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# Climate, Land, Energy and Water System Nexus Optimization Modelling for Nepal

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## Abstract

This paper introduces the amazing CLEWs Nepal model - a powerful tool that sheds light on the intricate interplay between climate policies and crucial resources like land, energy, and water. With more and more countries taking bold steps to combat climate change, it's crucial to understand the ripple effects of such decisions on other sectors. That's where CLEWs come in, providing decision-makers with valuable insights into the trade-offs and synergies involved in various climate policies.

This paper examines the impact of the increasing global demand for power on greenhouse gas emissions, water usage, and hydropower production in Nepal. The study projects that by 2050, under current scenario and based on optimum growth rate, the country will only need to generate 9 GW of power, which can be mostly fulfilled by hydropower. However, there will be rise in CO2 emissions, particularly from the transport and biomass sectors. To mitigate the impact of this growth, the study recommends improving irrigated farming and forest conservation. The implementation of the Nationally Determined Contributions (NDC) can also contribute to reducing CO2 emissions and increasing hydropower production. We've calibrated the model to reveal fascinating insights into the long-term energy consumption patterns across different sectors, varying crop production based on irrigation levels, and total water usage in public and power sectors. And that's not all - we've also factored in the emissions produced while optimizing energy, food, and water demands for the public. Our model offers a range of policy options for Nepal, including an NDC scenario, which can help reduce CO2 emissions and preserve vital resources like water and land. We've also identified the costs and technology mix necessary to successfully implement these policies.

***Keywords:*** *CLEWs, nexus, food, emery, land, water, emissions, OSeMOSYS*

## 1. Introduction

Food, energy, land, and water are all essential components for human sustenance and are highly interrelated. Understanding these interconnections can be aided by the creation of the climate, land, energy, and water systems (CLEWS) modelling framework. For each of the three resources and their integrated characteristics, the CLEWS approach uses current well-tested assessment procedures. It can reveal linkages between policies for the Sustainable Development Goals (SDGs) and nationally specified contributions under the Sustainable Development Goals (SDGs) on climate change as per the Paris agreement.

Providing food, energy, and water security to a world that is expanding in size and wealth is a key component of the 2030 agenda(Johnston, 2016). These goals must be reached while safeguarding natural resources and mitigating and managing climate change's effects.

The CLEWs model is developed in MOMANI and then run in OSeMOSYS which is a cloud model running platform. The visualization and comparison from the output will be the guiding factor for further improvement and informing policy makers to investigate best suited changes to plan for a sustainable future. The CLEWs framework incorporates some elements of the nexus concept because it was built using the UN's sustainable development (SD) paradigm(Country, n.d.). The CLEWS platform is currently being used by a number of finished and ongoing projects to examine various policy-related topics across a range of special and temporal scales, as well as between interactions involving two or more resources(ARIANPOO, SINGH, WRIGHT, & NIET, 2021).

More than 90% of GHG emissions are attributed to energy, agriculture, and land use change (van Vuuren et al., 2017). Bioenergy is using an increasing amount of cropland. Water withdrawals from agriculture and the energy sector account for 90% of global water withdrawals(“AQUASTAT | Land & Water | Food and Agriculture Organization of the United Nations | Land & Water | Food and Agriculture Organization of the United Nations,” n.d.)

Water treatment and supply account for about 4% of global electricity use. Crop cultivation uses 4% to 5% of total energy. Moderate to severe food insecurity affects 25% of the adult population worldwide. A quarter of the world's population lives in areas where there is a lot of water scarcity. 35 percent of the world's population does not have access to safe and clean cooking energy(Johnston, 2016). And under all of these, the world is not on course to reach the Paris Agreement on Climate Change, which was signed in 2015.

Nepal aims to ensure that 15 percent of overall energy demand is met by clean energy sources and 25% of families use electric stoves as their principal means of cooking by 2030 (GoN, 2020).

