NEPAL RENEWABLE ENERGY PROGRAMME

REPORT ON PROJECTION OF EMISSION ASSOCIATED WITH ELECTRICITY TRADING AS PART OF NEPAL'S LONG-TERM STRATEGY (LTS) to ACHIEVE NET ZERO EMISSIONS STATUS BY 2050

VROCK AND COMPANY

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NEPAL
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Contents

Abbreviations

AFOLU: Agriculture, Forestry and Other Land Use
CEA: Central Electricity Authority (India)
CES: Center for Energy Studies
CoD: Commercial Operations Date
COP: Conference of the Parties
DoED: Department of Electricity Development
DPR: Detailed Project Report
ESD: End User Service Demand
FCDO: Foreign Commonwealth & Development Office of the Government of UK
GDP: Gross Domestic Product
GoN: Government of Nepal
LEAP: Low Emissions Analysis Platform
LTS: Long Term Strategy
Mil.: Million
MPEMR: Ministry of Power, Energy and Mineral Resources Government of the People's Republic of Bangladesh
$MtCO_2e$: Metric tons of CO_2 equivalent
NEA: Nepal Electricity Authority
NDC: Nationally Determined Contribution
NREP: Nepal Renewable Energy Program
PRoR: Peaking run of the river
RCOD: Revised Commercial Operations Date
RE: Renewable Energy
RoR: Run of the river
TWh: Terawatt-hour
UNFCCC: United Nations Framework Convention on Climate Change
WASP: Wien Automatic System Planning
WAM: With Additional Measures
WECS: Water and Energy Commission Secretariat
WEM: With Existing Measures

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Background

In line with the 2015 Paris Agreement, the government of Nepal is formulating two key strategic documents to set a vision for Nepal's long-term low carbon economic development that is climate resilient. The Government submitted the second Nationally Determined Contributions (NDC) on 8th December 2020 which considers the principle of common but differentiated responsibilities and respective capabilities, in light of national circumstances.

As a part of the 2015 Paris Agreement, Nepal is preparing to submit a long-term low carbon economic development strategy known as Long Term Strategy (LTS) in 2021 to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat. The LTS will set out a clear pathway for a transition towards net-zero emissions by 2050 and climate-resilient economic strategies based on the review of best available information and scenario analysis of existing sectoral emissions dataset as per IPCC 2006 guidelines for GHG inventory.

The energy simulation and emissions modeling work to inform the development of the LTS was entrusted to the Center for Energy Studies (CES) with the support of GoN and UNDP. The analysis and findings submitted by CES[i] indicates that Nepal will not meet its net-zero emissions target by 2050. Even under the most optimistic mitigation scenario, the With Additional Measures (WAM Scenario) Nepal's net GHG emissions would be 26.4 $MtCO_2e$ by 2050. Significant investments will be required to reap the benefits (of the mitigation measures assumed) in terms of GHG mitigation and negative net abatement costs over the implementation period[1].

Nepal intends to meet the increased electricity demand resulting from its economic growth and GHG emission mitigation measures through its abundant hydropower resources. However, given the profile of river flow, a typical hydropower project in Nepal generates as much as 60% to 75% of the amount of the total generation in the monsoon months which creates the potential of exporting clean electrical energy to its neighbors in South Asia when their demand is typically higher. The exported energy can offset emissions from fossil-based generation and additionally, the dispatchable nature of hydropower can enable the adoption of intermittent renewables in the region. Exploiting Nepal's hydropower resources to meet domestic as well as regional energy requirements while also reducing GHG emissions in the region creates a win-win situation. Furthermore, if the carbon offsets that the export of clean hydropower from Nepal are included in its emissions inventory, then Nepal can potentially achieve its goal of net zero carbon by 2050.

The current UNFCCC does not explicitly allow for offset of carbon emissions through cross-country energy trade, where clean energy generated in one country could offset carbon emissions in another. Nepal has tremendous potential in hydropower and exporting clean energy surplus from Nepal can offset significant carbon emissions in our neighboring countries. The purpose of this report is to explore and quantify the project emission associated with electricity trading as part of Nepal's LTS to achieve Net Zero Emissions status by 2050.

Scope of the Assignment

The UK aid has been a partner for the Government of Nepal in developing the LTS and framing a green growth strategy that will help Nepal operationalize the LTS. UK aid funded Nepal Renewable Energy Program's (NREP) mandate is to promote the investment in renewable energy and promote low carbon development path for Nepal. NREP's mission to reduce GHG emissions

[1] Annual investment required under the WAM scenario will be 25% of national GDP in 2030 and 19.6 % in 2050 according to the CES Report

which is aligned with GON's LTS and consistent with UK aid's support for its development mobilized the funding to support this study for which it engaged VRock & Company. The Scope of Work for this study has been deliberately confined to the specific task of quantifying clean energy exports and the carbon offsets that this will enable in the region keeping in mind Nepal's goal of submitting the LTS by mid-July. The study also aims to inform and ensure fidelity for future efforts and initiatives related to the implementation of the LTS. More specifically, the study also aims to provide insights into the various energy demand forecasts that have been adopted by various planning agencies/ministries in Nepal and how non-hydro renewables could mitigate potential risks of not achieving the LTS' goals.

The Scope of Work provided to VRock was as follows:

Review recent documents related to electricity generation, supply, demand and trade and project electricity trading scenarios to compute associated carbon emission through electricity trade with participating countries. Specifically, the following activities were conducted:

1. *Assessment and projection of electricity demand, supply, generation, and trade –*
    a. *Review recent documents published by Water and Energy Commission Secretariat (WECS), Nepal Electricity Authority (NEA), UNDP funded Climate analytics and CES and other relevant sources.*
    b. *Finalize supply stack forecasts based on consultations with key stakeholder and methodology for projecting electricity trade for up to 2050.*
    c. *Project electricity demand, supply, generation, and trade up to 2050 under three different scenarios using three scenarios against Gross Domestic Product (GDP) as announced by Government of Nepal and consistent with the LTS document prepared by CES.*
2. *Projection of carbon emissions reductions from electricity trade based on above assessment and projections.*
3. *Based on the projection of supply, generation, and emission, identify cleaner electricity trade options including increased RE mix.*
4. *Prepare and present assumptions associated with the projections.*
5. *Present the final report to NREP.*

Methodology

The objective of this assignment is to make the case for carbon offsets from export of Nepal's clean energy to be accounted in Nepal's pathway to net-zero emission by 2050. To achieve this objective, we must settle on the electricity demand and stack supply options to meet the identified demand. We stacked supply under these five scenarios as agreed with NREP, as these scenarios bookend all range of possible outcomes:

1. Low GDP Growth Scenario (4.5% Growth)
2. High GDP Growth Scenario (10.3% Growth)
3. Reference Growth Scenario (7% Growth)
4. Reference Growth with Existing Measures (WEM)
5. Reference Growth with Additional Measures (WAM)

[Note: No policy interventions are assumed in the reference growth scenario. In the WEM and WAM Scenarios, existing and additional policy interventions to reduce carbon emissions respectively are assumed.]

These steps helped us determine Nepal's exportable surplus energy and quantify associated carbon offsets in neighboring countries. We additionally explored how accelerating adoption of non-hydro renewables impacts the generation mix and the outcome. The following methods were adopted during this study.

a. Assessing Demand

To assess Nepal's national energy demand, we reviewed documents published by key government and non-governmental institutions including the CES, WECS and NEA. The underlying demand within the study titled *Technical and Financially Feasible Long-term Vision and Long-Term Strategy* conducted by CES is used as the primary source for demand identification as Nepal's LTS is based on this study. However, the assumptions and conclusions made within WECS, and NEA's publications were reviewed in parallel to inform future demand forecasts.

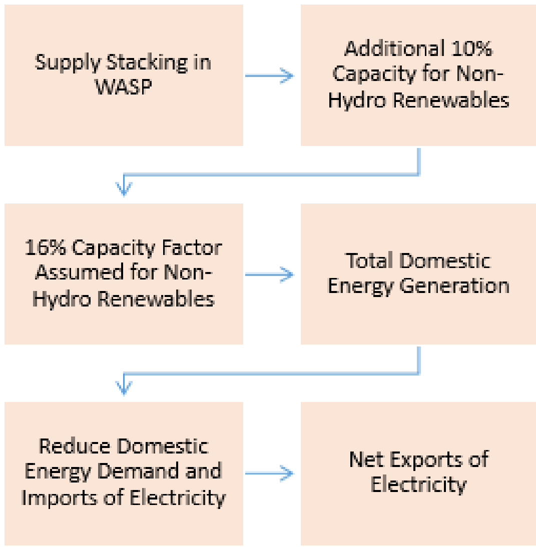

Figure 1: Supply Stacking Process

b. Stacking supply

For the supply stacking, the team reviewed electricity generation potential from hydro as well as intermittent or non-hydro renewables by compiling information on ongoing and pipeline projects (Capacity, Generation Profile, Expected Start Date, etc.) primarily from Department of Electricity Development (DoED), NEA and publicly available government policy and planning documents and reports. The supply was stacked according to the Commercial Operations Date (COD) required under the PPAs for projects that have signed PPAs with NEA. The onboarding of projects without PPAs were sequenced based on a combination of two factors – (a) the level of preparedness based on information triangulated from DOED, NEA, sector experts and various planning and policy documents and (b) to meet the projected domestic demand. The stack was developed in two different approaches to align with the five different electricity demand scenarios.

