Final author comments on "Water footprints of cities – indicators for sustainable consumption and production" by H. Hoff et al.

Introductory comments:

We are grateful for the careful reviews of our manuscript and will revise the manuscript accordingly.

In particular we will add a figure to the main text, which illustrates the calculations performed and the information flow. These will also be explained in detail in a supplement.

However we caution that the full grid cell results (yields and green and blue water virtual water contents for 19 crops and 5 years) comprise 7200 files with a total of 350 Gbyte. So we suggest to limit the publication of results to the respective net water fluxes per grid cell and international trade matrices per crop (about 300 Mbyte).

In response to all reviewers comments we would like to clarify that our analysis focuses on primary commodities, NOT on processed commodities (e.g. cotton and sugarcane mentioned below are primarily traded as processed commodities). Based on that limitation, we eliminate re-exports to the extent possible. Different from other studies, this method does not claim to completely cover all food-related flows of virtual water, but it requires fewer assumptions about the multiple processing steps in multiple locations.

Short comment by D. Vanham

GENERAL COMMENTS

The scientific contribution of this paper is significant and the topic relevant for HESS. In general the paper is well written and structured. The assessment of more regional Water Footprints (WF), in this case 3 cities, is definitely a necessity in WF analyses. The authors indicate that a "true WF", which incorporates a WF sustainability assessment, is needed. Also other indicators need to be included. This is also very true, especially to define integrated policy options, e.g. for the EU (Vanham and Bidoglio, 2013).

A major comment is that the methodology is not clearly enough described.

> *We will provide a detailed description of the methodology as a supplement (see our introductory comments)*

As I understand A WF of production was calculated as well as virtual water flows based on COMTRADE trade data. What is not clear, is whether a WF of consumption was calcu- lated?

> *We did this only in the sense of per-capita consumption of the 19 crops / primary commodities considered (see our introductory comments). We did not calculate fully consumption-based footprints, which would require input/output type analyses (see section 5.4). We will clarify this in the revision.*

The authors indicate that based upon production and local demands within grid cells, potential export grid cells are identified. In my opinion the Section "Methodology" should be adapted in order to answer some essential questions:

* What is defined as local demand and how is it quantified? Does local demand include livestock production/consumption? A list of 19 major crops is modeled, but no animal products. If I look at final results, e.g. soy in Berlin has a WF of about 120 m3/cap/yr which equals 329 lcd. This value is about the same as wheat in Berlin. As this value is so high, it includes soy for feed. I presume then the consumption of these crops incorporates the consumption of feed for livestock products?

> *Indeed, soy (which is primarily used as livestock feed and only to a minor extent for other food purposes) has been included in the analysis. This will be mentioned in the detailed methods description.*

How is this handled at grid level, e.g. in agricultural regions where livestock is produced? What is there identified as local demand?

> *We did not separate food and feed use of crops, as will be clarified in the revision.*

* What are the databases used? I only see the COMTRADE database was used for trade data. Where FAOSTAT data used for production data? Which database was used for consumption data?

> *We will be more precise in the revised paper in terms of the data used: production was modeled by GCWM (based on Portmann et al), and consumption was derived combining trade, production and population data*

* Why are 2 models used - GCWM and LPJmL? Is it not possible to use only one? When not why not? Doesn't LPJmL compute all necessary data?

> *LPJmL has lower resolution (not useful for cities) and lacks coffee/cocoa. But it provides water availabilities, which are not available from GCWM. Hence we combined results from the two models. We will provide this justification.*

When the 2 models need to be used, was there a comparison made of the results of the 2 models (when some components are modeled double)?

> *We have made comparisons, but they would expand the paper significantly without adding new information to the main storyline and may be used in another publication.*

* The assumptions listed page 2606 lines 1-6 off course limit the regional assessment strongly, as acknowledged by the authors, also in the Section "conclusions" on page 2620 line 22 upto page 2621 line 5. But these assumptions are justified. Even within cities there can be differences in consumption between "richer" and "poorer" districts. Data on this are lacking. Basically in their assessment national consumption data are spatially distributed

over population rasters.

Thank you for this comment.

* I recommend strongly to additionally present a figure with a flowchart/workflow of the methodology for clarity reasons.

We will include a flow chart in the main section and a better description of the methods as a supplement.

