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1 author:

Santosh Kaini
Ministry of Energy Water Resources and Irrigation/Nepal

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Climate change impacts on the renewable energy sector in Nepal

Santosh Kaini[1]

[1]Water Resources Research and Development Centre, Ministry of Energy, Water Resources and Irrigation, 44600, Kathmandu, Nepal

(Email: santoshkaini@yahoo.com)

Abstract

Hydropower, solar power, and wind power are Nepal's foremost potential renewable energy resources. This paper aims to highlight the impacts of climate change on the supply and demand sides of the renewable energy sector in Nepal. Due to climate change impacts on precipitation, temperature, permafrost thawing, solar radiation and wind speed, it is expected to affect renewable energy generation, transmission, distribution and consumption mechanisms. For sustainability of renewable energy projects especially hydropower projects, projects should be designed and constructed by regularly reviewing and updating the existing hydrological and hydraulic design standards based on past hydrological parameters and projected extreme climatic events. Damages to hydropower infrastructures induced by extreme climatic events could be further reduced by the establishment of early warning systems with robust institutional setups. Adaptation strategies to climate change impacts on renewable energy production include a proper mixture of storage and run-of-the-river projects, and the use of decentralized renewable energy technologies. A climate-resilient renewable energy sector is required to abate the climate change impacts on the energy sector.

1. Introduction

The energy sector is the main contributor to the global Green House Gas (GHG) emissions. The energy sector contributed around 35% of global GHG emissions in 2010, while Agriculture, forestry, and other land use (AFOLU); industry; transport; and building sectors contributed 24%, 21%, 14%, and 6% respectively (IPCC, 2014). This fact persisted and was nearly unaffected for the energy sector in 2019, contributing to one-third of total GHG emissions. The energy, industry, AFOLU, transport, and building sectors contributed 33%, 24%, 22%, 15%, and 6% respectively in 2019 (Dhakal *et al.*, 2022). This shows that the energy sector is largely contributing to climate change. On the other side, climate change is also impacting the energy sector. Climate change poses significant challenges to the energy system. IPCC has reported with high confidence that climate change affects energy generation through changes in temperature (hydropower, solar, fossil fuel, nuclear, bioenergy, transmission and pipelines), precipitation (hydropower, fossil fuel, nuclear and bioenergy), cloudiness (solar) and windiness (wind and wave) (Riahi *et al.*, 2022).

Climate change impacts on spatial and temporal variation in precipitation could further reduce temporal water availability in rivers in the coming decades (Kaini *et al.*, 2020). Due to climate change impacts, changes in precipitation patterns, permafrost thawing, temperature rise, increased extreme climatic events both in magnitude and frequency, and compounding and cascading disasters have increased risks to renewable energy sources including hydropower projects in Nepal. It is also expected that climate change impacts on the spatio-temporal variation of water flow in rivers could reduce water availability for competing uses (Kaini *et al.*, 2021).

Sustainable Development Goals (SDGs) have targeted to ensure access to not only affordable, reliable and modern energy to all but also substantially increase the share of renewable energy in the global energy mix by 2030 (United Nations, 2015). Energy supplier authorities always aim for increased production and try to fulfill the demand. Likewise, unwavering energy supply is expected from the consumer side. Although many countries are working to fulfill the target set by SDGs and local and regional energy demands, climate change impacts on the energy sector have posed a challenge by altering both the supply and demand sides of energy systems in recent years.

As limiting carbon footprint has become a global agenda in last decades, and considering the contribution of energy sector in global GHG emissions, development of sustainable, renewable and eco-friendly energy has received global priority. Hydropower, solar power, and wind power are the foremost sustainable energy resources. Among these three sources of energy, hydropower is a primary source of renewable energy in Nepal. Thus, this paper aims to highlight the impacts of climate change on renewable energy sector in Nepal with a focus on hydropower.

2. Holistic approach to climate change impacts on renewable energy sector

The holistic approach to climate change impacts on renewable energy sector includes supply sides and demand sides as shown in Figure 1. The supply side includes all the groundwork required for production (generation), storage, transmission lines and distribution systems while the demand side represents the consumption mechanism of power for different uses. Impacts to any component of the energy system at any location largely affect the remaining components.

