GREEN HYDROGEN: THE FUTURE PROSPECT FOR NEPAL'S ENERGY SECTOR

Sunil Adhikari[a]*

[a]*Infrastructure Development Directorate, Madhesh Province Government, Janakpurdham, Dhanusha, Nepal*

*Correspondence Email: 31sunil.adhikari@gmail.com

Abstract

Nepal possesses an immense technically and economically feasible renewable energy potential of 45,000 MW, yet its current energy consumption remains heavily dominated by traditional sources and imported carbon-based fuels, driving a massive national trade deficit. This study investigates whether green hydrogen, produced using surplus hydroelectricity, serves as a viable prospective pathway toward achieving energy independence and economic prosperity by assessing its contextual suitability and projecting its potential structural role in the national economy through 2050. Adopting a Multi-Criteria Decision Analysis (MCDA) approach, ten key technological, economic, environmental, and socio-political dimensions were evaluated using secondary literatures. The findings reveal a distinct capability paradox: green hydrogen demonstrates outstanding prospects for environmental impact and resource potential due to a projected 3,000 MW monsoon hydropower surplus by 2030—a surplus that is poised to rise exponentially as Nepal targets an ambitious roadmap of 28,500 MW installed capacity by 2035. Similarly, strong policy alignment via the *Green Hydrogen Policy 2024* further anchors this potential, though acute barriers persist regarding low technology maturity and high production costs (Cost-effectiveness) due to a complete reliance on international technology transfer. Furthermore, to explore the economic scale of this transition, a logical projection using the GDP expenditure approach was done, which indicates that green hydrogen could theoretically contribute a cumulative structural value of $13.52 billion between 2026 and 2050 in national GDP. This is calculated based on assumed baseline targets of $6 billion in long-term capital investments, $2.4 billion in domestic wage circulation, and $5.12 billion in potential import substitution across the fertilizer, diesel, coal, and LPG sectors. Ultimately, this analysis underlines that if Nepal is to sustain an ambitious 7.0% economic growth trajectory, the traditional "Business as Usual" model will be fundamentally insufficient; a transformative, extraordinary intervention like a green hydrogen economy is necessary to utilize this rapidly rising surplus, break the trade deficit trap, and shift the nation toward self-sustaining development.

Keywords: Green Hydrogen, Renewable Energy, Nepal, Hydropower Surplus, Energy Independence.

CHAPTER I: INTRODUCTION

1.1 Background

Nepal has immense potential in the generation of renewable energy, with an estimated technically and economically feasible capacity of 45,000 MW (Thapa & Pandey, 2025). Yet, as of 2022, its energy consumption mix remains dominated by traditional sources at 63.87%, while fossil fuels (including diesel, coal, petrol, and LPG) account for approximately 25.8%, and renewable grid electricity represents just 7.23% (Water and Energy Commission Secretariat [WECS], 2024). This significant reliance on carbon-based fuels cost the nation approximately 292.77 million USD in 2022, accounting for 14.1% of Nepal's total imports serving as a primary driver of the country's significant trade deficit (Thapa & Pandey, 2025). In addition to the heavy financial burden of fossil fuel import, Nepal’s agro-based economy remains vulnerable to the fertilizer supply gap. For instance, in FY 2021/22, the government imported 359,086 tons of chemical fertilizers, requiring a massive expenditure of foreign currency, which was still insufficient to meet the annual national demand of 800,000 tons in Nepal (Neupane et al., 2022).

In response to shortening this energy gap, the government has been focusing on developing renewable energy, especially hydroelectricity, throughout the decades. This focus is now expanding toward green hydrogen as a potential transformative energy carrier (Ministry of Energy, Water Resources, and Irrigation [MOEWRI], 2024). While hydroelectricity remains the backbone to the nation's renewable energy, hydrogen is essential to fulfill the diverse need of energy mix and utilize seasonal surpluses. Shakya and Ringius (2024) argue that the green hydrogen produced through electrolysis of water using surplus electricity can serve as zero-carbon fuel for hard-to-abate sectors and a critical feedstock for green ammonia production. Furthermore, the authors highlight combining this hydrogen with carbon dioxide byproducts from various domestic industries, such as cement manufacturing, Nepal can completely eradicate its dependency on imported chemical fertilizers, resulting in an estimated 700,000 to 900,000 tons of yearly production.

