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Hydrogen Production Assessment from Surplus Hydropower Potential In Nepal

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Abstract
Nepal is one of the richest countries in water resources with huge potential for hydropower generation. Most of the hydropower is ROR-type with a low-capacity factor due to which energy imbalance is seen. The majority of the energy share in the transport, industry and power sector is fulfilled by fossil fuels which are imported from second countries. This causes a great threat to national energy security. A huge amount of national GDP is used to import fossil fuels that are used for various applications which is also the major cause of global emissions. The world is shifting towards green energy sources and various countries are imposing regulations for their use in the energy mix. Green hydrogen could be one of the promising clean energy sources that can be produced and stored, unlike electricity. Hydroelectricity generation in the country is increasing gradually but the consumption is not gaining pace which suggests that a great amount of electricity may be surplus in the coming future. Surplus electricity can be used to generate hydrogen, potentially offering an economical alternative to other energy sources. This study forecasts the electricity demand, and generation up to 2050 and estimates the surplus electricity for hydrogen production at different scenarios. Hydrogen production increases gradually which ranges from 136,372 tonnes to 681,859 in the year 2030 while using 20% and 100% of surplus electricity respectively whereas it reaches 290,290 tonnes to 1,450,450 tonnes in 2050 while using 20% and 100% of surplus electricity respectively.

Keywords
Hydropower, Hydrogen,Green energy ,Surplus electricity

1. Introduction

The rise in global population has drastically increased the consumption of fuel for energy over some decades in various sectors. According to the International Energy Agency, the overall energy consumption in the world in the year 2019 was 418 million TJ out of which fossil fuel has the highest share whereas industry and transportation consumed the highest energy of around 58% of the total energy [1]. Conventional fossil fuel covers around 80% of the present energy demand which is a major cause of CO_2 emission and GHG [2]. Carbon dioxide emissions are responsible for $2/3^{rd}$ of the global emissions. The energy-related global CO_2 emission in 2022, is about 36.8 Gt, which is grown by 0.9% from last year [3]). Global emission has soured at an alarming rate. Global warming has become a severe issue in the 21^{st} century which results in several impacts such as climate change; impacts to an extent that has never been seen before in history. Addressing climate change and its impacts, in 2015 Paris Agreement was adopted to limit the global temperature increase to 1.5^0C above pre-industrial levels and to reach net zero emission by 2050. With concern to that, Nepal submitted its second Nationally Determined Contribution to increase the share of renewable energy by 15% in the entire energy mix [4] and focused its activities towards sustainable development goals [5].

Several countries are making progress toward adopting cleaner sources of energy. It is anticipated that global investments in clean energy will increase by 24% between 2021 and 2023, reaching a total of USD 1.7 trillion [3]. Alternatives are analyzed, Hydrogen has been in the limelight which could reduce the emissions from transport, industrial, and commercial sectors globally. Hydrogen is considered a future fuel, is abundant in nature, and sourced from various methods. It's remarkable attributes include a high heating value, ranging from 120-142 MJ/kg [6], in contrast to gasoline's 44MJ/kg, making it approximately three times as energy-dense without emitting carbon dioxide. Green hydrogen is emerging as an alternative energy carrier with near-zero carbon emissions. However, the carbon footprint of hydrogen production depends on the source, method, and technology used. Hydrogen derived from fossil fuels is referred to as "grey hydrogen," while hydrogen produced from fossil fuels with carbon capture is termed "blue hydrogen." "Green hydrogen" is used for hydrogen produced from renewable sources [7]. Green hydrogen production primarily involves gasification of biomass and water splitting through electrolysis using renewable energy sources such as wind, solar, and hydro-power. Hydrogen produced this way can be stored through pressurization or liquefaction for use in industrial heat, transportation, power generation, as well as for commercial sectors, providing a versatile energy solution. The combination of flexible production and combustion methods and its low emissions profile makes hydrogen an appealing and promising fuel for the future.