1. *For Reference, Low growth, and High growth scenarios*: Initially, supply was stacked to generate a minimum of 22 GW of generation capacity by 2050 to primarily meet domestic demand. This assumption is based on the government plan presented on the Energy White Paper (MoEWRI, 2018) and there is sufficient visibility on pipeline of projects to develop up to 22,000 MW of capacity. These stacking exercises were performed in Wein Automatic System Planning (WASP)[2].
2. *For all five scenarios (including WEM and WAM)*: With the stacking of electricity generating capacity no longer constrained by the objective of solely meeting domestic energy demand, under this scenario, we stacked capacity beyond what is required to meet the forecasted demand. Capacity was stacked under all circumstances to maximize Nepal's hydropower potential and as result, a maximum capacity of 45 GW was stacked under the Reference, Low Growth, High Growth and additional WEM and WAM scenarios. This additional stacking accounts for Nepal's potential to harness more than 40,000 MW through hydro projects and premised under the following assumptions:
    a. Excess electricity can be exported to neighboring countries and
    b. The export of clean electricity can offset fossil-based generation in the export market and these offsets will contribute to Nepal's net zero emission goals by 2050[3].

    Since WASP limits the amount of supply that can be stacked depending on the demand scenario, stacking the 45 GW for the reference, high and low growth scenarios was performed outside the WASP model in MS Excel. Electricity generation from intermittent renewables capacity was modeled outside WASP in MS Excel due to the limitations of the model as is

[2] WASP is one of the most widely used models in developing countries for power system planning. Within constraints defined by the user, WASP determines the optimal long-term expansion plan for a power generating system. Constraints may include limited fuel availability, emission restrictions, system reliability requirements and other factors. Nepal Electricity Authority uses this model for its system planning functions.

[3] India's Energy and Emissions Outlook: Results from India Energy Model P15, Niti Ayog Working Paper

currently configured for use by NEA. For intermittent renewables, 10 % of installed hydropower capacity was added as non-hydro renewables (solar, wind, biomass) within the generation mix in each of the five scenarios. An alternate scenario is also reviewed where 20% of the installed hydropower capacity is layered in as intermittent renewables within the generation mix. Under both scenarios, the total installed capacities are well below Nepal's resource potential for non-hydro renewables.

c. Deriving Energy Balance

Based on the demand assessment and supply stacking, the energy balances under various scenarios were computed in the WASP model. The energy balance outlines the electricity demand, the amount of such quantum met by domestic generation, the amount met by imports and the quantum of electricity available for export.

Due to limitations within the WASP model, the renewables were accounted for in a separate excel model. Based on the demand assumptions, renewable energy mix was either used to offset imports (especially during dry season) or to add to exportable energy surplus, to the extent possible. For intermittent renewables, a capacity factor of 16% was assumed to derive the energy profile.

d. Quantifying Carbon Offsets

At the final stage, to quantify carbon offsets, carbon emissions of our neighboring countries in India and Bangladesh were reviewed. We assumed any electricity exports generated to offset India or Bangladesh's emissions from coal-fired power plants. Guided by an extensive review of publications by the Central Electricity Authority (CEA) of India and international journals, net reductions from hydro were calculated based on the current carbon intensity of coal fired power plant in India which is almost one metric ton CO_2e (0.97 $MtCO_2e$) per MWh of electricity generation[4]. To account for potential improvements in coal power plant technology, we assume that the carbon intensity drops to 0.8 $MtCO_2e$ per MWh by 2050. We assumed the reduction per MWh of electricity export to be 0.9 tons CO_2 emissions in the base year (2020) and calibrated the metric to decrease to 0.8 tons of CO_2 emissions per MWh by 2050 to calculate offsets for the corresponding years.

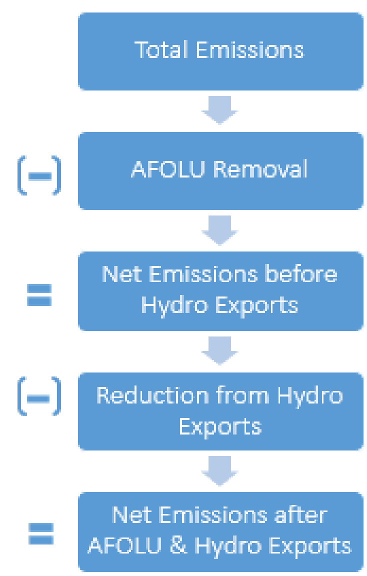

Figure 2: Computing Emissions

The GHG inventory was calculated using the formula:

*Amount of net emission offset by Nepali Exports = Exportable Electricity (MWh)*Emission factor (0.9-0.8) tons of CO_2 emissions/MWh*

In terms of offsets, the CES study outlines the net emissions under each scenario calculated by deducting Agriculture, Forestry and Other Land Use (AFOLU) removal, which is the carbon sequestered through forest sink. The carbon offsets from the exported hydro were further

[4] Annex 1

deducted from the net emissions to arrive at the final net emissions under various demand scenarios.

Energy Demand Analysis

The physics of alternating current, the traditional form of grid electricity implies that it is generated and consumed instantaneously, but the process of delivering that electricity is anything but instantaneous. The instant delivery is a result of meticulous planning and investment that spans multiple years. The meticulous planning that ensures that "electricity is always there" begins with a demand forecast. A reasonably realistic and accurate forecasting of electricity demand forms the fundamental basis for this planning and investment process.

The energy demand forecast is equally critical to an energy infrastructure developer that needs to decide on investment in a generation asset as it is to a utility where the demand forecast provides a picture of expected load in the system in future periods of time. The forecast gives the utility an estimate of the necessary power that it needs to procure, and the infrastructure needed to deliver that power. Similarly, the energy/electricity demand forecast is critical for a country to design policies and regulations that will allow a most efficient and cost-effective way of meeting its energy needs. The important issue is that depending on the objective of the party undertaking the demand forecast, the methodology and the outcome may vary.

There are two electricity demand forecasts that are most regularly referred to in Nepal. The first is from the WECS, an agency under the Ministry of Energy, Water Resources, and Irrigation (MoEWRI). The second is from the NEA, the country's sole public utility. To inform the development of the LTS, a third forecast for Nepal's electricity consumption was undertaken by the CES for the Ministry of Forest and Environment (MoFE). The LTS related energy forecast was developed using the Low Emissions Analysis Platform (LEAP) modeling framework to account for Nepal's GHG emission inventory.

While the objective of each study may be different one of the primary objectives is the same, which is to forecast the energy demand. It is therefore prudent to expect that the energy (and electricity) demand forecasts for the country should converge if not be the same as government policy, planning and investment for the sector will be driven by the forecast. The objective of analyzing and comparing these demand studies published by three independent entities is to provide insights into the objectives, methodologies, assumptions, and end results of the three demand forecasts. The insights distilled from this analysis will hopefully inform and guide future demand forecasts that Nepal will inevitably undertake.

Understanding the motivation behind the studies: The purpose of the "Electricity Demand Forecast Report 2015-40" conducted by the WECS was driven by its mandate to inform the plans and policies of the energy sector. The study uses the Model for Analysis of Energy Demand model (hereafter, MAED model) to forecast the national "energy demand based on medium and long-term scenarios of socio-economic, technological, and demographic developments". It should be noted that the MAED model calculates the energy demand, of which electricity demand is only one component. Whereas the objective behind the study conducted by NEA is entirely to forecast domestic electricity demand in its system, which does not include demand for other non-electrical energy (eg: petroleum products, biomass, biogas, LPG) or for that matter electricity demand that does not register in its system. Given its institutional responsibility to generate, transmit, and distribute electricity and as the only off-taker in the country's electricity market, NEA needs to have a good picture of the future demand of electricity. For this purpose, NEA uses a simple econometric model to exclusively forecast yearly generation and peak load requirements. To the contrary, the CES study on the long-term strategy for Nepal's Carbon Emission performs a mitigation focused demand analysis that aims to project carbon emissions and projected energy demand under different growth and policy scenarios.