SPECIFIC COMMENTS:

* The choice of Delhi for India (page 2604 line 24) was maybe not the best as case study for a newly industrialized country, as India is unique because it comes from a very long (religious) tradition in being primary vegetarian. In most other newly industrialized country this is not the case. However, the analysis of Delhi is interesting anyway.

We will acknowledge that fact, but changing the studied city will not be possible as this would involve comprehensive changes to the analysis.

* Page 2607 lines 1-11: This section is somewhat arguable, as the WF of imported coffee not always equals the WF of exported coffee. In many European countries the coffee is e.g. roasted locally, contributing to a slightly higher WF of production. The constribution will however be very small.

This is correct and will be mention in the revised version of the paper. However, including the post-harvest processing chain in the analysis would go beyond the scope of this paper. It would.require input/output type analyses for thoroughly capturing these effects – as mentioned in section 5.4.

* Page 2067 line 24: "Of that, 40% ....". This means only a treshold value was used, and not environemntal flows. Can a reference be given for this 40%.

We will provide a reference (Gerten et al 2011) and modify the text to acknowledge that this is a rough global average value. The 40% is a rough way of accounting for environmental flows and the spatio-temporal mismatches of water availability and demand.

* Page 2608 lines 10-23: If I look at figure 1, I see strong similarities for the EU with a recently published study (Vanham, 2013a). The industrialized and densely populated belt from the UK to Northern Italy is characterized by net VW imports, whereas other agricultural regions in Europe are characterized by net VW exports. This could be shortly stated in the manuscript.

Thanks for pointing to this publication, which we will cite and discuss relative to our paper.

* Page 2619: The authors list a few times for Berlin "The WF of luxurious diets ...". A reference should be given why this is a luxurious diet.

Sure. Reasons are the high livestock product fraction (here only represented by soy imports for livestock feed) and the high consumption of stimulants (also called "luxury foods").

* Recently work on the influence of diets on the WF of nations/regions was published, and should be referenced to in the literature overview in the introduction: e.g. Vanham (2013b) and Vanham et Al. (2013).

We will do that.

LITERATURE

Vanham, D. (2013a) An assessment of the virtual water balance for agricul- tural products in EU river basins, Water Resources and Industry, In Press, http://dx.doi.org/10.1016/j.wri.2013.03.002

Vanham, D. (2013) The water footprint of Austria for different diets. Water Science and Technology, 67(4), 824-830. http://dx.doi.org/10.2166/wst.2012.623

Vanham, D., and Bidoglio, G. (2013) A review on the indicator water footprint for the EU28, Ecological Indicators, 26, 61-75. http://dx.doi.org/10.1016/j.ecolind.2012.10.021

Vanham et Al. (2013) The water footprint of the EU for different diets" Ecological Indi- cators, 32, 1-8. http://dx.doi.org/10.1016/j.ecolind.2013.02.020

Referee 1 S. Pfister

This paper is a very interesting contribution to the topic of water footprinting. It provides a very good overview of current issues and enhances the analysis by applying a high spatial resolution trade model, that allows analysis of virtual water trade beyond country resolution.

A major shortcoming is the lack of providing detailed results in a format that allows reproducing the results and using them for further research. This concerns mainly the trade model, which is very vaguely described as well as the data in figures 1a-c. The figures are appropriate for illustrating the results but insufficient for further research. The main request is therefore to publish (as supplement) the grid cell results of the
trade for the evaluated crops (individually if possible) as well as the trade balances that have been derived from COMTRADE. This is the minimal requirement for transparency in my point of view. Furthermore providing detail results is essential for enhancing further research in this direction.

> *Thanks for pointing this out. We will strongly improve and extend the description of the methodology, including the models used. Also, we will present some data / results in greater detail (see our introductory comment)*

Another general comment is that uncertainties of the results are completely neglected. Quantitative assessment might be a major issue and beyond the scope of this study but still it should be addressed qualitatively. Since supplementary files are necessary, this might also be examined outside the main paper and just summarized.

> *Right, we will discuss the major uncertainties of our analysis. Some are already mentioned in the text.*

Generally, the paper might be condensed a bit in the discussion and conclusion part where some redundancy occurs.

> *We will do that.*

Detailed comments: Page 2605 lines 20ff: The selected crops cover a large share of global production. However, other major crops such as sugar cane and cotton are neglected. In some countries, the selected crops will be much less than the mentioned
71%. Maybe discuss this issue shortly. Also pasture is neglected which is relevant for meat consumption in the case of green water.