1.2 Problem Statement

In Nepal, while the total installed electricity generation capacity has reached 3,591 MW, the maximum peak demand remains only 2,901 MW in FY 2024/25, resulting in significant wet-season electricity spillage (Nepal Electricity Authority, 2025). Similarly, electricity surplus is likely to increase abruptly by 2035, as the Government of Nepal, in its energy roadmap, emphasizes reaching an installed capacity of 28,500 MW while increasing domestic electricity consumption to only 13,000 MW (Republica, 2025). Alternatively, Sunuwar (2022) argues that the power purchase agreement (PPA) capacity of the Nepal Electricity Authority has remained stalled for many years and continues to remain at 11,436 MW by 2024/25, raising questions about the assurance of electricity purchase from private hydropower developers. Therefore, unless the consumption market is assured and expanded, the pace of construction may also slow, making it difficult to achieve the expected 28,500 MW target. Thus, in addition to international electricity exports, there is a strong necessity to identify alternative consumption markets. In this context, green hydrogen produced using surplus electricity, can emerge as transformative energy carrier, thereby justifying an in-depth study on this topic.

1.3 Research question and aim

The research aims to answer the following question: Is green hydrogen a future prospect to Nepal's energy independence and economic prosperity? This question is answered based on following research objectives:

- To assess the suitability of green hydrogen as an energy solution in Nepal.

- To investigate the potential contribution of green hydrogen in nation's gross domestic product (GDP).

1.4 Methodological statement

This study adopts a multi-criteria assessment approach to evaluate the suitability of green hydrogen in Nepal. Key indicators are identified from literature and structured into a theoretical framework, and each indicator is assessed using a 1–5 scoring scale based on available secondary data. The aggregated scores are then used to position green hydrogen across different dimensions and identify areas of strength and limitation in the Nepalese context.

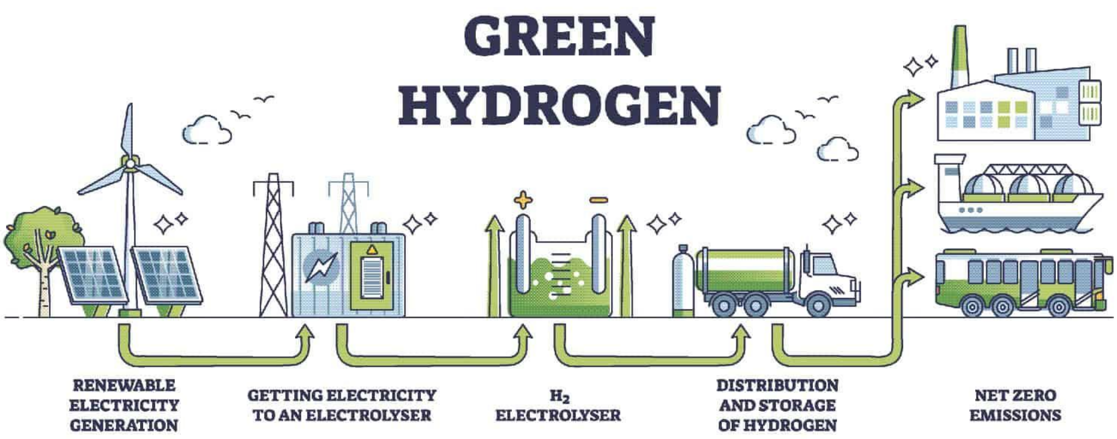
CHAPTER II: LITERATURE REVIEW

2.1 Green hydrogen and its role in clean energy

Green hydrogen is a zero-carbon fuel produced by the electrolysis of water, as depicted in Figure 1, using renewable energy sources like wind, solar and hydropower. As a versatile energy carrier, it enables the decarbonization of hard-to-abate sectors such as heavy industry, aviation, and shipping, while also providing long-term storage for intermittent renewable energy (Algburi et al., 2025). It is the cleanest form of hydrogen, offering a, sustainable, and reliable energy solution that addresses climate change with zero greenhouse gas emissions.

