

Socio-Economic Trade-offs of Large Hydropower Development for Community Livelihoods in Bagmati Province, Nepal

Gunaraj Neupane^{1*}, Yutthapong Pianrog¹, Kua-anan Techato¹, Hari Prasad Ghimire^{1,2}

¹Faculty of Environmental Management, Sustainable Energy Management, Prince of Songkla University, Hat Yai, Thailand, ²Everest Center for Research and Development Partners, Kathmandu 44600, Nepal. *Email: neupaneguna@gmail.com

Received: 13 October 2025

Accepted: 23 January 2026

DOI: <https://doi.org/10.32479/ijeep.22755>

ABSTRACT

Large hydropower development is widely promoted as a pathway for sustainable energy transition and economic growth, particularly in mountainous countries such as Nepal. However, its socio-economic implications at the community level remain contested. This study examines the impacts of large hydropower development on community livelihoods in Nepal's Bagmati Province using secondary time-series data covering the period 2015–2024. Guided by the Sustainable Livelihoods Framework, the study employs descriptive analysis, correlation analysis, multiple regression, and factor analysis to assess relationships between infrastructure development, employment, income, environmental impacts, and displacement. The results reveal a clear development–displacement paradox. While infrastructure development and household income increased over time, environmental impacts emerged as the strongest driver of displacement, outweighing the mitigating effects of economic and infrastructure gains. Employment and income improvements alone were insufficient to offset livelihood disruption. Factor analysis identified two dominant pathways: an economic–infrastructure pathway that enhances physical and financial capital, and an environmental–displacement pathway that erodes natural capital and increases livelihood vulnerability. The findings highlight that environmental degradation plays a central role in shaping livelihood outcomes in hydropower-affected areas. The study contributes empirical evidence from a Himalayan context and underscores the need for hydropower policies that prioritize environmental safeguards, livelihood restoration, and inclusive development to achieve socially sustainable energy transitions.

Keywords: Large Hydropower, Sustainable Livelihoods Framework, Displacement, Environmental Impacts, Infrastructure Development, Nepal

JEL Classifications: Q42, Q48, R11, O13, O18

1. INTRODUCTION

Hydropower development has been actively encouraged over the centuries in the national energy policies of many countries, especially developing and mountainous ones, where the hydrological potential is rich. Hydropower is frequently considered a source of energy with low carbon emissions and renewability that helps attain energy security, economic growth, and mitigate climate change (International Energy Agency [IEA], 2022; World Bank, 2021). In the world, major hydropower projects have been instrumental in the growth of electricity access and the promotion of industrialization, particularly in emerging economies in Asia, Latin America, and Africa (Zarfl et al., 2021; Sovacool et al., 2021).

Although these advantages are felt, the large hydropower projects have also created some major social, environmental, and livelihood related issues. The negative effects of damaging consequences, which include involuntary displacement, agricultural land loss, interference with traditional livelihoods, ecological degradation, and unequal distribution of benefits to the affected communities, are reported in the growing literature (Tilt et al., 2009; Kirchherr et al., 2023). They are frequently spatially localized in terms of their effects, with economic and energy benefits being distributed on regional or national levels, which causes inequalities in socio-economic terms and local opposition to hydropower development (Sovacool and Walter, 2019).

In recent years, researchers have been paying increasing attention to the necessity to evaluate hydropower projects not only in terms of technical and economic approaches, but also within the frames of integrated social-ecological and livelihood systems (Cernea, 2000; Kirchherr et al., 2023). The Sustainable Livelihoods Framework focuses on how big infrastructure schemes can transform the livelihood assets, such as the natural capital, physical capital, human capital, financial capital, and social capital, therefore, affecting the results of long-term well-being of displaced and host communities (Scoones, 2015). The empirical literature in China, India, Laos and Brazil indicates that the displacement caused by hydropower projects frequently results in livelihood insecurity, the lack of income diversification and erosion of social networks in case compensation and resettlement arrangements are designed poorly (Wilmsen and Rogers, 2023; Wang et al., 2022; Kirchherr and Charles, 2021).

South Asia is one of the most relevant areas to study such processes as the rapid development of hydropower infrastructure is combined with high population density and reliance on natural resources as the basis of livelihood. Large hydropower has been considered an important development pathway in countries like Nepal, Bhutan and India, but there is still empirical evidence on the socio-economic effects of hydropower at the local level that remains scattered and context-dependent (Kirchherr and Charles, 2021; Pandey et al., 2020). Nepal has a high potential of hydropower per capita, with most major projects being in hilly and river-basin areas where agriculture and forest cover, as well as informal economic activities, are major sources of rural livelihoods (Government of Nepal, 2018).

In Nepal, the Bagmati Province has become a target location of considerable hydropower investment because of its strategic location, river basins, and proximity to the major demand centers. Although hydropower development in the province has led to electricity supply in the region and the growth of infrastructure, the issues of displacement and land acquisition as well as the change in the environment and the livelihood of local communities, remain of concern (Shrestha et al., 2019; Adhikari and Dhungana, 2022). Available research in Nepal pays much attention to environmental effects, project viability, or energy planning at the national level, but contains little quantitative research on livelihood effects and community-level social-economic transformations (Paudel et al., 2021).

Further, there is also a remarkable methodological gap in the incorporation of socio-economic indicators, including employment, income, access to infrastructure, and displacement, in empirical models that measure the effect of hydropower in the long run. Most of the past research is based on qualitative case studies or short-term evaluations, which, albeit useful, do not give the possibility to determine the overall trends and statistically measure how hydropower development relates to livelihood outcomes (Kirchherr et al., 2023; Sovacool et al., 2021). The gap needs to be addressed to aid the evidence-based policy, enhance compensation and resettlement plans, and harmonize hydropower development with sustainable development goals.