Similarly, Nepal has targeted increase in clean energy generation from around 1,400 MW to 15,000 MW by 2030, with 5-10% coming from mini and micro hydro power, solar, wind, and bioenergy. Among these, 5,000 MW is a firm aim. The rest is reliant on the international community's contribution of funds(GoN, 2020). Nepal aims in improving self-sufficiency in food grains will result in a 0-5 percent trade surplus by 2030. Also, Agricultural productivity will have improved to 4 Metric Tons (MT) per hectare by 2024, up from 3.1 MT per hectare in 2019(NPC, 2019).

From 48 percent in 2019 to 80 percent in 2024, the number of households with basic food security will have increased and also from 8.9% in 2019 to 4% in 2024, the population deprived of the daily minimum calorie intake will have decreased(NPC, 2019)Between 2019 and 2024, an extra 300,000 hectares of land will be irrigated and the yearly timber production will be boosted from 19.4 million cubic feet in 2019 to at least 30 million cubic feet by 2024, making Nepal self- sufficient in timber(NPC, 2019).

The most pressing issue of our day is climate change, which is causing global temperatures to rise, an increase in the frequency of natural disasters, and a shortage of natural resources. Due to the effects of climate change, urbanization, and population expansion, it is anticipated that by 2050, the world's demands for water, food, and energy would have increased by nearly 50% (Khan, Linares, & García-González, 2017).

Nepal is developing, and the electricity production is going to be more than demand in few years’ times. There is immediate plan required on how the country is going to utilize its excess electricity. There can be several areas explored like going towards EV, going towards electric cooking, establishing medium and large-scale industries.

In the same way, the population is increasing day by day and the area available for food cultivation is limited. There is topmost need for transition in our farming system for producing more food with limited land resources available.

Similarly, the dependency on fossil fuel for transport, industry and cooking has posted a great threat in climate change due to the production of excessive greenhouse gases. A proper tackling strategy need to be adopted in time for the mitigation of upcoming dangerous situation.

To combat these issues and for long term energy expansion, Nepal also has posted some ambitious target. But there is no proper strategies on how the country is going to achieve the target. CLEWs modelling will create a baseline scenario for achieving various policies target.

Beside these, this model has built along term energy expansion model and forecasted the total green house gas emission by 2050 A.D.

### 1.1 Underlying Assumption

The OSeMOSYS energy modeling framework is expanded in the CLEWS Modelling framework (Ramos et al., 2021). A bottom-up modeling framework called OSeMOSYS was created to offer user-defined regions long-term cost optimization for their energy systems. In this context, "modelling framework" refers to software that creates certain models by filling them with user-defined data" (Gardumi et al., 2018)..

This method combines the nexus system and the interactions of each system with the climate in a single model, enabling effective resource allocation and consistent price Water, food, and energy (WFE) and their interactions with Nepal's climate data make up the three main parts of this model. The model is limited in only tracking the demands and constraints of the water.

The energy and land systems were first conceived and developed separately for the model, based on the Clustering approach. The model's links between each pair of systems were then established. The amount of water necessary to produce energy from each energy source, as well as the amount of energy needed for tasks like operating water treatment facilities, are examples of how the interactions between the water and energy systems are specified. Another illustration is the relationship between the energy and land systems, which is determined by the amount of energy needed for agricultural activities (such as the pumping of water or the operation of agricultural) Later, the model was updated to include the activity ratio of CO2 emissions generated by each activity.