Figure 1

Hydrogen production: The challenges and practical applications



Note. Green hydrogen production and distribution. (Source: Technetics Group, n.d.)

It addresses the intermittent nature of solar and wind by converting surplus power into hydrogen, which can be stored seasonally and converted back to electricity when needed and thus providing a renewable energy storage. As a transportation fuel, it is used in fuel cells and offers a sustainable, zero-emission alternative for heavy-duty trucking, shipping, and aviation (Fernández-Arias et al., 2026). It is used to produce green ammonia, synthetic fuels (e-fuels). It supports energy security as local production reduces reliance on imported fossil fuels. It enhances electricity network reliability by managing high penetration of variable renewable sources (Tata Power, 2025).

2.2 Nepal's renewable energy context and surplus hydroelectricity

Nepal is transitioning from a power deficit to a surplus, with over 3,800 MW of installed hydropower, roughly 9% of its 42 GW potential. Since most projects are run-of-the-river, the country generates a significant monsoon surplus, enabling exports to India and Bangladesh while promoting domestic e-cooking and EV charging (Bhatt & Joshi, 2024). However, production drops in winter, highlighting the urgent need for grid diversification and improved energy efficiency to balance seasonal fluctuations.

By 2030, a projected 3,000 MW surplus offers a transformative opportunity for green hydrogen production. With potential yields reaching 3.15 million tonnes, Nepal could replace 20% of its fossil fuel demand. If surplus electricity is provided at 80% of standard rates, Nepal's hydrogen production would become globally cost-competitive (Thapa et al., 2021). This strategic shift not only addresses the capacity-demand discrepancy but also positions the nation as a regional leader in sustainable, cost-effective energy solutions.

2.3 Techno-economic aspects of green hydrogen

Green hydrogen, produced via renewable-powered water electrolysis (PEM or Alkaline), is a critical decarbonization pathway. Its techno-economic viability rests on reducing electrolyzer capital costs and utilizing low-cost electricity (<$30/MWh). Current costs are declining but require high capacity factors, aiming for < $2/kg by 2030 through economies of scale and efficiency improvements (Shahzad et al., 2025).

Currently, the levelized cost of hydrogen (LCOH) varies widely but is moving towards competitiveness at a rapid rate. Saputro and Juangsa (2025), in a case study of Indonesia, argue the LCOH to be $7.8/kg, influenced by electricity consumption during operating expenses (OPEX) and electrolyzer expense as capital expenditure (CAPEX). To the contrary, Curcio (2025) suggests a hybrid solar/wind system can achieve an LCOH of approximately $3.01/kg. Therefore, green hydrogen requires renewable electricity costs of less than $20–30/MWh to be competitive with grey hydrogen. While medium- to large-scale projects are becoming increasingly feasible, very small projects often have a negative net present value (NPV) (Curcio, 2025).

2.4 Applications of green hydrogen

Green hydrogen is a transformative tool for decarbonizing hard-to-abate sectors. Within the transport sector, green hydrogen powers fuel cell trucks and aviation through direct combustion or synthetic fuels, addressing weight and range limitations of batteries (Project Drawdown, 2025). For heavy industries, it serves as a critical reducing agent in steelmaking, and provides high-temperature heat for cement and glass manufacturing (Mostafa et al., 2024). In fertilizer production, it replaces fossil-fuel-based hydrogen to synthesize green ammonia via the Haber-Bosch process, which can further be processed into green urea (Global Green Growth Institute [GGGI], 2025).

