Title

Enhancing CLEW Model for Ethiopia: long-term energy analysis and impacts

Authors

Claire Boespflug[a], Francesco Gardumi[a], Pegah Atarian[a], Alexandros Nikas[b]

Affiliations

[a] Division of Energy Systems, KTH Royal Institute of Technology, Brinellvägen 68, 10044 Stockholm, Sweden, cmbo@kth.se; gardumi@kth.se; patarian@kth.se

[b] Energy Policy Unit, National Technical University of Athens, Iroon Politechniou 9, 157 80, Athens, Greece, anikas@epu.ntua.gr

Summary

Ethiopia is highly vulnerable to climate change, while facing considerable energy, food, and water security challenges. Helping design holistically sustainable development strategies, therefore, requires a comprehensive analysis of its Climate-Land-Energy-Water systems (CLEWs) nexus that captures and mitigates the competition among these dimensions. In this research, we investigate the prospects of water, energy, and food security in Ethiopia until 2050 under different development pathways and climate change impacts, by introducing a CLEWs model for the country, putting together a set of scenarios to inform the update of its NDC, and showcasing the opportunities and risks associated with these scenarios.

Extended abstract

Ethiopia is the second-most populated country in Africa. Despite projections indicating continued rapid population growth, paralleled by economic expansion, the country faces many challenges hindering its development. First, despite abundant renewable resources, Ethiopia still relies heavily on traditional biomass use, which has led to extensive deforestation, thereby threatening ecosystem services (Benti et al., 2021). Furthermore, its population's access to fundamental water services remains limited, while the number of food-insecure individuals has risen over time (Tesfaye et al., 2021). Moreover, the scarcity of these essential resources is exacerbated by the significant vulnerability of the country to climate change (Shukla et al., 2021). The increased rainfall variability threatens water, energy, and food security considering most of the farmers rely on rain-fed agriculture and the electricity mix is dominated by hydropower (Mekonnen et al., 2022). Thus, Ethiopia's growing economy and population drive increasing demands for water, food, and energy, whose supply is threatened by climate change. The existing imbalances in these systems require a comprehensive analysis of the Climate-Land-Energy-Water systems (CLEWs) nexus to mitigate heightened competition among resources in future development strategies. This study investigates the prospects of water, energy, and food security in Ethiopia until 2050 under different development pathways and climate change impacts. A CLEWs (Ramos et al., 2022) integrated assessment model (IAM) is thus constructed to assess the interrelated impacts across systems and to analyse the effects of ambitious policies and global warming. This paper intends to introduce this new CLEWs model for Ethiopia as well as present recommendations for the upcoming update of the country's Nationally Determined Contributions (NDC). Moreover, the open-source CLEWs model is to be transferred to local academics and institutions for them to enrich and utilise for robust cross-sectoral policy making.

To represent the CLEWs nexus, the land, energy and water systems are included as technology-rich engineering representations, where a supply chain is constituted of several objects, that convert commodities. In this way, even land covers become processes, taking in water (from precipitation, and potentially irrigation) and delivering evapotranspiration, groundwater recharge, runoff and, for cropland, crops. We call these objects 'technologies' for simplicity. Interactions between energy, land use, water, and climate are incorporated through commodities in an open-access implementation of OSeMOSYS (Howells et al., 2011) for Ethiopia. Examples include water for irrigation, energy for pumping water, fuelwood for energy, and sectoral emissions (see Figure 1). This holistic approach enables to capture synergies and trade-offs across systems in implemented sectoral policy measures, providing valuable insights for policymaking. A thorough literature review has been conducted to formulate informed assumptions to model the CLEW systems and climate change impacts. Future water, energy, and food demands are derived from the literature or projected based on historical trends, population, and GDP growth rates. Concerning food technologies, representations of crops (with rain-fed and irrigated production, and low and high mechanisation competing on the bases of costs and resource availability) and livestock (cattle, goat and poultry) are included, encompassing productivity, emissions, costs, and requirements in land, water, and energy. Similar parameters are implemented to account for the wide range of energy supplies, encompassing forests (for biomass production), fossil fuel imports, and abundant renewables. Water is represented as flowing through the land covers and land use types, and its use is constrained by an overall limit on surface and groundwater withdrawal corresponding to their renewable resources (FAO, 2016). Four scenarios are formulated, including the reference one with all the above-mentioned assumptions and the continuation of current trends, and the NDC scenario introducing the cross-sectoral ambitious policies formulated by the government. These measures encompass reforestation, livestock shift from beef to poultry, improved water access, massive electrification, and energy efficiency measures, to mention a few. Then, the potential effects of climate change (on precipitation, hydropower, and crop yields) are applied to these scenarios to assess their impact.