It is based on this context that the current study analyzes the socio-economic implications of the giant hydropower development on the community livelihoods in the Bagmati Province of Nepal through the analytical approach that is quantitative in nature. The research aims to provide an empirical evaluation of the relationship between hydropower expansion and livelihood outcomes through time by incorporating secondary time-series data on displacement, employment, infrastructure development, and income indicators in the study. By so doing, the study adds to the accumulating body of literature on sustainable management of hydropower in developing sustainable solutions to the energy development issue in relation to the social equities and livelihood sustainability in Nepal and contributes to the body of policy-relevant insights.

2. LITERATURE REVIEW

2.1. Large Hydropower Development and Socio-Economic Change

The benefits of large hydropower projects have long been claimed as a source of economic growth because of their ability to generate usable electricity, encourage industrialization and bolster national energy security. According to empirical research, hydropower investments can help enhance macroeconomic growth, the development of regional infrastructure, and better access to electricity, especially in developing nations with a significant amount of hydrological resources (World Bank, 2021; International Energy Agency [IEA], 2022; Brown et al., 2020). In the context of development economics, hydropower is often discussed as a driver of modernization, enabling long-term productivity and structural reorganization (Sovacool and Brisbois, 2022).

Nevertheless, a considerable amount of literature brings forward that these aggregate gains tend to obscure the local socio-economic imbalances. Huge dams often necessitate massive land grabbing and relocation of the population, which impacts resource-reliant and rural communities more than others (Scudder, 2012; Kirchherr et al., 2023). Research in Asia, Africa, and Latin America continues to indicate that the communities found in and around hydropower projects have been severely affected in terms of livelihood disruption, employment, and access to natural resources, with the results being different, contingent upon the quality of governance and the compensation schemes (Kirchherr et al. 2023; Sovacool and Walter, 2019).

2.2. Displacement, Resettlement, and Livelihood Outcomes

One of the best documented social effects of huge hydropower development has been displacement. The Impoverishment Risks and Reconstruction (IRR) model by Cernea (2000) highlights the risks that relate to involuntary resettlement, such as landlessness, unemployment, marginalization, food insecurity, and social disarticulation. Practical examples of this framework prove that households in the situation of displacement tend to face a long-term slump in livelihood in case of poor planning of resettlement or its actual implementation (Wilmsen and Rogers, 2023; Wang et al., 2022).

According to quantitative and qualitative reports in China, India, and Southeast Asia, financial compensation can help restore a temporary income loss, but it is unlikely to go beyond the restoration of sustainable livelihood (Kirchherr et al., 2023). It is also common to encounter a lower agricultural productivity of resettled populations because of poor quality of land, limited access to markets, and the weakening of social networks (Wilmsen and Rogers, 2023). Such results indicate that the effects of displacement are not limited to economic losses but are also socially and institutionally based and affect the long-term welfare.

2.3. Hydropower and Employment, Income, and Infrastructure Development

In addition to displacement, hydropower projects may transform the local economies by creating workplaces, building infrastructure, and increasing services. The construction stages can generate temporary jobs, and the related infrastructure, including roads, transmission lines, and access to markets, can bring an economic impact in the long run (Kirchherr et al., 2023). Some of them document the positive impacts on income in the community in terms of better access to electricity and transport infrastructure after the development of hydropower (Dorcey et al., 2018; Athayde et al., 2021).

However, according to the literature, such advantages are characterized by a very uneven distribution. They often have temporary and skill-limited employment opportunities, which restrict the ability of residents (Sovacool et al., 2021). Moreover, the infrastructure can be enhanced to support project activities instead of community demands, so most spillover impacts on the livelihoods of locals are minimal (Sovacool et al. 2021). This two-sidedness is significant to emphasize the point of empirical evaluation that can differentiate between short-term project-specific benefits and long-term livelihood effects.

2.4. Environmental Change and Livelihood Vulnerability

Another pathway that is critical in influencing livelihoods is the environmental change caused by hydropower. Changes in river flow regimes, sediment movements, and ecosystem services may affect the agricultural, fisheries, and forest-based livelihoods (Zarfl et al., 2021; Grill et al., 2019). The study has revealed that environmental degradation associated with the construction of dams has contributed to higher livelihood vulnerability, especially to households that depend on subsistence agriculture and common-pool resources (Pandey et al., 2020).

Research combining the environmental and socio-economic statistics stresses the fact that environmental effects tend to increase the level of inequality because poor households have fewer adaptive forms (Scoones, 2015). In turn, the development of hydropower can increase the risk to livelihood, unless it is accompanied by comprehensive management of the environment and social protection (World Bank, 2021).

2.5. Methodological Approaches in Hydropower Impact Studies

Technologically, the hydropower impact evaluations use a wide range of methods, starting with a qualitative case study

based on their methodology and ending with the econometric analysis. Qualitative studies have been able to offer a profound understanding of displacement, government failure, and the perception of the community (Scudder, 2012; Wilmsen and Rogers, 2023). Nonetheless, these studies are not always generalizable and statistically rigorous.

More quantitative methods have been employed to evaluate the relationship between hydropower development and socio-economic indicators, such as income, employment, and access to infrastructure, such as regression analysis, index construction, and time-series analysis (Sovacool et al., 2021). Although these have been made, there are still gaps in the evolution of the multi-dimensional livelihood indicators in the longitudinal empirical accounts, especially in the low-income and mountainous settings like Nepal (Paudel et al., 2021).