Difference in Outcomes:

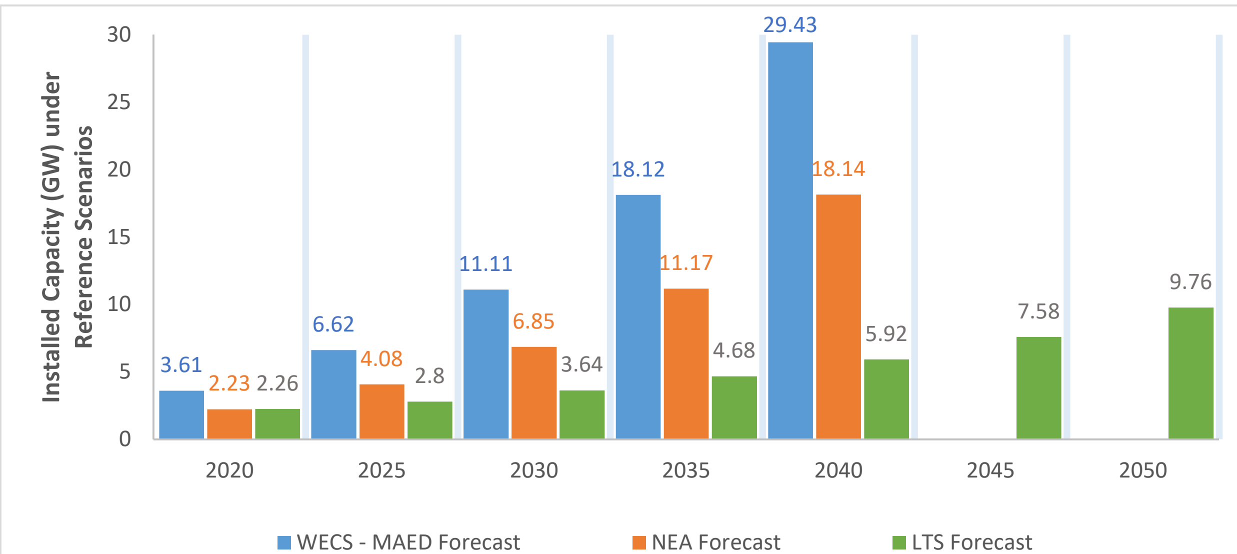

Figure 3: Reference Scenario Capacity Demand Forest Comparison between WECS, NEA and LTS Study (in GW)

[5] Note: The WECS and NEA Forecast goes out only till 2040

For the purpose of comparing the forecasts under the three different methodologies we have illustrated the reference scenarios which under the WECS and NEA methods envisions a 7.2% GDP growth and 7% for LTS study. As we can see from Figure 4 and 5, there is a wide divergence in the demand forecast between these three studies. One interesting observation between the NEA and WECS forecasts is that though conducted by two institutions with very different mandates and using very different forecasting models, there appears to be an exact match in the forecasted load. It appears that the NEA forecast was a backward calculation of the WECS forecast, where sectoral growth, economic assumptions and system losses have been engineered to provide forecasts that match with the WECS' outputs.[6]

The projected energy and capacity requirement under the NEA and WECS are much higher compared to the LTS study. For instance, for the year 2040, the WECS projects a capacity demand of 29.4 GW which is almost five folds higher than the demand forecast made by CES (5.9 GW). Comparably, the NEA and WECS projects an energy demand of 82.6 TWh in 2040 which is four times higher than the 22.15 TWh of energy forecasted by CES. The key parameters and assumptions that drove these differences will be investigated in the succeeding sections.

Fiscal Year	Total Electricity Demand - WECS - Reference Scenario (GWh)	Total Electricity Load = WECS - Ref.Scenario x 1.25 (GWh)	NEA - Total Generation Requirement (GWh)*
2019/20	8,110	10,138	10,138
2024/25	14,864	18,580	18,580
2029/30	24,957	31.196	31,196
2034/35	40,710	50,887	50,887
2039/40	66,097	82,621	82,621

* Based on NEA's Annual Report for FY 2018/19

Figure 5: Electricity load forecast of WECS and Total Generation Requirement as projected by NEA

	2020	2025	2030	2035	2040	2045	2050
WECS - MAED Forecast	10.14	18.58	31.2	50.89	82.62		
NEA Forecast	10.14	18.58	31.2	50.89	82.62		
LTS Forecast	8.23	10.41	13.54	17.52	22.15	28.29	36.39

Figure 4: Reference scenario Energy Demand Forecast Comparison between WECS, NEA and LTS Study (in TWh[5])

While there is a similarity in the energy demand forecast of NEA and WECS, a difference is noted in the capacity requirement in these two studies. This discrepancy is a result of the way the capacity is calculated. There are two issues in how WECS converts from electricity demand to installed capacity, both contributing to the inflated forecasts. The first is a miscalculation in the mathematical operation: to compensate for the 25 percent system loss, WECS multiplies the energy demand by a factor of 1.25. The correct step, however, should have been a 25 percent reduction from the generation requirement. Following this logic, the correct step to get the

[6] Of Supply and Demand. Deconstructing Nepal's hydropower Narrative IFC (not published)

generation number from the demand number would be 8,110.7 GWh / (1-25%) or 8,110 GWh / 0.75 resulting in an energy requirement of 10,817 GWh instead of 10,138 GWh (8,110 * 1.25). The second difference between how WECS computes capacity relative to NEA, is the two additional factors that are considered in the WECS forecast. The WECS forecast adjusts for capacity based on outages and additional power required to support peak load. Additional capacity requirements due to outages and peak load are factored into the system load factor calculations. Contrarily, NEA incorporates the system losses in the load forecast at 25 percent till 2040 and uses the load factor of 52%. However, the current system losses stand at 15% and the load factor is not reflective of current situation where the NEA has achieved a load factor of about 60% in the last two years.[7] These differences has served to significantly increase the generation capacity requirement and explains the divergence in the energy and capacity forecasts compared to actuals in 2020.[8]

Description of the Model Used: The model used by NEA is comparatively the least sophisticated model built around parameters such as income and price elasticity of electricity consumption, and connectivity, with growth assumptions on specific sectors (domestic, industrial, irrigation, commercial among others). This model projects electricity demand and not the end user energy demand and does not account for fuel switching. While the MAED model used by WECS accounts for limited diversity of demand categories, the model yet does not consider end use service demand (ESD). The CES study on the other hand uses the Low Emissions Analysis Platform (LEAP) model, a tool which assists in energy and low carbon development policy analysis. It is an integrated modeling tool that can be used to track energy consumption, production, and resource extraction in all sectors of an economy and GHG emissions from economic activity. The LEAP is a more robust and holistic bottom-up model that accounts for ESD and allows for the accounting of diverse demand categories such as segregation of urban vs. rural demand while assessing residential energy demand.

Understanding underlying assumptions: While the NEA and WECS energy demand projections are strikingly similar, a huge discrepancy is observed between projections made by these studies and the CES study. It can be observed that both the NEA and WECS forecasts are likely to result in grossly overstating the demand for electricity over the actual consumption. For example, the demand realized in Fiscal Year end 2020 was 7,894 GWh[9] (COVID is likely to have a suppression in demand) while the forecasted demand under the NEA and WECS study was 10,138 GWh, and CES forecast was 8,230 GWh. Some of the divergence between the NEA and WECS forecast can be explained by the fact the base year for the WECS study was 2014/15 (NEA forecasts has been engineered to match the WECS forecast) while it was 2019 for CES. Apart from the different forecasting models used, the different policy and growth scenarios assumed could drive incongruities in outcome.

NEA projects demand only under one reference scenario assuming an annual GDP growth of 7.2 percent. Whereas, WECS forecasts demand under four growth scenarios i.e. Business as Usual (BAU) growth assuming GDP growth rate at 4.5 %, a reference growth rate of 7.2% (which is comparable to the NEA and CES growth assumptions), a high growth scenario with GDP growth at 9.2% and a Reference Policy scenario which assumes a reference growth rate of 7.2 % with

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[7] Higher the load factor, lower is the capacity required to meet demand (Load Factor= Average Load/ Peak Load)
[8] IFC (2020). Of Supply and Demand. Deconstructing Nepal's hydropower Narrative
[9] NEA Annual Report 2077 BS (2020 AD)

added policy interventions such as 100% electrification in cooking by 2020, 75% electrification of water heating and 25% of electrification of passenger transport by 2025.

On the other hand, the CES study assumes a constant GDP growth of 7% across three different scenarios i.e., i) the reference scenario with no policy intervention ii) WEM scenario with policy measures mentioned in the existing national strategy, policies, and action plan documents and iii) WAM scenario with additional measures in addition to WEM measures to mitigate emissions. There are two more growth scenarios considered within the CES study which is iv) a low growth scenario assuming a GDP growth rate of 4.5 % and v) a high growth scenario with GDP growth of 10.3%. Both WAM and WEM scenarios assume improvement in energy efficiency and fuel-switching from fossil fuels to electricity in transport, residential, commercial, industrial and agriculture sectors that offers deep de-carbonization to achieve net zero target. For instance, WEM scenario targets efficiency improvements and electrification of processes within the industry sector and a 30 % electrification of both intracity buses and freight transportation through e-trains. Similarly, WAM Scenario targets 100% Electrification of industrial processes and a 68% electrification of intracity buses and freight services. Figure 6 below highlights some of the key assumptions.