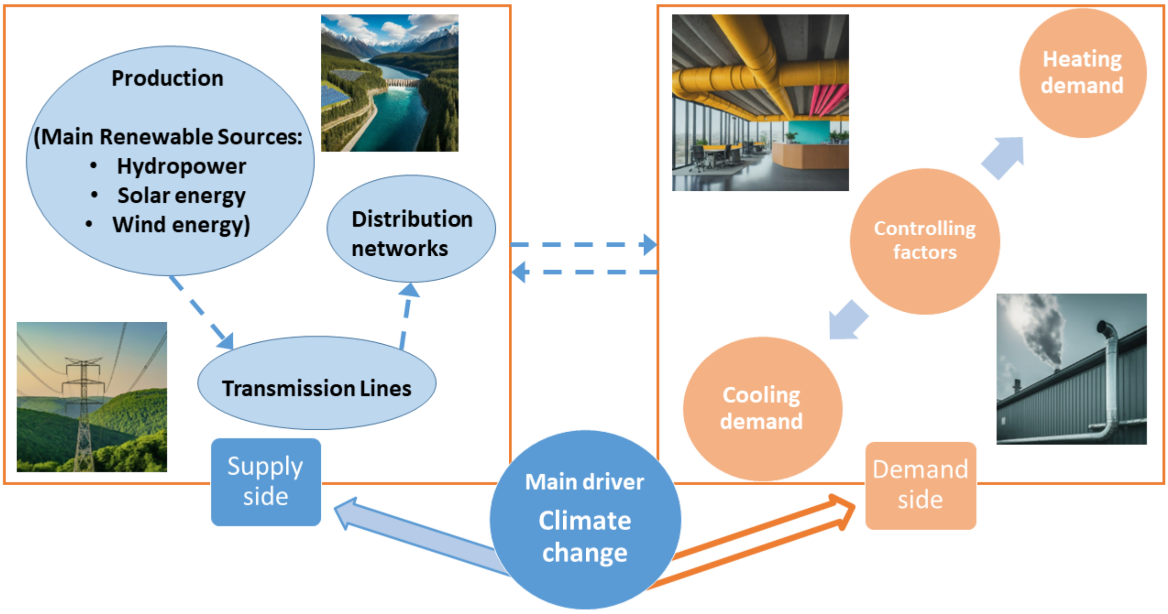

Figure 1: Framework for holistic approach to climate change impacts on renewable energy sector

Considering the supply side of renewable energy in Nepal, potential sources are hydropower, solar power and wind power. Hydropower is the main source of total electrical energy generation in Nepal. Contribution of hydropower, solar energy and thermal energy in total electrical energy generation in Nepal is around 95.5%, 2.5% and 2% respectively (Department of Electricity Development, 2024). However, there are no wind energy projects for electricity generation at production level yet, and are limited to small scale village level only. The demand side is affected by many factors including economic activities, social factors, consumer behavior, geography, technological innovations, however, heating and cooling demands considering changes in temperature and precipitation are the main controlling factors. Regarding the demand side, electric energy has been used mainly at residential, commercial, and industrial sectors in Nepal while very limited portion is used at other sectors including agriculture and transportation. In last decades, the climate change has become the main driver to extensively affect both the supply and demand sides of the renewable energy system.

3. Impacts of climate change on the renewable energy sector

Renewable energy sector is intertwined with water resources, temperature and solar radiation, and wind, as they are the sources for hydro-electricity, solar energy and wind energy respectively, and the transmission pathways, distribution lines, and consumption mechanism. Thus, climate change impacts on these factors affect in the energy production, transmission, distribution and consumption process. Like other sectors, climate change impacts wreaking recurrent hydrological extremes have made renewable energy sector vulnerable. Increase in episodic rainfall, permafrost thawing, temperature, severe drought, heat waves, and lighting triggered wildfires have exacerbated the vulnerability in renewable energy sector around the globe including Nepal. Frequency and magnitude of floods and landslides have been increased in recent years compared to earlier years. Due to climate change, likelihood of frequent and rapid floods and landslides has been rocketed. The climate change has affected both the supply and demand sides of the energy system.

3.1 Impacts on renewable energy supply side

Renewable energy generation (production)

Due to changes in permafrost thawing, precipitation, and temperature, climate change is expected to affect renewable energy generation by changes in water availability in the dry season as well as damages to the infrastructures by landslides and floods in the wet season. Likewise, changes in temperature, solar radiation, and wind speed directly affect solar and wind energy generation.

In hydropower production, the effect will be high at local and regional level compared to global scale (Kumar *et al.*, 2011). Due to projected decrease in water availability in dry season, the hydropower production could be reduced in this period. The hydropower generation in the Kulekhani Hydropower Project would decrease by up to 13% in the coming decades compared with the baseline period of 1976–2005 (Shrestha *et al.*, 2021). The uncertainty in the range of impacts due to climate change is also high. However, due to projected increase in rainfall, hydropower generation is expected to increase is few river basins in Nepal (Singh *et al.*, 2022). This shows that the changes are not uniform throughout the basins.

