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Transition to Deep Decarbonized Energy Systems in Nepal: The Macroeconomic Perspectives

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ABSTRACT

This study analyzed the macroeconomic impacts of the Nationally Determined Contribution (NDC) and the deep decarbonization pathways aligning with the 2°C and 1.5°C scenarios in Nepal using the computable general equilibrium (CGE) model. The analysis shows that the NDC, the 2°C and the 1.5°C scenarios would be achievable at the expense of national economic loss in Nepal. Results show that extending the NDC targets beyond 2030 without strengthening them would result in a greenhouse gas (GHG) emission reduction of 9.9% by 2050, which is far behind the level of reductions compared to that which could be required under the ideal mitigation pathways needed to confine the temperature rise to 2°C and 1.5°C compared to the pre-industrial levels. Results indicate that the NDC scenario of Nepal could be achievable at a carbon price of US$ 4.0 per tCO_2eq in 2050. However, the results of the CGE modelling analysis of Nepal showed that a much higher carbon price of US$ 21 per tCO_2eq and US$ 245 per tCO_2eq would be needed by 2050 to achieve the 2°C and the 1.5°C scenarios respectively.

1. INTRODUCTION

The increasing trend of global anthropogenic greenhouse gas (GHG) emissions and the subsequent negative impacts of climate change have urged both the developed and the developing countries to formulate and implement plans and actions that will drive to the low carbon pathway. Developing countries are more vulnerable to the impacts of climate change. The Climate Change Vulnerability Index (CCVI) released by global risks advisory firm Maplecroft rates 16 countries including Nepal as "extreme risk" to environmental, economic and social impacts due to climate change in the next 30 years [1]. The developing countries, the non-Annex I Parties to the United Nations Framework Convention on Climate Change (UNFCCC), are not obligated to cut down GHG emissions in the absolute term at present. However, many studies have shown that their involvement is necessary to achieve significant reduction of GHG emissions to stabilize the long-term GHG concentrations by the end of this century.

Nepal, a lower middle-income country lying within South Asia, is home to about 30.4 million people [2]. The country ranks 142nd on the Human Development Index with about 15% of the population in the country living below the income poverty line, *i.e.*, living below US$ 1.9 a day given in terms of purchasing power parity (PPP) [3]. The socioeconomic and the challenging mountainous topographical conditions of Nepal make it a highly vulnerable country in terms of climate change. The country as a party to the UNFCCC supports the global efforts to limit the increase in temperature to well below 2°C, preferably to 1.5°C compared to pre-industrial levels to minimize the associated risks and adverse impacts of climate change. Even though Nepal's contribution to the global GHG emission is only around 0.027% at present, the emissions due to increased use of fossil fuels are likely to rise in future. The country being an agricultural based economy, a larger portion of the GHG emissions in Nepal comes from the agricultural sector [4].

Despite having huge potential for renewable energy (mainly hydropower), the energy use in Nepal is primarily dominated by biomass. However, other renewable energy resources besides biomass remains to be captured sustainably yet due to several barriers including the geographical, technical, political, and economic barriers. Nepal relies heavily on imports to meet its entire demand for petroleum products thereby stressing the energy security concern of the country. The Government of Nepal has initiated a clean energy development pathway by prioritizing the generation and utilization of clean energy, most particularly through the development of large-scale hydropower and other renewable energy resources. Nepal has visions to achieve the socioeconomic prosperity by developing a climate resilient society and is formulating strategy to achieve net-zero GHG emissions by 2050 [5]. Introduction of such strategies and targets are anticipated to bring about alterations in the existing economy of the nation in terms of the structural changes of the production sectors, social welfare, energy and emission intensities and several other economic factors.

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Majority of the low carbon studies conducted for Nepal are limited to sectoral level analyses and fail to consider the macroeconomic aspects of imposing different GHG mitigation policies. Studies conducted for Nepal mostly focused on the implications of hydropower development, improvement in energy security, reduction of GHG and local air pollutants, employment generation associated with increasing shares of electric mass transport system and electrical vehicles and co-benefits of various carbon taxes [6-10]. But all these studies are focused in analyzing the implications of various low carbon development policies using the bottom-up technology specific modelling approaches and did not consider economy-wide consequences of low carbon and GHG mitigation policies. A very limited number of studies have analyzed the economy-wide consequences in terms of changes in gross domestic product (GDP), household welfare, energy and emission intensities of GDP, trade of commodities associated with low carbon development strategies and related policies in Nepal using the top-down modelling approach [11], [12].

As such, there exists a study gap relating to the economy-wide impacts of GHG emission mitigation and clean energy development to contribute towards meeting the long-term goal of the Paris Agreement in the context of Nepal. Meeting the long-term climate goal of the Paris Agreement demands an immediate or steep reductions in GHG emissions after 2030. The implementation of strong policies to mitigate GHG emissions would bring changes in the macroeconomic development and such changes would have greater consequences mostly in the cases of developing economies. It thus becomes vital to analyze the implications of such stringent GHG emission reduction policies on the economic development and social welfare especially in the context of developing countries like Nepal.

Though Nepal has already communicated its nationally determined contribution (NDC) commitments to the UNFCCC, a significant emission gap needs to be overcome in order to attain the 2°C and further the 1.5°C climate goals. There is thus a need of studying macroeconomic implications of imposing more stringent GHG mitigation targets beyond the NDC commitments to properly address and minimize the negative impacts such policies could bring about in the national economy.