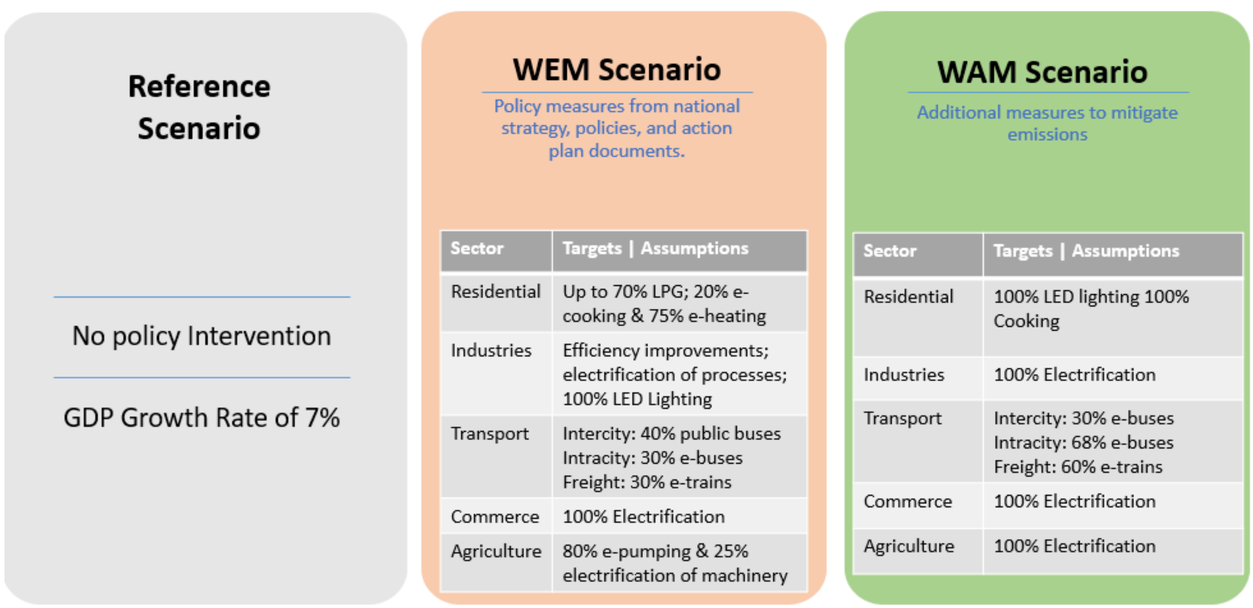


Figure 6: Assumptions under various Demand Scenarios

While both the WAM and WEM scenarios include aggressive targets for electrification across most sectors, the feasibility of achieving these targets needs to be confirmed with various government ministries. [10]

[10] A detailed list of assumptions under WEM and WAM scenarios can be found within the CES Study (pp. 49-50) .

Limitations of each study

A major limitation of the NEA study is it projects only electricity demand and does not take into account switching from other non-electric energy usage. Another fundamental shortcoming in NEA's model is its calculation of future demand scenarios is based on previous year's demand figures. The key issue with this approach is that this previous year's demand figure, which is NEA's previous year's sales figure, does not capture the unrealized demand due to structural bottlenecks such as lack of adequate infrastructure to ensure full supply. Another shortcoming in NEA's model, one that is a result of its inherent mathematical design, is its reliance on macro level data in its inputs rather than sourcing it at the consumer level. The result is a model that is not designed to adequately capture local trends in electricity consumption and, therefore, may not provide an accurate picture of its demand. As communicated in the earlier sections, while the WECS study is a more bottom-up model that considers diversity of demand, its oversights in conversion of energy demand to capacity results in an overestimation of capacity required to meet the forecasted demand.

What is evident from these studies is that results vary significantly depending on the model used and underlying assumptions. For future demand forecast, Nepal needs to align motivations of different line ministries and perform an analysis based on a clear and unified objective, whether it be meeting domestic demand or increasing carbon reduction through energy exports. Since the objective of this assignment aligns with that of the CES study and as Nepal's long-term strategy is based on the CES study, the forecast by CES is used as the primary source for demand identification. The capacity demand forecast from 2020-2050 is presented in the table below:

Capacity (GW)							
Scenario	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
High economic growth	2.263	2.981	4.261	6.181	9.021	13.481	20.481
Low Economic Growth	2.263	2.721	3.261	3.901	4.501	5.181	6.001
Reference Scenario	2.263	2.801	3.641	4.681	5.921	7.581	9.761
WAM Combined	2.263	7.521	14.621	20.141	26.501	34.721	45.401
WEM Combined	2.263	7.301	14.321	18.501	23.101	29.161	37.241

Figure 7: Demand Forecast in Capacity terms under 5 different Scenarios

Source: CES, 2_LTS CES model dataset for green growth analysis_2021.xlsx (SRS)

Supply Stacking

As discussed in the methodology section, two strategies were adopted while stacking supply to align with the five different demand scenarios.

The orange line in Figure 8 represents the first strategy where 22 GW of electricity supply and an additional capacity of 10% intermittent renewables is stacked within WASP and MS Excel to primarily meet domestic demand and minimize energy imports under low and high growth scenarios.

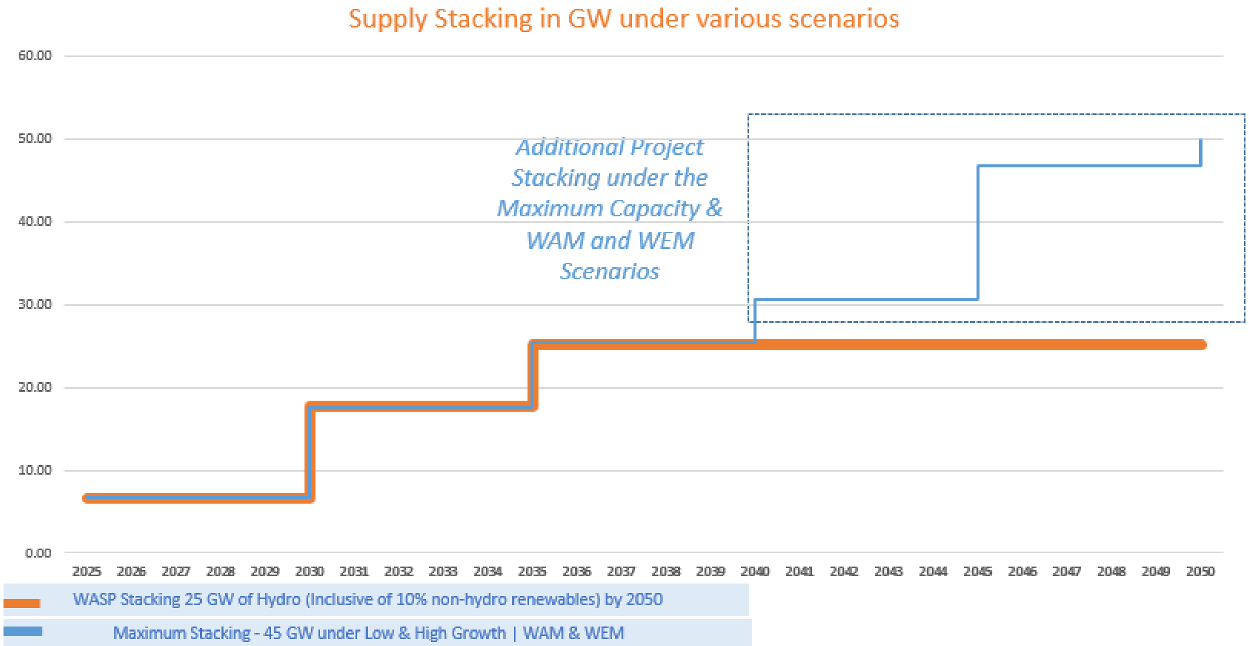


Figure 8: Supply Stacking in capacity terms under various scenarios

While the combined (hydro and non-hydro/intermittent renewables) capacity is sufficient to meet the energy demand under the reference, low growth and high growth scenarios, a total capacity of 45 GW and additional 10% intermittent renewable capacity is stacked under all five scenarios to achieve significant carbon offsets through energy export. The blue line in Figure 8 represents the stacking of additional capacity to meet the WAM and WEM targets and export.

Projects Considered for Supply Stack

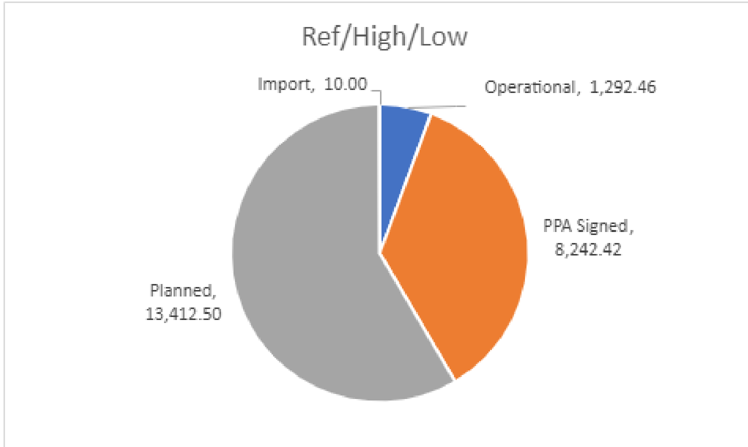


Figure 9 Projects considered for supply stack for reference, low and high growth scenarios

The chart in Figure 9 represents the 22.9 GW stacked in WASP under the Reference, Low and High Growth Scenarios and the chart in Figure 10 illustrates the 45.8 GW capacity stacked to meet demand for the WAM and WEM scenarios.

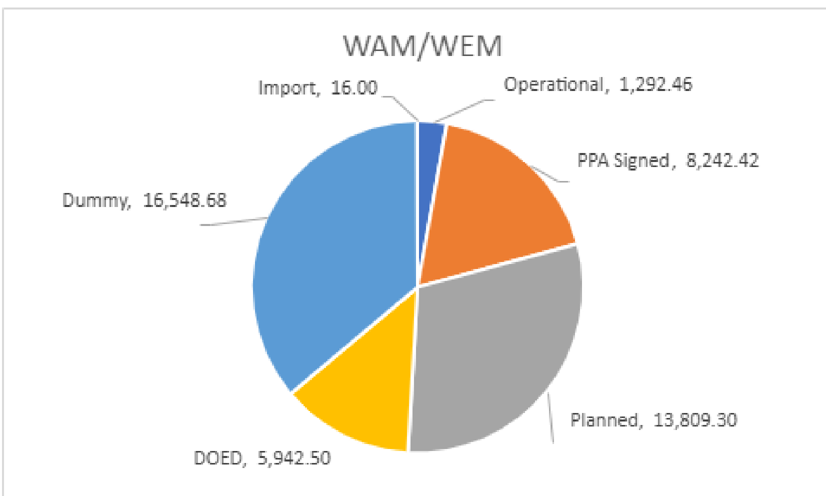


Figure 10 Projects considered for supply stack for WAM and WEM scenarios

Under the first stack, for reference, low and high growth scenarios alone, projects solely based on PPA signed with NEA, and government policy papers, particularly the White Paper are accounted. Within this supply stack, PROR projects dominate the generation mix (38%), followed by ROR (33%) and Storage Projects (29%).