2.6. Hydropower Development in Nepal: Empirical Evidence and Gaps

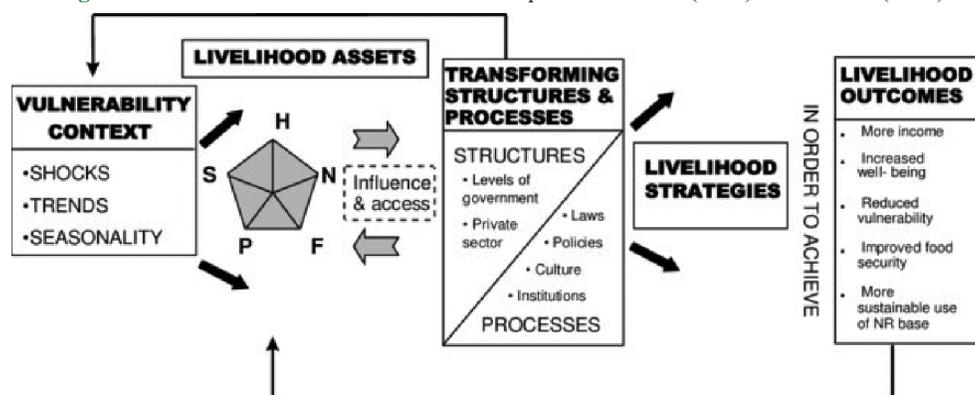
The steep topography and massive river systems have made Nepal a strategic hydropower producer. On the national level, the impact of hydropower on economic development, energy security, and export potential is in the spotlight (Government of Nepal, 2018; Shrestha et al., 2019). Nonetheless, the empirical study on the community-level socio-economic effects is sparse and scattered.

Available research in Nepal is mostly on the environmental effects, policy review, or project feasibility, and the number of quantitative evaluations of the livelihood outcomes is also limited (Adhikari and Dhungana, 2022; Paudel et al., 2021). Besides, in most studies, cross-sectional or qualitative data are used, which do not allow them to focus on uncertainty dynamics and causality. This disparity is especially noticeable in provinces like Bagmati, where hydropower generation runs along the interface of high population density and a diversified system of livelihood.

2.7. Theoretical Framework

This paper will use the Sustainable Livelihoods Framework (SLF) to gain a systematic and in-depth insight into the socio-economic effects of major hydropower development on the livelihoods of communities. The SLF conceptualizes the idea of livelihoods as a role of multiplying elements, such as vulnerability settings, livelihood resources, transforming structures and procedures, livelihood plans, and the consequences of livelihoods (Scoones, 2015; DFID, 1999). The framework has been popularly used in development and infrastructure impact studies to examine the ways external interventions, like massive hydropower projects, transform access to resources, the ways they alter institutional processes, and finally their impacts on livelihood outcomes of local groups. The conceptualization of hydropower development as an external intervention that impacts livelihood assets, livelihood strategies, and livelihood outcomes is used to select the variables to be used and the abstract to structure the study to be analysed through the Sustainable Livelihoods Framework (Figure 1).

The literature that is currently available shows that the huge development of hydropower has complex and contradictory socio-economic effects. Although the national and regional gains

Figure 1: Sustainable livelihoods framework adapted from DFID (1999) and Scoones (2015)

have been well-documented, the effects of livelihood at the community level are context-specific and have not been adequately quantified, especially in Nepal. Empirical research involving the combination of displacement, employment, and income with infrastructure indicators into a single analytical framework is obviously necessary.

To fill this gap, in the current study, a quantitative method will be used to determine the socio-economic effects of the huge hydropower development on the livelihoods of communities living in the Bagmati Province in Nepal over a period. Through this, it adds to the body on the topic of sustainable hydropower governance and offers evidence to policy interventions that may help achieve equilibrium between energy development and social equity and livelihood sustainability.

3. MATERIALS AND METHODS

3.1. Research Design

The research design used in this study was a quantitative, explanatory research design to explore the socio-economic effects of large hydropower development on the livelihoods of communities in the Bagmati Province in Nepal. Instead, a quantitative method was preferred so that it would be possible to analyze systematically the correspondence between the indicators of hydropower development and the livelihood outcomes based on longitudinal data and in accordance with the accepted traditions of the field of research on infrastructure and development impacts (Sovacool et al., 2021). The Sustainable Livelihoods Framework (SLF) served as the conceptual framework guiding the analysis of livelihood as capable of achieving outcomes depending on vulnerability situations, access to livelihood assets, transforming structures and processes, and livelihood strategies (DFID, 1999; Scoones, 2015).

3.2. Study Area

The research area was considered Bagmati Province, Nepal, which is a region of diverse ecological environments, including low plains and mid-hills and mountainous terrain. This location of Bagmati Province, with its river systems, strategic location and closeness to other large electricity demand centers, hosts several large hydropower projects. The province is a highly populated area, as well as that sustains mixed livelihood systems such

as agriculture, wage labor and small-scale enterprises. These features precondition the Bagmati Province as a relevant policy area and case to evaluate the socio-economic effects of large-scale hydropower development (Shrestha et al., 2019; Adhikari and Dhungana, 2022).

3.3. Data Sources and Materials

The study was based on secondary time-series data, which were published from 2015-2024, as it was chosen according to data availability, data consistency, and the topicality in terms of the development of hydropower and the policy environment. The chosen period reflects the current trends in the growth of hydropower in the framework of changing environmental and social protection systems and is congruent with the post-Sustainable Development Goals (SDGs) implementation (United Nations, 2015; World Bank, 2021). A were collected using a variety of publicly available and institutional sources, such as:

- National energy and hydropower reports published by the Government of Nepal
- Socio-economic and demographic statistics from national statistical agencies
- Infrastructure and development records from sectoral institutions
- Peer-reviewed publications and official reports related to hydropower development in Nepal

The use of multiple sources enabled data triangulation and enhanced reliability by reducing source-specific bias (Sovacool et al., 2021).

3.4. Variable Selection and Measurement

Variable selection was informed by the Sustainable Livelihoods Framework and prior empirical literature on hydropower and livelihood impacts (Kirchherr et al., 2023).

3.4.1. Dependent variable

3.4.1.1. Displacement rate (DR)

The rate of displacement was applied as a proxy measure of livelihood disturbance with regard to massive hydropower generation. It is the ratio of the number of households resettled and or acquired in connection with hydropower projects. Displacement has been well embraced as a fundamental socio-economic impact measure in studies of dams and infrastructure (Scudder, 2012; Kirchherr and Charles, 2021).

