Maximizing Water–Food–Energy Nexus Synergies at Basin Scale

Rogier E. A. Burger and Edo Abraham

Abstract

In this short paper, we show how solutions for mitigating resource security in one sector can be found in another. We demonstrate—by means of a case study in Burkina Faso and Ghana—how investing in the electricity grid in the south leads to increase food security in the north. A new nexus framework was developed ('MAXUS') which was built to understand, simulate and optimize intersectoral (and international) development strategies in the water, food and energy sectors. We believe this new type of geospatial integral resource management, supported by the exponential increase of data availability of the twenty-first century, could finally turn nexus models into decision support tools.

Keywords

Nexus optimization framework • Bottom-up approach • Integrated resource management • Remote sensing

1 Introduction

Population growth, meat-focused diets and emerging industries are increasing stress on water, energy and food (hereafter, WEF) supply around the globe. As stress on the resources rises, the interdependencies between the sectors become more apparent and often lead to unforeseen chain reactions. An example of which is a drought leads to reduced hydropower generation that leaves groundwater pumps inoperable, which in turn leads to disappointing harvests (CERC 2012).

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Because of these and many non-trivial/hidden interdependencies, synergizing water, food and energy policy is no easy task. Millions are spent to build reservoirs, food storage facilities, roads, canals, irrigated fields, electricity grids, energy production facilities, etc. These infrastructures are key to improve WEF security around the globe. With the strong connection of the WEF resources, infrastructure built in one sector impacts the others. With an unclear idea of this impact, newly built infrastructure may turn out to be ineffective and sometimes even harmful to other sectors. Especially, when the infrastructure of multiple sectors is developed in parallel, it is difficult to have a good understanding of the final outcome without an integrated analysis.

The need to obtain an integrated framework for policies and infrastructure design is now globally advocated (Asian Development Bank 2013; FAO 2014; Hoff 2011; UN 2014). As a result, several nexus models were developed but they have several uncertainties. The main critique of these models so far has been that many cannot serve as a decision support tool because they lack the ability to investigate specific governance actions or the implementation of technical interventions. These models generally have intensive data requirements and not flexible enough to perform for nexus studies at different scales with the same model framework (Bazilian et al. 2011; Kaddoura and El Khatib 2017; Dai et al. 2018).

In this paper, we propose a new optimization model framework for nexus studies titled 'MAXUS' (Burger 2018). It was built to fill the gap where current models fall short. It was built to customize a model for a specific nexus study. To test the methodology of MAXUS, it was applied to a case study for Ghana and Burkina Faso. Allocation of water and

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land resources for the final supply of WEF was optimized over space and time.

2 Materials and Methods

Considering the wide range of nexus issues, which may have different scales in space and time and have different data availability, flexibility of a nexus model framework, is indispensable. The challenge with nexus issues is succinctly captured by Bazilian et al. (2011, p. 5): “to draw system boundaries wide enough to encompass the enormity of the interacting vectors, while maintaining it small enough to be able to conduct useful analysis.”

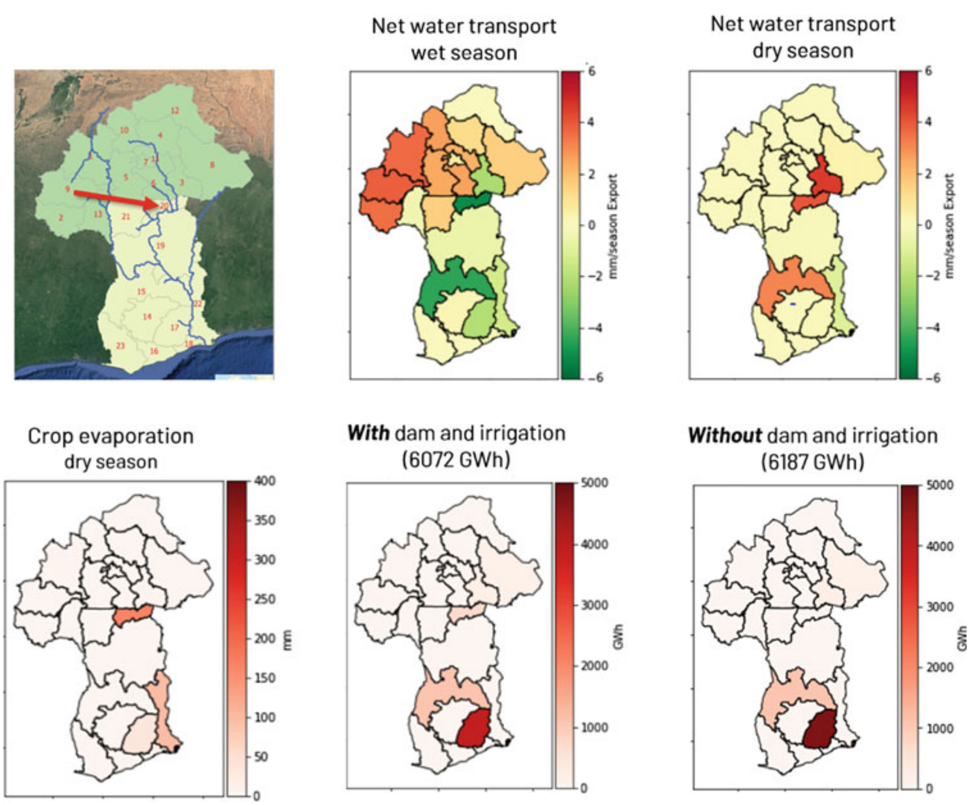
To make sure that important interactions are captured for the nexus study at stake, a systematic methodology is required. In MAXUS, we used a bottom-up approach to define the objective, balances, interactions, constraints, dimensions and decision variables for a given nexus study.

