Research in Globalization 8 (2024) 100226

Contents lists available at ScienceDirect

Research in Globalization

journal homepage: www.sciencedirect.com/journal/research-in-globalization

# Pathways towards net zero: Assessment of enablers and barriers in Nepal

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ARTICLE INFO

*Keywords:*
Feasibility assessment framework
Nationally Determined Contributions
Nepal's long-term strategy for net-zero emission
Mitigation options

ABSTRACT

Implementing mitigation measures to limit global temperatures to below 2 °C poses several challenges. Even though Nepal's global emission contribution remains minimal, the nation is committed to the net zero targets aligned with the Paris Agreement through Nationally Determined Contributions (NDC) and Long-Term Low greenhouse gas Emission Development Strategies (LT-LEDS) by 2045, where the biggest emitters like India, China and European Union (EU) aims to achieve net zero by 2070, 2060 and 2050 respectively. In this context, detailed and concrete insights on context specific factors that inhibit or enable Nepal's mitigation measures to robust climate action are still at its infancy. We assessed the enablers and barriers to implementing mitigation measures across the energy, transport and forestry sectors. For this, an adapted version of the Intergovernmental Panel on Climate Change (IPCC's) Feasibility Assessment Framework is used, with data triangulated through an extensive literature review, as well as qualitative data collected through semi-structured interviews with sector-specific experts (n = 25), policymakers (n = 15) and industry managers (n = 10). Our results indicated that geophysical and topographical barriers are relatively less prominent. However, the institutional capacity and governance, and cross-sectional coordination inhibit the implementation of mitigation measures. Addressing institutional barriers, such as policy gaps, regulatory frameworks, capacity building and coordination challenges, is essential for unlocking the full potential of enablers and overcoming obstacles. This research serves as a valuable guide for countries like Nepal, helping them gain insights into the challenges they may encounter on their journey to net zero targets.

## Introduction

Despite global and regional commitments (Maraseni & Reardon-Smith, 2019) and the 2018 IPCC call for net-zero emissions (NZE) by 2050 to limit warming to 1.5 °C (IPCC, 2018b), global CO2 levels remain high (Dash & Gim, 2019). The 2021 Glasgow Climate Pact prompted over 100 countries to pledge NZE targets (Höhne et al., 2020). Nepal, a poorer nation, aims for NZE by 2045, setting an example as others target 2050.

China, as the largest emitter, has pledged to achieve NZE by 2060, India has set its sights on reaching the NZE target by 2070, whereas the EU and numerous other nations have targeted NZE by 2050 (ECIU, 2023). Aligned with the trajectory of other nations, several developing countries such as Maldives, Laos, Sri Lanka, and Ethiopia have also made commitments to achieve NZE before the year 2050 (Shakya et al., 2023). Nepal, classified as one of the Least Developed Countries (LDCs), is highly susceptible to climate change effects and ranked 10$^{th}$ among the most affected countries globally (Eckstein, Künzel, & Schäfer, 2021). Nevertheless, it has a minimal global emission share, contributing less than 0.1 percent of the overall global emissions (GoN, 2021; WBG, 2022). According to Nepal's Third National Communication (TNC),[1] the country's net greenhouse gas (GHG) emissions are estimated at 28,166.06 Gg CO2 equivalent. The TNC has tracked emissions across four sectors: Industrial Processes and Product Use (IPPU), Agriculture, Forestry and Land Use (AFOLU), Energy, and Waste. The report highlights that the energy sector is the primary contributor to emissions at approximately 53 %, followed by AFOLU at 43 %, and others (waste and IPPU combined) at 4 %. In the energy sector, the commercial,

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[1] https://unfccc.int/sites/default/files/resource/TNC%20Nepal_Final_v2.pdf.

https://doi.org/10.1016/j.resglo.2024.100226
Received 5 April 2024; Received in revised form 12 May 2024; Accepted 13 May 2024
Available online 14 May 2024

institutional, residential, and agricultural sectors are the most substantial contributors, accounting for 73 % (10,753.55 CO2 eq), followed by manufacturing industries and construction at 16 % (2,256.22 CO2 eq), and transportation at 11 % (1,739.51 CO2 eq).

While Nepal's global emission contribution remains minimal, the country has marked its position in global climate governance through ratification of international conventions, participation in regional and global climate commitments and national policy initiatives aimed at addressing climate challenges. The nation is committed to robust climate action aligned with the Paris Agreement's principle of common but differentiated responsibilities (UNFCCC, 2015). As a party to the Paris Agreement, Nepal has submitted its first and second NDCs specifying its climate goals. Specifically, the second NDC[2] targets key sectors: energy, transport, clean cooking/residential, AFOLU, and waste, outlining emission reduction goals and policy targets. Moreover, Nepal has formulated a LT-LEDS[3] in line with the second NDC, aiming to achieve the ambitious objective of net-zero emissions by 2045. The strategy encompasses augmenting clean/renewable energy adoption, elevating energy efficiency in residential, industrial, and transportation domains, advancing clean mobility, fostering sustainable land use and agriculture, embracing circular economy principles, deploying carbon removal technologies, harnessing the benefits of clean energy trade, and actively seeking international collaboration and support to strengthen climate action efforts.

