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Complementarity of Wind, Solar and Hydro Resources for Combating Seasonal Power Shortage in Nepal

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Abstract: Power generation, predominantly coming from run-of-river type hydropower plants, has fallen short of demand in Nepal. The shortage is acute during the dry post-monsoon months, when river flows are at their minimum. Huge amount of fossil fuel is used to generate power during shortages. Large hydroelectric projects are under construction, but many natural and man-made factors have delayed their construction by years. A survey of the measured wind speed, incoming solar radiation and river water discharge at various sites in Nepal has been done. Wind and solar energy potentials have been found to be high during the dry season, when hydropower generation is low. River flow, and consequently, the hydropower generation are high during the monsoon season, at which time wind speed and solar radiation are very low. With a well-planned transmission system, wind and solar power could compensate reduced generation from hydropower plants during the seasons with low water flow in rivers. In the short term, installing wind and solar energy technologies- which have short gestation periods- is observed to be the right choice. Such a power system, with wind and solar power complementing hydroelectricity, has the potential to save capital and reduce carbon emissions for Nepal.

Keywords: discharge; speed; insolation; gestation; power; Nepal; shortage; carbon; potential; capital

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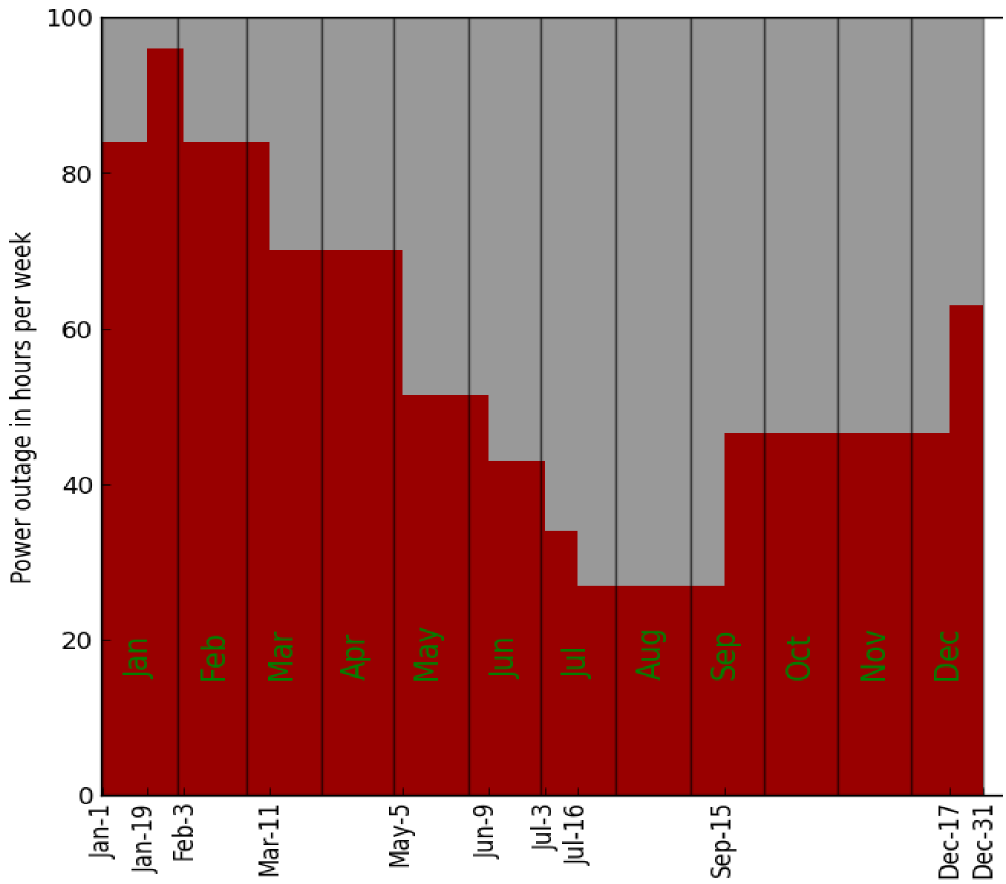
1. Introduction

1.1 Power Availability

The availability of power in Nepal can be best seen from the hours of power cut imposed round the year. Figure 1 shows that grid-electricity consumers in Nepal faced at least 28 hours of weekly power cuts (during July-September 2013). Commonly known as load-shedding, the power cuts peaked at 97 hours/week on January 19, 2013. Hence, consumers in Nepal have had to tolerate power cuts all round the year, although varying in duration with seasons. In this light, the issues of energy sustainability and power reliability necessitate a thorough study with useful recommendation for a secure power future of the country.