2.5 Recognition in national policy frameworks

Nepal officially prioritized green hydrogen through the *Green Hydrogen Policy 2024* to enhance energy security and utilize surplus hydropower (MOEWRI, 2024). This builds upon earlier recognition in the *National Environmental Policy 2019* and *Water Resources Policy 2020*, which promoted hydrogen for transport and resource management (MOEWRI, 2024). These frameworks align with Nepal’s net-zero by 2045 target and NDC 3.0 goals (Shakya & Ringius, 2024). Economic integration is further supported by the *Trade Policy 2025* and tax exemptions on essential production machinery (Government of Nepal, 2025).

2.6 Contribution of energy sector on GDP

Energy sector development attracts substantial investment, generates employment, and reduces dependence on imported fuels, thereby contributing to national GDP. It acts as a catalyst for economic growth, influencing key components of the expenditure approach to GDP, namely consumption (C), investment (I), government expenditure (G), and net exports (X−M). Additionally, energy has been considered a key driver of economic development and widely stands on the foundation of energy-growth nexus (EGN) theory developed in 1978 (Bashir & Khurshid, 2025). Furthermore, Fabozzi et al. (2022) argue that green growth, coupled by investment in green energy, enhances economic growth while protecting the environment. Similarly, in a case study of 94 countries, Alkathiri and Darandary (2025) identify that energy use, when incorporated as a key factor of production alongside labor and capital, is identified as a significant driver of economic growth and convergence.

2.6 Theoretical Framework

The feasibility of energy development in a country is assessed through a comprehensive evaluation of technological, economic, environmental, and socio-political dimensions. Therefore, for assessing the suitability of green hydrogen in Nepal, a set of indicators is identified from existing literature and structured into a multi-criteria framework, as presented in Table 1.

Table 1

Indicators to evaluate energy suitability for a region

Indicator	Definitions	Supporting Literature
Technology Maturity	Evaluates the Technology Readiness Level (TRL), ranging from laboratory-scale prototypes to full-scale commercialization.	(Naicker & Thopil, 2019; Amiri et al., 2024)
Cost-effectiveness	Measures the Levelized Cost of Hydrogen (LCOH) to determine the economic break-even point and market competitiveness	(Naicker & Thopil, 2019; Bhatia & Williams, 2023; Amiri et al., 2024)
Environmental Impact	Quantifies lifecycle Greenhouse Gas (GHG) emissions and carbon intensity per unit of energy produced	(Wang & Zhou, 2017; Naicker & Thopil, 2019; Bhatia & Williams, 2023)
Social Acceptance	Evaluates public perception, safety concerns, and community willingness to adopt hydrogen-based energy systems.	(Naicker & Thopil, 2019; Bhatia & Williams, 2023; Amiri et al., 2024)
Resource Potential	Assesses the availability of domestic renewable sources	(Wang & Zhou, 2017; Amiri et al., 2024)
Land-use Requirements	Measures the availability of the land for plants relative to topographical constraints and land conservation goals.	(Naicker & Thopil, 2019; Bhatia & Williams, 2023; Amiri et al., 2024)

Job Creation	Estimates the potential for local employment, specialized skill development, and long-term socio-economic value addition.	(Naicker & Thopil, 2019; Bhatia & Williams, 2023; Amiri et al., 2024)
Political & Regulatory Governance	Evaluates the stability of the legal framework, corruption control, and the existence of enabling policies	(Wang & Zhou, 2017; Naicker & Thopil, 2019)
Reliability	Measures the system's ability to provide stable, baseload energy and the efficiency of hydrogen as a storage medium for variable supply.	(Naicker & Thopil, 2019; Bhatia & Williams, 2023; Amiri et al., 2024)
Import Dependency	Assesses energy security by calculating the ratio of substituted fuel imports against total national energy consumption	(Wang & Zhou, 2017)

CHAPTER III: FINDINGS AND DISCUSSION

This chapter highlights comprehensive evaluation of green hydrogen feasibility in Nepal based on the set of ten indicators determined on previous chapter. By applying a Multi-Criteria Decision Analysis (MCDA) approach, each indicator has been assigned a score on a 1–5 Likert scale, where 1 represents an unsatisfactory and 5 represents an outstanding potential. These scores are determined from review of the available literatures and policies.