## 2. Methodology and modelling structure

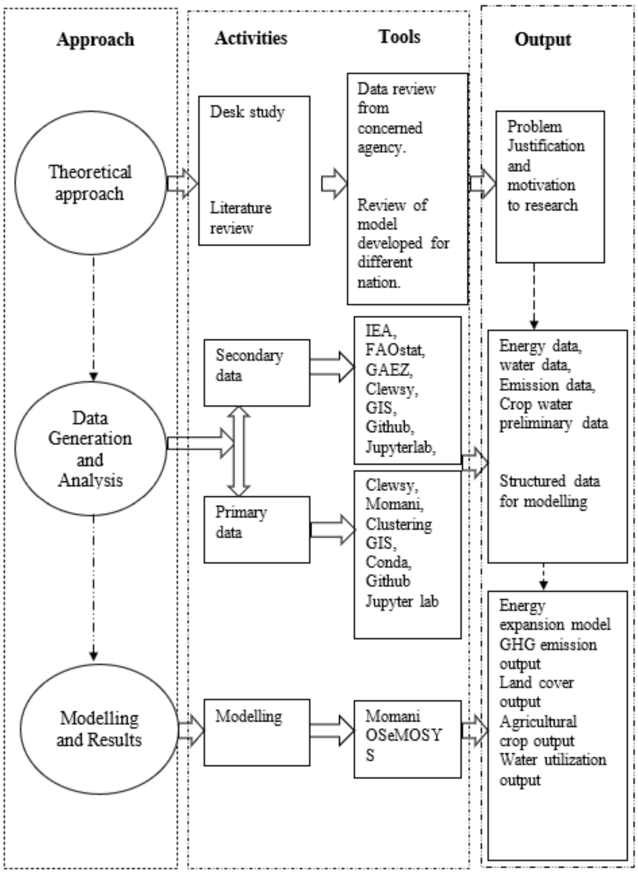


Figure 1: Research methodology and process figure

### 3.3 Power Generation capacity Details

Figure 4 shows the power generation capacity details in the modelling period. It is the least cost technology mix which will fulfill the electrical demand over the modelling period. As only three sources are considered, hydropower will be the most dominant source with reaching up to 9.7 GW by 2050 A.D. The percentage of solar and wind is very negligible as the availability factor and capacity factor comes into effect along with their life time in compared to hydro is low.

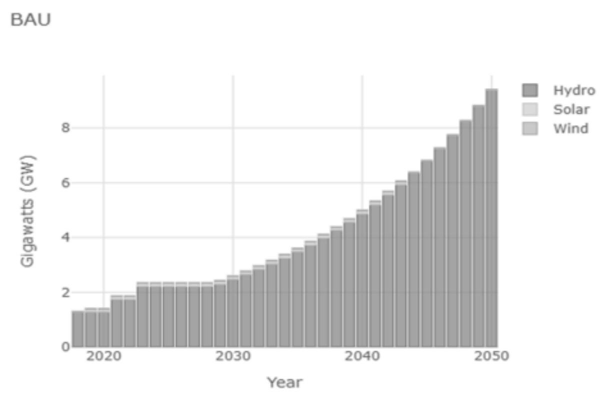


Figure 4: Power Generation capacity

### 3.4 Domestic energy production

Figure 5 depicts the least cost domestic energy production over the modelling period. It shows that there will be significant increase in the production of hydro energy from 22 PJ in 2018 A.D to 184 PJ in 2050 A.D. Biomass will be the highest produced domestic energy ion the modelling period whose share will rise to 551 PJ in the time frame.

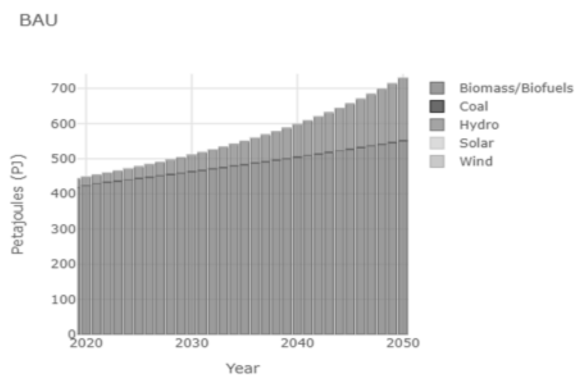


Figure 5: Domestic energy production

### 3.5 Energy imports

Figure 6 depicts the energy import scenario in business-as-usual case. The country will be still highly dependent on imports where the import of diesel is seen to be rising from 77.3 PJ to 638 PJ over the modelling period. The country will become independent on electricity by 2023 A.D. There will also be considerable rise in the import of petrol and coal for transport and industrial sector and LPG in industrial sector.