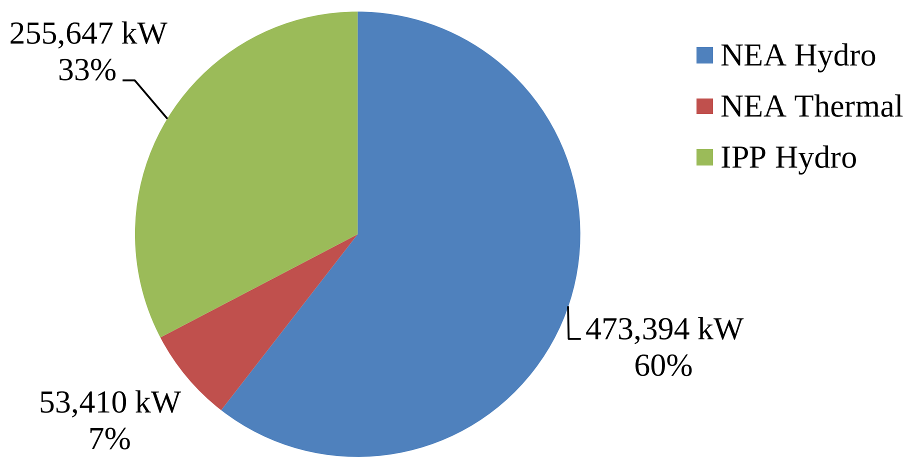
Figure 1. Load-shedding hours/week announced for a typical area of the capital Kathmandu in 2013 (Source: Notices updated at [1])



1.2 Sources of power

Broadly speaking, there are two parties that commercially generate power in Nepal: Nepal Electricity Authority (NEA), a government owned agency responsible for generation, transmission and distribution, and Independent Power Producers (IPP), which comprises of private entrepreneurs. By the end of the fiscal year 2013-2014, 93% of domestic power installations connected to the grid was hydropower plants (Figure 2). Thus, Nepal is a predominantly 'hydropowered' country. A small percentage (7%) of domestic generation came from thermal plants owned by NEA [2].

Figure 2. Distribution of Nepal's domestic grid-connected power installations (by capacity in kilowatts) in 2013-14 [2]



Note: A fiscal year (FY) in Nepal typically starts in mid-July.

Table 1 also shows the dominance of hydropower plant production over thermal generation in NEA's total electricity generation.

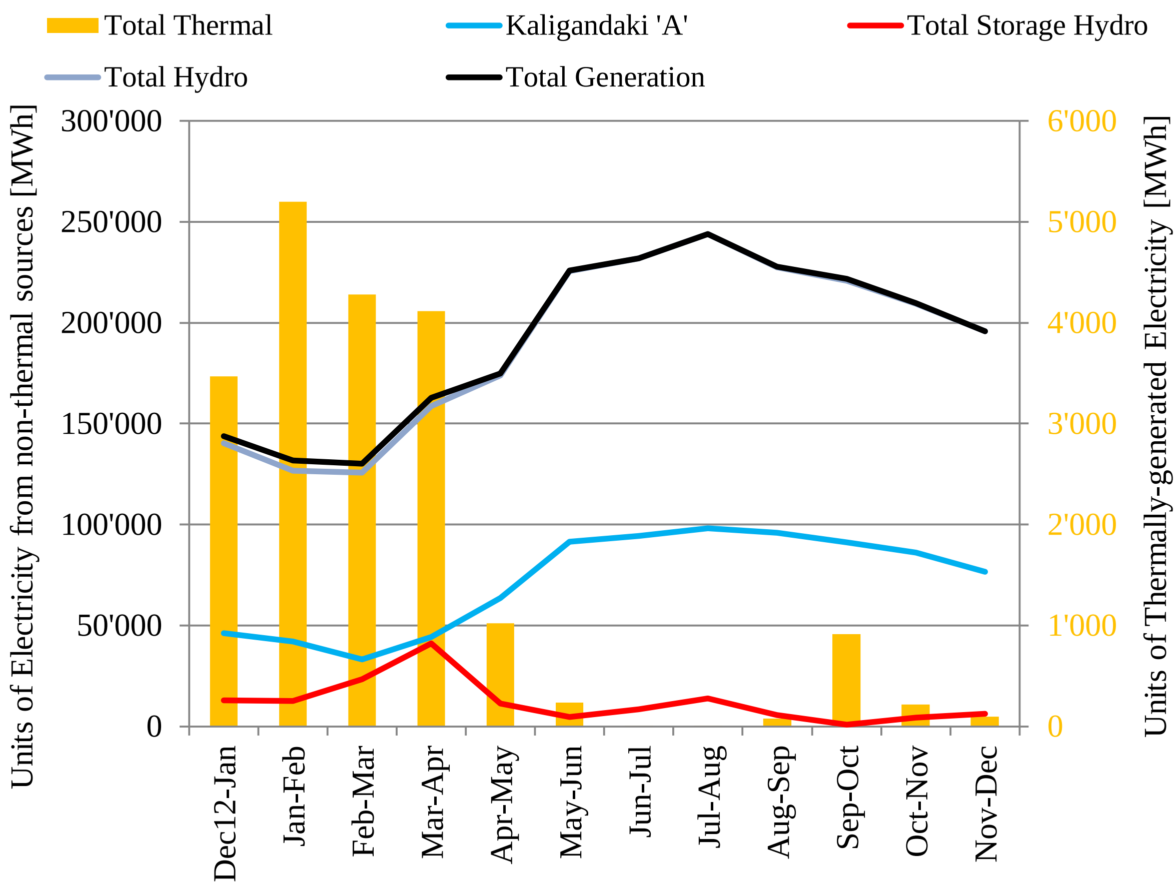
Table 1. Share of thermal and hydro generation of NEA transmitted to the grid in different years [2-5]