3.1 Summary of the evaluation

Table 2

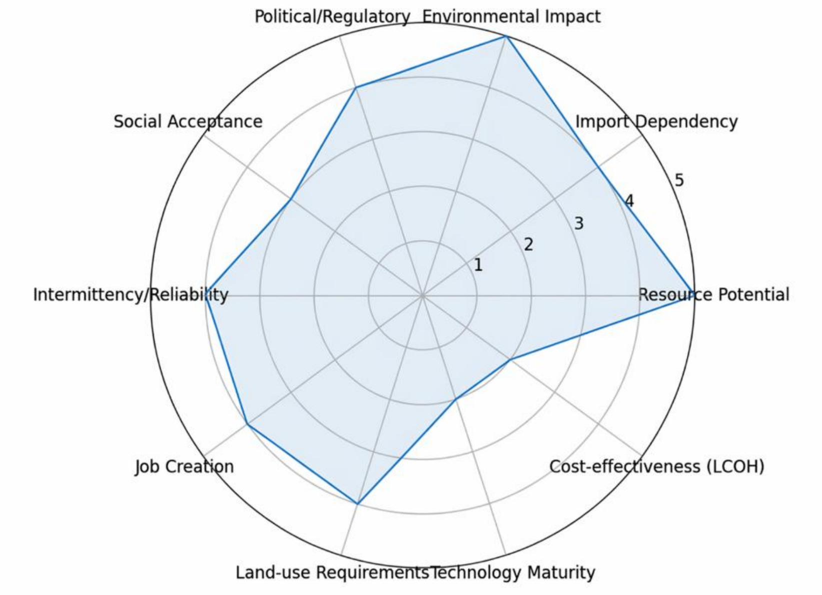
Green hydrogen suitability scoring

Indicator	Score	Status
Technology Maturity	2	Low
Cost-effectiveness	2	Low
Environmental Impact	5	Outstanding
Social Acceptance	3	Moderate
Resource Potential	5	Outstanding
Land-use Requirements	4	High
Job Creation	4	High
Political & Regulatory Governance	4	High
Reliability	4	High
Import Dependency	4	High

The image below, Figure 1, illustrates the potentiality of green hydrogen assessed based on multi criteria on scale of 1 to 5.

Figure 2

Green hydrogen suitability assessment (Nepal)



Note. (Source: Author, 2026)

3.2 Detailed assessment of the indicators

3.2.1 Technology maturity

Unlike solar and wind, green hydrogen technology is still in the pilot and commercialization phase in many developing contexts. Nepal lacks local manufacturing for specialized equipment like electrolyzer stacks and currently relies on international technology transfer (Thapa et al., 2024). Similarly, Nepal is in just process of developing the technical manpower required for full scale commercial operation (MOEWRI, 2024).

3.2.2 Cost-effectiveness

Thapa et al. (2021) argue that producing hydrogen in Nepal, as business as usual, at current electricity rate might cost 5.91-12.75 $ per kg, which is costlier in comparison to international market. The authors further suggest that hydrogen produced from hydroelectricity is 1.7 times more expensive that conventional technology. Furthermore, in order to compete with imported LPG, electricity rates must be reduced from 12 NPR/unit to below 3.55 NPR/unit for large plants (Thapa et al., 2024).

