

Response to Reviewer 2

S.P.K. Bowring, L.M. Miller, L. Ganzeveld, and A. Kleidon

We thank Reviewer 2 for their overall support of our submitted manuscript. Below is our response for this review.

The main motivation of this manuscript was to conceptually show how the Energy-Return-on-Investment (EROI) metric can be applied to a large-scale human intervention in the Earth System. Here we have applied it to the particular scenario of desert greening, because previous research on the stability of a green Sahara suggests that it would not be maintained in a steady-state by *natural* means (cf. Claussen et al. (1999)). Therefore, here we ask if the green state could be sustained 'unnaturally' using technological means. As this would involve a continual energy input, we use Energy-Return-on-Investment (EROI) to benchmark the energetic sustainability of this process. This question is of interest because although several researchers have investigated desert greening using regional/global modeling and site-scale experimental approaches, no attempt has been made to determine their energetic 'rationality', and thus whether such proposals are feasible from this energetic perspective. More broadly, the study also:

1. Shows how large-scale global feedback mechanisms can be incorporated into the EROI budget, which has not to our knowledge been previously explored;
2. Demonstrates that this is both possible and useful in the context of human interventions in said systems and mechanisms;
3. Applies it to a human intervention that has been actively proposed.

The purpose of re-iterating this motivation is the Reviewer's opinion that:

"The objectives of the paper are not clearly stated therefore it is difficult to judge whether they are achieved and whether appropriate methods are used."

We agree that the objectives of this paper were not made sufficiently clear at the outset, which we have addressed by modifications to the Title, Abstract, Introduction and Discussion sections of the paper. Our main objective can be clarified by changing the title to: **Quantifying the Applying the Concept of 'Energy-Return-On-Investment' of to Desert Greening of the Sahara/Sahel Using a Global Climate Model".**

Reviewer 2 makes an good point that we could have conducted
"small-scale irrigation experiments in the places where the authors found high EROI."

We fully agree that this would be fundamental to the practical investigation of optimally locating realistically-sized plots in which to undertake desert greening. However, our decision not to do so is based on the objectives of the paper, as above. Additionally, while certainly of interest to the authors, successfully identifying small scale plots involves order-of-magnitude increases in model runs than those needed to answer our objectives. This is because, as the Reviewer correctly notes,

"it is not evident... that the small-scale irrigation will have similar EROI magnitude and geography because of a much weaker surface-atmosphere system feedback."

We have included these helpful comments as modifications to the revised manuscript, to which we have added: *"While these results hold for the large-scale scenario used here, we stress that isolated irrigation of the high-EROI areas identified by our experiment is unlikely to produce the same absolute or relative (to other grid cells') EROI values. This is because the precipitation feedbacks involving irrigation and subsequent surface-atmosphere interactions depend strongly on the scale at which these processes are resolved by the applied model system. In other words, the spatial variance in EROI in our results are specific to the large-scale nature of our experiment. Further investigation would be required to identify high-EROI grid cells that are relatively independent of irrigation scale; this would require a far greater array of experimental runs to determine than the number employed here."*

Reviewer 2 also states that, *"Too much attention is paid to EROI"* and suggests either deleting large parts of the description from the manuscript or moving it to an appendix. We did look at optimizing the EROI-related text

on p.720-721, but in combination with the comments regarding clarification of EROI_A/B/C by Reviewer 1, we are strongly suggesting that this descriptive text remain in the revised manuscript.

Reviewer 2 did identify a shortcoming of the submitted manuscript, as we need to more clearly identify the Sahara/Sahel irrigated region on all related maps. As shown below, both Figure 3 and Figure 4 were revised.