Fiscal Year (FY)	Thermal Share of Total NEA Generation Units	Hydro Share of Total NEA Generation Units
2010-11	0.2%	99.8%
2011-12	0.1%	99.9%
2012-13	0.8%	99.2%
2013-14	0.4%	99.6%

Since two-thirds of the grid-connected hydro installations is owned by NEA (Figure 2), and almost all of the generation by NEA is from hydro-plants (Table 1), it is worth studying the generation pattern of the NEA-owned power plants, whose data is easily available in its annual reports.

Shortage of power is acute during certain months of the year in Nepal (Figure 1), so it is interesting to look at NEA's monthly energy generation pattern for a year. NEA's published monthly data follows the Nepali Bikram Sambat Calendar, in which there are twelve months, but the start and end dates of the twelve months do not coincide with those of the Gregorian (English AD) calendar. In fact, the Nepali month starts halfway through the English month. Thus, the monthly plots in Figure 3 encompass two months (e.g. Mar-Apr) for each data point.

Figure 3. A picture of the power situation in Nepal in 2013 as indicated by NEA generation [2](p. 23), [3](p. 30)



Note: Dec12 means December of 2012 in Figure 3. All other months on the label of the horizontal axis in Figure 3 are for the year 2013.

It is seen from Figure 3 that the trends in the total generation, total hydro generation and the Kaligandaki ‘A’ plant generation (the largest to date with 144 MW capacity), all are similar when viewed month-by-month. This indicates that the many run-of-river hydropower plants, Kaligandaki ‘A’ being the biggest one, determine the monthly and seasonal power production pattern of NEA. Figure 3 also shows how the energy generation contribution from storage type hydropower plants is very low most of the months. It can be easily calculated from Figure 3 that the difference between the peak (in Jul-Aug) and the minimum (in Feb-Mar) values of the total generation of NEA during the year 2013 is about 100,000 MWh. This huge gap is obviously undesirable, so NEA has been attempting to supplement the low power production in February-March through thermal plants and storage hydropower plants. Figure 3 shows that total generation from storage hydropower plants, along with thermal generation, are increased around the same time as total generation (as well as total hydro generation) reaches the lowest. Obviously, this was done to reduce the demand-supply gap in the months of January, February and March. However, the existing storage hydropower projects and the thermal plants are not sufficient at all, resulting in a huge deficit. This is obvious in the load-shedding patterns of Figure 1, with more than eighty hours/week of power cuts in the winter (Jan-Feb) and severe load-shedding in spring (Mar-Apr) as well.

1.3 Suggested Solutions

As a result of massive power cuts in winter and in spring, authorities and experts have been bound to think of power sustainability plans in Nepal. The most popular one, though, is the development of large hydropower plants (of at least several hundred MWs in capacity) with the highest priority to building plants with storage dams [2](p. 11). This plan, however, needs proper evaluation in the context of Nepal, and other alternatives need to be examined as well.

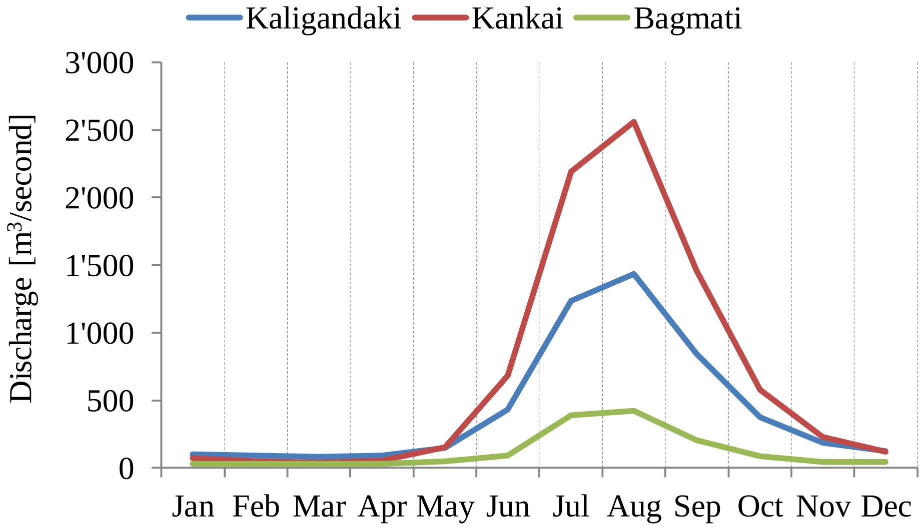
1.4 Hydro Problems Native to Nepal

1.4.1 Discharge Seasonality:

There is an interesting quantitative link amongst rainfall, river discharge, and hydropower production in Nepal. In general, 60-90% of rainfall experienced in Nepal is during monsoon (June to September) [6](p. 8). Monsoon rainfall is an important source of water for all the river systems of Nepal: 72 percent of rainfall flows as surface run-off from basins [7]. In Nepal, 10.7 percent of river basin areas are located in permanent snow regions (5000 m and higher), 17 percent in seasonal snow regions (between 3000 m and 5000 m), and the remaining 70 percent are in no-snow regions [7].