The consumption of hydrogen is clean but the current production of hydrogen is still emission-intensive. About 94 Mt of hydrogen was produced in 2021, a 5% increase from the previous year [8]. Only 4% of hydrogen was produced with the electrolysis process, remaining being produced using natural gas and other fossil fuels. Furthermore, only 33% of the electricity required in this process comes from renewable energy, leading the share of green hydrogen to a tiny 1% [9]. Green hydrogen technology can play a crucial role in reducing peak load demand and flattening the load curve. It acts as an energy storage solution for hydroelectricity during off-peak periods, making it available for use during peak demand times.

Technically Nepal has 72.54 GW hydropower capacity, whereas only 32.68 GW is techno-economically feasible [10]. The addition of a record-breaking 735 MW of hydropower has made the total 2190 MW of installed capacity in the country in the annual year 2021/22 which is only around 6.5% of total economic capacity. Total electricity availability in the system reached 11,064 GWh where 5234 GWh (~47.3%) was generated by NEA (Nepal Electricity Authority) and subsidiaries while 4,286 GWh (~39%) was procured from IPP (Independent Power Producers (IPPs). Additionally,1,543 GWh was imported from India which decreased by 45% from the previous year [11]. The additional electric plants are constructed actively by IPP sector, NEA, and its subsidiaries. Around 8895.9 MW projects are under construction phase whereas 10,912.9 MW projects are planned with survey licenses while thousands of MW projects are under government project banks [12]. Nepal aims to achieve a hydropower generation capacity of 3,000 MW within the next 3 years, 5,000 MW within 5 years, and further expand to 15,000 MW within the span of a decade. [13]. With the current energy consumption scenario around 3000 MW of produced electricity is expected to be in surplus by 2030 and the demand and supply gap is expected to increase every year. Electricity production in Nepal is mainly based on the Run-off River (ROR) type, around 90% due to which the present hydropower doesn't run at full capacity because of a shortage of hydro energy during the dry season whereas during the wet season, excess hydro energy is curtailed without producing power resulting in a low-capacity factor. Due to this reason, NEA is more focused on the storage type of hydropower. But the economic weightage of a storage facility is quite high.

The levelized cost of hydrogen production varies from $4 to $6, depending on production time and tariff rates of electricity in international market [14]. Nepal holds a competitive advantage over other nations due to its ability to utilize excess energy, which would otherwise go to waste, for green hydrogen production. This utilization can significantly reduce energy costs. If surplus energy is offered at reduced rates, the cost of producing 1 kg of hydrogen can drop dramatically to between US$ 1.17 and US$ 2.55 under various time-of-day tariff rates [15]. Utilization of surplus energy for hydrogen production and using hydrogen in various energy intensive sectors could be one of the reasonable options in the coming future. That could prevent the importing of fossil fuels worth billions of rupees, mitigate energy diversification and security problems, and prevent emissions from various sectors. For effective and rapid development in the energy sector a study must be done that could assess the surplus electricity for the hydrogen production and their application in various end uses like industry, transport and the power sector.

A study was carried out about the potential production of hydrogen from surplus electricity during off-peak periods that could replace conventional fossil fuel in 2008 [16] along with the laboratory production of hydrogen in Pulchowk Campus. The result indicates that around 27,000 to 140,000 tonnes of hydrogen could be produced using 20% and 100% surplus electricity respectively which could replace 25% of petrol, diesel, and kerosene demand in 2020. A new and advanced study is required with time and the development of technology. Recently in 2021, another study was carried out about the green hydrogen potential from surplus hydro energy using energy capacity balance projection data. This study indicates that 63,072 tonnes to 3,153,360 tonnes of hydrogen can be produced with 20% to 100% utilization of surplus energy in 2030 [15]. The study was limited to 2030 and a different approach toward surplus energy could be used thus a new study could provide a long-term vision towards hydrogen production using surplus energy.

This study estimates the electricity surplus by calculating the electricity generation and demand at different years considering 2022 as the base year. The surplus electricity is utilized to estimate hydrogen production in different scenarios.

The fifteen plan

The Plan defines various plan strategies and goals that the government has undertaken in various sector for the prosperity and happiness. The fifteenth plan has aimed to take Nepal to middle income country by 2030 along with advanced country by 2043 AD. It has formulated long-term vision to realizing the goal of "Prosperous Nepal, Happy Nepali", which is a 25-year long term vision. The government will construct various plans, policies and programs to achieve the economic, social and physical infrastructure targets. For the all-round development, the sustainable development goals are localized and internalized to federal, provincial and local level. The targets projections and estimation which are listed here are more likely to be achieved in the future as the government itself sets them in a practical and feasible way. The target that has been taken in per capita electricity consumption and electricity generation is given in table 1 [17]. The Ministry of Energy, Water Resources and irrigation is the responsible agency for achieving the target.