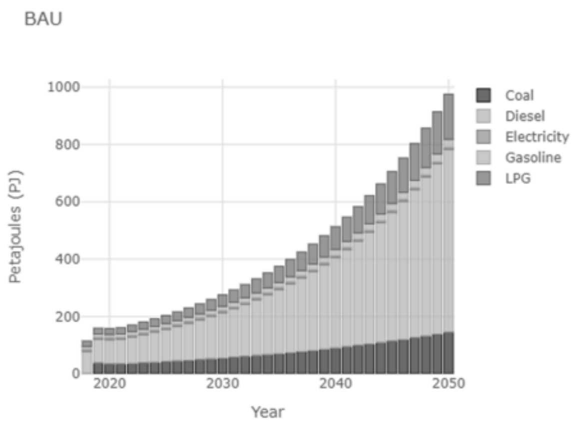


Figure 6: Energy Imports

### 3.6 Area by crop

In term of crops, the figure 4.6 shows area taken by crops to meet the present food demand over the modelling period. Rice is the highest area taking crop which is taking 15,150 sq.km of land in 2018 and which goes up to 25.5 sq.km by 2050 A.D. The total cultivated area from 33500 sq.km increases to 54500 sq.km to meet the growing food demand.

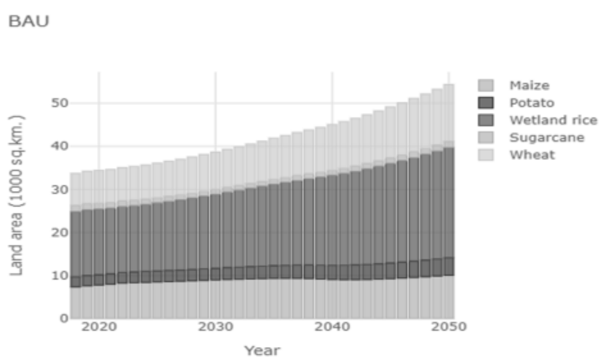


Figure 7: Area by crop

### 3.7 Area by land cover type

Figure 4.7 depicts the acquisition of land cover over the modelling period to meet the food and water demand. The forest has been constrained to be maintained over 40 percent of total land. The barren land and grassland is being used to convert to agricultural land to meet the crop demand. The barren land decreases from 24500 sq.km to 10000 sq.km in the modelling period whereas the agricultural land increases from 33000 sq. km to 54330 sq.km. There is also a rise in built up land for settlement over the modelling period.

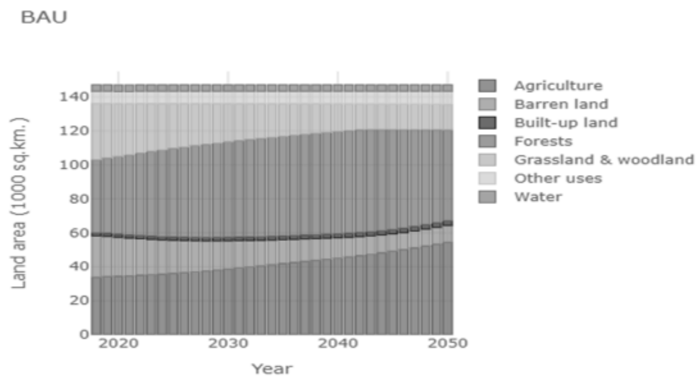


Figure 8: Area by land cover type

### 3.8 Crop production

Figure 4.8 depicts the crop production in millions of tons. It shows that the production of these five crops will almost double over the modelling period.