Since studies have revealed that monsoon rains contribute largely to the flows in Nepal, the flow or the discharge in rivers will vary with the amount of rainfall over the months. This means, usually, in June, July and August, river discharge is very high. This has been observed in many rivers in Nepal [8](p. 163), [9](p. 4), [10](p. 37), with three curves showing the pattern in Figure 4.

Figure 4. Average monthly discharge (in m^3/s) of three rivers of Nepal (adapted from [8-10])



The power output of a hydroelectric plant is described by the relation [11]:

$$\text{Power} \propto Q \cdot H \tag{1}$$

where, P is the generator output in kilowatts, Q is the water flowing through the turbine (discharge) in m^3/s (cubic meters per second) and H is the net head of water in meters. Equation (1) shows that the power produced by the water turbine is directly proportional to the amount of water in the flow. This implies that power production potential of many hydropower plants in Nepal is high during high-discharge months. Since run-of-river type hydropower plants contribute the most to NEA's generation, it is clear that Nepal's hydro-dominated grid is vulnerable to seasonal monsoon rainfall patterns and amounts. Run-of-river type plants will depend on the seasonality and the magnitude of rainfall every year. Additionally, storage type plants also depend upon monsoon rainfall to fill the reservoirs, thereby making them susceptible to the variations in total summer monsoon rain in the catchment area.

1.4.2 Fluctuating annual production:

Fluctuating annual energy output over the past decades has been another problem of the main storage type hydropower plant in Nepal. The fluctuation in the annual electricity generation of the 60 MW Kulekhani-I plant can be best viewed year-by-year in Figure 5. The difference in the annual energy production of the plant between the highest yield year and the lowest yield year is 1.25 times the mean annual production for the period 1982-2009 [12]. In terms of units of energy, this difference is 178,388 MWh.

Figure 5. The Total Annual Electricity Generation (MWh) from Kulekhani-I during 1982-2009 (green shows the minimum, red the maximum and orange the mean for the period) [12](p. 58)

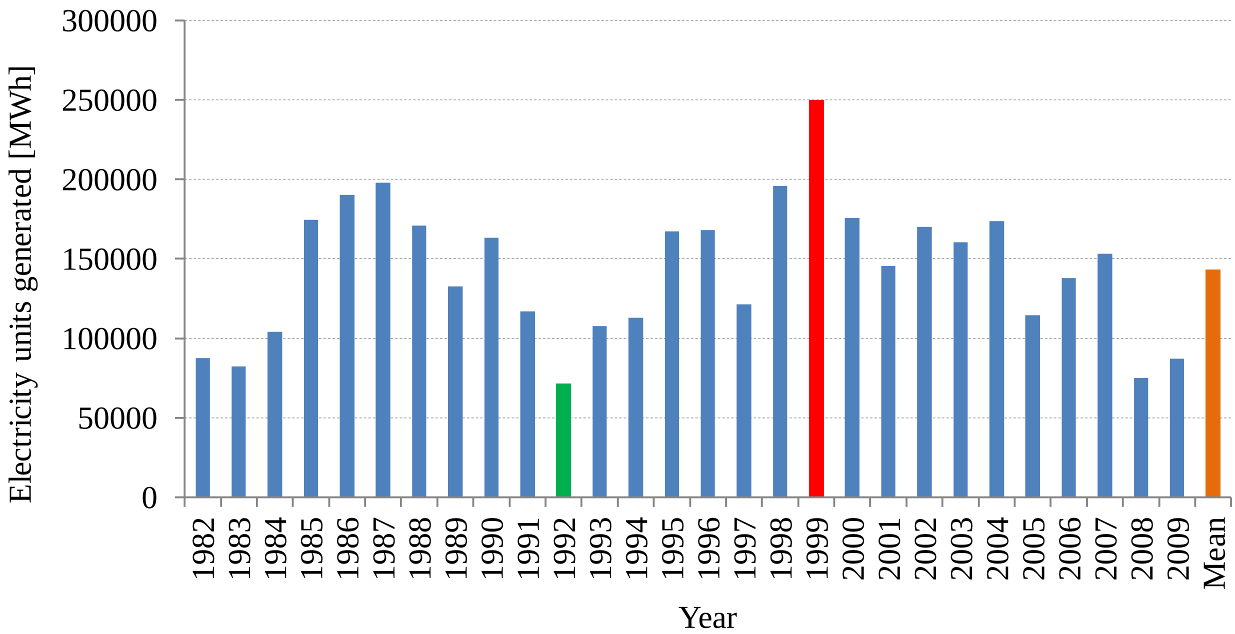


Figure 5 shows that the maximum generation (in 1999) is more than three times the minimum generation recorded in 1992.