Table 1: Electricity consumption and generation target

Year	Per capita electricity consumption	Electricity generation (installed capacity)
2019	245kWh	1250MW
2024	700kWh	5820MW
2030	1500kWh	15000MW
2044	3500kWh	35000MW

2. Methodology

2.1 Electricity generation

Electricity generation potential is calculated based on the fifteenth plan set by the National Planning Commission, considering 2022 AD as the base year. The actual present electricity generation capacity is used for the base year. The data given (installed capacity in MW) in Table 1 is represented in the chart with given years and a new chart of installed capacity is created based on the initial chart with the base year followed by 2025 and the consecutive years with 5-year gap up to 2050 AD. The total electricity generation in GWh is calculated by multiplying the installed capacity by the overall plant factor. The plant factor of the base year is used for the entire calculation which is 64.56% [11].The formula that is used to calculate the electricity generation is given by;

$$EG = [(IC \times 64.56\% \times 365 \times 24)/1000] \text{ GWh}$$

Where EG is electricity generated, and IC is installed capacity in MW.

2.2 Electricity Demand

Electricity demand is also calculated based on the fifteenth plan. The data given (per capita electricity consumption) in Table 1 is represented in the chart with given years and a new chart is created based on the initial chart which give per capita electricity consumption with the base year as 2022 followed by 2025 and the consecutive years with 5- year gap up to 2050 AD. The electricity demand is calculated by multiplying per capita electricity consumption with the forecasted population. The population growth rate considered is based on the current population growth rate of Nepal and follows a similar pattern of projected growth rates as published by the United Nation Department of Economic and Social Affairs (UNDESA) [18]. The formula that is used to calculate the electricity demand is given by;

$$ED = \left[N \times \frac{PC}{10^6}\right] \text{ GWh}$$

Where ED is electricity demand, N is population, and PC is per capita electricity consumption.

2.3 Surplus Electricity

Surplus electricity is remaining electricity that is assumed to exist after fulfilling the electricity demand of the entire nation which if not exported to foreign countries could be used for hydrogen production at cheaper rates. Surplus electricity is calculated from the demand and generation of electricity in the respective year. The formula that is used to calculate the surplus electricity is given by;

$$SE = [EG - ED] \text{ GWh}$$

Where SE is surplus electricity

2.4 Hydrogen production potential

The hydrogen production potential is based on the expected surplus electricity that could be used for the production of hydrogen. The energy required other than production such as storage, purification, transportation, etc. is not considered in this study. The energy required for the unit kg of hydrogen production is considered constant and the electricity required for the electrolyser is taken 50.067 KWh. Different five scenarios are considered where different share of surplus electricity is considered to be used for the production of hydrogen. In Scenario 1, 20% of surplus electricity is used for hydrogen production while in Scenario 2, 40% of surplus electricity is used for hydrogen production. Likewise, Scenarios 3,4, and 5 are created which use 60%, 80%, and 100% of surplus electricity respectively. The formula that is used to calculate hydrogen production is given b;

$$HP = [SE \times SP/(50.067 \times 1000)] \text{ tonnes}$$

Where SP is the scenario percentage

3. Results and discussion

3.1 Electricity generation estimation

The future electricity generation is estimated based on the targets on installed capacity set fifteenth plan, SDG and NESV. The electricity generation potential in different years up to 2050 is as shown in Figure1.