3.2.3 Environmental impact

Green hydrogen aligns with Nepal's goal to achieve net-zero emissions by 2045 (Shakya & Ringius, 2024; Thapa & Pandey, 2025). In addition, Thapa and Pandey (2025) further highlight that replacement of diesel transport by hydrogen could displace 4.7 million metric tons of carbon-dioxide emissions annually by 2035.

3.2.4 Social acceptance

There is a need for intensive campaigns to raise public awareness about the safety and benefits of green hydrogen (Shakya & Ringius, 2024). In addition, due to the highly flammable nature of hydrogen, it requires to integrate high stafety standards to gain public trust (Poudel et al., 2024).

3.2.5 Resource potential

Nepal targets a significant seasonal hydroelectricity surplus, with a projected spill of approximately 3000 MW by 2030 (Thapa & Pandey, 2025). This surplus energy, especially during monsoon, can be utilized for water electrolysis to produce green hydrogen (Neupane et al., 2022). Additionally, Thapa et al. (2021) argue that using this surplus hydroelectricity Nepal can produce up to 67,277 to 336,400 tons of green hydrogen.

3.2.6 Land-use Requirements

Hydrogen production facilities (electrolyzers) have a small physical footprint compared to large-scale renewable farms, which is ideal for Nepal's terrain (Lama et al., 2025). Similarly, Neupane et al. (2022) argue that decentralized hydrogen plants can be located near existing hydropower plants, minimizing new land disturbances.

3.2.7 Job Creation

The green hydrogen hubs are expected to generate high skilled employment during its development and operational phases. In addition, the 2050 vision for a hydrogen economy expects to create between 27,000 and 54,000 new jobs in green hydrogen-related sectors (Shakya & Ringius, 2024).

3.2.8 Political & Regulatory Governance

The legal foundation for green hydrogen has been laid by government through its *Green Hydrogen Policy, 2024* (Shakya & Ringius, 2024). In addition, Shakya and Ringius (2024) highlights that the policy includes provisions for tax exemptions and subsidies to attract private investors. Furthermore, the collaboration between Nepal Electricity Authority and Kathmandu University, dated 27 May 2022, indicates significant determination from government entities as well to promote green hydrogen as an alternative energy source (Kathmandu University [KU], 2022).

3.2.9 Reliability

Hydrogen acts as an energy vector for the power sector, providing large-scale storage to balance seasonal hydropower fluctuations (Lama et al., 2025). It can convert surplus wet-season electricity into a storable form to meet the energy deficit during the dry season (Thapa & Pandey, 2025).

3.2.10 Import Dependency

Green hydrogen can displace approximately 586,878 tons of imported diesel for heavy-duty transport by 2035 (Thapa & Pandey, 2025). In addition, local production of green ammonia could reduce dependency on the 700,000 to 900,000 tons of chemical fertilizer imported annually (Shakya & Ringius, 2024). To be specific, Shakya and Ringius (2024) argue that with 4 to 8 billion dollar investment in green hydrogen, it can result "25% replacement of coal, 20% replacement of diesel and 15% replacement of LPG with hydrogen in targeted sectors and 60% substitution of fertilizer import" within 2050.

3.3 Gap analysis

The evaluation presented in Sections 3.1 and 3.2 reveals a clear capability paradox within the green hydrogen sector. While Nepal demonstrates strong resource potential and notable environmental advantages, critical barriers persist in terms of technological maturity and cost-effectiveness.

However, the strong political commitment, the reliability of ongoing progress in green hydrogen initiatives, and the potential for a significant reduction in energy imports show a highly positive sign for the sector. The 2024 policy framework provides the necessary institutional stability to move beyond these initial hurdles. Therefore, the strategic implementation of this policy in shaping international technology transfer and targeting capital investment can unlock the future prospect of energy independence for Nepal through green hydrogen.