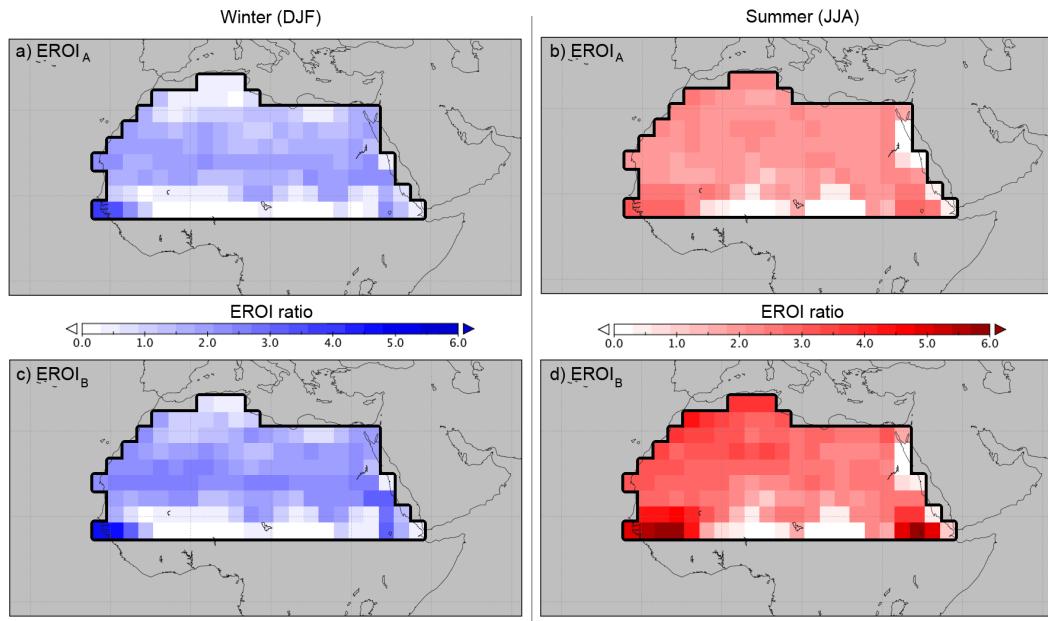


Figure 3: Seasonal mean EROI_A (**a,b**) and EROI_B (**c,d**) over the irrigated region in December, January, February (DJF) (**a,c**) and June, July, August (JJA) (**b,d**). Winter values are taken from the 700mm yr^{-1} simulations, while summer values are taken from the 1000mm yr^{-1} simulations. The black solid line shows the outer bounds of the irrigated region.

EROI_C was also noted as not clearly explained. This is partially addressed by rearranging the "Viewed specifically from..." paragraph on p.733 for clarity and including the following sentence within that revised paragraph: "Because radiative forcing is given in units of W m^{-2} , and the reductions entailed by greening would need to be converted to energy (in Joules), some

multiplier representative of the mean energy required to otherwise reduce one unit of radiative forcing could allow this factor to meaningfully enter EROI calculation.”

Other necessary small changes noted by the reviewer such as misspellings or inconsistent units will be addressed in the final revised manuscript.

The authors thank the Reviewer once more for their substantial contribution to the revised manuscript.

References

Claussen, M., C. Kubatzki, V. Brovkin, A. Ganopolski, P. Hoelzmann and H.J. Pachur, (1999), Simulation of an abrupt change in Saharan vegetation in the Mid-Holocene, *Geophysical Research Letters*, **26** pp. 2037-2040.

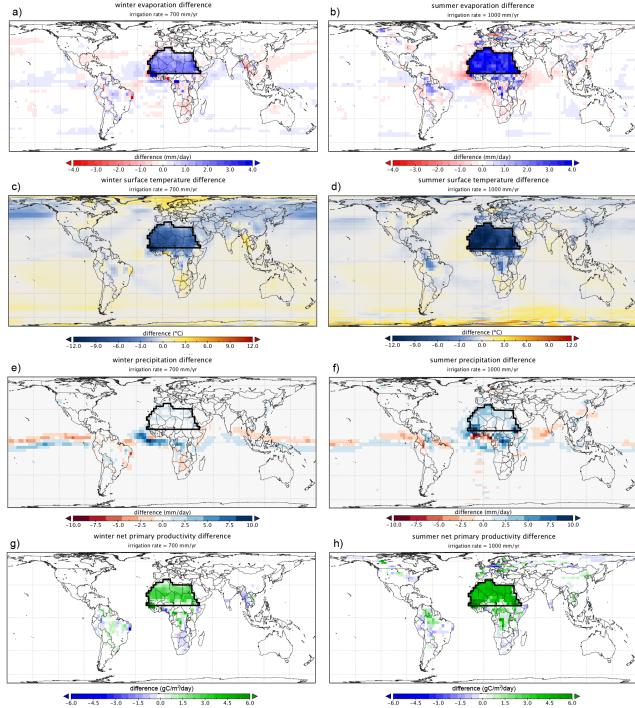


Figure 4: Differences in evaporation (a,b), surface temperature (c,d), precipitation (e,f), and net primary productivity, or NPP (g,h) during and winter (left) and summer (right); *winter* compares the 700 mm/yr and control simulations for Dec. - Feb., while *summer* compares the 1000 mm/yr and control simulations for June - Aug., with the black solid line bounding the Sahara/Sahel identifying the irrigated region. Note the significant differences in both variables in regions outside the irrigated region, particularly in Southern Africa, Southern Europe and Northern Latin America. The corresponding southward shift in the inter-tropical convergence zone (ITCZ) is clearly visible in both winter (e) and summer (f).