In the pursuit of attaining the climate objective of NZE while meeting prescribed targets, a range of enablers and barriers come into play. Enablers encompass factors that reinforce or amplify the mitigation strategies outlined in the LT-LEDS and the second NDC. Concurrently, barriers, including limitations in resources, technical know-how, financial constraints, and social and political acceptability, have the potential to impede the realization of NZE (Steg et al., 2022). A considerable body of literature has assessed diverse facets of mitigation options for NZE in Nepal, including the implication of carbon tax as a strategy to achieve NZE (Pradhan et al., 2018); recognition of NZE and their co-benefits (Shakya et al., 2023); exploration of the nexus between mitigation actions and government policies (Baniya & Aryal, 2022); implications of a green growth approach for fostering a coherent climate policy (Baniya, 2023); as well as the importance of the establishment of local institutions and funding allocation for the implementation of national climate strategies in low-income countries and Nepal (Havukainen, Mikkilä, & Kahiluoto, 2022). However, there remains a dearth of research specifically probing the investigation of enablers and barriers that Nepal encounters in its quest for NZE. Examining enablers and barriers of NZE in Nepal is a fundamental step to ensure that the transition is effective, efficient, equitable and sustainable. It also lays the groundwork for a comprehensive approach that considers the country's unique context and challenges. Specifically, LDCs like Nepal require tailored approaches to enhance the feasibility of implementing relevant mitigation options by targeting context specific barriers and enablers.

Among all others, our study primarily focused on three major sectors: energy (hydroelectric power; HEP), transport (e-vehicle and e-railways), and forest to identify factors that enable and/or inhibit the deployment of mitigation options. The energy and transport sectors have been considered due to their dominance in total national emissions in Nepal. Additionally, the forest plays a crucial role as a significant carbon sink. Past assessments on climate mitigation in Nepal underscore the inclination of Nepal's mitigation policies towards the energy, forest, and transport sectors (Baniya & Giurco, 2021), yet detailed and concrete insights on context specific challenges are not explored for these sectors. Thus, this study aims to identify the key enablers and barriers that Nepal faces while working towards achieving NZE as envisioned through the LT-LEDS (Eckstein et al., 2021; GoN, 2020, 2021; Steg et al., 2022; Suroso et al., 2022; WBG, 2022).

## Research framework and methods

### *Research framework*

Every nation has specific challenges and opportunities to achieve its national climate targets. The detailed national and sectoral pathway toward NZE compatible with the Paris Agreement objectives is characterized by multiple factors and uncertainties when deploying mitigation options. That is why a comprehensive assessment of context-specific challenges in aligning development aspirations with net zero pathways is essential. In this context, (Jewell & Cherp, 2020) investigated the economic and political feasibility of mitigation options. In contrast, (Nielsen et al., 2020) examined the institutional and social feasibility, which has major implications on the realistically achievable mitigation potential of possibilities. To analyze the national climate policy, (Havukainen et al., 2022) applied an institutional analysis and developmental framework, which is limited to a context and situations that influence the institutions' decision-making. Nevertheless, these frameworks didn't consider several other dimensions (Steg et al., 2022), such as the availability of geophysical resources and broader environmental impacts of mitigation opportunities that can likely augment or constrain the implementation of mitigation.

To overcome these shortcomings, in this paper, we applied an adapted version of the comprehensive Feasibility Assessment Framework used in the IPCC Sixth Assessment Report (IPCC, 2022) to explore the feasibility of implementing various mitigation strategies (Table 1). It incorporates six dimensions: geophysical, environmental-ecological, technological, economic, sociocultural, and institutional. The impacts of the strategy could be positive or negative or have both aspects (Table S1) and depend upon context, region, scale, and implementation time. For example, the physical potential of HEP is high in areas with abundant water resources but low in water-scarce regions. This framework can address relevant concerns regarding various factors and thus, foster the understanding of options that can achieve their full mitigation potential. Hence, the dimensions and indicators for assessing the barriers to and enablers of implementing mitigation strategies developed by (Steg et al., 2022), which is an extension of the feasibility assessment framework employed in SR1.5 (IPCC, 2018a), were utilized in this study.

### *Research methods*

#### *Data collection strategy*

We conducted a comprehensive analysis by examining the second (latest) NDC document, LT-LEDS, and the TNC report. Nepal submitted its second NDC to the UN Framework on Convention of Climate Change secretariat, which outlined national and sectoral targets on different timelines, while the LT-LEDS prepared in 2021 aimed to achieve NZE based on the second NDC. The TNC report helped us determine the contribution of various sectors to GHG emissions. The analysis of these crucial documents and a quick review of the relevant literature contributed to i) collate different mitigation strategies that have been under consideration across the three sectors and ii) inform the development of the interview protocol for the semi-structured interviews (Fig. 1). The key highlights of the second NDC documents are as follows:

- Outlines mitigation efforts as a commitment to promote renewable energy, focusing on hydropower, electric mobility, and managing forests and waste.
- Highlights key policy priorities on adaptation, incorporating eight thematic areas and four cross-cutting areas.

[2] https://unfccc.int/documents/496436?gclid=CjwKCAjwg-GjBhBnEiwAMUvNW2Fk5nhE5Yz13-AYbrOGb4yDf_mcrnooyLaeZVlfOu_S07Uwev5azBoCAS8QAvD_BwE.

[3] https://unfccc.int/sites/default/files/resource/NepalLTLEDS.pdf.