This paper aims at analyzing the macroeconomic consequences of various decarbonization pathways in the context of Nepal during 2010-2050 under the three underlying targets, namely the enhanced nationally determined contribution targets of Nepal, the 2-degree and the 1.5-degree targets. This study presents the findings of the macroeconomic implications of introducing such policy targets using a multi-sector, recursive dynamic computable general equilibrium (CGE) model of Nepal. The analysis presented in this paper goes further beyond the NDC targets to address the macroeconomic impacts of the 2°C and the 1.5°C GHG emission pathways. The economy-wide implication of various decarbonization pathways is focused to determine the structural changes in the GDP, variations in the GHG emission intensity, consumer welfare, and economic implications.

2. NDC OF NEPAL

Nepal submitted its first NDC in 2016 and second NDC in 2020 to pursue and support efforts to limit global average temperature rise to below 2°C leading to 1.5°C above pre-industrial levels [4], [5]. Though Nepal's contribution in the global emissions is negligible, the country is committed to contribute towards lowering the risks and adverse impacts of climate change in line with the Paris Agreement. As Nepal lies among the most vulnerable countries to climate change, these risks are in addition to the already existing climate change related impacts and vulnerabilities. Therefore, the Government of Nepal (GoN) has formulated its enhanced NDC for the period of 2021 to 2030 with an aim to drive the nation towards emission reduction pathways consistent with the 1.5°C temperature limit target of the Paris Agreement [5].

The second NDC of Nepal conveys the country's vision of attaining socioeconomic prosperity by developing a climate-resilient society. The second NDC communicates about the increased ambition relating to the activity-based and policy-based targets in key economic sectors and the emission reduction targets in some sectors. It mentions single year targets for 2030 covering four sectors, namely: energy, agriculture, forestry and other land use (AFOLU), industrial processes and product use (IPPU), and waste. The targets are however conditional subject to international support [5]. Table 1 provides brief highlights on the mitigation targets of the second NDC of Nepal at the sectoral level. Besides, Nepal has also communicated its long-term strategy to net zero emissions to the UNFCCC with commitment to accelerate the climate action and achieve net zero emissions by 2045 [13].

3. METHODOLOGY

3.1 The CGE Model

A multi-sectoral recursive dynamic CGE model has been constructed in this study using the supply and use (SU) table of 2005 for Nepal to analyze the consequences of the GHG mitigation targets on the Nepalese economy during 2010-2050. The CGE model is solved in one-year step towards 2050 using the Mathematical Programming System for General Equilibrium Analysis (MPSGE) as the modelling language embedded within the Generalized Algebraic Modelling System (GAMS) interface [14]. Such type of modelling tool has been extensively implemented to analyze the macroeconomic influences of energy and climate policies at varying levels, such as the global [15], national [16], [17], and sub-national levels [18-21].

The CGE model considered in this study deals with the energy commodity transaction and their related GHG emissions in detail. The model is composed of a number of equations without any objective functions and includes complementary variables to obtain a solution to the problem. The formulated equations depict the behavior of the different activities and sectors. The behavior of different sectors is captured using fixed coefficients. The behaviors of the production and consumption activities are described by non-linear, first-order optimality conditions whose decisions are guided respectively by the maximization of profits and utility. In addition, the formulated equations also considers a set of constraints which needs to be satisfied by the system and are basically known as the macroeconomic balance and the balance of payment [22]. The mathematical description of the CGE model considered in this study is based on the AIM/CGE manual [22]. Similar mathematical explanations have also been considered in several studies [19]-[21].

The economic structure of the CGE model considered in this study is presented in Figure 1. The formulated CGE model of Nepal includes a production block, the income and expenditure blocks of the government and household and a market block showing the domestic and international transactions. The description of each of these blocks are similar to that in [17]. The three factors, namely capital, labor, and intermediate inputs are the fundamentals for producing goods and services. Different buyers such as the government, household, investors, international market, and intermediate demand purchase these goods and services to meet their basic demands at the equilibrium condition [23], [24].

Table 1. Mitigation targets of the second NDC of Nepal.

Sector	Targets
Energy	
Electricity	Increase clean energy generation from 1400 MW to 15000 MW by 2030; based on mini and micro-hydro power, solar, wind and bioenergy.
Transport	Sales of electric vehicles to occupy 25% share of all private passenger vehicle sales in 2025 and 20% share of four-wheeler public passenger vehicle sales in 2025, causing a 9% decrease in fossil fuel dependency;
	Increase electric vehicles to occupy 90% share of all private passenger vehicle sales and 60% share of all four-wheeler's public passenger vehicle sales by 2030 reducing the fossil fuel dependency by 28%;
	Promote public transportation facilities by developing 200 km of electric rail network by 2030
Residential	25% of households to use electric stoves for cooking by 2030; Install 500 thousand improved cookstoves by 2025; install an additional 200 thousand household biogas plants and 500 large scale biogas plants by 2025;
	Targets to reduce emissions by 11% in 2025 and by 23% in 2030 from the cooking sector
AFOLU (Forestry)	Maintain 45% of the total land area of Nepal under forest cover by 2030; manage 50% of Terai forests and 25% of middle hills and mountain forests sustainably by 2030
Waste	Treat 380 million litres per day of wastewater before being discharged by 2025; manage 60,000 cubic meters/year of faecal sludge by 2025