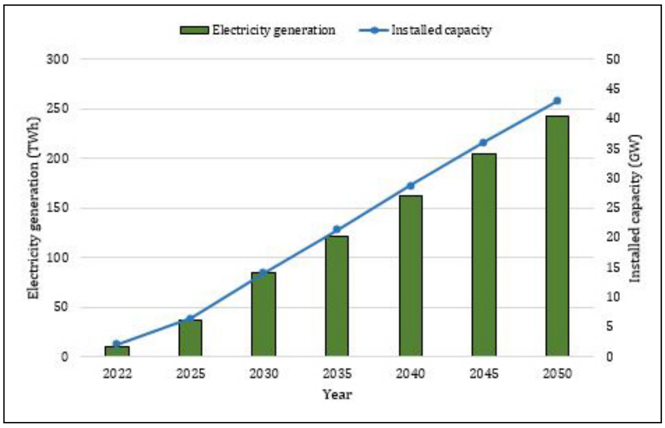

Figure 1: Electricity generation forecast

The electricity generation profile shows that the generation continues to grow.The electricity generation in 2025 will be around 37 TWh which is more than thrice the generation in 2022 which is around 9.5 TWh .The electricity generation growth rate gradually decreases as the installed capacity is estimated to reach the economically feasible hydropower capacity in 2050 generating around 243 TWh of electricity annually.

3.2 Electricity consumption forecast

The consumption forecast in different years in Nepal is as shown in Figure 2 which is calculated by using the equation explained in methodology section.

The electricity consumption in the base year was about 8.82 TWh, With increase in population and per capita electricity consumption the total electricity demand will also increase. However, the growth rate of electricity demand is estimated to decrease gradually with the years to pass. The demand is estimated to rise up to 50.69 TWh by 2030, 101.81 TWh by 2040, and eventually 170.51 TWh by 2050. The rate of consumption has been estimated to rise rapidly up to 2030 and then remain more or less stationary from then on.

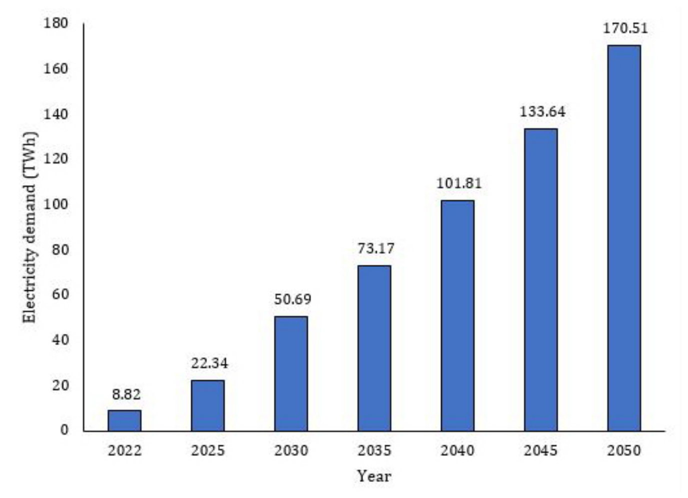

Figure 2: Electricity demand forecast

3.3 Estimated surplus electricity

Surplus electricity is based on the above generation profile and demand forecast for different years. The amount of surplus electrical energy that is estimated to occur in the future along with the summary of electrical energy generation and demand forecast is shown in the table below

Table 2: Estimation of surplus electricity in different years

Year	Elec. generation	Internal elec. demand	Surplus elec.
2022	9.52	8.82	0.70
2025	37.03	22.34	14.69
2030	84.83	50.69	34.14
2035	120.94	73.17	47.77
2040	162.74	101.81	60.93
2045	204.44	133.64	70.80
2050	243.18	170.51	72.67

Electricity demand and generation are almost balanced in the base year but the surplus electricity increases with the years to pass. The surplus electricity has been estimated to amount to 14.69 TWh by 2025 which has been forecast to increase all the way up to 72.67 TWh in 2050 which is more than seven-fold of the total internal generation in the base year.

3.4 Possibility of hydrogen production

Hydrogen production by water electrolysis is assumed to use 50.07 KWh based on the literature review. Though the pattern of electrical energy that is going to be surplus in the future looks optimistic, all the electrical energy might not be available for hydrogen production due to the fact that electricity may be exported to some extent and the hydrogen technology may not be mature and large enough. In order to account for these aspects, five different scenarios for using surplus energy have been developed below:

- Scenario-1 (20% Use of Surplus)
- Scenario-2 (40% Use of Surplus)
- Scenario-3 (60% Use of Surplus)
- Scenario-4 (80% Use of Surplus)
- Scenario-5 (100% Use of Surplus)

On the basis of the above scenarios, the possibility of hydrogen production in different years has been estimated which is as shown in Figure 3. Even, using only 20% of surplus electricity in the future, hydrogen production has been estimated to be around 136,372 tons in 2030, 243,402 tons in 2040, and 290,290 tons in 2050. If all the surplus energy (Scenario-5) is to be used in 2050, hydrogen production would be massive at around 1,451,450 tons.