A case study was developed for Burkina Faso and Ghana in which the approach was applied. Economic cost minimization was set as an objective while satisfying given water, food and energy demands of both countries. First, the nexus optimization was performed to explore the benefits of a multipurpose dam proposed in Ghana, then, to explore possible locations for additional irrigation and reservoir capacity. Both these cases highlight how a nexus analysis can be used for infrastructure development.

3 Results and Discussion

In Ghana, plans have been made for the construction of a multipurpose dam, near Pwalugu (Volta River Authority 2014), of which the location is shown by the red arrow. It will be developed to serve for hydropower, as well as irrigation. To investigate the benefits of such construction, the proposed extra water storage and irrigation capacities are added (by changing constraints) to the region in the MAXUS model. An optimization is solved for this new infrastructure. In this optimization, the water, food and energy demand is to be satisfied under minimal costs. Decision variables are food production, transport and storage, import and export; water transport, storage and irrigation; electricity transport, import and thermal power production.

In the figure, we show how the new dam is used to store water coming from the northern regions in the wet season and to discharge in the dry season. Part of the discharged water is used for irrigation in the region itself. With land being cropped, water is also being evaporated. Because of a significant change in crop evaporation, the total hydropower production has decreased, even though additional hydropower capacity was installed. Still, which is remarkable, less thermal power was required to be generated. Because of the relocation of hydropower generation, from south to north, transmission losses could be reduced, and consequently, more net energy is left. The power now produced is closer to the demand.

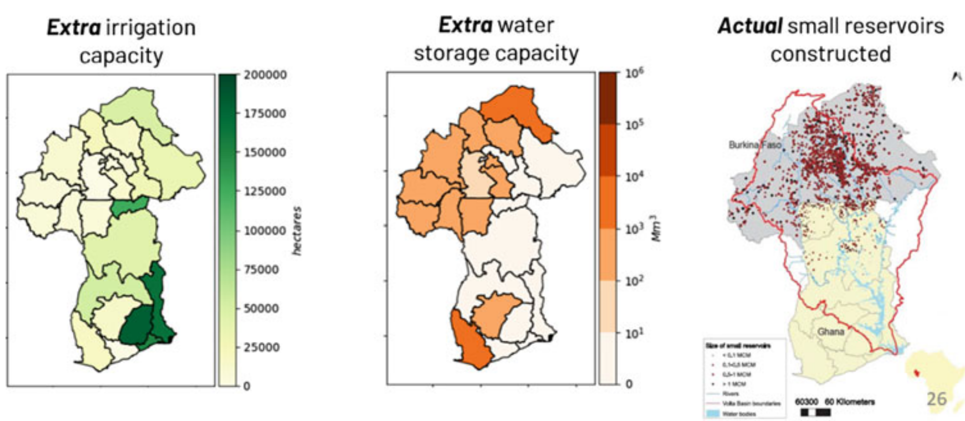


If the impact of infrastructure expansion can be determined for the optimization by the model, a new question arises: where (and when) is infrastructure worth the investment? To answer that, a new strategy is adopted. By making infrastructure expansion part of the optimization problem, MAXUS determines where infrastructure is beneficial against a certain cost.

The results show that two regions become for the larger part equipped with irrigation capacity. The region of the capital of Ghana and the region for new plans are proposed. This is no coincidence. Both regions are just downstream of a hydropower dam and therefore water storage. In the capital region, water has benefitted from all possible hydropower production before it is used for irrigation purposes and in addition is close to a large centre of food consumption—the capital Accra. The region where the dam is proposed is home to a large river junction, located relatively close to Ouagadougou the capital of Burkina Faso, another node of large demand. This region becomes key in supplying the north. Storage is built mostly in the northern areas. Here, there is relatively little storage capacity and building it provides essential water resources for irrigation. Besides storing water here means that it can always be used for hydropower on a later stage. IWMI (2012) reports that this is actually the place where a large number of reservoirs have been constructed in the last decades.

4 Conclusion

By using a newly developed optimization framework, we have shown how dependencies of WEF infrastructure can be found and taken into account for infrastructure planning. In an example, we showed that MAXUS is able to find non-trivial, multisectoral spatial (and temporal) trade-offs for the construction of a dam. We demonstrated in another example how strategic locations for irrigation capacity and water storage can be derived even though they would affect one another and the WEF sectors. The MAXUS model framework can be applied to a wide range of nexus studies; allowing adaptation objective functions, balances, decision variables, constraints and dimensions. It is scalable in time and space and therefore also has a flexible data input structure as to respond to different data availabilities worldwide. With the potential growth of geospatial and material flow data availability in the coming years, with the aid of remote sensing and new data management tools like block chain (Kshetri 2017), we believe that integrated nexus optimization models could be the foundation to provide decision support at basin/country level.



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