Source: [5]

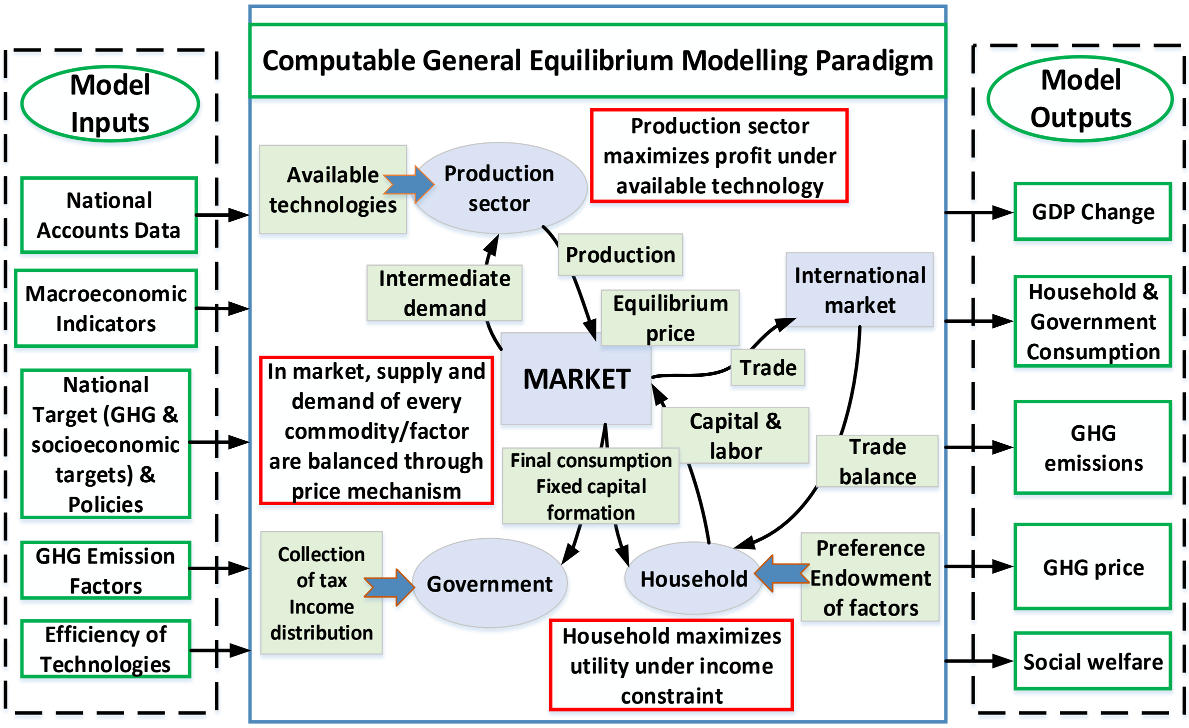

Fig. 1. An overview of Nepal CGE model structure.

Each production activity in the production block maximizes profit subject to the availability of the production technology. The activities of each production sector are characterized by the nested constant elasticity of substitution (CES) function. Government and households form the final consumer of goods and services. The two primary factors of production, *i.e.*, capital and labor are endowed by the household. The rental of these primary factors, rental from fixed factors (*i.e.*, land and natural resources) and lump sum governmental transfers forms household income. This income is either used for final consumption, investment or saving by the households. The CES function is used for representing the nested structure of household consumption for energy goods composite while the Cobb-Douglas function is used for representing the non-energy goods composite. The government collects the taxes including both the direct and indirect taxes, import tariffs and other taxes. Besides the government consumption, the government expenditure comprises of revenue transfers to public services and export rebates.

In the market block, this study considers that the goods supplied to the market can either be produced domestically or imported. This study assumes the international trade to follow the Armington's assumption, according to which the imported and domestically produced goods are imperfect substitutes [25]. The domestically supplied goods are represented by a CES function of domestic and imported goods in this study while a constant elasticity of transformation (CET) function is used for representing exports and domestic demand for goods.

3.2 Structure of Nepal CGE Model

The CGE model of Nepal is developed using a SU table of 2005 (fiscal year 2004/2005) obtained from the Central Bureau of Statistics, National Planning Commission of the GoN [26]. The original SU table of 2005 is categorized into 32 sectors and 51 commodities. To ease the computation time and cost, the SU table of Nepal considered in this study is aggregated into 31 sectors and 29 commodities to highlight the main attributes of the policy issues related to low carbon development in the country (see Appendix 1). There are three sectors in the agriculture, forestry and fishery category, 1 sector in the energy, 12 sectors in the manufacturing industries and construction, 3 sectors in the transport and 12 sectors in the service category. The energy sector includes electricity, and imported fossil fuels including the coal, lignite, and petroleum products. The transport sector is categorized into land, air, and other transport services.