Whereas, for the second stack, to build a maximum supply to meet the increased domestic demand of the WAM and WEM scenarios, list of additional projects was acquired from DOED and NEA and further planned projects were added in the pipeline. In addition to these, dummy projects were stacked by breaking down the Karnali Chisapani Storage Project's capacity, since it is highly unlikely that the project comes online by 2050. Within this supply stack, ROR projects dominate the generation mix (43%), followed by PROR (39%) and Storage Projects (18%). The charts, however, do not depict the 10% intermittent renewable capacity added under each scenario. The list of projects stacked under each scenario has been attached separately with this document.

Energy Balance and Trade

The total supply stacked within both WASP and Excel after accounting for both hydro and intermittent renewables correspond to the total domestic energy generation. The net energy balance, or the net tradable amount, is calculated by deducting the total domestic energy demand from the total energy generation. Although domestic demand is met through domestic generation as well as through imports, imports were not deducted separately, as it was incorporated in the total domestic demand, to arrive at net energy exports. The net exports are then used to calculate the carbon offsets that can be achieved in India or Bangladesh, depending on future trade scenario.

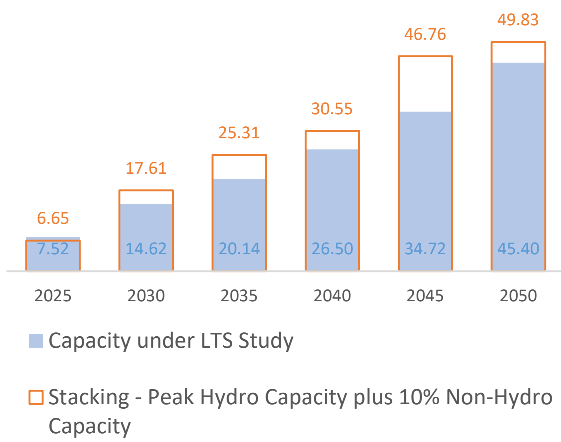


Figure 11 Capacity in GW identified under LTS and Supply Stacking under the WAM Scenario

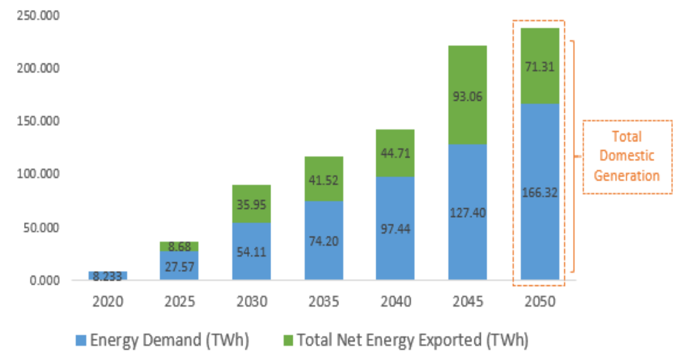


Figure 12 Energy Balance under the WAM Scenario in TWh

Figure 11 provides a visual representation of the supply stacking exercise against the demand projected under the WAM scenario. This bar stack depicts the capacity required to meet the projected demand and the orange outline depicts the supply stacked. The supply stack is developed according to the CODs of the projects as mentioned in government papers and consultation with NEA and experts.

Figure 12 showcases the energy balance under WAM scenario where the blue bar represents the total demand for energy and the green bar represents the net energy exported. This figure depicts significant increase in net energy exports to about 93 TWh in 2045 owing to the increased added capacity. However, there is a decline in energy exports in 2050 to about 71 TWh as capacity additions cease beyond 2045. All the exports under different scenarios are inclusive of intermittent renewables.

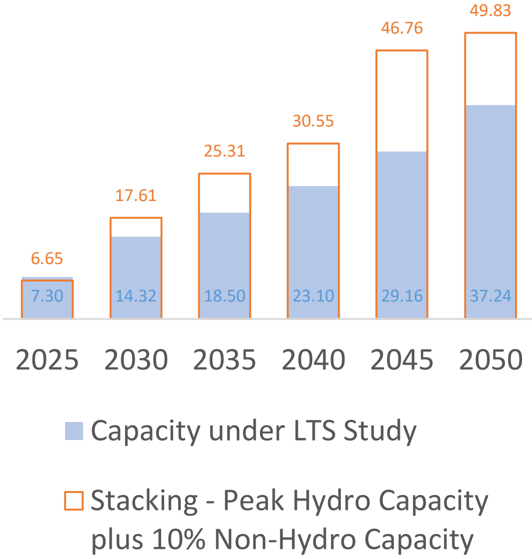


Figure 13 Capacity in GW identified under LTS and Supply Stacking under WEM Scenario

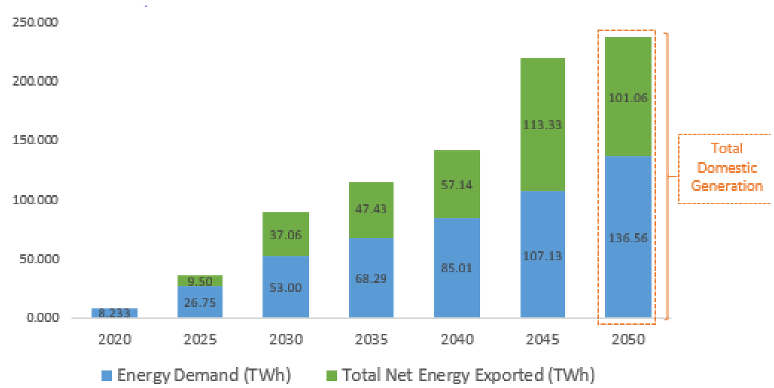


Figure 14 Energy Balance under the WEM Scenario in TWh

Similarly, Figure 13 represents supply stack against the demand projected under the WEM scenario. In parallel, Figure 14 showcases the energy balance under WEM scenario. This figure shows substantial increase in net energy exports under WEM scenario as well to about 113 TWh in 2045 owing to the increased added capacity followed by a decline in energy exports in 2050 to about 101 TWh.

Carbon Offset Scenarios

In this section we will be looking at the carbon offsets under various scenarios. It is to be noted that for the reference, high and low growth scenarios, we will be comparing offsets under both stacking scenarios of 22 GW of capacity and 45 GW of hydro capacity additions and an additional 10% renewables capacity addition. In the graphs included in this section, the blue lines depict the emissions forecast under the CES study after deducting the carbon offsets through AFOLU sequestrations and the grey line highlights the net emissions after AFOLU absorptions and carbon offsets through electricity exports. As such, the vertical distance between the two lines corresponds to the net carbon reductions through electricity exports.

Carbon Offset Under Reference Scenario

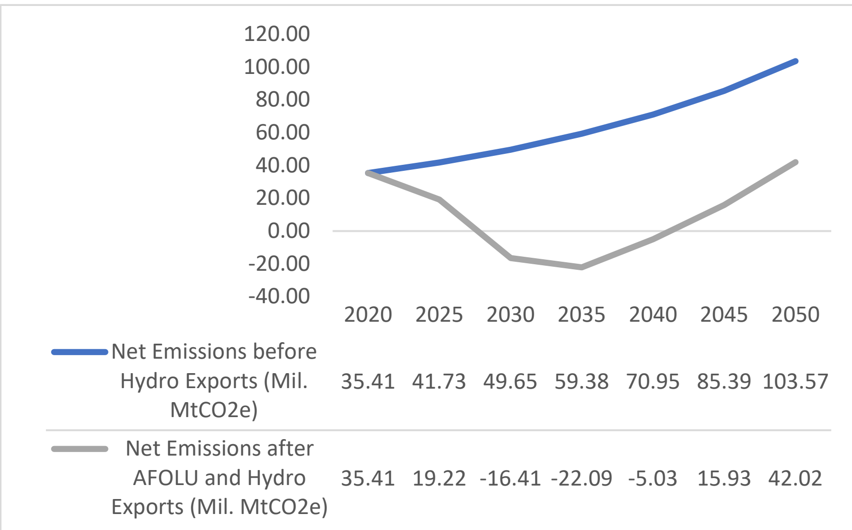
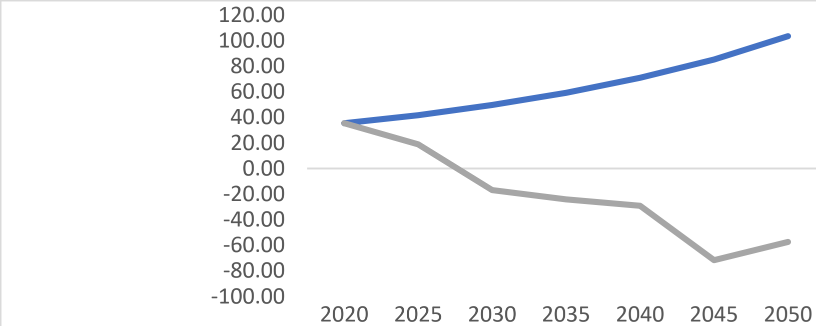


Figure 15 Carbon offsets under Reference Scenario (22 GW and 10% intermittent renewables)

Under the reference scenario, prior to hydro exports the net emission amounts to about 104 million metric tons of CO_2e. With a stacking of 22 GW of supply, corresponding emissions decreases to 42 mil. MtCO_2e. It can be observed that net zero under this scenario is achieved by 2030 and there is even a net negative carbon emission status leading up to 2040 owing to the 22 GW of hydro and an additional 10% intermittent renewable capacity stacking. However, emissions eventually increase starting 2045 resulting in a net positive emission considering increased emissions associated with increased demand due to rise in economic activity.