3.4.2. Independent variables

3.4.2.1. Infrastructure development index (IDI)

Composite index of gains in physical infrastructure (road network, access to electricity, and government facilities related to hydropower development and installation). The development of infrastructure has an impact on physical capital and market connectivity, thus the livelihood opportunities (Sovacool et al. 2021).

3.4.2.2. Employment rate (ER)

It is the ratio of the economically active population taking part in employment. The changes in human and financial capital due to hydropower-related economic activities can be observed in employment (Kirchherr et al., 2023).

3.4.2.3. Income level (IL)

Real household income per capita. The income is an important indicator of financial capital and the livelihood outcomes (Scoones, 2015).

3.4.2.4. Environmental impact index (EII)

A composite measure of environmental change that has taken place with respect to hydropower development, such as a change in land use and disturbance of ecology. Both natural capital and livelihood vulnerability are influenced by environmental effects (Zarfl et al., 2021; Grill et al., 2019).

3.5. Index Construction

The composite indices (IDI and EII) were developed by conventional socio-economic index development standards. Min-max scaling was initially applied to individual indicators to obtain comparability across variables. Equal weights were then summed on normalized indicators, and this is in accordance with the conventional rules of building composite indicators, in which there are few empirical reasons to justify unequal weighting (Nardo et al., 2005; OECD, 2008). This strategy improved openness and reproducibility.

3.6. Analytical Techniques

3.6.1. Descriptive analysis

Descriptive statistics, i.e. mean, standard deviation, maximum and minimum values were calculated to summarize and analyze the data features and analyze the temporal trends throughout the study period. Descriptive analysis was necessary to give important background to the further inferential findings (Field, 2018).

3.6.2. Regression analysis

To analyze the relationship between the hydropower development indicators and rate of displacement, a multiple linear regression model was used. The empirical model was the following:

$$DR_t = \beta_0 + \beta_1 IDI_t + \beta_2 ER_t + \beta_3 IL_t + \beta_4 EII_t + \varepsilon_t$$

where DR_t denotes the displacement rate at time t , IDI_t represents infrastructure development, ER_t denotes employment rate, IL_t represents income level, EII_t denotes environmental impact, and ε_t is the error term.

Regression analysis is a common technique that is used in research in relation to the development of hydropower and its impact on livelihoods to find statistically significant relationships between the development of infrastructure and socio-economic outcomes (Paudel et al., 2021).

3.6.3. Diagnostic and validity checks

To make the regression results robust and valid, there were standard diagnostic tests that were done. Variance Inflation Factors (VIF) were used to evaluate the presence of multicollinearity between the explanatory variables. R^2 and adjusted R^2 were used to test model performance and statistical significance was tested at a 5% level. These are the steps that are based on best practices in economics (Wooldridge, 2016).

3.7. Factor Analysis

An analysis of the latent relationships between socio-economic and environmental indicators was done using EFA. Before extracting variables, the Kaiser-Meyer-Olkin (KMO) measure and Bartlett test of sphericity were used to test the sampling adequacy and correlation structure. Principal component analysis was performed on the data through the varimax method, and the components with an eigenvalue above one was extracted. Factor analysis is an analytical tool that is applicable across the fields of livelihood and development research to connote dimensionality and extract constructs (Hair et al., 2019; Field, 2018).

3.8. Ethical Considerations

This research was based on secondary data, which is aggregated and obtained through sources of information found in the public and in reports of institutions. Since no primary data was to be collected and no direct application to human subjects was to be involved, formal ethical approval was unnecessary. However, the principles of ethical research were maintained due to the proper citation of data, transparency, and the sound interpretation of the research results (World Bank, 2021).

3.9. Data Reliability and Limitations

The reliability of the data was improved by cross-checking different sources. Nonetheless, the use of secondary data can also present certain constraints of data completeness, consistency of measurement, and the comparatively smaller time frame (2015-2024). The interpretation of the results was conscious of these limitations, as it is recommended in secondary data-based longitudinal research (Sovacool et al., 2021).

4. RESULTS

4.1. Descriptive Statistics and Temporal Trends (2015–2024)

Table 1 provides the descriptive statistics of the most important socio-economic and environmental variables involved in the development of large hydropower in Bagmati Province between 2015 and 2024. The findings are that there is observable variability by variables, which are dynamic socio-economic variations regarding the expansion of hydropower during the study.

Table 1: Descriptive statistics of socio-economic indicators (2015–2024)

Variable	Unit	Mean	Standard deviation	Min	Max
Displacement Rate (DR)	% of households	6.8	1.9	3.9	9.7
Infrastructure Development Index (IDI)	Index (0–1)	0.56	0.14	0.32	0.78
Employment Rate (ER)	%	61.4	4.7	53.2	67.9
Income Level (IL)	NPR/year	289,400	48,600	212,000	358,000
Environmental Impact Index (EII)	Index (0–1)	0.49	0.13	0.26	0.71

The average rate of displacement, 6.8, means that a significant percentage of households were displaced by land acquisition and resettlement in the case of hydropower expansion. The development of infrastructure showed consistent growth, and the IDI has increased by an average of 0.32 in 2015 to 0.78 in 2024, which yields better road access, electrification, and public facilities. Income levels rose with time, but they were highly varying, which indicated unequal livelihood benefits. The indicators of environmental impact were also on an increasing trend, which shows cumulative ecological pressures in hydropower-impacted regions.

4.2. Correlation Analysis

Table 2 reports Pearson correlation coefficients among the study variables. The results reveal several meaningful relationships that provide preliminary insights into the socio-economic dynamics of hydropower development.

Displacement rate was positively and significantly correlated with environmental impact ($r = 0.63$, $P < 0.01$), indicating that areas experiencing higher ecological disturbance also faced greater displacement pressures. Infrastructure development showed a moderate negative correlation with displacement ($r = -0.48$, $P < 0.05$), suggesting that improved infrastructure may partially mitigate displacement impacts. Income and employment exhibited weaker correlations with displacement, highlighting the complex and indirect nature of livelihood responses.