4. DATA AND ASSUMPTIONS

Besides the national account statistics given by the SU table, the development of the CGE model of Nepal required information of the energy balance, demographics, socioeconomic data, prices of energy and technologies, and emission factors. These parameters are exogenously inputted into the CGE model. The "National Population and Housing Census 2011" of the Central Bureau of Statistics (CBS) of Nepal provide projections of population by physiographic regions during 2011-2031 [27]. This study has considered the projected population growth rates for medium variant provided by the CBS to estimate the population of Nepal by physiographic regions during 2021-2031. The future estimations of population during 2031-2050 are based on the population growth rates provided by the United Nations Population Division [28]. The population of Nepal considered in this study is estimated to grow from 26.5 million in 2010 to 35.3 million in 2050, increasing at a compound annual growth rate (CAGR) of 0.7% during the period. According to the reported value of the Central Bureau Statistics (CBS) of Nepal, the working age population (aged 15 to 59 years) has undergone an increase from 54% to about 57% in a span of about 10 years during 2001 to 2011 [29]. To account for the future labor factor growth, the working age population in this study is assumed to follow the pattern of population growth in future.

The GDP growth rates projected by the Water and Energy Commission Secretariat (WECS) of Nepal lies in the range of 4.5% to 9.2% in low to high economic growth scenarios, respectively during 2015-2040 [30]. The government of Nepal has targeted an average GDP growth rate of 9.6% during the fiscal year 2019/2020 to 2023/2024 in its Fifteenth plan with an aim to make a significant progress towards development [31]. For GDP projection, this study assumed a growth rate of 9.6% of the Fifteenth plan during 2021-2025. While during 2025-2050, a GDP growth rate of 7.33% has been assumed, an average of the growth rates of the various low to high economic growth scenarios mentioned by the WECS. As such the estimated GDP considered in this study is estimated to vary from US$ 8.0 billion in 2010 to US$ 117.3 billion in 2050 (considered at a constant price of 2000/01).

Both the export and the import prices are provided exogenously to the model. The CGE model considered in this study assumes the "law of one price" for energy prices among the various sectors. Besides the carbon dioxide (CO_2) emissions, the methane (CH_4) and nitrous oxide (N_2O) emissions are also considered as GHG emissions in this analysis. The coefficients of GHG emissions are computed using the supply and use data, and the estimated GHG emissions in 2005 which is calculated based on the national emission inventories of Nepal [32-34]. The emission factors for each fuel type were obtained from the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines for national GHG inventories and the United States Environmental Protection Agency [35-37]. The GHG emissions from energy use and material use of fossil fuels have been treated separately in this study to avoid the problem of double counting. In the absence of country specific information, the elasticities of substitution and transformation considered in this study are borrowed from several international studies [19], [38-41].

The capital in the CGE model of Nepal is categorized into the existing stock and new investment. The capital stock is updated by the model itself using the investment (fixed capital formation), depreciation, and economic growth. In this analysis, the depreciation rate for the existing capital is assumed to be 5% and that for the energy equipment of the household is assumed to be 10%. The depreciation rates considered in this study follows a common rate as mentioned in [42]. The installed capital is assumed to be immobile and non-transferable among sectors, whereas the new investments can occur in any sector. An existence of linear relationship is assumed between the capital stock and the capital endowment in the CGE model of Nepal. The labor is considered to be fully mobile across various sectors within the country in this study.

5. SCENARIO DESCRIPTION

This study has constructed three alternative scenarios besides the business-as-usual scenario. The following sub-section provides the details about the formulated scenarios.

(i) Business-as-usual (BAU) scenario: The BAU scenario assumes the continuation of the ongoing policies without any climate policy measures during the study period of 2010 to 2050. The study first developed a bottom-up technology-rich energy system model of Nepal using the MARKAL (acronym for MARKet ALlocation) modelling framework [43], [44]. A soft link was established between the MARKAL model (termed as the Nepal-MARKAL model from now onwards) and the CGE model by considering the sector specific GHG emission and techno-specific data generated from the energy system model as an input to the CGE model. Through the iterative method, the BAU scenario is modelled to generate the same level of GHG emissions during 2010 to 2050 as that generated under the BAU scenario of the Nepal-MARKAL model. Figure 2 shows the schematic diagram of the linkage between the bottom-up Nepal-MARKAL and the top-down CGE model for Nepal.

(ii) Nationally Determined Contribution (NDC) scenario: The NDC scenario assumes the successful implementation of the decarbonization targets of the enhanced NDC of Nepal. As depicted in Table 1, Nepal has communicated ambitious mitigation targets in the energy sector to be achieved by 2030 in its updated NDC. This includes expanding clean energy generation capacity to 15 GW, increasing sales of electric vehicles to cover 90% of all private passenger vehicle and 60% of all public passenger vehicle sales, developing electric rail network, increasing share of electric cookstoves by 25%, and increasing installation of improved cookstoves and biogas plants [5]. Considering these ambitious targets of the updated NDC, a bottom-up energy-environmental-economic Nepal-MARKAL model has been developed. The GHG emissions generated from the Nepal-MARKAL model under the NDC scenario is considered as an input in this scenario to analyze the macroeconomic implications of imposing such energy targets of the NDC.

(iii) 2-degree (2°C) scenario: The 2°C scenario considers a stricter climate system than the NDC scenario and assumes an emission constraint in 2050 that aligns with the global 2°C stabilization target. In the absence of any specific GHG emission reduction target for Nepal that aligns with the global 2°C stabilization target, this study has computed the country specific GHG emission allowances aligned with the 2°C global stabilization target using the equal per capita burden scheme based on the convergence approach mentioned by [45]. Using this approach, Nepal's emission share in the global GHG emission in the convergence year 2050 is estimated using the following relation:

$$S_y = \frac{S_0(y_c - y) + P_c(y - y_0)}{(y_c - y_0)} \quad (1)$$

where, S_y is the share of the country's emission in the total global GHG emissions in the year y, S_0 is the share of country's emission in the total global GHG emission in the start year y_0, P_c is the country's predicted population share in the convergence year y_c.

