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Interactive comment

Interactive comment on "Global scenarios of irrigation water use for bioenergy production: a systematic review" *by* Fabian Stenzel et al.

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Stenzel F, Gerten D, Hanasaki N (2020) Global scenarios of irrigation water use for bioenergy production: a systematic review. Hydrology and Earth System Sciences

General comments This paper provides a synthesis of 16 global overview studies of potential future blue water use of a widespread bioenergy industry, including some consideration of industrial processing water use, and reference to associated green water use of bioenergy plantations. The review is based on relatively few studies, and the treatment of underlying drivers of geographic variation in water availability, bioenergy water use, and productivity is not very detailed compared to previous studies. Limitations of available data and underlying assumptions are noted, but not explored in depth.

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The important concept of water use efficiency (unit bioenergy produced per unit water used) forms the basis of some of the underlying calculations, but its use as a unifying central concept that can be integrated across scales to enhance the sustainability of a bioenergy industry is not explored as much as it could be. Although the synthesis of potential blue water demand in the context of other human water needs is very useful, the perspective of the review at times appears to be that of advocating for irrigation of bioenergy plantations without due consideration of economic or environmental sustainability (this is clearly not the intent of the authors, but the writing makes it appear so), and thus needs major revision, especially in the Introduction and Discussion, as noted below in specific comments.

Specific comments Abstract P1 L2: The meaning of the phrase “final energy production” is ambiguous and should be defined. P1 L9: Remove parentheses and change to “for agricultural, industrial, domestic and other water withdrawals”. In general, limit the use of parenthetical phrases embedded in sentences, which there appear to be a lot of. P1 L14: The concept of bioenergy water use efficiency should be added to the list, as it can be used as a means to match appropriate crop species to regional climates, potentially decreasing blue water demand. It can also be considered a trait targeted in crop improvement programs (e.g. through traditional breeding or genetic modification) with the objective of decreasing crop water use, and thus the need for irrigation.

Introduction P2 L26: It is argued that bioenergy feedstocks “will probably have to be grown on large managed plantations and include substantial irrigation”. Rather than accept that as a fait accompli, an efficient society would figure out how to sustainably produce bioenergy as part of a broader renewable energy portfolio that is “climatically-competent” and sustainable. If irrigation is used for energy production, it should only be done in areas that have rates of groundwater recharge high enough to offset removals, otherwise you are “borrowing” (some would say stealing) from the future. Solar energy should be produced where there is abundant incident radiation, but otherwise unfavorable for plants or other uses (barren lands, rooftops, etc.). In the same way that wave