**Table 1**
Dimensions and indicators for assessing the barriers to and enablers of implementing mitigation options (Adapted from IPCC Sixth Assessment Report).

| | |
|---|---|
| Geophysical feasibility: availability of required geophysical resources | Physical potential: the extent to which there are physical constraints to implement the option<br>Geophysical resource availability (including geological storage capacity): availability of resources needed to implement the option (e.g., minerals, fossil fuels)<br>Land use: claims on land when implementing the option |
| Environmental-ecological feasibility: impacts on the environment | Air pollution: changes in air pollutants, such as NH4, CH4, fine dust<br>Toxic waste, ecotoxicity, and eutrophication<br>Water quantity and quality: changes in the amount of water available for other uses, including groundwater<br>Biodiversity: including changes in the area of conserved primary forest or grasslands that affect biodiversity and management aimed at conservation and maintenance of land carbon stocks |
| Technological feasibility: the extent to which the required technology can be implemented at scale quickly | Simplicity: is the option technically simple to operate, maintain, and integrate<br>Technology scalability: can the option be scaled up quickly to a meaningful level<br>Maturity and technology readiness: R&D (and time) needed to implement the option |
| Economic feasibility: financial costs and benefits and economic effects | Costs now, in 2030, and in the long term, including investment costs (investments per ton CO2 avoided), costs in USD/tCO2-eq, and hidden costs<br>Effects on employment and economic growth |
| Sociocultural feasibility: public engagement and support, and health, well-being, and distributional effects | Public acceptance: the extent to which the public supports the option and will change their behavior accordingly<br>Effects on health and well-being (excluding environmental-ecological impacts)<br>Distributional effects: equity and justice across groups, regions, and generations, including security of energy, water, and food and poverty eradication |
| Institutional feasibility: institutional capacity, governance structures, and political support | Political acceptance: the extent to which politicians and governments support the option<br>Institutional capacity and governance, cross-sectoral coordination: capability of institutions to implement and handle the option, and coordinate it with other sectors, stakeholders, and civil society<br>Legal and administrative capacity: the extent to whichsupportive legal and administrative changes can be achieved |

- Despite being a negligible contributor, the second NDC document imposes new progressive mitigation targets compared to the first NDC.
- Recognizes governance, finance, economic aspects, equity and inclusiveness, monitoring, reporting and verification as the important elements during implementation.

The selection of the three sectors was carefully carried out, considering their significant contribution to GHG emissions, as outlined in the TNC report, to ensure that our study has significant policy implications for various stakeholders in Nepal. The analysis of the energy sector is limited to the HEP because it is the dominant form of energy in Nepal.

*Design of interviews and data analysis*

For analyzing the Nepalese scenario, we conducted semi-structured interviews with three main stakeholder groups, including sector-specific (25), policymakers (15), and the industrial sector (10). By involving this diverse range of stakeholders, we aimed to gather valuable insights and perspectives from experts and practitioners in the energy, transport, and forest sectors. The sector-specific group consisted of participants from relevant ministries, including the Ministry of Energy, Water Resources and Irrigation; Ministry of Physical Infrastructure and Transport; and Ministry of Forests and Environment (Table 2). Their selection was based on recommendations made by the heads of their organizations. The policymakers group comprised individuals who held positions such as department chiefs associated with the ministries and personnel involved in the formulation of the NDC and LT-LEDS. These participants were selected based on their expertise and involvement in the respective sectors. Additionally, participants from the industrial sector were individuals from private sectors involved in electric transport, such as dealers, experts, and those engaged in Clean Development Mechanism projects. These participants were selected based on their interest, availability and involvement in the sector.

The interviews were conducted using a questionnaire aimed at understanding the contemporary knowledge, barriers and enablers to implement mitigation strategies to achieve the targets of NDC (Table S2). The bulk of textual information obtained was recorded, tabulated and cleaned – providing us with an elaborative list of enablers and barriers in specific sectors. Then, they were categorized according to the dimensions and indicators of the feasibility assessment framework.

All six dimensions, namely, geophysical, environmental-ecological, technological, economic, sociocultural, and institutional feasibility and their associated indicators, were given equal weightage for the scoring purpose based on the feasibility assessment framework (Steg et al., 2022). In addition to providing qualitative descriptions of the enablers and barriers, interview respondents scored the enablers and barriers to indicate the relative importance of the responses. The strength of enablers and barriers for all indicators of six dimensions were coded as 100 (high), 50 (medium) and 0 (low) based on the judgment of the expert interview respondents. Some indicators were not applicable to a mitigation strategy or may not affect the feasibility of the option, coded as N/A. Thus, the outcomes of this assessment from three sectors indicate the extent to which different factors would enable or inhibit the deployment of the selected mitigation strategy in these sectors.

## Results

This study identified and assessed several key enablers and barriers for three dominant sectors, which shed light on the factors that can support or hinder the progress towards the goals envisioned by NDC (Table 3; Fig. 2).

Our results depict that among all the dimensions considered in the study, institutional and technological factors were hindering the most in all three sectors, while environmental-ecological factors were found to be enablers to meeting the targets set by NDC. The results also reveal the existence of prominent enabling factors in the forest sector compared to the energy and transport sector.