For this purpose, the global emission trajectory which is consistent with the likelihood of restricting the temperature rise to 2°C is taken from the Shared Socioeconomic Pathways (SSP) database of the International Institute for Applied Systems Analysis (IIASA) [46]. Considering the intermediate challenges depicted by the SSP2 scenario, the calculation showed a need of a GHG emission reduction of at least 54% in 2050 from the BAU scenario to be consistent with the probability of limiting the temperature rise to 2°C. Thus, the 2°C scenario in this study considered the GHG emission constraint of 54% in 2050 to explore the implications of achieving carbon neutrality of the energy system in the pathway to limit the maximum temperature rise to 2°C by the second half of the century. All the underlying socioeconomic assumptions are however like the BAU scenario.

(iv) 1.5-degree (1.5°C) scenario: The 1.5°C scenario assumes a GHG emission constraint aligned with the global 1.5°C stabilization target. With all the underlying socioeconomic assumptions remaining the same as that in the BAU scenario, a GHG emission constraint of 80% is imposed in 2050 in this scenario, to explore the implications of achieving the carbon neutrality of the energy system and contributing towards limiting the maximum temperature rise to 1.5°C. Similar to the 2°C scenario, the need of a GHG emission constraint of 80% by 2050 which is consistent with the likelihood of restricting the temperature rise to 1.5°C is estimated using the country specific GHG emission pathway aligned with the 1.5°C scenario following the approach described by [45].

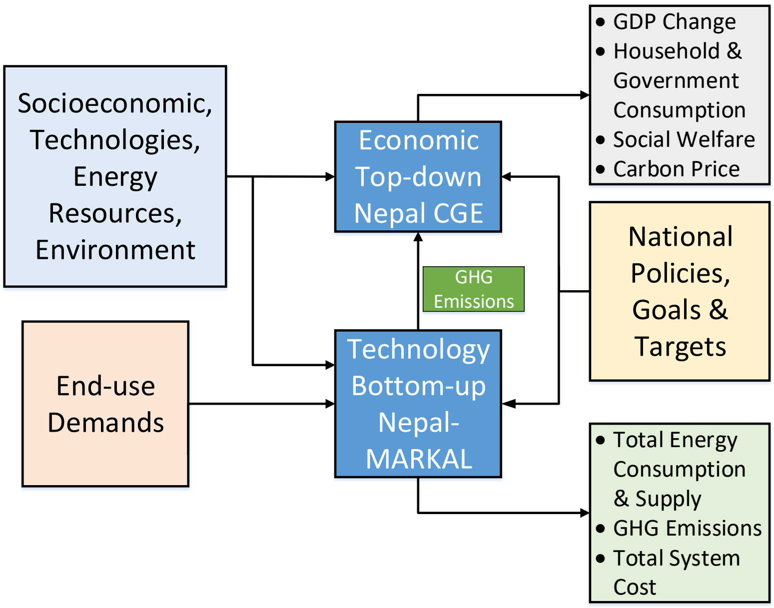

Fig. 2. Soft linkage between the bottom-up and top-down model.

6. RESULTS AND DISCUSSIONS

6.1 Impacts on GDP

The GDP of Nepal would grow at a compound annual growth rate of 6.8% during 2010 to 2050, *i.e.*, from 7.8 billion US$ in 2010 to 107.5 billion US$ in 2050 under the BAU scenario (see Figure 3). The share of household and government consumption, export and import of commodities as a percentage of GDP and fixed investment demand would change during the study period. The household and government final consumption expenditure occupies a major portion in the national GDP. Together, they accounted for a major share of 70.0% in the national GDP during 2010 to 2045 under the BAU scenario. While towards 2050, their combined share would reach 69.3%. The share of the household investment demand as a percentage of GDP lies in between 20.4% to 32.5% during 2010 to 2050 under the BAU scenario. The trade deficit considered as a percentage of GDP is expected to continuously decrease over time from 22.9% in 2010 to 1.7% by 2050.

When compared to the BAU scenario, the results of the CGE modelling analysis of Nepal shows that the imposition of the NDC, 2°C and 1.5°C scenarios would cause a decline in the GDP of the country. There would be a slight reduction in GDP by 0.1% in 2050 under the NDC scenario. The GDP would be reduced moderately by 1.6% in 2050 in the 2°C scenario. While the imposition of the stringent mitigation target depicted by the 1.5°C scenario would cause the GDP to decline by 7.7% in 2050 in comparison to the BAU scenario (see Figure 4). While in the cumulative terms, the GDP losses would be 0.1%, 0.7% and 3.1% respectively under the NDC, the 2°C and the 1.5°C scenarios during 2010 to 2050 when compared to the cumulative GDP of the BAU scenario.