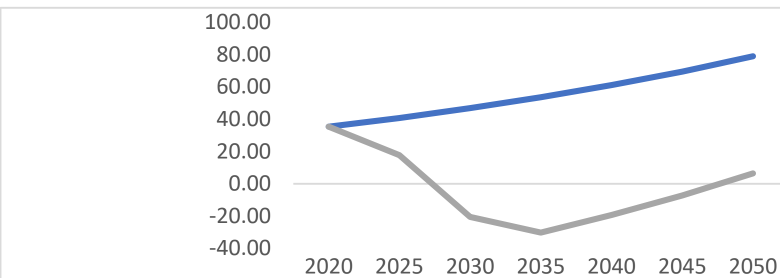


	2020	2025	2030	2035	2040	2045	2050
Net Emissions before Hydro Exports (Mil. MtCO2e)	35.41	41.73	49.65	59.38	70.95	85.39	103.57
Net Emissions after AFOLU and Hydro Exports (Mil. MtCO2e)	35.41	18.90	-16.66	-24.08	-29.04	-71.56	-57.41

Figure 16 Carbon offsets under Reference Scenario (45 GW and 10% intermittent renewables)

In the alternative stacking scenario, where capacity of 45 GW from hydro and 10% from intermittent renewables is added to meet not only the domestic demand but to meet offset goals, we see a sustained negative emission starting 2030. A maximum reduction of ~ 72 mil. MtCO_2e from net zero status is achieved in 2045. However, one can witness a reduction in emissions offset from 2045 to 2050, which indicates that the carbon emissions associated with economic growth may not be offset by hydro exports without further capacity additions.

Carbon Offsets Under Low Growth Scenario

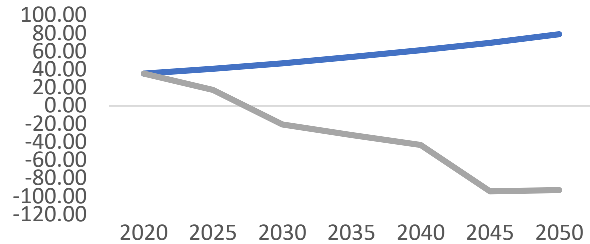


	2020	2025	2030	2035	2040	2045	2050
Net Emissions before Hydro Exports (Mil. MtCO2e)	35.41	40.74	46.79	53.69	61.07	69.43	78.93
Net Emissions after AFOLU and Hydro Exports (Mil. MtCO2e)	35.41	17.83	-20.47	-30.24	-19.29	-7.15	6.38

Figure 17 Carbon offsets under Low Growth Scenario (22 GW and 10% intermittent renewables)

Assuming a GDP growth of 4.5 percent under the low growth scenario, without hydro exports, emissions will continue to rise from 35 MtCO_2e in 2020 to 79 mil. MtCO_2e in 2050. With the minimum stacking of 22 GW, plus 10% from intermittent renewables, Nepal will reach its zero-carbon emission goal as early as 2030. It can be seen in the adjacent figure that the emissions will decrease 2030 onwards and increase beyond 2035. This trend leads to an eventual emission of 6 mil. MtCO_2e by 2050, which precludes achievement of Nepal's net zero targets.

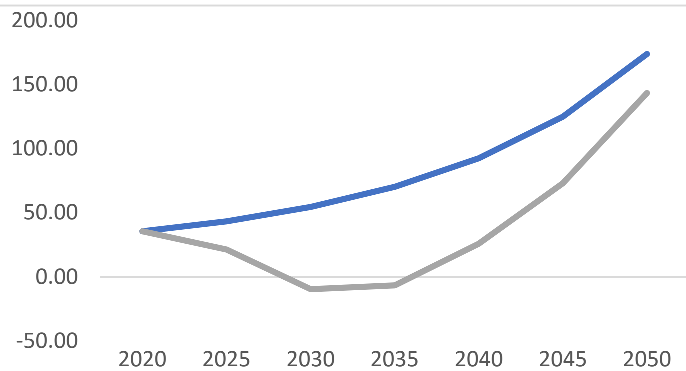
Alternatively, with capacity stack of 45 GW and 10% intermittent renewables, emissions will continue to decrease 2030 onwards with offsets as much as 100 mil. $MtCO_2e$ by 2045. We observe a slight decrease in offsets resulting in net emission of 93 mil. $MtCO_2e$ by 2050.



	2020	2025	2030	2035	2040	2045	2050
Net Emissions before Hydro Exports (Mil. MtCO2e)	35.41	40.74	46.79	53.69	61.07	69.43	78.93
Net Emissions after AFOLU and Hydro Exports (Mil. MtCO2e)	35.41	17.51	-20.72	-32.24	-43.27	-94.61	-93.03

Figure 18: Carbon offsets under Low Growth Scenario (45 GW and 10% intermittent renewables)

Carbon Offset Under High Growth Scenario



	2020	2025	2030	2035	2040	2045	2050
Net Emissions before Hydro Exports (Mil. MtCO2e)	35.41	43.15	54.34	70.10	92.28	124.92	173.74
Net Emissions after AFOLU and Hydro Exports (Mil. MtCO2e)	35.41	21.21	-9.75	-6.73	25.69	73.01	143.39

Figure 19 Carbon offsets under High Growth Scenario (22 GW and 10% intermittent renewables)

Under a high economic growth scenario, without any offsets driven by hydro exports, net emissions persistently rise and reach 174 mil. $MtCO_2e$ by 2050. With capacity additions of 22 GW hydro and 10% intermittent renewables, a brief period of negative emissions between 2030 and 2035 is observed followed by an increasing emissions trajectory driven by high economic growth. Maximum offsets of ~ 10 mil. $MtCo_2e$ is noted in 2030 but the reduction is not sustained in the following years. We observe an emission of 143 mil. $MtCO_2e$ by 2050 which is not significantly lower than the status quo emissions.

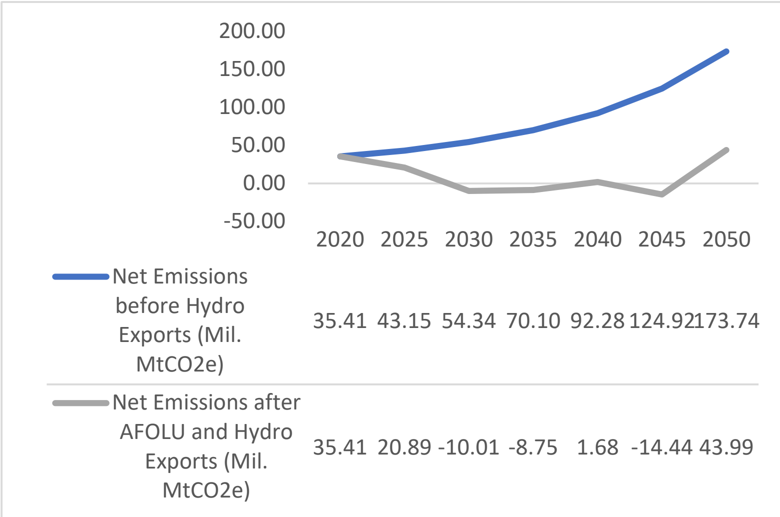


Figure 20 Carbon offsets under High Growth Scenario (45 GW and 10% intermittent renewables)

Then again, if we stack a capacity of 45 GW hydro and a 10% intermittent renewable capacity, we achieve a net zero carbon status as early as 2030 and we retain a negative or zero carbon status till 2045. However, we see a rise in emissions between 2045 to 2050, where emissions reach to about 44 mil. MtCO_2e by 2050. This increasing trend of emissions is most likely accelerated by the high economic growth. This is the only scenario where we are unable to meet our carbon reduction targets by 2050.

