap funding to solar PV projects above 1 MW and,
- supports the private sector in accessing international funds.

These measures would significantly contribute to the progress of Nepal's renewable energy sector.

5.8 Open up further opportunities for cross-border electricity trade

Nepal's opportunity for power export growth – both of hydropower and solar PV – is significantly bolstered by the 25-year Power Trade Agreement signed with India on June 1, 2023. This agreement, promising to purchase 10,000 MW of electricity from Nepal within 10 years and allowing Nepal to sell up to 50 MW to Bangladesh, creates an unprecedented opportunity for expanding cross-border electricity trade. Leveraging this agreement, Nepal should further develop its solar PV capacities, alongside its growing hydropower projects. Such an expansion would not only cater to the dry season demands but also align with Nepal's potential role as a significant renewable energy exporter in the region. The agreement underscores the importance of enhancing infrastructure and policies to support efficient energy trading, including electricity wheeling, power exchange trading, and unbundling of NEA's functions.

The existing and planned hydropower projects in Nepal, especially during the wet season, provide a basis for such expansion. Moreover, the deployment of large-scale solar PV can extend Nepal's electricity export capabilities into the dry season. Direct market access for Nepali developers to the Indian electricity market would be beneficial in several ways:

- Nepali IPPs could develop expertise in power exchange trading, focusing increasingly on electricity generation for export. This is supported by the Hydropower Development Policy (2001) and the Electricity Act (1992), which allow for electricity export through agreements with the Government of Nepal. Further, the proposed amendment to the Electricity Act (1992) aims to establish power trading companies[169], enhancing power exchange and inviting more investment from India. Such direct exchange mechanisms could significantly scale up solar PV in Nepal, providing valuable daytime electricity for export, especially in the dry season.
- Implementing these provisions would also contribute to reducing India's reliance on coal, thereby lowering greenhouse gas emissions and improving air quality, which would have direct positive effects for Nepal.

[166] Infrastructure Development Company Limited (IDCOL), 2021. "Annual Report 2021." (link)
[167] Asian Development Bank (ADB), 2016. "$20 million grant to spur private sector solar power investment in Nepal." Dec. 8, 2016. (link)
[168] Oslo Børs, 2023. "Scatec makes first drawdown under non-recourse loan facility for Mendubim solar project in Brazil." Mar. 23, 2023. (link)
[169] Ministry of Energy, Water Resources and Irrigation (MoEWRI), 2020. "Electricity Bill 2077." (link)

NEA's experience in transmitting wholesale power to India could form the foundation for similar arrangements within Nepal, such as for electricity wheeling. This system would enable solar IPPs (or IPPs operating both hydropower and solar plants) to use national transmission lines for selling power directly to large customers. A successful example of this model is also seen in the South African Development Community (SADC), where IPPs sell power to utilities (nationally and across borders) and use transmission systems for wheeling power directly to designated consumers[170]. Such opportunities could significantly expand the market for solar electricity and reduce supply costs for the industry.

The consideration of an independent system operator to manage transmission capacity and the unbundling of NEA's functions, as proposed in the draft of the new Electricity Act, should also be pursued. This unbundling would allow separate entities[171] to operate in generation, transmission, and distribution, fostering a more competitive electricity market[172, 173]. These reforms and expansions in cross-border trade opportunities would not only enhance Nepal's broader energy security and sustainability goals but also contribute to the market growth for solar PV.

5.9 Identify areas where grid-connected solar PV is most beneficial to NEA

Engagements with NEA and private developers indicate challenges in some areas for solar PV installations due to inadequate grid capacities. Despite lower land costs in these areas, grid limitations hinder development. To address this, NEA could collaborate with development partners to conduct geospatial mapping to identify locations with sufficient power evacuation capacities or areas where PV could enhance NEA's voltage profile. Regular updates of these geospatial maps are essential. The recent 100 MW solar power initiative in specific locations aims at enhancing supply reliability mostly in the eastern and western Terai regions. This type of initiative should be replicated at a larger scale to help ensure stable and resilient electricity supply across the country.

[170] International Energy Agency, 2021. "Cross-border electricity trading for Tajikistan: A roadmap." Nov. 2021. (link)
[171] Ministry of Energy, Water Resources and Irrigation (MoEWRI), 2020. "Electricity Bill 2077." (link)
[172] Ibid.
[173] Shrestha, Prithvi Man, 2023. "Draft bill on granting power trading licence to private sector reaches Cabinet." *The Kathmandu Post*, Aug. 9, 2023. (link)

6. Conclusions

In Nepal, where hydropower dominates the electricity sector, seasonal water availability significantly affects the stability of the electricity supply. This issue is exacerbated by climate change, which disrupts river flows, leading to challenges in maintaining consistent electricity generation. The reliance on hydropower, contributing to 95% of the country's installed electricity capacity over half of which is run-of-river (ROR) projects, is particularly problematic during the dry season, resulting in the need for costly electricity imports from India.

To mitigate these seasonal variations and enhance energy security, solar electricity has been identified as an effective complementary solution. With solar power generation peaking during the dry season, it can help conserve water in hydropower reservoirs, extending the electricity storage capacity into the drier months. This is crucial as Nepal's electricity demand is projected to triple by 2030, and the planned hydropower projects may not meet the increasing demand. Solar PV offers a cost-effective and rapidly deployable opportunity in line with Nepal's commitment to achieving net zero emissions by 2045 under the Paris Agreement.