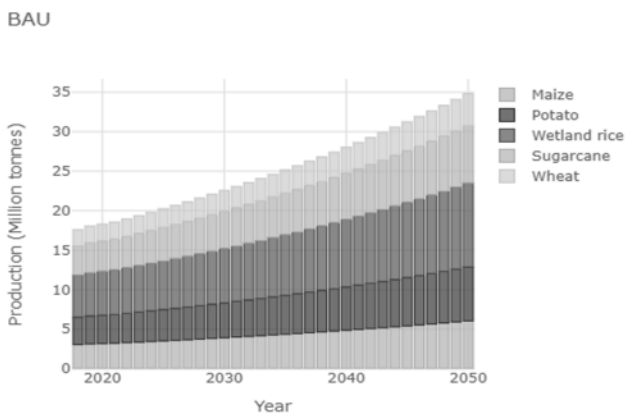


Figure 9: crop production.

### 3.9 Yield

Figure 10 shows the productivity increase in terms of yield over the modelling period. As the farming is going over low rain feed high rain feed and medium irrigation to high irrigation, there is rise in productivity. The yield of sugarcane almost double as per the model. Similarly, there is also a significant increase in yield of other crops too. Increase in yield implies less consumption of land to produce the same tones of products.

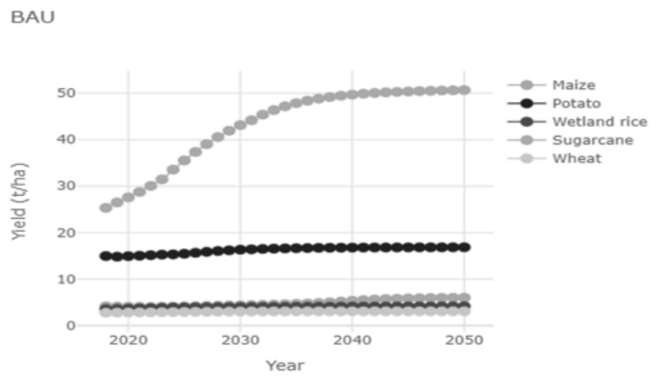


Figure 10: Yield

### 3.10 Water Demand

Figure 11 shows the water demand of the modelling period. Majority of water demand in Nepal is for public which is 9.8 billion cubic meter in 2018 A.D and rises to 10.9 billion cubic meter in 2018 A.D. the water requirement in agricultural sector through irrigation doubles by 2050 A.D. and the water requirement in power sector goes 8-fold over the period i.e., from 0.11 billion cubic meter to 0.922 billion cubic meter.

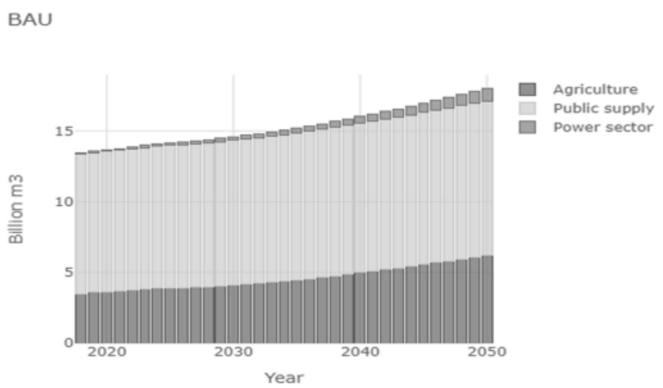


Figure 11: Water demand

### 3.11 Water balance

Figure 12 depicts the water balance diagram of Nepal. There is rainfall of 191 billion cubic meter annual and the irrigation demand is increasing as already depicted in the previous figure. All these waters is balanced through surface water run-off and evapotranspiration as shown in the figure itself.