*Energy*

This study identified geophysical resource availability in the form of snowcapped mountains as a key enabler for hydroelectricity production in Nepal. The strength of geophysical resources and effects on economic growth were scored higher as enablers. One respondent working at the Nepal Electricity Authority described how:

> Nepal's hydropower sector has immense potential for clean energy development, not only to meet the domestic demands but also for energy export to neighboring countries. It is instrumental in

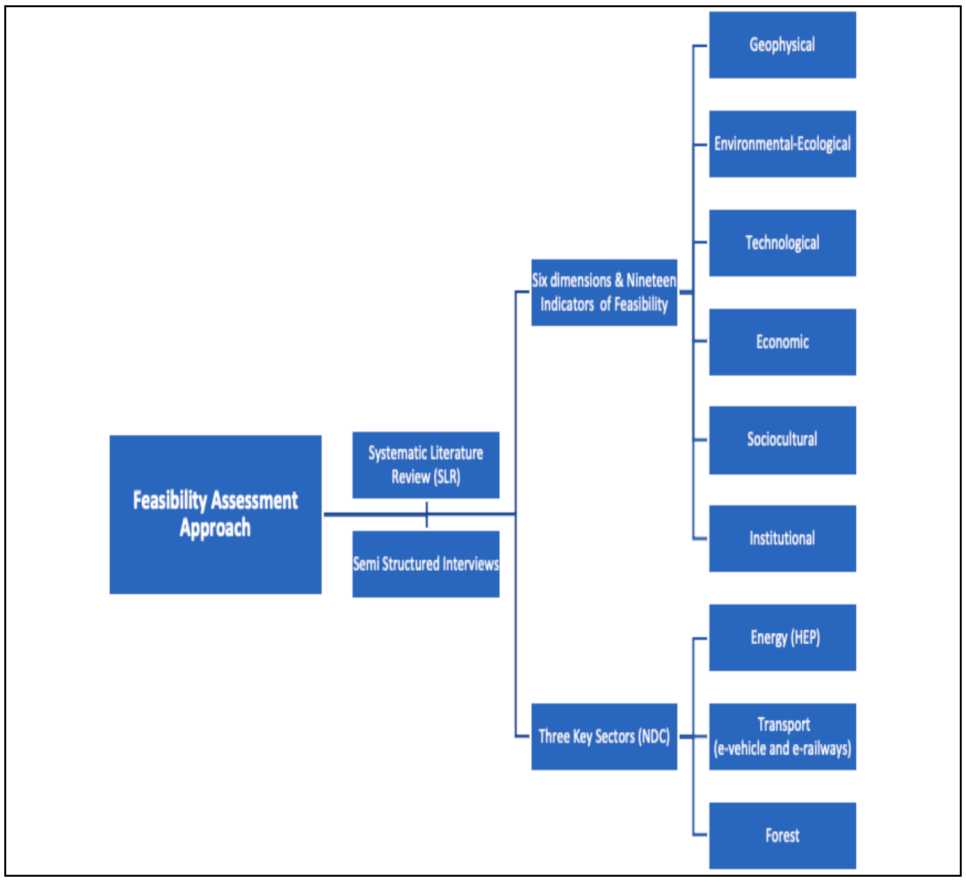


**Fig. 1.** Research Design.

attaining the national NZE target. The inherent potential of HEP, geological slope advantage, water availability from first grade snow-fed rivers and trained manpower are the enablers in the sector, whereas seasonal variability in river flow, climate-induced disasters, and transmission and distribution issues are some of the challenges in the sector that inhibit the growth of HEP.

Another significant enabler was the minimal contribution of this clean energy source to air pollution and its contribution towards long term economic growth. However, the technical scalability of hydropower was identified as a major barrier in this sector. Additionally, the loss of biodiversity and the impacts on riverine ecosystems due to the obstruction of natural water flows were identified as barriers. The strength of institutional capacity, governance and cross-sectional coordination was rated higher as barriers within the dimensions of energy. Institutional factors, such as administrative hurdles during the approval and licensing phase, were also recognized as another major barrier.

*Transport*

In the transport sector, the environmental benefits of electric transportation compared to vehicles powered by fossil fuels were identified as a major enabler. Another critical enabler included the social acceptance of electric transportation by the public and motivated customers. However, geophysical complexities in the form of rugged and unstable slopes and topographies were identified as key barriers, which act as bottlenecks to the smooth operation of electric transportation in Nepal. As one transport sector expert noted:

> The attention of private electric vehicles is gaining traction, mostly in urban areas of Nepal; however, there has been sluggish growth in the public e-transport sector. Also, there is a dilemma among consumers regarding the tax rebates and subsidies on electric vehicles. The policymakers should make rational and consistent decisions through evidence-based policies focusing on the sustainable transport system.

Also, a senior official at the Department of Railways described how:

> Although the institutional setup was built-up and conceptualized to develop, manage and operate railway systems in Nepal,e-railways are still in the infancy stage in Nepal. We need significant shifts at the policy level in order to realize the concepts of e-railways.

Land use changes resulting in biodiversity loss and the depletion of forest resources were also observed as barriers. Moreover, inadequate technical know-how and scalability were observed as other barriers, along with the existing policy inconsistencies, which has hindered the successful operation of the electric transportation system in Nepal. The strength of various dimensions, including socio-cultural, economic and institutional capacity, governance and cross-sectional coordination, was rated higher as barriers within the transport sector.

*Forest*

This study identified a multitude of factors as enablers to meet mitigation targets in the forest sector, including the inherent quality of forest in sequestrating atmospheric carbon, improving watershed conservation, regulating ecosystem services, improving water quality, ensuring habitat conservation, protecting the ecological niche and providing a livelihood for the rural economy. Nevertheless, the dilemma presented by the "development versus conservation" policy discourse was recognized as a barrier while deploying this sector as a mitigation option.