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energy will be produced in coastal areas, wind energy where there is abundant wind resources, hydropower where there is abundant surface water, bioenergy should be produced in regions of the globe where it is climatically "indicated", but without competing with food production. That is why it is so important to develop energy crops that have low water demand, are resilient to environmental stress (like drought), and are as water-efficient as possible. Further, the water balance of all crops grown for bioenergy (and food) should be quantified and considered in the context of the local climate (e.g. precipitation, evapotranspiration, surface/subsurface runoff, and groundwater recharge). In that context, regionally-appropriate crops can be selected, and their water-use efficiency improved through breeding programs or other means. P2 L29: King et al. (2013) provide a comprehensive review of green water use of major herbaceous and woody candidate bioenergy species, and should be cited here. P2 L39: With looming freshwater shortages already occurring in many parts of the world, is it defensible to suggest irrigation be used to sustain high-productivity bioenergy farming? I understand that quantifying the potential blue water demand of a widespread bioenergy industry in the context of other uses is the premise of the current paper, and therefore warranted, but in this reviewer's opinion that should be considered an absolute last resort, and preferably, society will design bioenergy production systems that are climatically robust and environmentally sustainable, and therefore based mostly on green water. In addition, any discussion of irrigating bioenergy crops should consider the economic aspects. Irrigation is expensive and economically-justified for high-value food crops (sometimes), but it is generally not used in forestry, even for high-value saw timber products, so would it hold up for a low marginal value commodity such as energy? It might require economic incentives such as carbon credits/trading in order for bioenergy irrigation to become economically competitive with other energy sources, for example. The Introduction would be improved by placing the current study in the broader context of environmental and economic sustainability. P3 L43: This is a good point, and certainly I agree that all bioenergy field experiments should report the water balance of the systems studied, including precipitation, ET, runoff/drainage/groundwater recharge, and irrigation. P3 L52 to L62: The authors appear to be discussing bioenergy water use at two different scales, which if articulated a little more clearly would be useful in advancing the current discussion, and ultimately development of a sustainable bioenergy industry. The first scale is that of total water use of individual bioenergy production systems at the ecosystem scale (e.g. m3 water per hectare per year), which can be broken into green and blue components, and is affected by crop productivity, management, inter-annual variation in weather, long-term climate change, etc. The second scale is the integration of water use of all the individual bioenergy systems present across the landscape to local, regional, and ultimately global scales (e.g. km3 globally per year) to give the overall blue water requirement in the context of the current review paper. The nomenclature adopted in this paragraph, and therefore concepts expressed throughout paper, relating to “water withdrawals”, “water demand”, “water consumption”, and “water requirements”, although explicitly attempting to be clarified by the authors, still confounds the spatiotemporal scaling aspect, and thus needs a bit more refinement. P3 L65 to L70: How do these questions advance the science beyond the previous global syntheses upon which this study is based (e.g. Berndes 2002, Beringer et al. 2011, Gerbens-Leenes et al. 2012, etc.)? There are many excellent sources on blue and green water aspects of bioenergy providing the foundation of the current study (Table A1), and their synthesis is certainly an important contribution, but the writing of the Introduction and the wording of these questions do not highlight (very well, in my opinion), what new is being contributed here. I’m sure it is there and I will discover it upon reading the rest of the paper, but so far it seems mostly repetition of previous work. P3 L72 to L80: So here it is, there have been previous assessments of green and blue water requirements of a potential widespread bioenergy industry, but there is large variation in the estimates and insufficient analysis of underlying sources of variation and assumptions, that need to be standardized. This could be the first statement of the Introduction, followed by an analysis of the relevant literature to substantiate the point. Without supporting their argument, it is stated that local or regional studies cannot be straightforwardly up-scaled or compared to global studies.

In the age of rapidly advancing process-based ecosystem-landscape-global modeling, remote sensing and increasingly powerful geospatial analytics, paired with well-tested methodology for ground-based ecosystem studies that can fully close bioenergy crop water budgets, this statement seems anachronistic. It seems then, that the main contribution of the current work could be to illustrate how such global scale syntheses can be standardized in data requirements/formats, analytical framework, scopes of inference, supporting assumptions, and reconciliation across spatio-temporal scales. If this is in fact the intention of the authors, then the Introduction needs a major rewriting to clearly make the case.

Methods P4 L86: Remove second comma. P5 Figure 2: This figure is unnecessary. The information is stated in a preceding line of text, and is in the body of Table A1. Suggest replacing Figure 2 with table A1 in the body of the text. P5 L95: Remove comma. P5 L98: The degree of assumed bioenergy deployed may vary greatly among sources, but can be presented as a range, with accompanying discussion of the reasons for the variation and implications. That is typical for such overview review studies. P5 L99: The amount of biomass harvested for bioenergy divided into the water used (ET) to grow it on a unit-area of land is termed "bioenergy water use efficiency" (at the farm gate), and was introduced for a variety of prominent woody and herbaceous candidate crop species by King et al. (2013). The values given in King et al. (2013) are based on measured productivity and site specific meteorological data (calculated PET or measured ET), which could inform this discussion up to L119 of the current study, and at the least should be cited here (at least for aspects that do not include industrial water use). The current study nicely and logically extends the water use efficiency concept to larger spatiotemporal scale (km3 GtC-1), illustrating its utility as a scaling factor in addition to my earlier comments on its use to increase environmental resilience and bioenergy production efficiency at the farm gate. (Incidentally, water use efficiency is a central concept in plant physiology used to describe the efficiency of C uptake relative to transpirational water loss at the leaf level (umol CO2 mmol water m-2 leaf area s-1), which was scaled in King et al. (2013) to compare the water efficiency of different bioenergy crops at the ecosystem level, and is used here to scale industrial water use to the global level. Water use efficiency is thus a unifying concept of central relevance, warranting more explicit discussion.