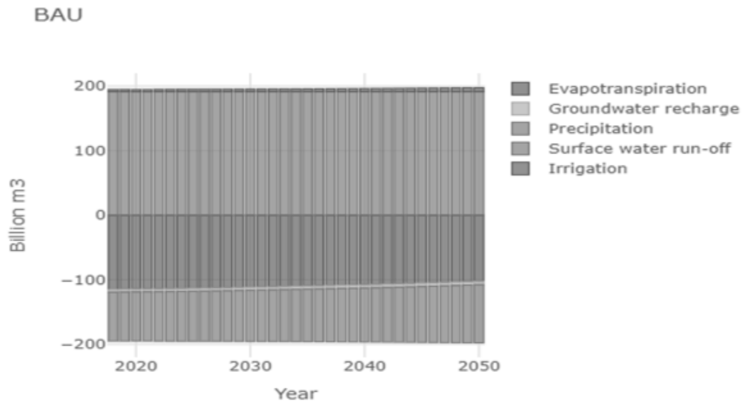


Figure 12:Water Balance

### 3.12 Co2 emissions by sector

Figure 13 shows the sectoral Co2 emission by source. The emission rises from 49 million tons in 2018 to 119 million tons by 2050 if no any intervention is made. The transport sector will be the major contributor with almost 42 million tons of Co2 equivalent emission by 2050. Similarly the industries will be raising their emissions from 3.57 million tons to 14.2 million tons of Co2 equivalent by 2050.

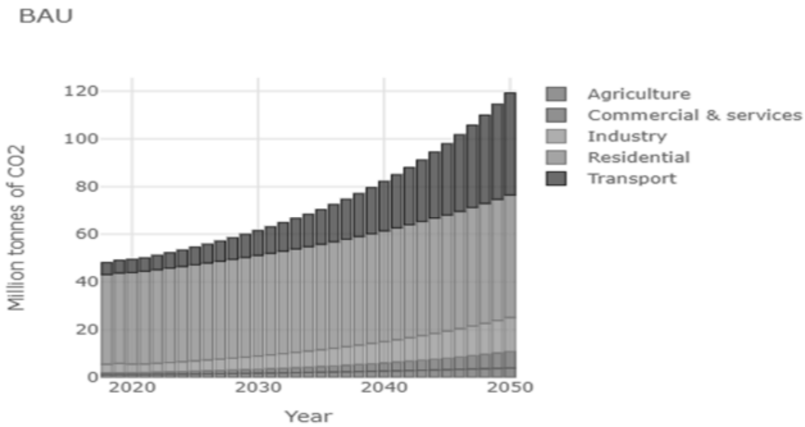


Figure 13: Co2 emission by sector

### 3.13 Co2 emission by Source

Based on the nexus connection of the land energy and water system, the corresponding impact mad e by them is depicted in figure 14. Biomass/ biofuels sector is the leading Co2 emission source. The individual Co2 emission contribution of each fuel source at business-as-usual scenario is rapidly increasing. The emission rises from 49 million tons in 2018 to 119 million tons by 2050 if no any intervention is made. At current rate of diesel vehicle, the emission from diesel will only be 9 folds over the modelling period.

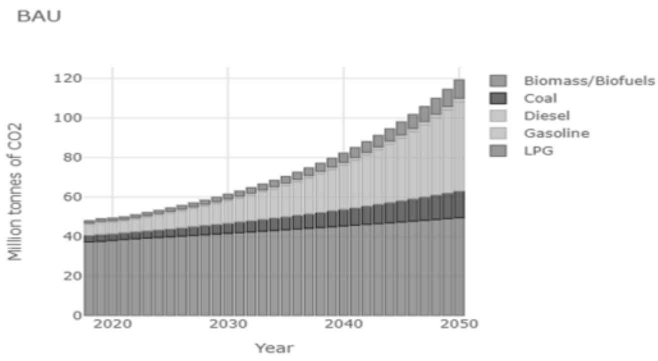


Figure 14:Co2 emission by source

### 3.14 Area by crop(irrigated)

Figure 15 depicts the irrigated area requirement for various crops over the modelling period. There is rise in irrigated area for rice and sugarcane from 9000 sq. km and 667 sq.km to 22000 sq.km and 1434 sq.km respectively over the modelling period. Similarly, potato and wheat are showing more requirement towards high rain feed system.