A senior policymaker at the Ministry of Forest and Environment

**Table 2**
Number of respondents by category.

| Stakeholders | Institutions | Sector | Number of respondents |
|---|---|---|---|
| **Sector specific (n = 25)** | Ministry of Forests and Environment | Forest | 9 |
| | Ministry of Energy, Water Resources and Irrigation | HEP | 8 |
| | Ministry of Physical Infrastructure and Transport | Transport | 8 |
| **Policymakers (n = 15)** | National Planning Commission | HEP, Transport and Forest | 3 |
| | Department of Forests and Soil Conservation | Forest | 2 |
| | REDD Implementation Centre | Forest | 1 |
| | Department of Roads | Transport | 2 |
| | Department of Transport Management | Transport | 1 |
| | Department of Railways | Transport (railway) | 1 |
| | Department of Electricity Development | HEP | 1 |
| | Climate Change Management Division, MOFE | HEP, Transport and Forest | 3 |
| | Nepal Electricity Authority | HEP | 2 |
| **Industrial Sector (n = 10)** | Dealers and Suppliers of Electric Vehicles | Transport | 3 |
| | REDD and CDM Project (experts and initiator) | Forest and HEP | 3 |
| | Experts and Researchers | Forest, Transport and HEP | 4 |

described how:

> The drafting and approval of NDC documents without realistic consideration of attaining NZE by 2045 seems ambitious. Despite that, forest conservation in Nepal is highly appreciated around the globe and has been a leading sector in achieving the NZE targets. Challenges in the form of a lack of institutional coordination and financing mechanisms persist in the forest sector.

## Discussion

This study identified and analyzed the enablers and barriers that Nepal faces in implementing its mitigation options and assessed the feasibility of Nepal's ability to achieve NZE by 2045.

### *Energy sector*

Deploying clean energy is one of the most promising ways to achieve the global ambitions to limit global warming to no more than 1.5 ℃. Several studies have shown the possibility of achieving Paris climate goals through large-scale extensive deployment of renewable technologies (Bhattarai et al., 2023; Renné, 2022). Our findings also reveal HEP as a key potential sector with multiple enablers to foster the transition to the net zero pathway. This result is exacerbated by the findings of (Gunatilake, Wijayatunga, & Roland-Holst, 2020), stating an estimated generation capacity of 83 GW HEP and (MoFE, 2021b) showing an increasing trend of HEP production in Nepal. Our study showed that the deployment of HEP as a mitigation option in Nepal has several advantages, possessing inherent favorable geophysical and topographical capability and availability of water resources such as water towers in the form of snowcapped Himalayas, runoff river system and mountainous topography. Technologically, HEP is well-known and easily adaptable,

**Table 3**
Sector-wise NDC Targets, their Enablers and Barriers.

| Sector | Target in NDC | Enablers | Barriers |
|---|---|---|---|
| Energy | Expansion of clean energy generation from 1400 MW to 15000 MW of which 5–10 % to be generated from mini, micro-hydro, solar, wind and bio-energy, by 2030. | • Physical potential and geophysical resource availability (snowcapped mountain)<br>• Source of clean air in comparison to fossil fuel<br>• Simple technology and readily available<br>• Import substitution and self-sufficient<br>• Public acceptance and politically acceptable | • Hindrance in mass production<br>• Obstruction on natural flow of water obstruction aquatic ecosystem services<br>• Loss of biodiversity in downstream<br>• Problem in public acceptance due to migration and resettlement issues.<br>• Inconsistent policies and plans<br>• Project delays and limited legal and administrative capacity |
| Transport | • Sales of electric vehicles in 2025 will be 25 % of all private passenger vehicle sales, including two-wheelers and 20 % of all four-wheeler public passenger sales.<br>• Development of 200 km of the electric rail network by 2030. | • Clean compared to fossil fuels<br>• Willingness to buy from the public<br>• Motivated consumers<br>• Politically accepted and incorporated in policies, plans and budget | • Rugged and unstable topography<br>• Generation of toxic waste like batteries<br>• Land use change, loss of forest resources and loss of biodiversity<br>• Not any charging stations in operation<br>• Technologically dependent on other nations – no raw materials, mechanism of assembling<br>• Costly due to full import dependent<br>• Topographically unviable and unreachable to public due to gap in e-public vehicle.<br>• Inconsistency in policies and plan<br>• Political instability and lack of commitment |
| Forest | Maintaining 45 % of the total area of the country under forest cover by 2030. | • Government forest and community forest<br>• Habitat conservation and ecosystem<br>• Sequestration of carbon<br>• Improvement in watershed conservation and regulating ecosystem services.<br>• Technically simple<br>• Dependent on livelihood so public acceptance<br>• Improvement in economic activities due to community forest benefit sharing, co-production | • Politically acceptable but conflict in project implementation, developmental projects<br>• Policies gap in localization<br>• Conflict in federalism |

(*continued on next page*)

**Table 3** (*continued*)

| Sector | Target in NDC | Enablers | Barriers |
|---|---|---|---|
| | | and co-generation<br>• Equitable sharing mechanism | |

proven by the fact that Nepal has a long history of using this technology since 1911 (Gunatilake et al., 2020; Shrestha, 2016). However, our study has pinpointed scalability as a major barrier to realizing the full potential of HEP in Nepal. So, if Nepal were to achieve the national climate goals, the radical shift in scaling up HEP through mega and large-scale projects is crucial.