Carbon Offset Under Reference +WAM

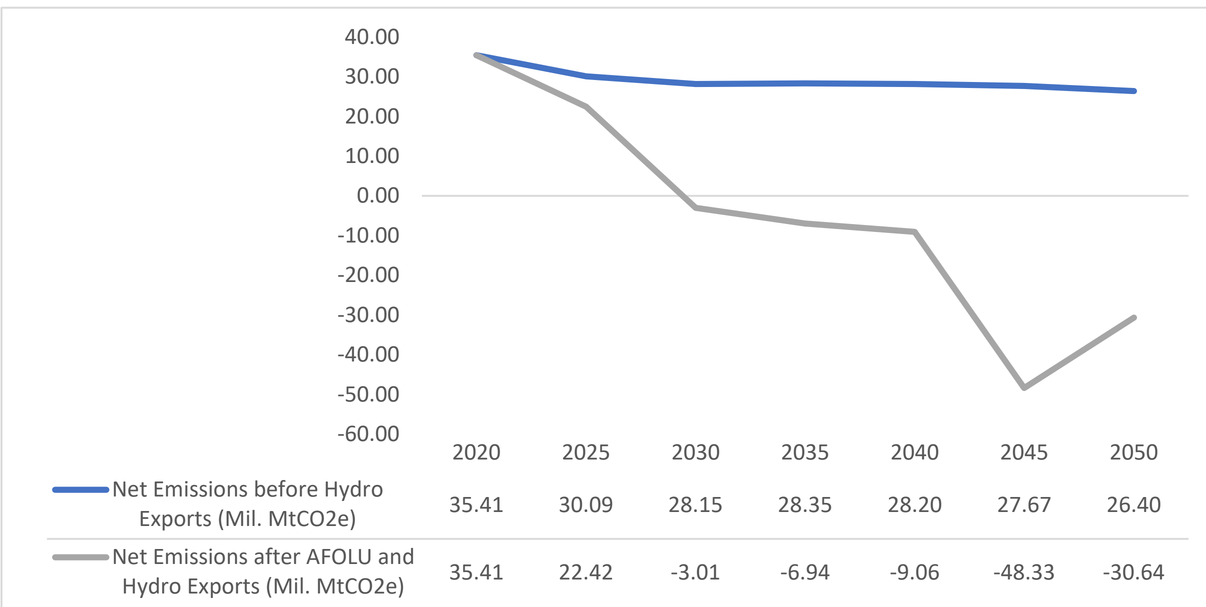
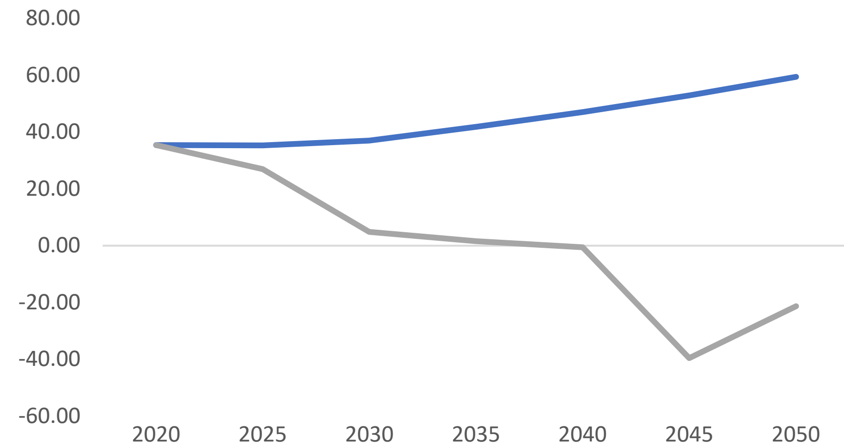


Figure 21 Carbon offsets under Reference+WAM Scenario

Under the WAM scenario, it is assumed that the government adopts additional policy interventions to reduce carbon emissions. As a result of the additional mitigation measures, we are able to reach net zero as early as 2030. With the 45 GW of hydro capacity and 10% intermittent renewables stacked, we can offset about 31 mil. MtCO_2e by 2050 on behalf of our neighbors through hydro exports. While the emissions are decreasing till 2045 and Nepal remains carbon negative through 2050, there is a slight increase in carbon emission from 2045 to 2050. Without capacity additions beyond 2045, this decrease in carbon offsets is expected.

Carbon Offset Under Reference +WEM



	2020	2025	2030	2035	2040	2045	2050
Net Emissions before Hydro Exports (Mil. MtCO2e)	35.41	35.37	37.03	41.89	47.10	52.97	59.51
Net Emissions after AFOLU and Hydro Exports (Mil. MtCO2e)	35.41	26.98	4.91	1.57	-0.52	-39.58	-21.34

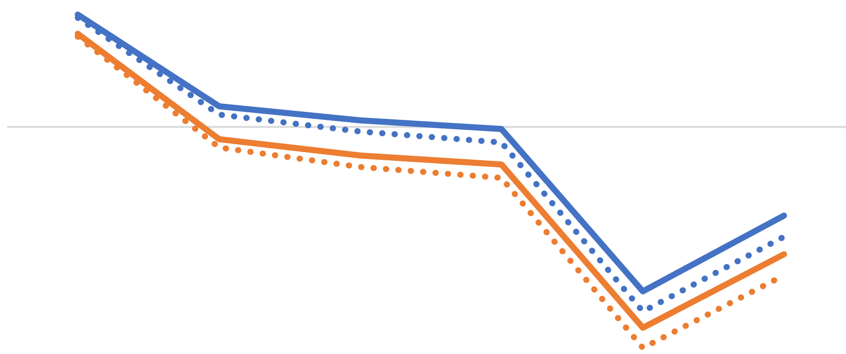
Figure 22 Carbon offsets under Reference+ WEM Scenario

Under the WEM scenario, it is assumed that existing policy measures are implemented by the government to reduce carbon emissions. With fewer policy interventions compared to the WAM scenario, a significant increase in carbon emissions of 60 mil. MtCO_2e is observed without hydro exports. However, since WEM scenario results in a lower domestic energy demand, Nepal is able to export more clean energy. As a result, number of emissions within WEM and WAM scenario are quite similar. We achieve a net negative emission of 21 mil. MtCO_2e by 2050.

This similarity in emission scenarios under WEM and WAM has an implication in the strategy that we pursue in attaining zero carbon emissions. It will be a policy prerogative to stay within the WEM scenario and rely on exports to reduce emissions or adopt additional mitigation measures under WAM scenario and rely less on exports to meet our emission standards.

Offsets by Intermittent (Non-Hydro) Renewables

While hydro exports allow us to maximize hydro potential, intermittent renewables will play a key role in our long-term strategy to achieve net zero due to its short gestation period and reduced execution risks. Considering these strategic advantages, we layered non-hydro renewables within our generation mix to emphasize its impact on potential emission offsets. The solid blue line and



	2025	2030	2035	2040	2045	2050
WEM - 10% Non Hydro	26.98	4.91	1.57	-0.52	-39.58	-21.34
WEM - 20% Non-Hydro	26.23	2.96	-1.17	-3.76	-44.45	-26.42
WAM - 10% Non- Hydro	22.42	-3.01	-6.94	-9.06	-48.33	-30.64
WAM - 20% Non-Hydro	21.67	-4.95	-9.68	-12.31	-53.20	-35.72

Figure 23: Potential Emissions offset under WEM and WAM Scenarios including intermittent renewables within generation mix

orange lines in the adjacent graph depict the emission profile under the WEM and WAM scenarios, respectively, where 10% of hydro capacity is incorporated as intermittent renewables within the generation mix. The dotted blue and orange lines represent the emission offsets with an increased fraction of 20 % of hydro capacity added as intermittent renewables in the energy mix. Although, an increase of 10 percent intermittent renewables does not result in a massive reduction in emission, an additional offset of about 5 mil. $MtCO_2e$ is achieved under both WEM and WAM Scenarios.

Study Findings Key Policy Takeaways

The key finding of this study is that there exists substantial carbon offset potential for Nepal, stimulated primarily by exports of electrical energy under all five scenarios explored in this study. The CES study highlights that even with additional mitigation measures to reduce GHG emissions undertaken under WEM and WAM scenarios, it will still be challenging for Nepal to attain its net zero carbon emissions by 2050. The study projections depict substantial export potential under the WAM and WEM Scenarios of 59.92 TWh and 99.82 TWh of energy, respectively by 2050. Therefore, hydro exports can play a pivotal role in Nepal de-carbonizing and eventually becoming a carbon negative economy. It is important to acknowledge that this goal is achievable only if trade of electricity is feasible between countries in the region. Trade unlocks a realm of opportunities and will allow Nepal to achieve net-zero emission target as early as 2030 under WAM Scenario. Trade facilitates net zero even under the WEM Scenario with minimal policy interventions.

The key message of the study is that trade of electricity is fundamental to Nepal's twin objectives of realizing its hydropower potential and decarbonizing its economy. The cyclic nature of Nepal's hydro generation is well established. This variability means an overflowing of hydro energy during the wet seasons when river flow is robust, and reduced generation when river flows are anemic in the dry season potentially resulting in surpluses and deficits within a year. Developing Nepal's hydropower potential to solely meet our domestic energy demand is not an optimal strategy. To do so will require the development of significantly more capacity than our peak power demand to meet our energy requirements during the dry season. Alternatively, we could meet our demand by developing the more expensive reservoir projects with inter-seasonal storage and peaking projects to cater to intra-day variations in electricity demand. Either strategy will result in massive surpluses. Equally importantly, developing hydropower to meet domestic demand will not allow to exploit the full hydropower of our resources. For example, the installed capacity for Upper Karnali and Arun 3 projects were originally designed at 300 MW and 402 MW when to meet domestic demand but were later upscaled to 900 MW each when optimized for the export market.

Inward looking strategies, whereby Nepal's decision on generation capacity is based on domestic demand for electricity is not a credible strategy from a carbon neutral perspective either. When modeling the supply stack to meet demand in the WASP model, around 22 GW of hydro and 10% hydro capacity for non-hydro renewables were stacked for the reference, low and high growth scenarios. Imports are avoided completely until 2050 except for the high growth scenario which required 2.4 TWh of electricity to be imported. This does not lead to a net-zero target by 2050, with projected emissions as high as 142.63 million $MtCO_2e$ under the high growth scenario. Emissions are significantly less under the reference and low growth scenarios at 40.48 million $MtCO_2e$ and 4.56 million $MtCO_2e$ respectively, a northward deviation from the net-zero target.