Table 2. Generation statistics for Kulekhani-I for the period 1982-2009

	Generation in MWh	Magnitude relative to the Mean
Mean	143,155.50	1.00
Maximum (in 1999)	249,680.00	1.74
Minimum (in 1992)	71,292.00	0.50
Range	178,388.00	1.25
Standard Deviation	43,623.52	0.30

Hence, building storage plants with the intention of bridging the gap between demand and supply may not always have the desired effect, especially if annual fluctuations in production are significant.

1.4.3 Potential Landslide Effects:

River Bhotekoshi was accidentally blocked and dammed by a landslide in summer 2014 in Jure, Barhabise. The result was damage in power infrastructure (two hydropower plants, Sanima and Sun Koshi, by name) by the resulting flooding. Two gates of the Sun Koshi Hydropower dam were washed away and the power house of the Sanima Hydropower Project was inundated [13]. Nepal is already a water-induced disaster prone area. Data based on the period 1983-2010 shows that, every year, an average of 283 people are killed due to just flood and landslides in the country [14](p. 29). Thus, a repeat of potent landslides and flooding in large hydropower stations in Nepal cannot be ignored. Such incidents will result in abrupt power interruptions, which can only aggravate the existing power deficit in Nepal.

1.4.4 Prolonged development:

Timeline of development of the 144 MW Kaligandaki ‘A’ plant is shown below [15]:

1979	Feasibility study of the project was carried out with financial assistance
1991	Previously prepared feasibility study was updated
1993	Detailed engineering design and preparation of tender documents commenced
1993	Preparatory works like access road construction started with internal resources
1997	Construction of hydropower components started under loan assistance
2002	Project construction work completed
2002	Generation unit tested in May
2002	Commercial production began from August

The timeline shows that it took 23 years from the feasibility study, and 5 years from the start of construction of hydropower components, to actually begin commercial production. Moreover, in many steps, financial assistance and loans from international development partners was necessary [15]. This is a reflection of the slow development of hydropower projects in Nepal. A project of several hundred Megawatts, especially one with reservoir, would take a lot of time for completion. This would not be desirable in energy planning, especially when quick short-term measures are needed for shortening power cut hours. Thus, alternatives to hydropower should also be considered in the short term, keeping in view some of the critical downsides of the slow trend of development of projects.

2. Results and Discussion

There are alternatives to the 'all-hydro' strategy being preferred in Nepal. Two renewable energy resources, solar radiation and wind, seem to be promising alternatives for Nepal.

2.1 Solar Potential

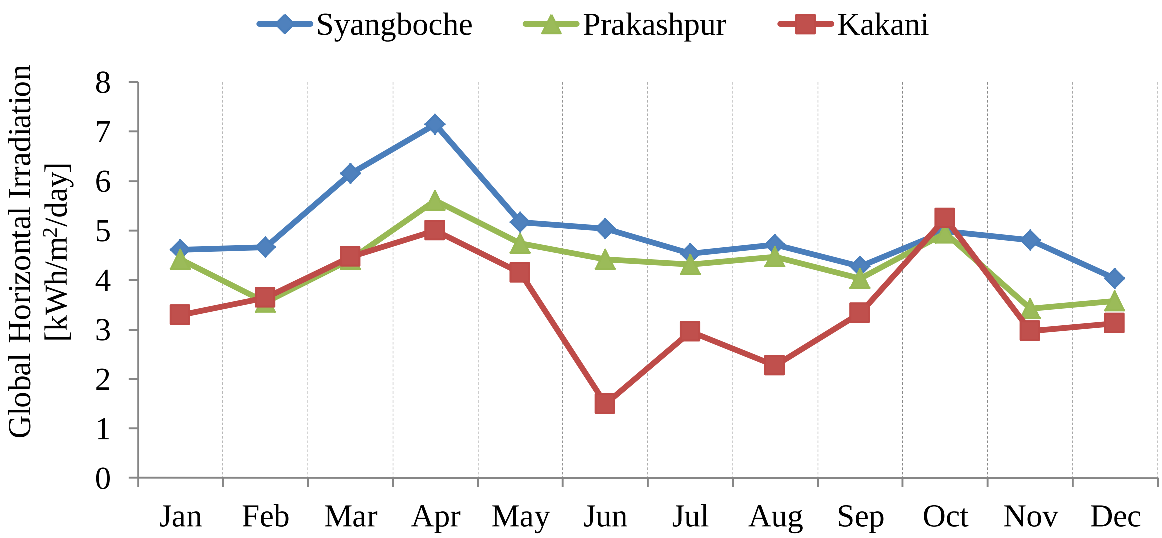
Global Horizontal Irradiation (GHI), or Global Horizontal Solar Irradiance, is a very important value for the determination of the solar energy potential of a particular site. The ground-measured GHI values are available for three stations: Syangboche, Sunsari and Kakani, for different time periods, as Table 3 shows [16](p. 5).