In spite of these intrinsic competitive advantages, the existence of seasonality due to dependence on run-off river type HEP (Shrestha, 2016) is a major bottleneck. As a result, the country is not being able to generate its maximum potential and thus, a gap between supply and demand still exists in the domestic energy market. (NEA, 2021) also reports this situation with 1320 MW of peak electricity demand against the installed generation capacity of 1,182 MW only during the fiscal year 2018/19. In addition, (USEIA, 2023) reports that only one third of the installed capacity is self-sufficient during winter and dry seasons. In order to meet the demand in lean seasons, Nepal is compelled to import electricity from other countries, with a record that 31.8 % of total electricity was imported from India in FY 2020/21(Gunatilake et al., 2020). Besides, power reliability and generation capacity are further affected by climate change and other extreme climate events (Bhattarai et al., 2022; Shrestha et al., 2014). According to our study, Nepal faces many challenges related to institutional barriers when it comes to timely project planning and implementation in the mega hydropower projects which is consistent with the findings of (Bhattarai, Maraseni, & Apan, 2022; Shrestha, 2016; Shrestha et al., 2014). Even though HEP is a widely accepted social and political agenda in Nepal, existing institutional barriers were also observed in the form of bureaucratic hurdles in obtaining permits and licenses and a need for clear policy guidelines and regulatory frameworks. The procedural dilemmas and project delays are mainly attributed to institutional factors including coordination issues and several layers of administrative procedures. For instance, (NEA, 2021) reports only 172 projects could actually commence construction despite the issuance of survey license to 302 projects (total capacity of 15,885 MW). Moreover, our study also found that inconsistencies in policies and decision making due to frequent changes in government and political instability have also led to delays in project implementation and investment in the sector, which is also supported by (Laudari et al., 2021). Overall, the pathway towards mitigation targets set by the second NDC in production of 15000 MW HEP can be achieved through streamlining regulatory processes, facilitating smother implementation mechanisms and collaborating among relevant agencies and stakeholders.

### *Transport sector*

Globally, the transport sector contributed 14 % of the total GHG emissions which is equivalent to 7.6 GtCO2e (UNEP, 2022). This indicates that the sector requires abrupt intervention for the steady transition towards low-carbon societies. Our study found adopting e-transport in Nepal not only replaces the utilization of fossil fuels but also has a multiplier effect on HEP demand and production. The Nepalese transport system relies heavily on fossil fuels and accounts for 1,741 Gg of CO2e emissions, which is 37 % of the total GHG emission in Nepal (MoFE, 2021b). The cost of import of petroleum constituted 18 % of the total imports, out of which, fuels used in the transportation sector amount to 95 % (USEIA, 2023). This implies the transition to an e-transport system stimulates economic growth and promotes environmental benefits through enhanced national energy security.

Nevertheless, a multitude of influential factors such as economic, infrastructure, operational and geophysical are found to be critical barriers. Also, our study identified that the expansion of the use of electric based transportation is exacerbated by technical adaptability. Constraints identified in the form of no/little production facilities for e-vehicles in Nepal make them exceptionally costly compared to neighboring countries. For example, the starting price of the Tata Nexon electric vehicle in India is around $19,000, while the same model is priced at around $28,000 in Nepal. Similarly, the starting price of the BYD E6 electric vehicle in China is around $25,000, whereas the same model is priced at around $35,000 in Nepal. Also, the pity situation for adopting these technologies can be illustrated by the slow pace of introducing charging stations for e-vehicles in the country. Still, there is a dilemma in the mass construction and operation of these stations. Nepal possesses merely 30 publicly accessible charging stations in contrast with countries like China and Norway, which have over 1.3 million and 13,000 publicly accessible charging points, respectively in the year 2020 (IEA, 2019; Shi et al., 2019). This has highly inhibited the Nepalese public in shifting from petroleum-based automobiles to electric ones, especially in the case of long-distance travelers. The adoption of e-vehicles has always been prioritized as a political agenda, which is identified as an enabler in our study. However, the policy formulation and its effective implementation is instrumental in determining the pathways toward consumer perception and the use, import and sale of e-vehicles. For instance, the Government of Nepal (GoN) declared the reduction of excise duty and customs duty from 10 % to 40 % in the 2020–2021 financial budget itself (MoF, 2021). The sale and import of e-