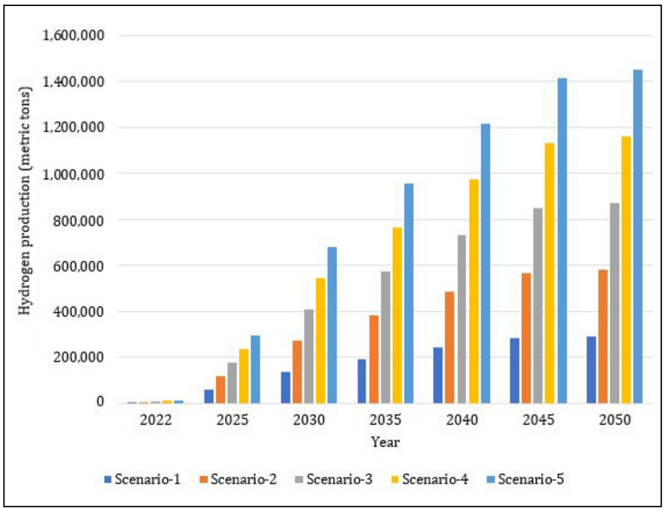

Figure 3: Hydrogen production in various scenarios

To put into perspective, hydrogen produced in 2050 using all the surplus electricity is capable of replacing about 7.26 MMT of coal imports which could produce 16.35 million tons of CO_2 equivalent of emission in the atmosphere if burnt in the industries as an energy source which is also equal to 10.88 MMT of fuelwood that if burnt for energy would produce around 20.15 million tons of CO_2 equivalent of carbon emission in the atmosphere. However, the utilization of hydrogen would provide the same energy and produce water vapor in the atmosphere as an emission that has no negative environmental impact.

The production of hydrogen depends on various factors such as the availability of the present energy source, present technology and infrastructure, scale of production, production methods and their efficiency, environmental impacts, governmental regulations and policies, end-use application, and mostly on cost. The cost of energy sources, capital investment, and operating and maintenance costs are the costs incurred during production whereas the cost of energy sources i.e., electricity is one of the major factors. Thus, if the surplus electricity is provided at a cheaper rate for the production of hydrogen, then hydrogen could compete economically with other fossil fuels as an energy source for general use. The energy cost of producing hydrogen ranges from \$5.91 to \$12.75, depending on the production time and tariff rates. In contrast, Nepal has a competitive edge over other countries since excess energy that would otherwise be spilled may be used to produce green hydrogen, lowering energy costs [15]. With technological advancement, the rate of hydrogen production could be significantly low. Hydrogen is used in various applications worldwide including transport, power generation, Oil refinery, and various industries. In the context of Nepal, Hydrogen can play a major role in transport and industries. Energy-intensive industries such as Chemical industries, Cement and brick industries which consume fossil fuels and produce high emissions can benefit from the hydrogen application as an energy source

4. Conclusion

The fifteenth plan has estimated the electricity generation and per capita electricity demand for coming years. From this study, the electricity demand and generation are found increasing with the years. The surplus electricity is expected to increase with the years and will become around 72 TWh in 2050AD. The surplus electricity found is used for calculating the production of hydrogen. 34,139 GWh of electricity is assumed to be surplus in the year 2030 which can produce around 272,743 tonnes of hydrogen while using 40% of surplus electricity. and 681,859 tonnes of hydrogen while using 100% of surplus electricity. Whereas in 2050, the surplus electricity increases to 72,670 GWh which can produce around 580,580 tonnes of hydrogen while using 40% of the surplus electricity and 1,451,450 tonnes while using 100% of surplus electricity. The actual amount of hydrogen production can be greater than the calculated one as the calculation is based only on surplus electricity on the other hand hydrogen can be produced from the base energy that will consumed.

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