By 2050, the share of the household and government final consumption expenditure in the total national GDP would be 66.7% under the 1.5°C scenario. While it would reach 69.2% by 2050 in the NDC scenario and 68.8% in the 2°C scenario. There would not be any remarkable changes in the share of the household investment demand by 2050 under the NDC scenario in comparison to the BAU scenario. However, the share of the household investment would increase to 33.0% in 2050 under the 2°C scenario while it would rise to 35.2% under the 1.5°C scenario. The volume of trade deficit would remain almost similar as in the BAU scenario under both the NDC and the 2°C scenarios. However, the trade deficit as a percentage of GDP would increase to 1.9% in 2050, *i.e.*, an increase by 8.4% in 2050 in comparison to the BAU scenario.

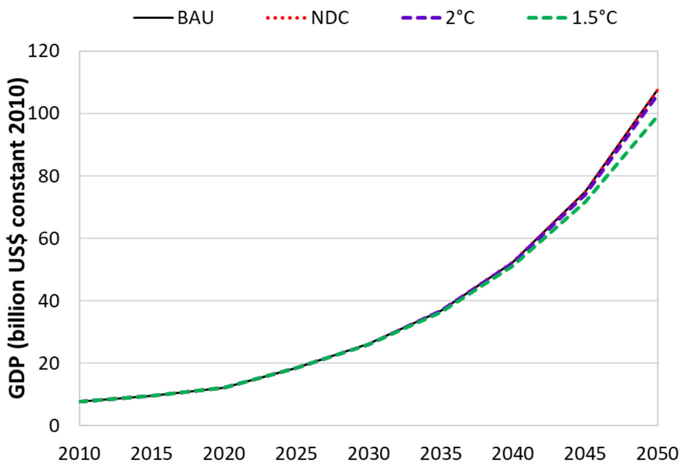

Fig. 3. GDP under all scenarios.

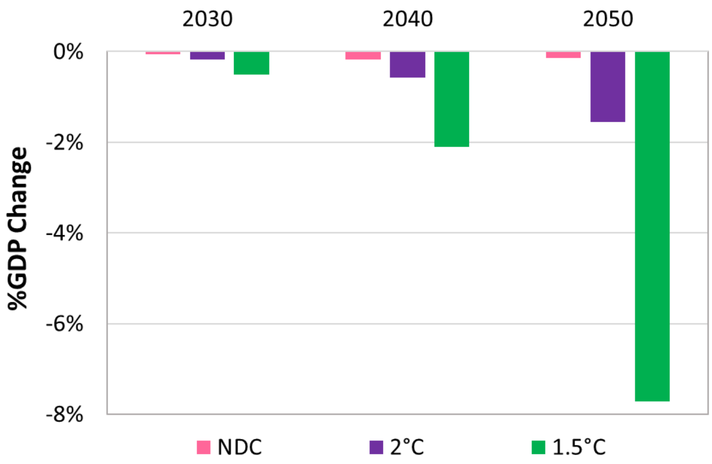

Fig. 4. Variations in GDP compared to BAU in all scenarios.

6.2 Impacts on Household and Government Consumption

The household and government consumption constitutes a major portion of the total national GDP. Household consumption demand formed the major portion of the total consumption demand in Nepal during 2010 to 2050 in all scenarios (see Figure 5). The share of the household consumption increased from 86.9% in 2010 to 76.5% in 2050 in the BAU scenario. The government consumption would undergo a significant increment while the household consumption would face a severe decline in the 1.5°C scenario in 2050 compared to those in the BAU, NDC and 2°C scenarios. The share of the government consumption would increase to 38.5% in 2050 in the 1.5°C scenario from 23.5% in 2010. This means that the government consumption would increase by 45.5% in 2050 in the 1.5°C scenario when compared to the BAU scenario. The government consumption would increase by 6.3% in the 2°C scenario and by only 0.5% in the NDC scenario in 2050 compared to the BAU scenario. The government will play an important role when the economy is in downturn by increasing spending in the developmental activities to accelerate the economic growth. When compared to the NDC and the 2°C scenarios, the need of steeper reductions in the GHG emissions would increase the government consumption expenditures in the welfare benefits of the society, mainly in the service and electricity generation sectors, infrastructure investments, electric machinery, and transport sectors in Nepal.

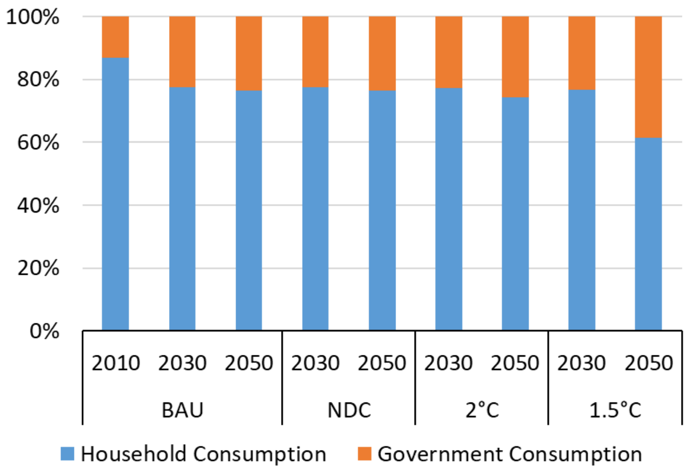

Fig. 5. Household and government consumption in all scenarios.

Table 2. Welfare loss in all scenarios compared to BAU.