Results and Discussion P6 L127: The term “freshwater abstractions” is ambiguous and undefined. Please define what you mean here. P6 L129 to L137: This paragraph argues that the current study is only based on 16 previous synthesis studies of blue water use of bioenergy plantations because that is all that is available in the literature. It is recognized that most reports of water use of BPs do not include estimates of ET or green water use. I agree with this perspective, however, I think the paragraph (and paper) would have more impact if it took the point of view of arguing for a more comprehensive quantification of water use of bioenergy systems, rather than seeming to advocate for irrigation. I know it is not the intent to argue for irrigation of BPs, but in justifying the current analysis it gives that impression. It should be an objective of future, and to the extent possible, past bioenergy studies, to be placed in the context of full water balance quantification, partitioning sources into green and blue pathways, and identifying potential means of increasing water use efficiency and decreasing blue water demands. In that context, the current discussion can present the potential blue water use of BPs compared to other human water demand based on current knowledge. Blue and green water use are comparable, we just don’t have the needed data to do so, which should be an argument forwarded for here. P7 L139 to L183: This is useful discussion of the modeling frameworks of the various studies comprising the data base for the current study, and the advantages of broad scale modeling (such as ESMs) compared to more detailed, process-based or empirical approaches. As an empiricist, I think there is value to a joint-approach using broad scale assessments in tandem with parameterizations and validations based on finer scale process understanding. P9 L207: Change “is varying a lot” to “varies widely”. P9 L215: Great gains have been made in tree productivity for species such as Pinus taeda, Pinus radiata, Eucalyptus spp, etc., in breeding programs targeted at timber production, and there is great potential and need to do this for bioenergy crops, especially for the traits of productivity and water use (efficiency). This should not be discussed as something that is not possible, but rather there is great potential for that has not yet been realized. P9 L222: Awkward sentence structure. P11 Fig 4: Change "inlets" to "inlays" in legend. P12 L286: "table" is misspelled. P13 L293: Change "no more" to "no longer". P13 L294: Change "increase" to "increases". P13 L303: Delete "of". P13 L307 to L317: This discussion of potentially increasing human water withdrawals by 50 % to irrigate BPs in the face of (increasing) significant human water stressed populations highlights my earlier point of economics and the role of bioenergy in a broader renewable energy portfolio. As the demand for water in other sectors increases, its price will rise, making it less likely to be used to produce a low marginal value commodity like energy. Rather, market forces will direct water use towards food production or other, while energy is produced more cheaply elsewhere. If climate change decreases productivity potential of the land significantly, as predicted (e.g. Beringer et al. 2011), this becomes all the more dire. Partitioning source-studies into "demand", "withdrawal", and other studies in this context (e.g. Fig. 4) was very useful, resulting in widely varying trajectories, that perhaps could be explored a bit more in the discussion in terms of drawing inferences regarding future water availability and use in bioenergy plantations.

Conclusions P13 L322: I did not feel a wide range of parameters were discovered and explored in the current paper, rather just the primary ones mentioned here. P14 L325: Insert "future human water use" or similar descriptor before "publications". P14 L326: As I said earlier, I would also suggest for field studies of including: meteorological conditions of study sites and water availability around the globe or relevant areas, water use and productivity of the bioenergy crops investigated, and the complete water balance of bioenergy production systems, including partitioning of blue and green water sources. To the extent possible, blue water demand should be decreased as much as possible by careful selection of climatically favorable areas, selection of water efficient species/genotypes, and improvement of water use efficiency through breeding programs and development of "smart" irrigation technologies. These topics are beyond the scope of the current paper, but the reader could be pointed in the right direction with

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a few key citations. P14 L335 to L347: Here the impact of widespread bioenergy farming on biodiversity, economic feasibility, other land uses, etc., are finally considered, which seems too little-too late in the paper. I would discuss these broader aspects up front in the Introduction, acknowledging their importance but justifying why they are not the subject of the current paper, then you can focus on estimating the potential future bioenergy blue water demand scenarios based on current knowledge, identifying areas that limit understanding that should be the focus of future research. P14 L340: I would add the qualifier "assuming it is economically justifiable" or similar after "irrigation".

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