Table 3. Sites and the respective durations over which GHI was measured and averaged

Site	Location	Months, Year
Syangboche	27.81N, 86.71E (3700 m altitude)	January 2002 to December 2002
Prakashpur	26.64N, 87.15E (67 m altitude)	June 2001 to May 2002
Kakani	27.73N, 85.15E (2064 m altitude)	June 2000 to May 2001

The average monthly GHI values for all three sites are high for the months March-May, and become very low during November-January, as Figure 6. Thus, the prospects of generating energy from PV technologies remain high during the spring but low in winter. It should be noted that in Figure 6, all the 12 months are not necessarily of the same year; Table 3 should be referred to for the exact year to which the month belongs in each of the three sites.

Figure 6. Monthly average ground measured Global Horizontal Irradiation (GHI), kWh/m^2/day [16]



2.2 Wind Potential

Mathematically, the power available in the wind, as seen by a wind turbine, is proportional to the air density, to the area swept by the turbine and to the cube of incoming wind speed [17]:

$$\text{Power} = \frac{1}{2}\rho A v^3 \tag{2}$$

where ρ is the air density, A is the area swept by the rotor and v is the wind speed. As Equation (2) shows, the wind speed can greatly alter the power available in the wind, assuming a constant area (being swept by the wind turbine rotor) and constant air density. Even when the air density is changed, power in the wind is not dramatically affected as it would when wind speed is changed by the same proportion.

When the wind speed (at a height of 20 meters) of three places in Nepal is studied, the monthly mean of the wind speed (averaged over 1-hour intervals) is found to be as seen in Figure 7.

Figure 7. Monthly average wind speed in m/s for three sites [16]

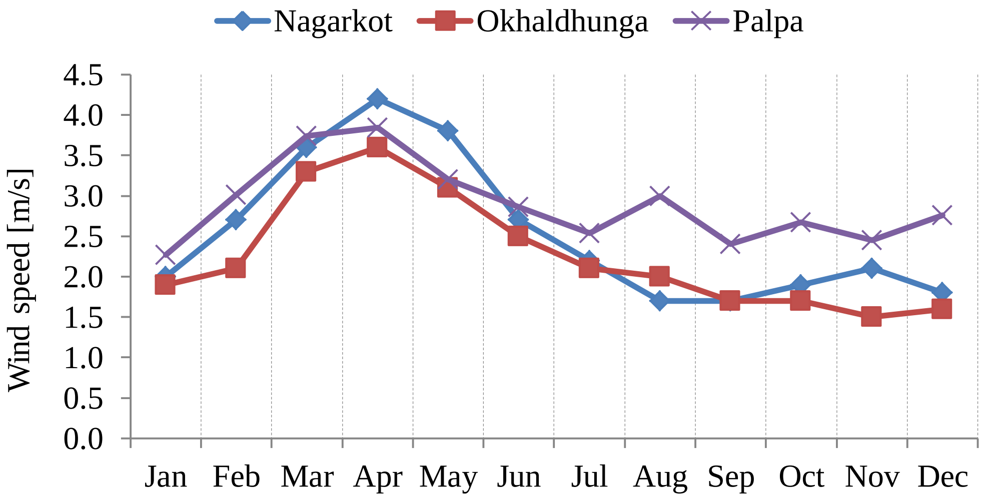


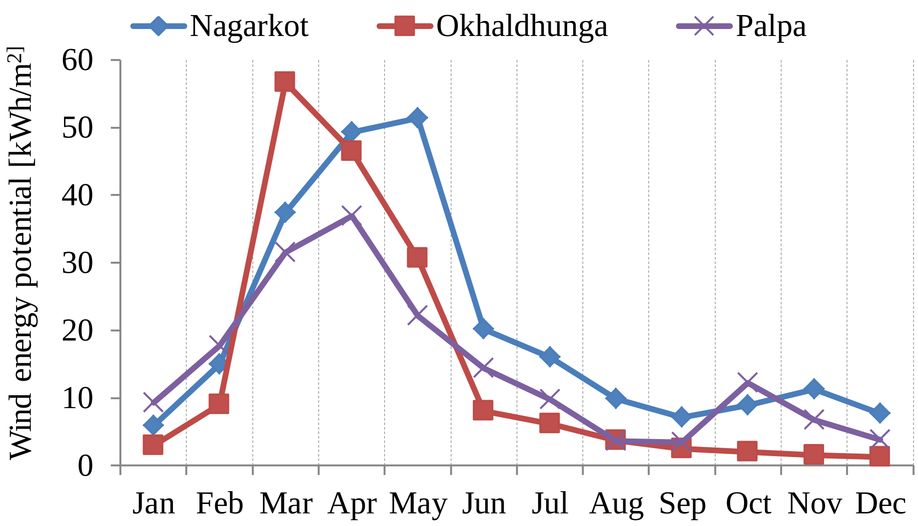
Table 4. Sites and the respective durations over which speed was measured and averaged [16]

Site	Location	Months, Year
Nagarkot	27.70N, 85.52E (2163 m altitude)	January-December 2003
Okhaldhunga	27.32N, 86.50E (1720 m altitude)	January-December 2004
Palpa	27.86N, 83.53E (1418 m altitude)	September 2005 – August 2006

The wind speed is very high in March, April and May, compared to the winter months of November, December and January. Besides wind speed, the wind resource of a vast region or a country is also mapped in terms of the wind energy potential in kWh/m^2 per year [18].