| Thematic Sectors | Geophysical | | | | | | Environmental-Ecological | | | | | | Technological | | | | | | | | Economic | | | | Socio-Cultural | | | | Institutional | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Physical Potential | | Geophysical Resource Availab. | | Landuse | | Air Pollution | | Water Quality and Quantity | | Biodiversity | | Toxic waste | | Simplicity | | Technology Scalability | | Maturity and Technology readiness | | Costs in 2030 & long term | | Effects on employment and economic growth | | Public acceptance | | Effects on health and wellbeing | | Distributional effects | | Political acceptance | | Institutional capacity and governence, cross sectional coordination | | Legal and administrative | |
| | E | B | E | B | E | B | E | B | E | B | E | B | E | B | E | B | E | B | E | B | E | B | E | B | E | B | E | B | E | B | E | B | E | B |
| Energy (HEP) | 50 | 0 | 100 | 0 | 50 | 0 | 50 | 0 | 0 | 50 | 0 | 50 | N/A | N/A | 50 | 0 | 0 | 50 | 50 | 0 | 100 | 0 | 100 | 0 | 0 | 50 | 0 | 50 | 0 | 50 | 50 | 0 | 0 | 100 | 0 | 50 |
| Tranport(E-vehicle & E-railway) | 0 | 50 | N/A | N/A | N/A | N/A | 50 | 0 | N/A | N/A | 0 | 50 | 0 | 50 | 0 | 100 | 0 | 100 | 0 | 100 | 0 | 50 | 0 | 100 | 50 | 0 | 50 | 0 | 0 | 100 | 50 | 0 | 0 | 100 | 0 | 50 |
| Forest | 100 | 0 | 50 | 0 | 50 | 0 | 100 | 0 | 100 | 0 | 100 | 0 | N/A | N/A | 100 | 0 | 100 | 0 | N/A | N/A | N/A | N/A | 50 | 0 | 50 | 0 | 100 | 0 | 50 | 0 | 0 | 50 | 0 | 50 | 0 | 50 |
| *Note:* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Strength of enblers | 0 | 50 | 100 | N/A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Strength of barriers | 0 | 50 | 100 | N/A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

**Fig. 2. Enablers and barriers to the deployment of mitigation options.** * The study incorporated 6 dimensions and 19 indicators as envisioned by the Feasibility Assessment Approach. These dimensions and indicators were tested in three key sectors, namely Energy (HEP), Transport (e-vehicle and e-railway) and forests, as stipulated in the NDC document of Nepal. **Note:** Blue bars indicate the extent of enablers of deployment within each dimension and Brown bars indicate the extent of barriers to deployment within each dimension.

vehicles (cars, jeeps and vans) importing 1,113 electric four-wheelers is nearly five times of what was being imported during the same period (MoFE, 2021a). However, there is a stark contrast in the public e-vehicle for mass transport. Even though the GoN capped customs tax at 1 %, the importers need to pay an additional 13 % VAT and 5 % tax on public e-vehicles. In addition, the other hidden charges, such as number plate charge, drives the final price of public e-vehicles more than four times compared to diesel buses (MoFE, 2021b). In contrast to Nepal, countries such as China have implemented an extensive range of subsidies and incentives for public e-vehicles. That includes financial incentives for bus and taxi operators to purchase public e-vehicles, subsidies for the construction of charging infrastructure and exemptions of purchase taxes, which has enabled the country to become a global leader in the deployment of electric buses, with over 400,000 electric buses in operation in the year 2019 (IEA, 2019).

In recent years, GoN has prioritized the nationwide electric railway network and completed the feasibility study (Pokharel & Acharya, 2015). However, our study found several challenges for the accomplishment of this ambitious target owing to the terrain and geological complexities. Majority of the railway system in mountainous regions would likely be either over bridges or through tunnels, posing severe issues in the alignment of railway tracks, which obviously would increase the construction and development project cost. Due to these bottlenecks, even though Nepal initiated its maiden 53 km railway service back in 1927, connecting Janakpur of Nepal with Jainagar in India and another between Amlekhgunj and Raxaul in India, the network shrunk instead of expanding, leaving Janakpur-Jainangar railway non-functional and finally discontinued after 2014 (Pokharel & Acharya, 2015). This indicates the national mitigation target envisioned for e-railways seems far a distance.

To promote the adoption of e-vehicles and e-railways and simultaneously overcome barriers in Nepal, implementing supportive policies such as tax incentives, subsidies, and infrastructure development for electric vehicle charging networks encourage consumers to switch to clean transport options. Collaborative efforts between the government, private sector, and international partners can also play a crucial role in raising awareness, enhancing consumer confidence, and facilitating the widespread adoption of electric vehicles.

*Forest sector*

Forest sinks are the most advocated mitigation strategy worldwide to reach global and national climate targets (Maraseni & Cockfield, 2011; Smith, Vaughan, & Forster, 2022). Likewise, the conservation and restoration of forests can significantly contribute to achieving NZE in Nepal (Maraseni, Cockfield, & Apan, 2005; Maraseni et al., 2014). The country has already made efforts to increase forest cover through various programs such as community forestry, leasehold forestry and national parks and reserves (Bhatta, Zander, & Garnett, 2022; Laudari et al., 2022). According to MoFE, Nepal's forest cover has increased from 39.6 % in 1993 to 44.74 % in 2018, indicating the success of the sustainable forest management initiatives in Nepal (DFRS, 2018). In addition, Nepal can enhance its carbon sequestration capacity, essential for reducing GHG emissions. Our results are consistent with this trend of improvement in the forest cover in Nepal. The enablers identified in the study, including geophysical, environmental and ecological, technological and socio-cultural, help the attainment of the NZE targets and thus, clearly depict one of the successful modes of mitigation strategy in Nepal. This is in line with the findings of (Laudari et al., 2022), have navigated the rise and fall of Nepal's sixty-five years of forest restoration practices.