Harnessing the country's hydro potential to the fullest is the key to position Nepal on the net zero trajectory. Stacking 45 GW of projects under the reference, low and high growth scenarios, positions Nepal to export substantial electric energy, at 201.23 TWh, 214.94 TWh and 162.18 TWh, respectively. This has a direct knock-on effect on Nepal's carbon emissions as the country stands to meet net zero targets and offset an additional 61.44 $MtCO_2e$ and 97.32 $MtCO_2e$ in the region in 2050 under the reference and low growth scenarios. For the high growth scenario, however, the country still stands to emit 40.75 $MtCO_2e$ in 2050, missing the net zero target by 2050.

Stacking generation projects to increase exports might be a credible strategy for Nepal's carbon targets, but assuming a fix economic growth rate despite massive hydro exports is a bit counter intuitive. For instance, exporting energy northwards of 77.90 TWh of energy from as early as 2030 under the low growth scenario with growth capped at 4.2% seems implausible. Similar concerns arise in the reference growth scenario as well leaving us with high growth as the only plausible scenario under such massive exports. But as illustrated in the preceding paragraph, Nepal is unable to achieve net zero emissions under the high growth scenario. As such, the magnitude of potential energy exports under the reference, low and high growth scenarios are misleading, leaving us to focus on WAM and WEM scenarios for an accurate reflection of potential electricity exports and subsequent carbon offsets.

The study indicates substantial energy exports and carbon offsets under the WEM and WAM scenarios, which is positive news for Nepal. The country is projected to export 101.06 TWh and 71.31 TWh of energy under the two scenarios in 2050. This corresponds to additional offsets of 21.34 and 30.64 million $MtCO_2e$ after achieving net zero targets in 2050. The incremental emissions offset under the WAM scenario is at 9.3 million $MtCO_2e$ compared to the WEM scenario, but it is contingent on substantial investment in carbon negating measures domestically. While further studies are needed to ascertain the best strategy under these scenarios from a cost-benefit perspective, larger benefits seem to accrue in Nepal's favor under the WEM scenario which combines the lower mitigation costs with higher revenue from exports. This emanates from the possibility of offsetting carbon emissions from exporting energy as opposed to displacing domestic emissions.

Much of the discourse on electricity trade focuses around Nepal's hydro resources, with minimal attention given to non-hydro renewables in the country's efforts to net zero emissions by 2050. This argument stems from the limited energy generation from such non-hydro renewables and challenges of integrating an intermittent source of energy into the system. In all the supply scenarios considered in this study an additional 10% of non-hydro capacity (which leads to 6.35 TWh of energy generation in 2050) is assumed. Under an additional scenario where 20% of non-hydro renewable capacity is added, the additional energy generation doubles to 12.70 TWh in 2050. The primary benefits of non-hydro renewable adoption, however, does not emanate from additional energy generation and exports. Non-hydro renewables, with their low execution risks compared to hydro projects, favorable pricing trends and generation profile that complements hydro generation have an important contribution towards early achievement of net zero goals.

Timely completion of hydro projects including both generation and transmission infrastructures are key success factors to help Nepal realize its net zero aspirations. Our analysis assumes that the hydropower capacity will come online as projected to meet energy demand and emission reduction targets. If history is any indication, then this is a tall order given the track record of developing hydropower projects relative to our aspirations. There are numerous bottlenecks that have contributed to this but the competing narratives between hydropower development and forest conservation is a primary one. Developing hydropower to not only meet our energy needs but also our emission reduction targets present a unique opportunity that aligns the interests and objectives of hydropower development and conservation.

Substantial investment in energy infrastructure will be required which will need to be accompanied by a conducive policy environment to attract the needed investment. Energy trade also requires cost-competitiveness of Nepal's exported energy in the regional energy market and a favorable climate mitigation centric policy regime for clean energy and the market mechanisms that favor the energy characteristics of hydropower, particularly its dispatchable nature. Such enabling provisions will not only ensure Nepal's sustained approach towards net zero emissions by 2050 but will also augment India's pathway towards a net zero trajectory by 2050 by enabling the accelerated the adoption of intermittent renewables. In their absence, however, Nepal will have to resort to meet internal generation needs, limiting harnessing its' hydro resource, which, in turn leads to a 'Nash equilibrium' sort of a situation whereby both Nepal and India will lose out from potential carbon offset benefits from energy trade.

Limitations and Scope for future Research

The study was conducted in a compressed timeline to meet a quick turnaround requirement to meet Nepal's goal of submitting the LTS by mid-July. As such, it primarily deals with Nepal's net electricity export potential and its knock-on effect on carbon emissions under the scenarios identified under the CES study. While the projections themselves are important on a standalone basis, understanding the bigger picture and transforming ideas and aspirations for a net zero situation by 2050 into reality requires substantial additional work. For starters, estimating the investment requirements in generation and transmission assets and power trading infrastructure to benefit from energy exports under the plausible scenarios, particularly the WAM and WEM scenarios mandates further exploration. Such an estimation will empower policy makers to decide on the optimal, least-cost net-zero trajectory for Nepal.

An additional area of investigation that will require substantial analysis is on ensuring cost-competitiveness of Nepal's hydro energy in India and other regional power markets. Realizing Nepal's carbon offset projections through energy exports is highly contingent on the cost-competitiveness in the export market. Price will be a key criterion for such energy purchase decisions at the offtake end. While some portion of the project set-up costs can be addressed through policy certainty and appropriate incentives from the government of Nepal's end, it is equally important for the carbon emissions framework to incentivize adoption of renewable energy by ensuring an effective carbon-pricing and trading mechanisms.

An interesting outcome of this study involves a policy choice between the WAM and WEM scenarios for achieving net-zero targets for Nepal. Investing in substantial carbon offset measures domestically in the WAM scenario seems to provide marginal offset benefits in 2050 as compared to the WEM scenario, where additional energy exports will require investment in infrastructure. A comprehensive exercise to evaluate the costs and benefits of the policy choices is warranted, which will demonstrate the true Value for Money in Nepal's zero emission strategies.

Nepal needs a coherent generation and transmission planning strategy developed in coordination with multiple stakeholder ministries. Contestation among ministries and departments is rampant, and coordination difficult. Yet, a collaborative effort is must that feed into our generation and transmission strategies. Getting the right message across is important to win the trust and support of multiple stakeholders. After all, policies developed in isolation achieve little benefits, as evidenced by Nepal's past shortcomings.

Another key aspect that needs further investigation is the effect of climate change on the long-term commercial and environmental sustainability of hydropower. The catalyst for this study was to assess how Nepal may achieve its decarbonization goals by exporting hydropower. Even though Nepal's contribution to global emissions is miniscule on a per capita basis, the impact of climate change will be disproportionately felt by Nepal and its ecosystem. These impacts will also impact the generation profile of its hydropower projects which rely on monsoon rains and snow melt. If the cornerstone of Nepal's decarbonization strategy is reliant on hydropower, then a comprehensive evaluation of the effects of climate change on hydropower needs to be undertaken.

Annex I

Projection of Carbon Emission Reduction

Bibhakar Shakya, Ph.D.

Coal is the main fuel for electricity generation in India and its usage continues to increase to supply the growing demands. Coal-based power plants contribute about 70% of the total generation capacity in the country as of 2018 (CES, Dec 2018). Because of this significantly higher use of fossils fuels, India is the 3rd largest contributor in the world in terms of total fossil fuel CO_2 emission in 2016 (CES, March 2018). And, in India, the power sector (electricity generation) contributes close to 50% of total CO_2 emission.

It is estimated that the contribution of coal-based electricity will be slowly replaced by renewable resources in the future, however, coal-based power plants are projected to contribute about 45% and 40% of installed generation base capacity in 2022 and 2027 respectively (CES, March 2018). It can be fairly assumed that India will need to build more coal power plants to meet its growing future demands of electricity. It can also meet part of its electricity demand from its neighboring countries like Nepal that can provide hydro-based net-zero CO_2e electricity instead of building more coal power plants. From the environmental perspective, both Nepal and India can benefit from electricity trade: India to decrease its greenhouse gas emissions and Nepal to improve its trade deficit.

Therefore, for our project, we can safely assume that Nepal is exporting electricity to India that will be otherwise, generated by using coal power plants.

The various studies cited in the reference below suggest anywhere from 0.97 to 0.82 tons of CO_2 emissions/MWh. The heat rate of coal and improvement in supercritical coal technology can also impact CO_2 emissions (CES, March 2018).

We can safely project that the reduction per MWh will be 0.90 tons CO_2 emissions in the reference year and calibrate to decrease in the future (technology improvement) to 0.80 tons of CO_2 emissions/MWh in the final phase of the modeling year.

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Assessment of Greenhouse Gas Emissions from Coal and Natural Gas Thermal Power Plants using Life Cycle Approach. International Journal of Environmental Science Technology (IJEST), 2014

[i] Final Report on Technical and Financially Feasible Long-term Vision and Long-term Strategy for Net Zero Emission for Nepal was submitted by CES on March 21 to the UNDP