Scenario	% Loss in cumulative terms		
	2020-2030	2030-2050	2010-2050
NDC	0.05	0.30	0.23
2°C	0.22	1.50	1.18
1.5°C	0.59	8.51	6.59

6.3 The Welfare Loss

There would be a decline in the consumption of the household demand and an increase in the government consumption demand in all the alternative scenarios (see Figure 5). The increase in the welfare losses is closely associated with the decline in the household consumption across the scenarios (see Table 2). The imposition of NDC targets would only cause a slight loss in the welfare of society. However, there is a high chance of neutralizing the welfare losses under the NDC scenario as well as minimizing the losses in the 2°C and the 1.5°C scenarios when combined with the enhanced technological development.

6.4 GHG Emissions

The total GHG emission is estimated to increase from 14.1 million tonne CO_2 equivalent ($MtCO_2eq$) in 2010 to 86.0 $MtCO_2eq$ in 2050, increasing at a CAGR of 4.6% during the study period under the BAU scenario (see Figure 6). In case of the NDC scenario, the GHG emissions would reach 77.5 $MtCO_2eq$ in 2050, *i.e.*, a reduction by 9.9% as compared to the BAU scenario. By 2050, the GHG emissions would reach 39.2 $MtCO_2eq$ in the 2°C scenario and 17.3 $MtCO_2eq$ in the 1.5°C scenario. If Nepal's emission is locked into the NDC's pathway till 2030, then an abruptly high annual GHG emission reduction rate post 2030 would be needed to achieve the 2°C and the 1.5°C targets.

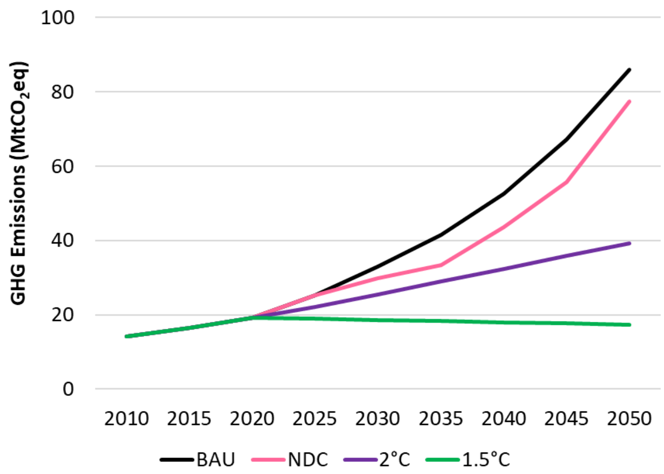

Fig. 6. GHG emission trajectories in all scenarios.

The study indicates that with the increased deployment of energy efficient technologies and renewable energy sources Nepal would progress towards reduced emission intensive economy over a long period of time in all the scenarios (see Figure 7). However, in comparison to the BAU scenario, a much higher decline in the GHG emission intensity, calculated in terms of the GHG emission per unit of GDP, would be needed by 2050 to attain the 1.5°C scenario. The GHG emission intensity would decrease from 1.8 kgCO_2eq per US$ in 2010 to 0.8 kgCO_2eq per US$ in 2050 in the BAU scenario. Under the NDC scenario, the GHG emission intensity would need a reduction of 60.2% by the year 2050 compared to the 2010 level. In the 2°C scenario, the GHG emission intensity would need a steeper reduction by 79.5% compared to 2010 by the year 2050. While under the 1.5°C scenario, a sharper reduction of the GHG emission intensity leading to 90.4% decline would be needed by the year 2050 compared to the 2010 level. The strong uncoupling between the GHG emissions and the GDP growths in the 1.5°C scenario are the results of the speedy growth towards the cleaner fuels and efficient technologies.

6.5 Economic Implications of NDC, 2°C and 1.5°C Pathways

Figure 8 shows that the carbon price would reach US$ 245 per tCO_2eq in 2050 from US$ 10 per tCO_2eq in 2025 to achieve the 1.5°C scenario. It would increase from US$ 6 per tCO_2eq in 2025 to reach US$ 21 per tCO_2eq in 2050 in the 2°C scenario. However, the NDC targets would cause the carbon price to increase from US$ 3.8 per tCO_2eq in 2025 to reach US$ 4.0 per tCO_2eq in 2050 in the NDC scenario. A greater GHG price are associated with higher reductions in the household consumption of goods and services. Such higher prices would demand for a speedy switch from inefficient technologies to low carbon energy resources and technologies.

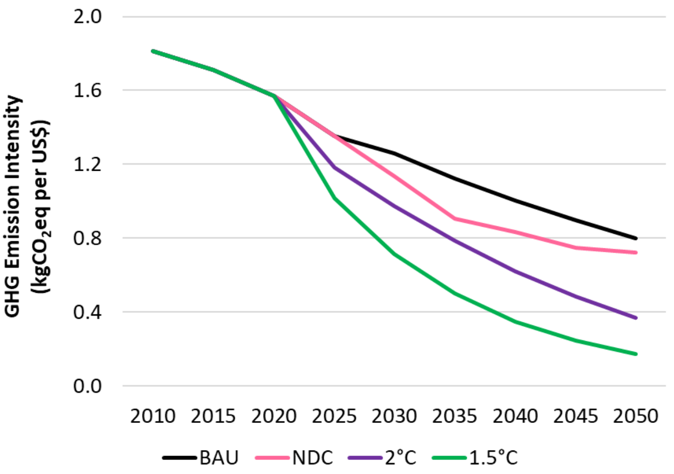

Fig. 7. GHG emission intensity in all scenarios.