> *Thanks, we will discuss that. We focus on food demands, without accounting for cotton. We can mention some countries where the selected crops amount to much less than 71%, but the focus of our paper is on the three cities / countries.*
> *We will also make clear that our method cannot cover the livestock sector comprehensively, neither grazing nor feed with residues (see next comment).*

Page 2606 lines 4ff: The assumptions of equal consumption is definitely rather rough (as you discuss below). While urban population might have higher food demand in terms of quality, rural population might have higher consumption since they might feed animals with left overs. I think this is fair for a first approach but might be discussed in further detail for other cases than Berlin For imports I think there might be a relevant difference between rural and urban population due to purchase power and logistics. This might be considered in further detail.

> *We agree that the assumption of equal consumption is rather rough and will briefly discuss that (though we are not aware of any literature that has systematically addressed the rural-urban differences in food consumption).We prefer not to get into a discussion on livestock feed conversion efficiencies e.g. related to leftovers vs. concentrate feed.*

Page 2606 lines 25ff: this is a very complex topic and no detail is provided on how it is exactly done. Here the principal procedure needs to be presented (in the supplement) and also the resulting trade flows. Otherwise the results are not transparent enough.

> *We will improve the description of the methodology and present some resulting trade flows (see our introductory comments)*

Page 2607 lines 2ff: here it is indicated what has been done for German Coffee but
not explained in detail (comment above). The question of processing and losses in reexports has not been discussed (I think discussing it is enough)

> *We will discuss this. For addressing these issues in detail however, more sophisticated*

methods such as MRIO (as pointed out in section 5.4) need to be used.

Page 2608 lines 13ff: It would be interesting to also consider the balance of individual crops since some cells are importer and exporter at the same time (through different crops). As suggested above, this can be provided as raster files as supplement.

See above response.

Page 2609 lines 11. I think it is important to mention that also pastures, cotton, sugar cane and palmoil are not considered. Based on Pfister et al 2011 (in the references) cotton contributes around 4% of total blue water consumption in crop production (num- ber 5 crop out of 160) and is especially important for imports. Based on the same reference, Sugarcane is number 5 crop in total water consumption and number 6 in blue water consumption. Palm oil is number 11 for total water consumption. I think this could be mentioned here (especially cotton).

Yes, this is an important point, we will mention that – please note our introductory comment that we've limited the analysis to primary commodities.

In addition to table 1 it would also be interesting to have a table with country / crop virtual water imports for each city (like provided in aggregate form in figure 3).

We think all the relevant information is already included (see table 1, figure 2 and figure 3) but will check whether this can be further improved.

Page 2609 lines 15-17. For the distances of blue water it is the opposite picture for the comparison of Lagos and Berlin.

True, but as indicated in the text, the blue water contribution (wheat and rice) for Lagos is tiny; we will clarify this.

Page 2609 lines 21ff. This factor 10 has also been shown in the results of the study by Pfister et al 2011 (same range of values for maize in table 2) and therefore seems robust. In order to better understand the factor for different water productivity i think adding the related yield in Table 2 would help to directly understand this.

We will do that and refer to the study by Pfister et al.

Page 2610 lines 17ff. Since Berlin has only blue water footprint of 15m3 per capita and year cotton might be dominating the result, since global average blue water footprint of cotton production per capita and year is also around 15m3/year and capita based on Pfister et al. 2011 and therefore is probably higher in Berlin (as cotton consumption is supposedly higher in Europe than on world average)

We will mention that, but we also emphasize that this study focusses on water footprints related to food consumption and on primary commodities (see our introductory comment)

The comparison with 115L/d personal water use is interesting. However, i think this is domestic water use and not drinking water as noted in the paper (e.g. incl. toilet flushing).

True, we will correct that.

Page 2610 lines 24. This is due to the selection of crops. Tea, which is in consumed India, has on the global level total water consumption which his 25% of the one from coffee and therefore Delhi might have a relevant water footprint from tea consumption.

That is a valid point, we will look for consumption / VW content data for tea and mention this in the text.

Page 2613 lines 6ff. The rainfed share might be overestimated. Based on results in Pfister et al. 2011 blue water is more than 2% and might be around 10% of total water consumption in Brazil soy production. I suggest to check some literature estimates here.