4.3. Regression Results: Determinants of Displacement Rate

Table 3 presents the results of the multiple linear regression analysis examining the determinants of displacement rate in Bagmati Province.

The regression model accounts for about 71% of the change in the displacement rates, which means that it has good power in explaining the variation, though the time series is limited. There was a strong negative relationship between infrastructure development and the displacement ($= -3.15$, $P < 0.05$), which implies that better physical infrastructure and access to services could mitigate livelihood disturbance. The environmental impact, on the other hand, had a high positive and statistically significant impact on displacement ($= 4.87$, $P < 0.05$), highlighting the importance of ecological degradation in the causes of resettlement pressures. Other predictors were not significant to employment rate and income level, indicating that economic gains are not sufficient to counter displacement risks.

4.4. Diagnostic and Robustness Checks

Multicollinearity diagnostics indicated no serious violations of regression assumptions (Table 4). All Variance Inflation Factor (VIF) values were well below the commonly accepted threshold of 5.

Table 2: Pearson correlation matrix

Variable	DR	IDI	ER	IL	EII
DR	1				
IDI	-0.48*	1			
ER	-0.21	0.36	1		
IL	-0.29	0.52*	0.41	1	
EII	0.63**	-0.34	-0.19	-0.27	1

* $P < 0.05$, ** $P < 0.01$

Table 3: Multiple regression results explaining the displacement rate

Variable	Coefficient	Standard error	t-value	P-value
Constant	1.92	0.74	2.59	0.041
IDI	-3.15	1.22	-2.58	0.043
ER	-0.04	0.03	-1.32	0.229
IL	-0.000004	0.000003	-1.27	0.244
EII	4.87	1.39	3.51	0.012

Table 4: Multicollinearity diagnostics

Variable	VIF
IDI	2.31
ER	1.89
IL	2.56
EII	2.74

These results confirm that the regression coefficients are stable and not distorted by excessive multicollinearity.

4.5. Factor Analysis Results

Exploratory factor analysis was conducted to identify latent dimensions underlying the socio-economic and environmental indicators. The Kaiser–Meyer–Olkin (KMO) measure was 0.71, and Bartlett’s test of sphericity was significant ($\chi^2 = 46.2$, $P < 0.001$), indicating suitability for factor analysis.

The two extracted factors explained 73.6% of the total variance. Factor 1 represents economic and physical capital, while Factor 2 captures environmental stress and displacement, reinforcing the multidimensional livelihood pathways conceptualized by the Sustainable Livelihoods Framework. The rotated factor loadings of the extracted factors are presented in Table 5.

5. DISCUSSION

5.1. Synthesis of Key Empirical Findings

This paper is quantitative research on the socio-economic effects of the large hydroelectric development on the livelihoods of the community in the Bagmati Province in Nepal between the years 2015 and 2024. The results show that there is an evident development-displacement paradox, as better infrastructure

Table 5: Rotated factor loadings

Variable	Factor	Factor
	1 (Economic–Infrastructure)	2 (Environmental–Displacement)
Income Level	0.82	0.21
Employment Rate	0.76	0.18
Infrastructure Index	0.84	-0.24
Environmental Impact	-0.19	0.87
Displacement Rate	-0.31	0.81

and higher income levels are observed, and the environmental pressure and household displacement remain. Figure 2, which is synthesized, shows that as the infrastructure was developed, the trend in income was increasing steadily over the period studied, but the rates of displacement and indicators of environmental impact also increased, which suggests skewed livelihoods.

These results support the recent evidence on the planet that large hydropower projects have mixed socio-economic impacts, producing net development benefits and at the same time causing localized social and environmental externalities (Scudder, 2012; Sovacool et al., 2021). This paradox is especially acute in the Nepalese case because of the high level of population density in river basins, a high reliance on natural capital, and the lack of diversification of livelihood.

5.2. Infrastructure Development as a Partial Livelihood Buffer

Regression analysis shows that the development of infrastructures has a negative and significant negative relationship with displacement, which could be viewed as a mitigating factor of livelihood disruption. Mobility, access to markets, and adaptive capacity can be improved by improving road connectivity, electrification, and access to public services, and this will help to mitigate the severity of displacement impacts. This outcome is in line with other international research findings that indicate that the resilience of hydropower-impacted communities can be enhanced through infrastructure investment (Dorcey et al., 2018).

Nevertheless, the continuity of displacement even as infrastructure levels increase raises the question of the constriction of infrastructure-based forms of development. The hydropower-related infrastructure in Nepal is frequently focused on the logistics of a project and transmission requirements as opposed to restoration of livelihoods on a community basis (Kirchherr and Charles, 2021; Adhikari and Dhungana, 2022). It follows that although the process of infrastructure development can smooth out the pressures of displacement, it does not eradicate the structural livelihood loss of land acquisition and resettlement. The above result highlights the importance of complementing the infrastructure investment with specific livelihood restoration and social protection interventions.

5.3. Employment and Income: Insufficient for Livelihood Restoration

Despite the improvement of the levels of income and the employment rates during the study time, neither of these variables was statistically significant in the regression model as a predictor

Figure 2: Temporal displacement, infrastructure development, employment rate and household income in Bagmati province, Nepal (2015-2024)