Hydropower projects both completed and under construction have been affected by the Glacier Lake Outburst Floods (GLOFs), floods and landslides. A GLOF event in July 2016 significantly damaged headworks and powerhouse of Upper Bhote Koshi hydropower project. The flood due to GLOF event in upper reach of Bhote Koshi in China carried bed load with large boulders and damaged the headworks and other infrastructure (Bruen, Witnik and Sthapit, 2017).

Unprecedented and episodic rainfall and rainfall trigged landslides have damaged the hydropower projects in Nepal. In August 2014, heavy rainfall trigged landslide at Jure, Sindhupalchowk consisting of soil and rock blocked the Sunkoshi river creating a temporary dam. Sanima Hydropower Project powerhouse was submerged and Sunkoshi Hydropower project was also heavily damaged due to Jure landslide including washing out of two gates. Furthermore, the flood and landslide in the Dordi river corridor, Lamjung during July 2021 damaged four hydroelectricity projects including Dordi-1, Upper Dordi, Supe Dordi 'Kha'. Likewise, Madame Khola and Super Madi hydropower projects in Kaski district were damaged during the flood in July 2021. Moreover, due to flood in the Bhojpur, Sankhuwasabha, Panchthar, and Taplejung districts in June 2023, around 30 hydropower projects including Lower Hewa Khola Hydropower Project, Kabeli B-1, Super Hewa Khola Hydropower Project, and Isuwakhola Hydropower Project were seriously damaged. These are the few examples of climate change impacts on hydropower projects.

Regarding the solar and wind energy in Nepal, although solar and wind energy potential in Nepal are 47,628 MW and 1,686 MW respectively (Neupane *et al.*, 2022), the production level is paltry. Changes in solar radiation and cloudiness pattern is expected due to climate change, which affects the power generation from solar plants. Based on data analysis from 1990 to 2010, annual Solar Radiation showed increased trend in Hilly and Terai belt while decreased trend was reported in upper hilly and Himalayan belt of Nepal (Adhikari, Karna and Roy, 2021). This shows that changes in spatial potential of solar energy generation is expected in future. Solar plants are also at risk from wildfires and hailstones induced from extreme weather events. There is wide scope for studies on impacts of climate change on solar energy in Nepalese context.

Likewise, changes in wind speed resulting changes in wind power is expected in Nepal. A study conducted in Kagbeni, Mustang have projected an increase in the wind speed by 5.3% consequently increasing the wind power by 13.4% in 2030-2050 compared to 2001-2005 (Adhikari and Shrestha, 2019). Although wind power has been used at a small scale in few villages in Nepal, it has not been commercially generated in Nepal. Further research on climate change impacts on wind patterns and wind energy is necessary for future energy planning in Nepalese context.

Transmission lines and distribution networks

Transmission lines and distribution networks are also at the risk from climate change impacts. The transmission line of Upper Bhote Koshi was affected by Jure landslide occurred in 2014. Power from Upper Bhote Koshi was interrupted for months after the failure of three transmission line towers as new towers need to be constructed after negotiating a new right-of-way (Bruen, Witnik and Sthapit, 2017). Also, a flood induced by continuous rainfall in Sunsari district in October 2021 damaged the ongoing construction works in sub-station Inaruwa which increased the project cost and delayed the completion time. Similarly, a landslide induced by erratic rainfall in the Dang district in October 2022 collapsed the Lamahi-Ghorahi 132 KV transmission line and interrupted the power in the region. In addition, extreme wind events could damage transmission and distribution lines and poles. Increased temperature decreases the energy carrying capacity of transmission and distribution power lines. Increased wildfires triggered from increased temperature and lightning extreme events have increased risk to energy networks. Extreme wind speeds could cause mechanical failure of lines as well as collide the transmission and distribution lines (Yalew *et al.*, 2020).

3.2 Impacts on energy demand side

Overall impacts of climate change on demand side is lower compared to the impacts on supply side. Due to changes in temperature, precipitation, solar radiation and wind speed patterns, energy demand is expected to accelerate for heating and cooling at residential, commercial and industrial buildings. Climatic extreme events are likely to alter the peak demands of energy with potential blackouts and short-term energy impacts (Yalew *et al.*, 2020). However, provision of heating and cooling mechanism largely depends upon the socio-economic status of the region. Application of energy efficient appliances and use of appropriate building materials could reduce the overall energy demand at residential, commercial and industrial buildings.