3.4 Potential contribution to GPD (2026 – 2050)

Nepal currently targets a rapid economic growth rate of 7.0%, a significant leap from the historical average of 4.5% to 5.0%. For the nation to sustain this trajectory, doubling its GDP by 2035 and reaching a $200 billion plus economy by 2050, the traditional "Business as Usual" model is insufficient. Achieving such ambitious milestones requires a fundamental structural transformation and the introduction of high-value industrial sectors. Green hydrogen presents a transformative opportunity to serve as this new economic engine, moving Nepal beyond its current dependency on subsistence agriculture and imported fossil fuels.

The potential contribution of this sector can be investigated using the expenditure approach to GDP, represented by the identity: $GDP = C + I + G + (X - M)$

By converting the strategic targets for investment, employment, and import substitution into monetary values, based on the targets suggested by Shakya and Ringius (2024), we can estimate the structural impact of green hydrogen on each component of the national balance sheet through 2050.

Investment (I): The transition requires a projected capital injection of $4 to $8 billion (assumed average of $6 billion) by 2050.

Consumption (C): The sector is projected to create between 27,000 and 54,000 jobs (assumed average of 40,000). At an estimated average annual salary of $5,000, this creates a new domestic wage flow of $200 million annually. As these wages circulate through the local market, they boost private consumption, triggering a secondary multiplier effect across the service and retail sectors.

Net Exports (X - M): The most critical impact on Nepal's fiscal stability is the reduction of Imports (M). Based on 2022-2025 import data, achieving the 2050 substitution targets will stop massive foreign exchange leakage:

60% Fertilizer Substitution:	~$130.8 Million saved annually.
20% Diesel Substitution:	~$170.0 Million saved annually.
25% Coal Substitution:	~$64.0 Million saved annually.
15% LPG Substitution:	~$62.5 Million saved annually.
Total Annual "M" Reduction:	~$427.3 Million.

Therefore, Table 3, illustrated below, summarizes the structural contribution of green hydrogen in nation's GDP by 2050.

Table 3

Summary of GDP contribution

GDP Components	Cumulative Value (2026-2050)
Investment (I)	$6 billion
Consumption (C)	$2.4 billion*
Net Export (X-M)	$5.12 billion*
Total	**$13.52 billion**

*Note: *Calculated using linear growth model.*

Therefore, in a future $200 billion plus economy, this $13.52 billion cumulative contribution ensures that Nepal's growth is self-sustaining. By producing its own fuel and fertilizer, the nation protects its 7% growth target from the 'Trade Deficit Trap' that often slows down developing nations.

CHAPTER IV: CONCLUSION

4.1 Conclusion

In conclusion, green hydrogen is a transformative solution for Nepal’s energy sector and economic growth. The study highlights how the nation can leverage its massive surplus of hydroelectricity to produce zero-carbon fuel, thereby reducing a heavy reliance on imported fossil fuels and chemical fertilizers. By evaluating various techno-economic indicators, it can be concluded that while technology maturity and cost-effectiveness remain initial challenges, the environmental benefits and resource potential are outstanding. Similarly, National policy frameworks, such as the *Green Hydrogen Policy 2024*, are already aligning with net-zero goals to foster energy independence, and promote study and production of green hydrogen. Finally, the transition to hydrogen can be a strategic move to stabilize the trade deficit and stimulate the national GDP.

4.2 Limitation of the study

There are a few key limitations to this study that should be noted. First, this research is based mostly on a review of existing literature. Because green hydrogen is a new field in Nepal, there is a lack of local data and prior studies to draw from. Second, the scoring and rating scales used to evaluate different sectors are based on subjective judgment rather than hard, mathematical measurements.

Similarly, while the study identifies barrier areas like technology and cost, it does not provide a step-by-step technical guide on exactly how to build these systems. In addition, the GDP contribution forecast is very much approximate calculation. Since, this study does not use a complex 'dynamic model' to track these interlinked connection on the components of GDP, the forecasted numbers should be viewed as a logical projection of the project's scale rather than a perfect economic forecast.

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