The wind energy potential of the three places shown in Figure 7 have been plotted in Figure 8, for all twelve months. Here again, like with wind speed, March, April and May show the highest potential. Similarly, November-January exhibit low wind energy potential in the three places.

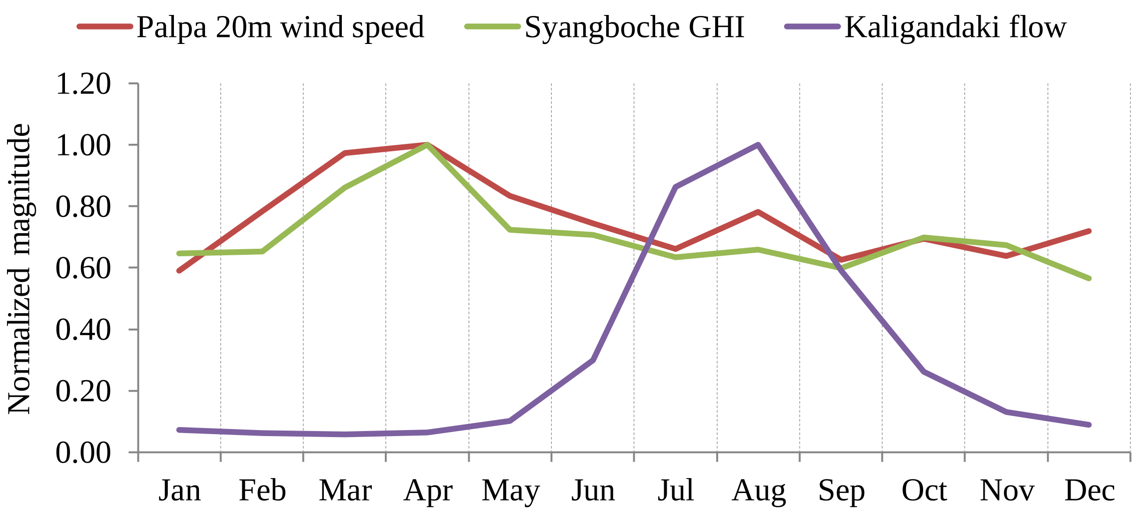
Figure 8. Wind energy potential in kWh/m^2 per month at 20m height [16]



2.3 Comparison

From Figures 4,6,7,8 above, it is clear that wind and solar energy can potentially compensate the deficiency in energy production during winter and spring in Nepal. Yet, it would be necessary to show the monthly patterns of wind speed (m/s), solar radiation (kWh/m^2/day), and river discharge (m^3/s) in the same graph. Since the magnitudes and units are different for these quantities, each will be normalized by its respective peak value occurring in the monthly charts just to make the comparison in one chart easy. Also, only one site will be chosen for the comparison of each of wind speed, solar radiation and river discharge to avoid cluttering in the comparison graph (Figure 9).

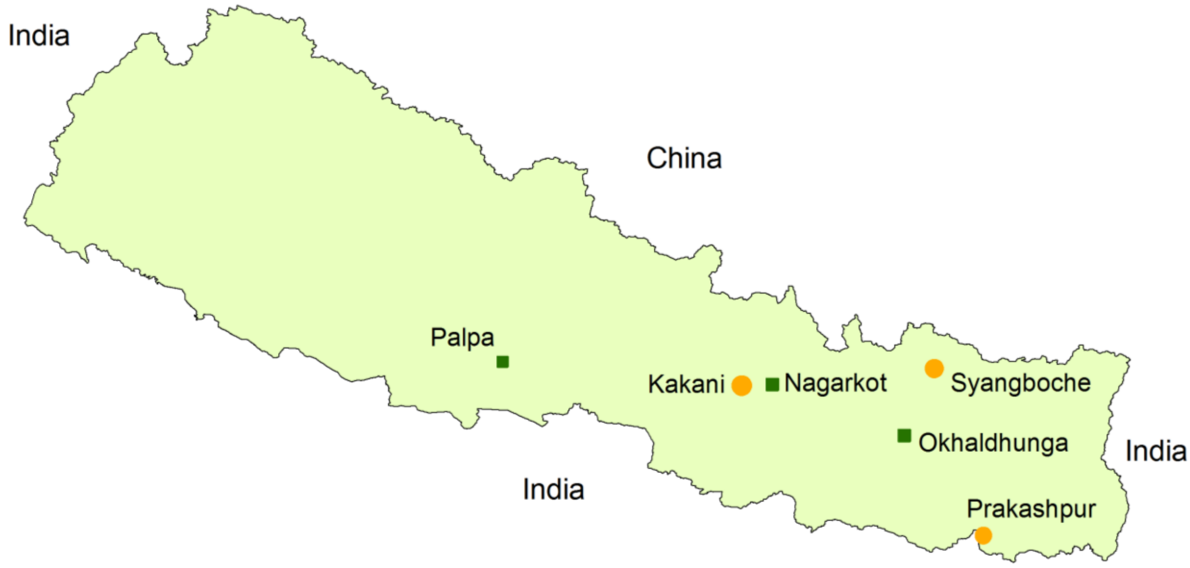
Figure 9. Comparison of the three energy resources- wind, solar, hydro- on a monthly basis