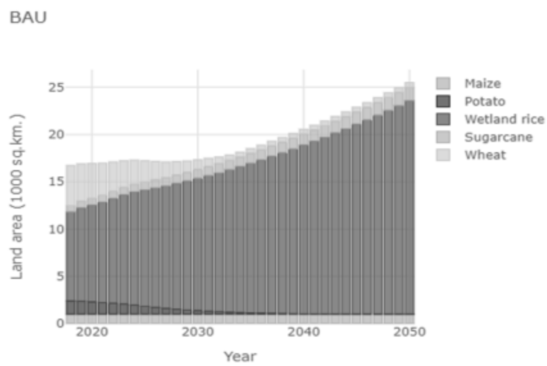


Figure 15: Area by crop(irrigated)

### 3.15 Area by crop (Rain feed)

Figure 4.15 depicts the same data as figure 16 but in terms of rain feed. Potatoes and wheat are showing increased rain feed land usage for meeting up the optimized scenario.

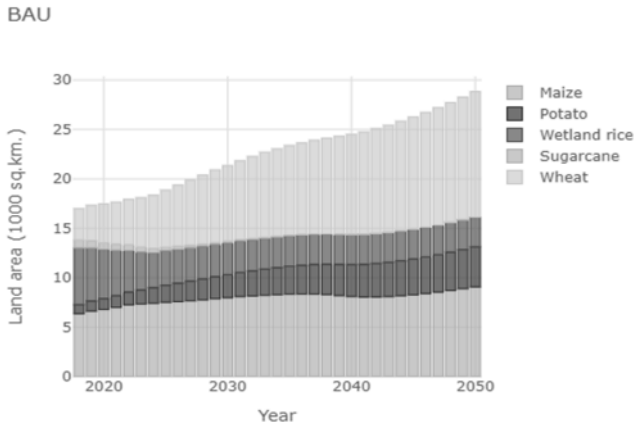


Figure 16: Area by crop (rain feed)

## 4. Conclusion

According to the model's projections, hydropower will be the most efficient source of power generation to meet the country's growing energy demand, which is expected to reach almost 9 GW under a business-as-usual scenario. However, without intervention, the country will remain heavily dependent on biomass and fossil fuels for energy production.

Transportation and biomass (wood) use will continue to be major contributors to CO2 emissions. To address this issue, efforts should be made to improve irrigation in agriculture, which has the potential to nearly double crop yields. Furthermore, forests can play an important role in sequestering CO2 emissions, mitigating the effects of climate change.

Despite the potential for hydroelectric power, the country will only require 9 GW of energy by 2050 AD if the industrial and residential sectors do not switch to electric means. However, by utilizing barren land for improved irrigated farming, it is possible to generate a surplus of food grains in the country.

Some other conclusions are as follows:

- $CO_2$ emission will almost double be reaching 119 million tons of $CO_2$ equivalent.
- Improved irrigated farming can double the yield (case: sugarcane)
- Power sector will require almost 8 times more water by 2050 A.D and twice for irrigation.

## 6. Recommendation and Future Works

It is essential to conduct modelling for energy, land, water, and climate before setting ambitious targets in Nepal. Sustainable energy planning should always consider the impact on land, crops, and climate. To increase the demand for electricity within the country, an immediate and feasible approach is necessary. To achieve the goals set out in Nepal's Nationally Determined Contributions (NDC), modelling should be conducted to implement a strategy that meets them.

In addition, modelling should be done in the areas of land, energy, and crops to ensure trade and food security. Appropriate subsidies should be adopted for electric means of cooking and electric vehicles to increase electricity demand in the country. Nepal should explore opportunities for electricity export to maximize the use of its water resources.

It is also essential to model the Nationally Determined Contributions (NDC) goals before setting the implementation strategy. Modelling in land energy and crop should also be done to ensure trade and food security.

Furthermore, it is important for Nepal to consider electricity export, as optimizing the use of water resources will be essential for future sustainability. Finally, this model can be used to model any scenario for setting policies on the land, energy, water, and climate sector in Nepal. By adopting these recommendations, Nepal can ensure sustainable development and management of its resources.