Besides, Nepal has already implemented some forest-based carbon projects, such as the Community Forest Carbon Project, the REDD$^{++}$ program, and the Forest Carbon Trust Fund (Pandey, Cockfield, & Maraseni, 2014, Pandey, Maraseni, & Cockfield, 2014). These projects work by channeling funds from various sources, including international carbon markets, to support forest-based carbon projects that reduce GHG emissions and promote sustainable forest management. These have successfully mobilized funds for forest-based carbon projects in Nepal and have contributed to reducing GHG emissions from the forest sector (Shrestha, Karky, & Karki, 2014). Policies implication has always played a substantial role in achieving the targets set by NDC and LT-LEDS. Studies from Bhutan also suggest that the strong political will and legislative framework have backed up in maintaining forest cover succeeding carbon neutrality (Yangka, Rauland, & Newman, 2019). Along with conservation policies, the government has been promoting policies that encourage using forest resources for economic development, such as logging and infrastructure development. For example, in 2016, the government announced a plan to increase the country's hydropower capacity by building more than 100 hydropower projects in the next decade, which will require clearing a significant amount of forest area. This may have a significant negative impact in terms of biodiversity loss and associated effects, however, the policies promoting sustainable forest management and development can lead to forest conservation and economic development (Lohani Sitoula, Neave, & Coffey, 2023; Raihan, 2023).

Overall, the analysis depicts that Nepal requires more policy efforts to enhance the feasibility of mitigation options in the energy and transport sector, while less effort is needed to address feasibility challenges for deploying forests. In Nepal, enhancing forest carbon sinks is one of the most advocated strategies (Smith et al., 2022). Despite the dominant role of forest on Nepal's pathway towards NZE, it is not devoid of challenges such as wildfire risks. Likewise, ensuring NZE by 2045 in the transport sector requires a paradigm shift through policy reforms, including tax rebates and building infrastructures such as charging stations and maintenance and repair centers (Mali et al., 2022) with particular attention towards public e-transport. The development of railways is still at the inception phase, and thus, accomplishing NZE via e-railways seems currently infeasible. Initiatives and efforts like financial management, building inter-organizational coordination and policy reforms (land acquisition, land clearance and environmental assessment) are crucial to achieving NZE in the railway sector. Unless serious interventions towards facilitating HEP project management are carried out in the HEP sector, the production of 15000 MW by 2030 seems ambitious. For a feasible transition towards NZE in the HEP sector, concentrated and coordinated efforts in streamlining regulatory processes, strengthening transmission and distribution facilities, innovative financial mechanisms, and institutional reforms are mandatory. Furthermore, steps are required to be explicitly channeled to reduce and remove institutional barriers that inhibit the deployment of mitigation options. The feasibility assessment framework applied in the study emphasizes the requirement of consideration of multiple factors so that we can address challenges to ensure steady, upscaled and sustained implementation options. Some of the mitigation measures are mutual in nature. For illustration, if the huge potentiality of HEP is harnessed, it can augment both the adoption of the e-transport system and maintain the forest cover. However, we also analyzed that the enabler for one of the targets is a barrier for other. For instance, topographic variation is considered the enabler in the case of HEP production, however, in the case of transportation (e-vehicle and e-railway), uneven topography is recognized as a major barrier.

## Conclusion

This study identifies and analyzes enablers and barriers to the deployment of mitigation options in the energy, transport and forest sectors in Nepal to achieve NZE targets. It helped gain insights into the specific challenges that developing countries might encounter while achieving climate objectives. Since developing countries often lack sufficient resources to implement their mitigation options, our study contributes to the existing literature by critically examining contemporary and emerging factors Nepal faces while implementing its mitigation

options outlined in its NDC document.

The critical evaluation of enablers and barriers in this study revealed the requirement to reduce institutional, economic and technological barriers in Nepal. Our assessment demonstrated that Nepal requires concerted policy efforts to improve the mitigation measures in the energy and transport sector, while less action is needed to address challenges in the forest sector. The study pinpointed dimensions and indicators that require urgent policy efforts and interventions. The pathway towards mitigation targets in the energy sector can be achieved by removing critical barriers through streamlining regulatory processes, facilitating smooth project implementation mechanisms and effective collaborations among relevant agencies and stakeholders. For the e-transport sector, implementing supportive policies such as tax incentives, subsidies, and infrastructure development for electric vehicle charging networks encourages consumers to switch to clean transport options.

The study focuses on macro-level policies, enablers and barriers, while behavioral, cultural, and social factors could impact theoretical and practical mitigation pathways. Also, other sectors, such as waste, industries, and agriculture, identified in the NDC document should be explored in further studies to ensure steady, upscaled and sustained implementation of mitigation measures to attain the NZE goals.

## Consent to participate

Verbal informed consent was obtained prior to the interview.

## Consent to publish

The participant has consented to the submission of this study to the journal.

## Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

## Ethical approval

Ethical clearance was obtained from the Ministry of Forests and Environment in Nepal.

## CRediT authorship contribution statement

**Shreejana Bhusal:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mukesh Dangol:** Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Manoj Bhatta:** Writing – original draft, review & editing, Resources, Conceptualization. **Tek Maraseni:** Writing – review & editing, Validation, Supervision. **Supriya Mathew:** Writing – review & editing, Validation, Supervision.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability statement

The data and materials that support the results or analyses presented in this paper will be available upon request to the corresponding author.

## Acknowledgements

The authors are thankful to all the respondents for their valuable time and contributions. We are grateful to the Ministry of Forests and Environment, Ministry of Physical Infrastructure and Transport and Ministry of Energy, Water Resources and Irrigation for their insights, support and approvals.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resglo.2024.100226.

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