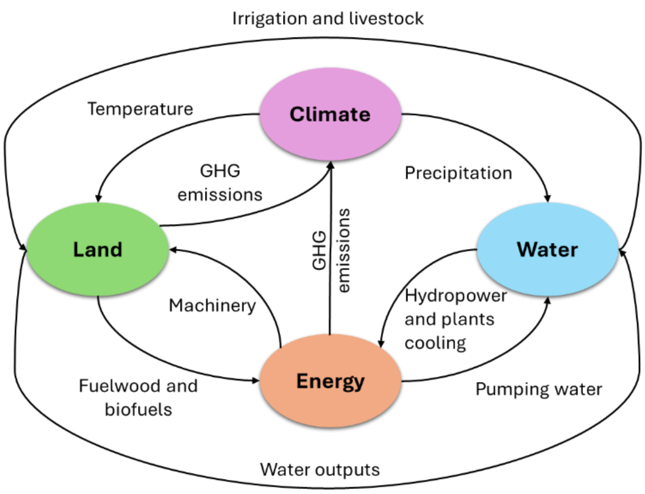

Figure 1 Schematic representation of the CLEW nexus

Our analysis highlights intense land competition in Ethiopia, fuelled by economic development and rising food demand. The low agricultural productivity and cattle-based livestock in the reference scenario would lead to intense deforestation as croplands and grazing land encroach on forests (as illustrated by Figure 2). On the contrary, the NDC scenario's promotion of mechanised irrigated agriculture and livestock shift to poultry would allow pressure on land resources to be alleviated and forests to be expanded (as represented in Figure 2), while boosting the economy. The implementation of ambitious policies showcases the possibility of increasing modern energy and water access and increasing food security while significantly mitigating emissions. According to the model's projections, the 2030 NDC conditional target would indeed be met if the set of policies is applied, facilitated by widespread electrification and a resilient electricity mix that is less reliant on hydropower. This, along with energy efficiency initiatives, could largely drives Ethiopia's sustainable development. Nevertheless, considerable increase in agricultural productivity could strain water security, with irrigation demands nearing renewable limits (as highlighted in Figure 3). Therefore, it is crucial to properly map and manage water resources. The NDC pathway's irrigation-based agriculture could offer resilience to climate change-induced crop-yield losses and, in turn, further land conversion.

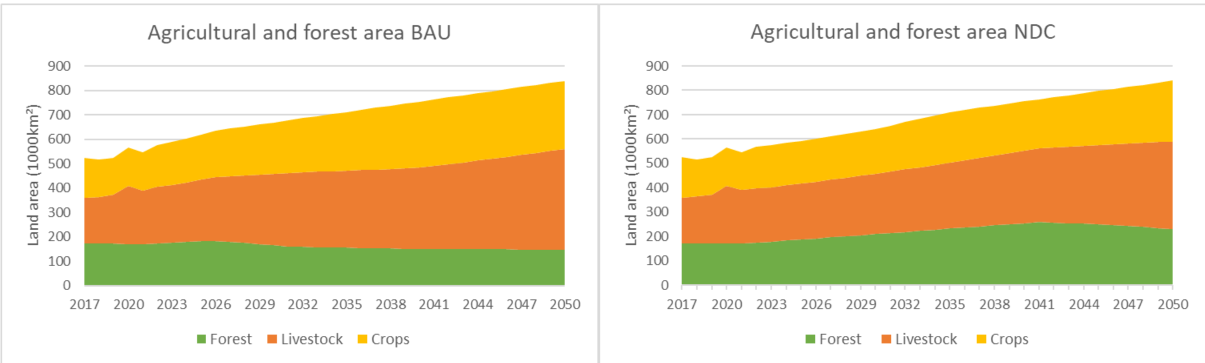

Figure 2 Agricultural and forest area in Business-as-usual (BAU) and Nationally Determined Contribution (NDC) scenarios