**7. Acknowledgement**

I am also very grateful to Dr. Shree Raj Shakya for providing necessary guidelines and suggestions and linkages in getting familiar with the modelling tool. More importantly, I would like to thank Professor Dr. Taco Niet of Simon Fraser University, Canada who gave me the idea and materials to start developing the model for Nepal.

## 8. References


1. Almulla, Y., Broad, O., Shivakumar, A., Gardumi, F., Ramos, E., Avgerinopoulos, G., & Howells, M. (2017). Model Management Infrastructure (MoManI) Training Manual. *KTH-DESA*, 1–61.
2. AQUASTAT | Land & Water | Food and Agriculture Organization of the United Nations | Land & Water | Food and Agriculture Organization of the United Nations. (n.d.). Retrieved December 7, 2022, from https://www.fao.org/land-water/databases-and-software/aquastat/en/
3. ARIANPOO, N., SINGH, F. P., WRIGHT, A. S., & NIET, T. (2021). *BC Nexus Model*. Retrieved from https://emi-ime.ca/wp-content/uploads/2021/04/EMI-2020-Arianpoo_report_BC-CLEWs.pdf
4. Country, C. (n.d.). *Understanding Modelling Tools for Sustainable Development MODULE: CLEWS COUNTRY MODEL: A READER*.
5. Gardumi, F., Shivakumar, A., Morrison, R., Taliotis, C., Broad, O., Beltramo, A., … Alfstad, T. (2018). From the development of an open-source energy modelling tool to its application and the creation of communities of practice: The example of OSeMOSYS. *Energy Strategy Reviews*, *20*, 209–228. https://doi.org/10.1016/J.ESR.2018.03.005
6. GoN. (2020). *Second Nationally Determined Contribution (NDC) Nepal*. 0–21.
7. Howells, M., Rogner, H., Strachan, N., Heaps, C., Huntington, H., Kypreos, S., … Roehrl, A. (2011). OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development. *Energy Policy*, *39*(10), 5850–5870. https://doi.org/10.1016/J.ENPOL.2011.06.033
8. Johnston, R. B. (2016). Arsenic and the 2030 Agenda for sustainable development. *Arsenic Research and Global Sustainability - Proceedings of the 6th International Congress on Arsenic in the Environment, AS 2016*, 12–14. https://doi.org/10.1201/b20466-7
9. Khan, Z., Linares, P., & García-González, J. (2017). Integrating water and energy models for policy driven applications. A review of contemporary work and recommendations for future developments. *Renewable and Sustainable Energy Reviews*, *67*, 1123–1138. https://doi.org/ 10.1016/J.RSER.2016.08.043
10. Ministry of Finance. (2021). *Economic Survey 2020/21 Government of Nepal Ministry of Finance*. 147. Retrieved from https://www.mof.gov.np/uploads/document/file /1633341980_Economic Survey (Engslish) 2020-21.pdf
11. NPC. (2019). *The Fifteenth Plan (2076/77-2080-81) National Planning Commission , Government of Nepal Kathmandu Nepal*. 1–418. Retrieved from https://npc.gov.np/images/category/ 15th_plan_English_Version.pdf
12. *OSeMOSYS Documentation Release 0.0.1 KTH-dESA*. (2021).
13. Ramos, E. P., Howells, M., Sridharan, V., Engström, R. E., Taliotis, C., Mentis, D., … Rogner, H. (2021). The climate, land, energy, and water systems (CLEWs) framework: a retrospective of activities and advances to 2019. *Environmental Research Letters*, *16*(3), 033003. https://doi.org/10.1088/1748-9326/ABD34F
14. van Vuuren, D. P., Stehfest, E., Gernaat, D. E. H. J., Doelman, J. C., van den Berg, M., Harmsen, M., … Tabeau, A. (2017). Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. *Global Environmental Change*, *42*, 237–250. https://doi.org/10.1016 /J.GLOENVCHA.2016.05.008