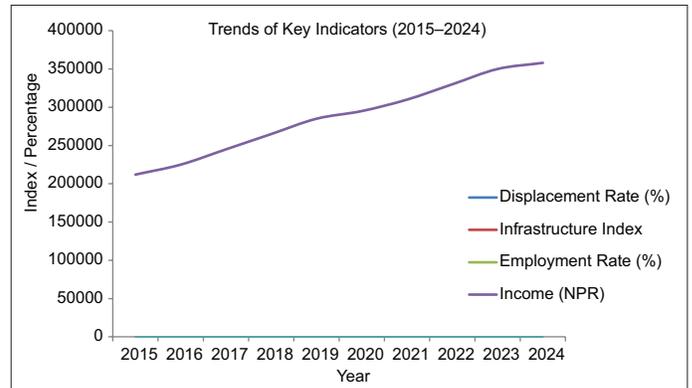
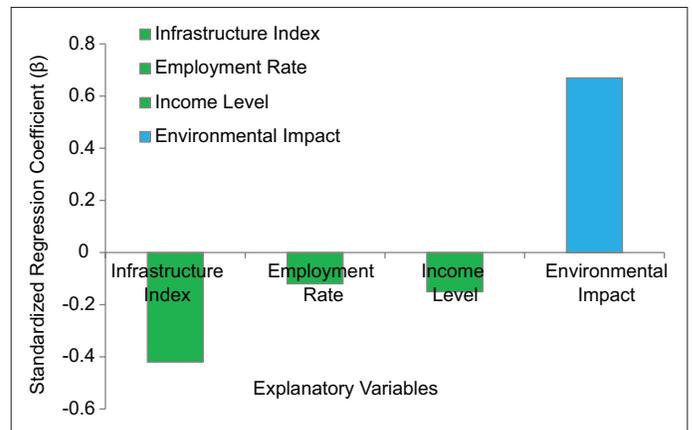


Figure 3: Relative influence of socio-economic and environmental factors on displacement based on standardized regression coefficients



of displacement. This observation implies that economic benefits cannot counter the livelihood displacement, which is a common observation in the hydropower literature across the globe (Cernea, 2000; Kirchherr and Charles, 2021).

Hydropower projects in Nepal tend to create only temporary jobs, which depend on skills and are usually focused on the construction process and require a short-term duration, which restricts the long-term livelihood gains of displaced households (Paudel et al., 2021). Payments and incomes can bring short-term economic relief but hardly substitute lost farmland, ecosystems and social networks. The poor explanatory value of income and employment is therefore indicative of the multidimensional aspects of livelihoods, in which natural and social loss of capital is substitutable to a limited extent by financial capital.

5.4. Environmental Impacts as the Dominant Driver of Displacement

Environmental impact was found to be the best, most consistent predictor of displacement; both regression coefficients and the comparison of the standardized effect size indicate such (Figure 3). Changes in the environment attributable to hydropower, which can be our conversion of land use, changes in river flow, and degradation of ecosystems, directly negate natural

capital, which makes livelihood more susceptible and compels resettlement.

The last result is in line with the worldwide research that proved that one of the leading processes that connect large dams to displacement and livelihood stress is environmental degradation (Zarfl et al., 2021; Grill et al., 2019). Even mild environmental changes in Nepal, where most of the population is reliant on land, water, and forest, can cause severe socio-economic impacts in the country due to the reliance on the natural environment (Pandey et al., 2020; Shrestha et al., 2019). This means that the findings underscore the fact that environmental protection is not a marginal issue but a core factor of social sustainability when developing hydropower.

5.5. Interpreting Results through the Sustainable Livelihoods Framework

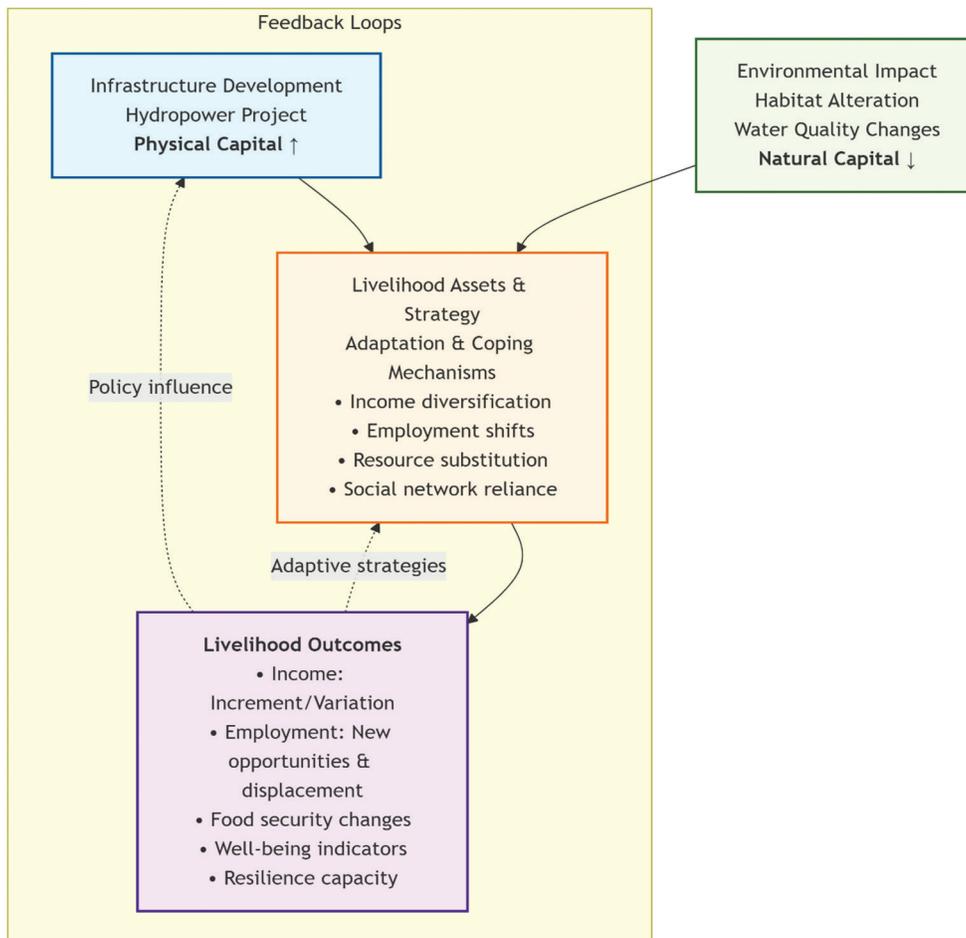
The empirical findings are overwhelming as they contribute to the applicability of the Sustainable Livelihoods Framework (SLF) in interpreting the livelihood impacts of large hydropower development in Bagmati Province. The output of the factor analysis and regression analysis indicates that two pathways, which are interrelated and predominant, are identified: an economic-infrastructure pathway as the one that enhances physical and financial capital, and an environmental-Displacement pathway as the one that destroys natural capital and leads to increased vulnerability of livelihoods.