Despite the potential benefits, Nepal's solar power sector faces several challenges, such as low tariff ceilings, inadequate power evacuation capacity, and inconsistent policy implementation. These issues need to be addressed to fully harness solar PV's potential in complementing the hydropower-dominated electricity mix.

A series of policy measures is recommended by this report to enable Nepal's solar energy sector to contribute meaningfully to the country's affordable, secure, and robust power system:

- Establish stable and fair tariffs for solar energy.
- Remove the existing caps on non-hydro renewable energy sources.
- Encourage investment in energy storage.
- Allow IPPs to complement their existing ROR and PROR projects with onsite solar power.
- Promote innovative solutions like floating solar panels, canal top, and agrivoltaics.
- Enhance concessionary financing for grid-connected solar PV.
- Expand power trade with India, particularly exports.
- Identify areas where PV can support grid stability.

These policy measures are pivotal for enhancing the resilience and sustainability of Nepal's electricity system, ensuring it can meet the growing demand and environmental commitments while overcoming the limitations of its current hydropower reliance. Nepal's electricity system, currently strained and heavily dependent on hydropower, could be made more robust through well-planned additions of solar electricity, especially when matched with storage solutions like daily pondage and seasonal storage in hydropower facilities.

7. Annexe: Review of the Investment Challenges

To better understand the financial prospects of solar PV projects, the internal rate of return (IRR) for such projects has been estimated by the authors through financial modelling. The analysis presented is based on a generic model developed for multiple applications including utility-scale plants. The factors considered are shown in Figure 21. The direct cost of the technology, interest rates, and installation costs are based on recent market data from Nepal. Like any model, it captures the main aspects that determine financial viability at the cost of neglecting peripheral aspects. The model used here ignores the costs for exploration, site assessment and connection to the transmission lines. Therefore, the outcomes cannot be considered accurate predictors of financial performance and hence caution is necessary for interpreting them. Yet they serve as a reference for comparison as the results are projected to be consistent with the realities modelled in their magnitude. The main conclusions are presented under authors' notes at the end of chapter 4.8.1.

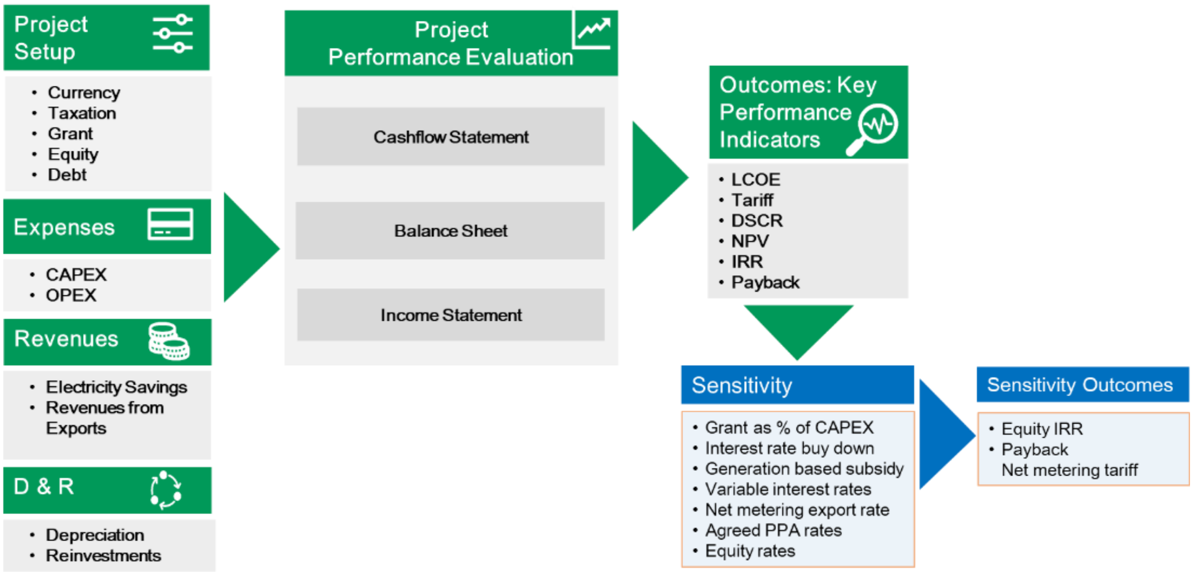

Figure 21: The financial model for solar PV projects

Table 7: Financial scenarios considered in the analysis

		Principal assumptions	*System type:* *System size:* *System cost:* *Discount rate:*	Utility-scale PV 2 MW_P 440 USD/kW_P 8%
Scenarios	**Feed-in-tariff NPR/kWh**	**Project IRR**	**Equity IRR**	**Payback period**
				Project payback
Scenario A: 100% debt *at 13% interest*	4.80	0.9%	Not applicable	never
	5.94	4.2%		13 years
	6.60	6.0%		12 years
	7.30	7.8%		11 years
	8.40	10.5%		9 years
100% debt *at 8% interest*	4.80	3.2%	Not applicable	14 years
	5.94	7.4%		10 years
	6.60	8.5%		10 years
	7.30	10.4%		9 years
	8.40	14.0%		7 years
				Equity payback
Scenario B: 50% debt *at 13% interest* 50% equity	4.80	3.7%	4.9%	13 years
	5.94	7.2%	9.9%	11 years
	6.60	9.1%	12.7%	9 years
	7.30	11.0%	15.7%	9 years
	8.40	13.9%	20.4%	6 years

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