4. Policy interventions on climate change and renewable energy

Nepal is insignificantly responsible for climate change contributing only 0.027% of total global GHG emissions, however, multiple sectors including water supply, irrigation, energy, and the entire ecosystem are often the most vulnerable to their impacts. Nepal has targeted to achieve net-zero emissions by 2045 and the energy sector is a vital for emission reductions (GoN, 2021b). Considering the importance of renewable energy to global GHG emissions and its potential for generation, the Government of Nepal has planned to increase the clean power generation to 15,000 MW by 2030 aiming a substantial contribution from hydropower sector (GoN, 2020). National climate change policy has encouraged to generate and use renewable energy and energy efficient technologies (GoN, 2019). Likewise, National adaptation plan has provisioned for clean and efficient energy technologies as well as conceptualized climate resilient renewal energy for rural and vulnerable areas (GoN, 2021a). All of these policies have explicitly and implicitly focused on renewable energy and climate change adaptation and mitigation.

Although hydropower is the main renewable energy source in Nepal, production substantially decreases during the dry season in most of the Run-of-the-river (RoR) type of projects due to a significant temporal variation in precipitation. Hydropower projects with ROR and without or with minor storage are susceptible to climate variability. Considering the scattered settlements, rugged topography, and fragile geology in hills and mountains of Nepal, decentralized renewable energy technologies like solar and wind energy are possible options to intensify energy access in the region, as construction of physical infrastructures are also difficult. Hence, as an adaptation strategy to climate change impacts on renewable energy production, government should continue to focus on a proper mixture of storage and RoR projects and decentralized renewable energy technologies. These decentralized renewable energy technologies are relatively more climate resilient compared to hydropower.

Furthermore, Second Nationally Determined Contribution (Nepal) has planned to establish a multi-hazard monitoring and early warning system covering all provinces by 2030 (GoN, 2020). If such planned early warning systems are implemented, the losses due to climate change impacts on hydropower projects will be significantly minimized. Damages to hydropower infrastructures induced from extreme climatic events could be further reduced by regularly reviewing and updating the existing hydrological and hydraulic design standards based on past hydrological parameters and projected climatic parameters.

5. Exigency for Climate-resilient renewable energy sector

Damages to physical infrastructures during construction periods result in extended project period, consequently, resulting on increased financial burdens. Subsequently, the operation period delays and results delay in revenue generation. Similarly, damages to operational energy projects not only increases maintenance/rehabilitation cost but also fallouts on revenue generation as it takes times to resume the operation. Such damages directly or indirectly affects the socio-economic activities. Although there is an uncertainty in the range of impacts due to climate change, a climate-resilient renewable energy sector is essential for raising the economic prosperity of Nepal through energy sector.

A climate-resilient renewable energy sector is required to abate the climate change impacts on the energy sector. Possible solutions for climate-resilient renewable energy sector include (i) design and construction of projects considering past climatic parameters as well as unexpected extreme climatic factors, (ii) digital solutions to data and information sharing among the stakeholders in a coordinated manner regarding the extreme weather events, (iii) construction of storage hydropower projects, (iv) fortification of energy infrastructures from extreme weather events contributing to improved safety, (iv) increased access to affordable clean energy by installation of decentralized renewable energy technologies like solar and wind energy which are less vulnerable compared to hydro-electricity, (v) establishment of early warning systems with robust institutional setup for minimizing the losses from possible compounding and cascading disasters.

6. Conclusion

Similar to other sectors, climate change impacts on renewable energy sector is also unequivocal, affecting both the supply and demand sides of energy. Although the natural landscape in Nepal has provided substantial potential for hydropower projects, it is also contributing to more risk of GLOFs, flash floods, landslides, Landslides Dammed Outburst Floods (LDOF), and flooding. Climate change has been impacting on spatial and temporal variation of precipitation, temperature, solar radiation and wind speed, which directly affects renewable energy generation. As most of the hydropower projects in Nepal are based on the run-of-the-river (RoR) type, production substantially decreases during the dry season due to a significant temporal variation in precipitation and water availability in rivers. Hydropower projects with ROR and without or with minor storage are susceptible to climate variability, especially in Nepal where rainfall variability is high. In this regard, a proper mixture of storage and RoR projects should be planned. Furthermore, decentralized renewable energy technologies could promote in addressing the access to modern energy as envisioned in SDGs and possible measures for climate change adaptation.

Future renewable energy projects especially hydropower projects should be designed and constructed by regularly reviewing and updating the existing hydrological and hydraulic design standards based on past hydrological parameters and projected extreme climatic events and possible compounding and cascading disasters. Damages to hydropower infrastructures induced from extreme climatic events could be further reduced by establishment of early warning systems with robust institutional setup as envisioned in Second Nationally Determined Contribution. Scientific, policy, and applied research considering climate change impacts on renewable energy sector are essential for the planning, implementation, and operation of climate-resilient energy systems.

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