Development of hydropower, as illustrated in Figure 4, is an outside influence in the livelihood system, which triggers parallel processes and, in many cases, competition. On the one hand, the development of hydropower infrastructure results in the accumulation of physical capital (enhancements in accessibility to roads, electricity, and services) that can be used to generate income and work opportunities. Conversely, environmental effects, including habitat change and change in water quality, lower natural capital, which directly influences the livelihoods of people who rely on resources and increases the pressure of displacement.

The interaction between these structural changes involves assets of livelihood and adaptation that encompass diversification of incomes, employment, replacement of resources and dependency on social networks. The negative outcomes illustrated by the feedback loops in Figure 4 can be slightly mitigated by a policy influence and an adaptive response but cannot be entirely neutralized by the long-term risks of environmental degradation and displacement. As a result, the livelihood performance is ambivalent and is marked by income disparity, a dynamic labor market, food insecurity, and disparate resilience.

This dynamic and dual route is indicative of larger-scale evidence in Asian and Latin America on the development gains coupled with ongoing struggles of livelihood risks and social inequities in the development gains (Wilmsen and Rogers, 2023; Scoones, 2015).

Figure 4: Sustainable Livelihoods Framework-based pathways and feedback loops of hydropower development impacts on community livelihoods



This research paper takes the framework a step forward by making empirical evidence directly related to the feedback processes in the SLF, transforming the previously mostly theoretical model into an analytical instrument of evaluating the success of hydropower governance and livelihood maintenance.

5.6. Policy Implications for Hydropower Development in Nepal

The results carry significant implications to the hydropower planning and policy in Nepal. To begin with, livelihood restoration programs should not rely on compensation and infrastructure development alone to consider the environmental sustainability and livelihood diversification in the long run. Second, environmental impact mitigation is to be considered as fundamental social protection because a decrease in ecological degradation can reduce the displacement pressures.

Third, the employment and income programs associated with hydropower projects must be aimed at skill building, local employment, and livelihood opportunities after the construction, instead of construction projects in the short term. Lastly, livelihood-oriented indicators, including fear of displacement and loss of natural capital, and adaptive capacity, would be incorporated into hydropower monitoring and evaluation systems, which would enhance accountability and ensure that energy development is congruent with national sustainable development goals.

5.7. Limitations and Future Research Directions

This research has weaknesses, even though it has contributed. The secondary time-series limits the possibility of recording household-level heterogeneity and subjective livelihood experiences. Also, the time horizon (2015-2024) is rather short and might not lead to the identification of long-term structural effects. Household-level panel data, mixed-method studies, and comparative studies across river basins should be considered in future research as they will enhance the knowledge of the distributional and intergenerational livelihood impacts.

6. CONCLUSION AND POLICY RECOMMENDATIONS

6.1. Conclusion

The paper analyzed the socio-economic effects of mega-hydropower project developments on local livelihoods in the Bagmati Province, Nepal, based on secondary time-series data from 2015 to 2024 and an analytical methodology based on a Sustainable Livelihoods Framework. The results indicate that hydropower development has created both development benefits and livelihood pressures at the same time, which shows a clear development-displacement paradox. Though the development of infrastructure and income level had been growing throughout the study time, the environmental impacts proved to be the strongest force of the displacement, overpowering the compensating effects of the economic and infrastructure advancement.

The empirical data indicate that infrastructure development will not be able to entirely offset the pressure of displacement, but it can somewhat offset the livelihood loss in terms of land and ecological degradation.

Increased employment and earnings, which were evident, were not high enough to counteract displacement risks, which highlights the multidimensionality of livelihoods in areas where hydropower is built. Factor analysis also showed two prevailing pathways, which are economic-infrastructure benefits and environmental-infrastructure stress, indicating that hydropower development reorganizes lives by competing and imbalanced processes.

This empirically operationalized research of the Sustainable Livelihoods Framework allows advancing hydropower impact research beyond a descriptive study and offers policy-relevant findings that are quantitative and based on a Himalayan setting. The results are added to the literature on sustainable governance in hydropower, which includes the point that social sustainability is not only a matter of economic gains but also of the critical role of environmental integrity and the protection of livelihoods.

6.2. Policy Recommendations

Based on the empirical findings, the following policy recommendations are proposed to enhance the social sustainability of hydropower development in Nepal.

6.2.1. Prioritize environmental safeguards as livelihood protection

As the most influential determinant of displacement, environmental impacts were pointed out. Environmental protection should also be regarded by policymakers as a primary social protection mechanism, but not as a component of secondary requirements in the form of regulations. High environmental impact assessment, implementation of mitigation measures, and maintenance of ecological flow control can greatly minimize the pressure of displacement and livelihood risk.

6.2.2. Shift from compensation-centric to livelihood-restoration approaches

Financial compensation and infrastructure provision alone are insufficient to restore livelihoods. Monetary rewards and provision of infrastructures are not enough to rebuild livelihoods. The hydropower policies must embrace holistic livelihood restoration models that embrace land-based compensation, income diversification, skills development and long-term support of the affected family. This is in line with the best international practice in handling involuntary resettlement.

6.2.3. Design inclusive employment and skill-development programs

The jobs created by hydropower projects should not be short-term employment for people in the construction. The hiring policies, vocational training, and post-construction employment opportunities should be targeted to the local community to enhance the long-term livelihood of the affected communities and decrease reliance on compensation checks.

6.2.4. Integrate livelihood indicators into hydropower monitoring systems

The livelihood indicators, such as displacement risk, natural capital depletion, and adaptive capacity, should be included in

the national and provincial hydropower monitoring systems. The inclusion of these indicators into the project evaluation and reporting mechanisms would enhance accountability and ensure that social effects are addressed just as much as technical and financial performance.