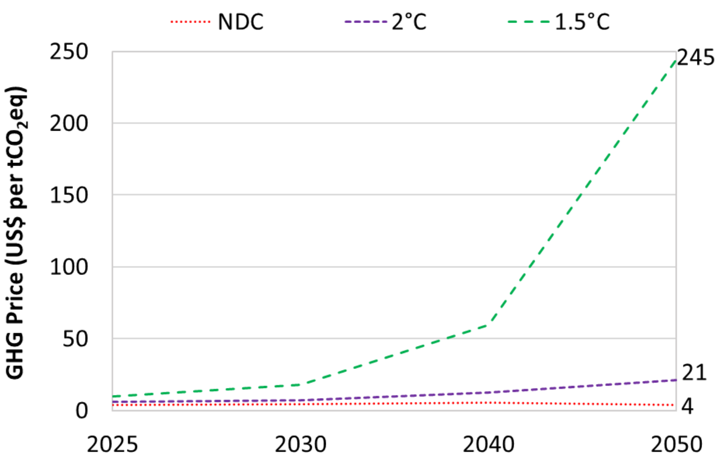

Fig. 8. Carbon prices in all scenarios.

7. CONCLUSION

This study was conducted with an aim to analyze the macroeconomic implications of the NDC targets and the deep decarbonization pathways of the 2°C and 1.5°C scenarios in the context of Nepal. To contribute towards the long-term goal of the Paris Agreement, this study analyzed the macroeconomic consequences of imposing more ambitious mitigation targets beyond the NDC. Results show that the level of emission reduction in the NDC scenario seems to be low compared to what would be necessary under the ideal mitigation pathways needed to limit the temperature rise to 2°C and 1.5°C compared to pre-industrial levels. In short, extending the NDC targets beyond 2030 without strengthening them would result in GHG emission reduction of 9.9% by 2050, which is far behind the level of reductions required to drive Nepal towards the pathways of 2°C and 1.5°C temperature goals. Even after achieving the emission targets envisioned in the NDC of Nepal, an emission gap of 325 $MtCO_2eq$ over the period of 2021-2050 would remain between the NDC and the 2°C scenarios. This emission gap over the period of 2021-2050 would be much higher (*i.e.*, 657 $MtCO_2eq$) between the NDC and the 1.5°C scenario. To fill this gap, there would be a need of improved financial flows to encourage both the national and global innovations and requires adoption of low carbon resources and technologies that provide GHG mitigation in Nepal.

The cost of carbon mitigation in achieving the deep decarbonization pathways depend strongly on the low carbon technology options considered in the analysis. Although the analysis shows the possibility of attaining 80% of GHG emission reductions by 2050 at a GDP loss of 7.7% through the deployment of energy efficient technologies, this would represent a challenge in terms of the technology use, their availability and affordability to achieve the carbon neutrality of the energy system and contribute towards meeting the 1.5°C target. To assess the possibility of carbon neutrality of the energy system by 2050 or further enhance to assess the feasibility of net-zero emission by 2050, it becomes necessary to explore other mitigation options not considered in this analysis including the drastic societal changes, large scale afforestation, and carbon offset through hydroelectricity export**.**

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APPENDIX

Appendix 1. Definition of sectors and commodities in the Nepal CGE model.

Category	Sectors	Produced/Imported commodities
Agriculture, forestry, and fishery	1.Agriculture and hunting	1.Agriculture, hunting and related service products
	2.Forestry and logging	2.Forestry and logging products
	3.Fishing and aquaculture	3.Fish and other fishing products
Energy sectors	4.Electricity, gas, steam, hot water supply, and imported fossil fuels	4.Electricity, gas, steam, and hot water 5.Coal and lignite 6.Petroleum products
Industries	5.Mining and quarrying	7.Mineral products
	6.Food, beverages, and tobacco products	8.Food products, beverages, and tobacco
	7.Textiles, leather, and footwears	9.Clothing and leather products
	8.Manufacture of wood and wood products 9.Paper and printing	10.Wood products; pulp and paper products; printed matters
	10.Rubber and plastic products	11. Rubber and plastics products
	11.Basic metals	12.Basic metals
	12.Fabricated metal products 13.Machinery and equipment	13.Fabricated metal products; electric machinery and others
	14.Manufacture of furniture	14.Furniture
	15.Construction	15.Construction services
	16.Other manufacturing products	16.Other manufacturing products
Transport	17.Land transport	17.Land transport services
	18.Air transport	18.Air transport services
	19.Other transport services	19.Water transport services 20.Supporting and auxiliary transport services
Services	20.Financial intermediation 21.Insurance and pension funding	21.Finance and insurance
	22.Real estate activities	22.Real estate services
	23.Education	23.Research and education
	24.Health and social work	24.Health and social service
	25.Water supply system	25.Water
	26.Wholesale and retail trade	26.Wholesale and retail trade services
	27. Hotels and restaurants	27.Lodging, food, and beverage serving services
	28.Public administration, defense, and social security	28.Public administration
	29.Other services 30.Renting of machinery and equipment 31.Post and telecommunications	29.Other services