Clearly, the wind speed and the solar irradiance peak when the river discharge is very low and vice versa. Such a behavior of the energy resources can be made useful by utilizing all three resources throughout the year. Instead of heavily using thermal power plants or shedding load in March-May, it is effective to just harness the solar and wind resources then, as they seem to complement the hydro resources during the year.

Another important thing to note is that the places selected for wind and solar power generation are distributed round the country, as shown in Figure 10.

Figure 10. Measurement sites that recorded wind and solar parameters (green squares- wind; yellow dots- solar)



Thus, to harness the three complementary energy sources, it is necessary to have a good transmission network in the country, so that storage is unnecessary. There are two options to be used for transmission- High Voltage Alternating Current (HVAC) and High Voltage Direct Current (HVDC). HVAC is already being used widely in the country but HVDC has not been considered yet. The possibility of adopting an HVDC transmission system should also be considered, given that HVDC could transmit current over very long distances with fewer losses than AC. Also, HVDC needs fewer cable lines that HVAC [19].

2.4 Fossil Fuel Costs

The cost structure of fossil fuel for the government agency Nepal Oil Corporation and for the people is shown in Table 5.

Table 5. Sample fossil fuel purchasing scenario [20]

Price type	Price (in Nepali Rupees) per liter	
	Petrol	Diesel
Purchase price in Raxaul, India on Sep 16, 2014	74.05	77.02
Total cost price for Nepal Oil Corporation	121.18	104.43
Retail selling price in the capital Kathmandu	134.50	105.50

If we consider an exchange rate of 100 Nepali Rupees = 1 US$, then we see that per liter of diesel, US$ 1.055 is paid by the public. If the UPL (units per liter) of diesel is assumed to be 3.2 kWh, fuel-wise, energy cost is US$ 0.33/unit. This excludes operation and maintenance cost of the thermal plants owned by NEA. Compared to the cost of electricity in the grid for homes in Nepal, this is about 4 times more expensive. Also, since 19,623.58 MWh units of electricity were shown to be consumed in

2013 [2-3], the expenses for diesel fuel used for power generation are calculated to be US$ 6.47 million. Thus, NEA could save more than 5 million US dollars annually on diesel fuel alone, if alternatives to diesel generators could be found. This is a strong case for harnessing wind and solar energy resources in Nepal.

2.5 Carbon emissions

The important parameter to use when it comes to Green House Gas (GHG) emissions is the EF (Emission Factor) of the diesel-powered thermal plant. EF would give the kilograms of the GHG per liter of diesel fed to the thermal plant. Thus, a simple calculation would reveal the total annual GHG emission from the thermal plant in use in Nepal.

The choice of emission factors has an impact on the results of the GHG emissions calculation. ISCC has developed a list of relevant emission factors based on experience from a two year ISCC pilot phase and from the operational phase in 2010 [21].

According to the ISCC [21], an EF of 0.87 kgCO2eq/kWh is used as a reference for a diesel-powered generator, assuming electrical efficiency of 36% [21]. Going by this, 19,623.58 MWh of thermally generated electricity units would yield 17,072,514.6 kgCO2eq of emissions in 2013 in Nepal.

4. Conclusions

Nepal has been spending a huge proportion of budget on importing fossil fuel to lessen the present power deficit, and also on hydropower construction to meet the future electricity needs. Yet, there are problems with both these actions. The externalities- capital and environmental- of generating power from fossil fuel are obvious. However, even hydropower plants in operation thus far have exhibited problems serious enough to hinder alleviating the power crisis of Nepal. One of those issues is the overrun of the project development and construction by years and even decades. This hints at the possibility of cost overrun as well. Thus, with such slow development of hydro projects, for at least a decade or so the power crisis will not be mitigated. This problem could be addressed by the adoption of solar and wind power technologies in suitable sites. Firstly, in several places of Nepal, it has been found that solar and wind energy resources peak when hydropower generation is very low and vice-versa. Secondly, solar and wind farms do not take decades to come into operation. They have relatively short gestation periods. It is a common practice to build wind farms with a design life of twenty years. This design life perfectly fits the power puzzle of Nepal, as experience has shown that the hydropower project of capacity 144 MW took some twenty years to complete. Thus, if a transmission system with extensive network connecting all the solar and wind energy hotspots is built, the acute power deficit in the dry season can be mitigated.

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Conflict of Interest

The author declares no conflict of interests.

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