6.2.5. Strengthen participatory planning and local governance

Social acceptance can be improved, and project outcomes can be better with meaningful community participation in the process of hydropower planning and decision-making. The conflict may be minimized through strengthening local institutional capacity and integrating community feedback in project design and implementation to facilitate equitable sharing of benefits.

6.3. Implications for Future Research

Further research must expand on the current study with household-level panel data and combine both mixed-method research to capture both distributional and gender-differentiated influences of hydropower development. Interprovince and inter-river-basin comparisons would also contribute to a better comprehension of context-specific livelihood processes and help to develop regionally specific policy interventions.

REFERENCES

- Adhikari, J., Dhungana, H. (2022), Hydropower development and social impacts in Nepal: A review of policy and practice. *Energy Policy*, 162, 112768.
- Athayde, S., Mathews, M., Bohlman, S., Brondizio, E.S., Futmema, C., Hurd, J., Silva, L.G.T. (2021), Mapping social-ecological impacts of hydropower across river basins. *Energy Research and Social Science*, 74, 101985.
- Brown, P.H., Magee, D., Xu, Y. (2020), Socioeconomic impacts of hydropower development: Updated evidence from Asia. *Energy Economics*, 86, 104631.
- Cernea, M.M. (2000), Risks, safeguards, and reconstruction: A model for population displacement and resettlement. In: Cernea, M.M., McDowell, C., editors. *Risks and reconstruction: Experiences of Resettlers and Refugees*. United States: World Bank. p11-55.
- Department for International Development. (1999), *Sustainable Livelihoods Guidance Sheets*. London: DFID.
- Dorcey, A.H.J., Steiner, A., Acreman, M., Orlando, B. (2018), Large dams and sustainable development: A framework for assessment. *Water Policy*, 20(4), 620-635.
- Field, A. (2018), *Discovering Statistics using IBM SPSS Statistics*. 5th ed. United States: SAGE Publications.
- Government of Nepal. (2018), *National Energy Strategy of Nepal*. Nepal: Ministry of Energy, Water Resources and Irrigation.
- Grill, G., Lehner, B., Thieme, M., Geenen, B., Tickner, D., Antonelli, F., Babu, S., Borrelli, P., Cheng, L., Crochetiere, H., Ehalt Macedo, H., Filgueiras, R., Goichot, M., Higgins, J., Hogan, Z.,... & Zarfl, C. (2019), Mapping the world's free-flowing rivers. *Nature*, 569(7755), 215-221.
- Hair, J.F., Black, W.C., Babin, B.J., Anderson, R.E. (2019), *Multivariate Data Analysis*. 8th ed. United States: Cengage Learning.
- International Energy Agency. (2022), *World Energy Outlook 2022*. IEA. Available from: <https://www.iea.org>
- Kirchherr, J., Charles, K.J. (2021), The social impacts of dams revisited. *Energy Research and Social Science*, 71, 101799.
- Kirchherr, J., Disselhoff, T., Charles, K.J. (2023), Hydropower governance, social safeguards, and sustainability. *Renewable and Sustainable Energy Reviews*, 171, 113010.
- Nardo, M., Saisana, M., Saltelli, A., Tarantola, S. (2005), *Tools for Composite Indicators Building*. Belgium: European Commission.
- OECD. (2008), *Handbook on Constructing Composite Indicators: Methodology and User Guide*. France: OECD Publishing.
- Pandey, R., Bardsley, D.K., Pandey, V.P. (2020), Climate change and livelihood vulnerability in mountain regions. *Sustainability Science*, 15(3), 743-757.
- Paudel, Y., Nepal, R., Jamsab, T. (2021), Electricity development, energy access, and economic growth in Nepal. *Energy Reports*, 7, 1633-1645.
- Scoones, I. (2015), *Sustainable Livelihoods and Rural Development*. United Kingdom: Practical Action Publishing.
- Scudder, T. (2012), *The Future of Large Dams: Dealing with Social, Environmental, Institutional and Political Costs*. Barcelona: Earthscan.
- Shrestha, R.M., Kumar, S., Martin, S. (2019), Hydropower development in Nepal: Policy and sustainability issues. *Energy Policy*, 126, 286-295.
- Sovacool, B.K., Brisbois, M.C. (2022), Energy justice and the sustainability of large-scale infrastructure. *Energy Policy*, 165, 112927.
- Sovacool, B.K., Walter, G. (2019), Internationalizing the political economy of hydroelectricity. *Energy Policy*, 134, 110960.
- Sovacool, B.K., Walter, G., Van De Graaf, T., Andrews, N. (2021), Energy justice and hydropower development. *Renewable and Sustainable Energy Reviews*, 146, 111228.
- Tilt, B., Braun, Y., He, D. (2009), Social impacts of large dam projects: A comparison of international case studies and implications for best practice. *Journal of Environmental Management*, 90(Suppl 3), S249-S257.
- United Nations. (2015), *Transforming our world: The 2030 agenda for sustainable development*. United Nations General Assembly. Available from: <https://sdgs.un.org/2030agenda>
- Wang, J., Li, Y., Chen, Z. (2022), Hydropower-induced displacement and livelihood outcomes in rural China. *World Development*, 150, 105708.
- Wilmsen, B., Rogers, S. (2023), Hydropower resettlement and livelihood sustainability. *World Development*, 165, 106193.
- Wooldridge, J.M. (2016), *Introductory Econometrics: A Modern Approach*. 6th ed. United States: Cengage Learning.
- World Bank. (2021), *Hydropower Sustainability Assessment Protocol*. World Bank. Available from: <https://www.worldbank.org>
- Zarfl, C., Berlekamp, J., He, F., Jähnig, S. C., Darwall, W., Tockner, K. (2019), Future large hydropower dams impact global freshwater megafauna. *Scientific Reports*, 9(1), 18531.