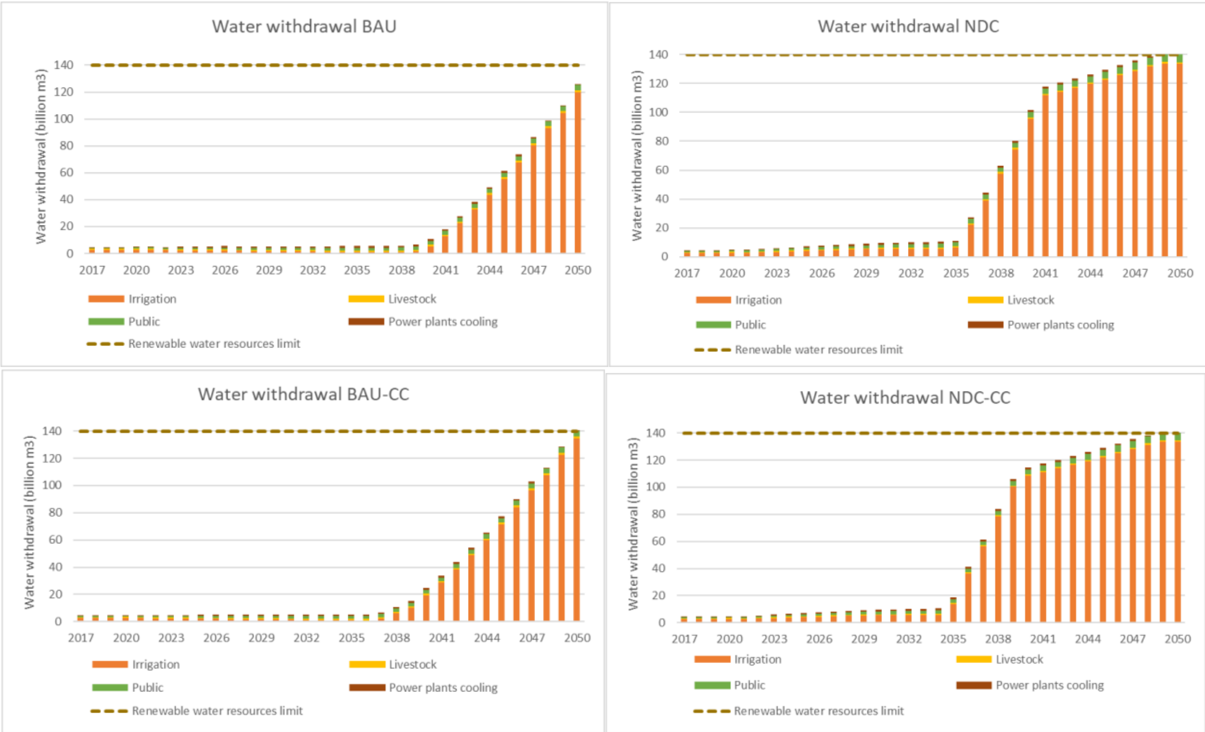

Figure 3 Total water withdrawal by sector in all scenarios[1] (compared to the renewable water resources limit)

In conclusion, meeting future water, energy, and food demands through current practices, in Ethiopia, entails increased irrigation, deforestation, and fossil fuel imports, posing significant GHG emissions risks and ecosystem threats. Implementing the ambitious cross-sectoral measures framed by the government would ensure resilient crop production, enhance access to modern energy, and reverse deforestation, aligning with NDC targets while fostering economic growth. However, addressing water withdrawal nearing renewable limits requires enhanced water management policies, usage monitoring, and groundwater potential mapping.

Key words: CLEWs model, OSeMOSYS, Ethiopia, Energy systems, Nationally Determined Contribution

[1] BAU-CC and NDC-CC respectively refer to the BAU and NDC scenario with climate change impacts considered

References

Benti, N.E., Gurmesa, G.S., Argaw, T., Aneseyee, A.B., Gunta, S., Kassahun, G.B., Aga, G.S., Asfaw, A.A., 2021. The current status, challenges and prospects of using biomass energy in Ethiopia. Biotechnol. Biofuels 14, 209. https://doi.org/10.1186/s13068-021-02060-3

FAO, 2016. AQUASTAT - FAO's Global Information System on Water and Agriculture [WWW Document]. URL https://www.fao.org/aquastat/en/countries-and-basins/country-profiles/country/ETH (accessed 2.9.24).

Howells, M., Rogner, Strachan, 2011. OSeMOSYS: the open source energy modeling system: an introduction to its ethos, structure and development.

Mekonnen, T.W., Teferi, S.T., Kebede, F.S., Anandarajah, G., 2022. Assessment of Impacts of Climate Change on Hydropower-Dominated Power System—The Case of Ethiopia. Appl. Sci. 12, 1954. https://doi.org/10.3390/app12041954

Ramos, E.P., Sridharan, V., Alfstad, T., Niet, T., Shivakumar, A., Howells, M.I., Rogner, H., Gardumi, F., 2022. Climate, Land, Energy and Water systems interactions – From key concepts to model implementation with OSeMOSYS. Environ. Sci. Policy 136, 696–716. https://doi.org/10.1016/j.envsci.2022.07.007

Shukla, R., Gleixner, S., Yalew, A.W., Schauberger, B., Sietz, D., Gornott, C., 2021. Dynamic vulnerability of smallholder agricultural systems in the face of climate change for Ethiopia. Environ. Res. Lett. 16. https://doi.org/10.1088/1748-9326/abdb5c

Tesfaye, M., Moges, S., Melesse, A.M., Agide, Z., 2021. Long-term water–energy–food security and resources sustainability: a case study of Ethiopia by 2030 and 2050. Int. J. Energy Water Resour. 5, 343–356. https://doi.org/10.1007/s42108-021-00119-3

Acknowledgements

This work was supported by the Horizon Europe Project "IAM COMPACT", under Grant Agreement No. 101056306. The sole responsibility for the content of this paper lies with the authors; the paper does not necessarily reflect the opinions of the European Commission.