OK, we only used the data from Mekonnen et al., so we will mention Pfister (and Portmann or others) in addition.

Page 2613 lines 19ff. Cocoa is partially irrigated in these countries although the ma- jority not.

We will clarify this matter, a quick check in Portmann does not show any irrigated cocoa there.

Page 2615 lines 25ff This is why Ridoutt and Pfister 2010 (ref in paper) suggested using the change in green water consumption only in water footprinting.

We will mention this suggestion, but also others views on this issue, such as assigning the full green water consumption to the respective ecosystem service (here food production) that depends on this water consumption.

Page 2617 lines 20ff This is also an economic issue.

We may mention this.

Page 2619 lines 27ff Monea also contributes to improved water productivity (manage- ment).

We understand that you wish to state that income generated from exports can also be used to improve water productivity; we will do that.

Page 2621 lines 6ff. This is not completely true. Feng et al. 2011 (http://dx.doi.org/10.1080/09535314.2011.638276) compared bilateral trade and MRIO based water footprint analysis. I think this has to be added but agree that more work is required.

We will consider citing that reference, as we haven't come across any MRIO applications for a comprehensive water footprint analysis yet.

Page 2621 lines 17ff. Similar to Galli et al. (from a ecological footprint perspective) the issue has also been addressed from a carbon footprint / LCA perspective (Ridoutt and Pfister 2013, DOI: 10.1111/jiec.12026) also suggesting a celar structure of footprints without overlaps (especially also from a product labeling perspective).

Okay, but it is an open question whether to integrate different (water, carbon, ecological and other) footprints or to keep them separate "without overlaps".

Figures 4a and 4b Quality of this figures needs improvement. Since it allows comparing modeled and reported data, the reported data area should be clearly drawn into the maps on the left side of the figures.

We will do that

Referee 2 Anonymous

This is a very interesting paper, may be the first paper which looks into the water foot- print of cities. The paper raises a concern of increasing water footprints in the growing urban cities; and it is relevant as most of consumptions and production decisions are not taken together in the spatial context in today's globalized world , and (both de- cisions) do not reflect the scarcity of natural resources in terms of prices. The latter, however, holds because of different kinds of distortion in the factor markets, and in such case over emphasis of scarcity conditions of resource and it link to the consumption centers only may distract the countries from taking the tractable responses to improve resource condition and ensuring food security for its own people.

> *This is very true, eventually socio-economic "footprints" (i.e. costs) and benefits have to be integrated with resource / environmental footprints, for guiding sustainable policies. We will highlight this in the revised text.*

*Saying it, it is also true that urban centers are not consumption centers only. They produce services and goods (not agriculture obviously) using huge domestic water consumption and extract*ing groundwater resource (may not be true in Berlin, but very much true in Delhi).

> *Right, but we focus here on the food sector. Many of the non-agricultural water uses are also non-consumptive, hence cannot be compared directly in terms of their water footprints with agriculture. We will mention this nevertheless in the revision.*

Because of higher density of The paper talks about a subject of water footprints of cities without any scope of drawing any responses within the urban context to reduce such increasing footprints

> *There is a section on opportunities for more sustainable consumption, but we will try to be more explicit about potentials on the consumption side for reducing footprints.*

as the focus was primarily on agriculture sector, with production decision taken far away from consumption centers. Hence the usual carbon footprint stories of urban cities are quite different from the water footprint stories presented in this paper.

> *We would prefer not to get into comparisons of water and other footprints, which would go beyond the scope of this study. But it can be briefly mentioned.*

Other comments-

Pg 2603-Line 3 The argument is too general. The authors need to specify the gap between net importing and exporting countries are increasing in terms of what? Is it only food?

> *We will add that we indeed mean food imports (as the whole paper focusses on food-related water footprints).*

Pg 2606 line 4 second assumption too bold.

> *We agree (and mention that in the text right below), but we haven't found any literature that would allow specifying dietary differences between cities and rural areas, and we believe that the patterns of subnational virtual water flows estimated using national average values are fairly robust.*

In this context, I want to say that quality also matters.in urban centers of developing countries, one can observe consumptions of better quality agricultural goods (say rice) but in lesser quantity.

> *We will mention that this work needs to be continued not only towards kcal consumption, but also nutritional value ("quality") of food*.

Pg 2606 line 25- Bilateral trade framework assumption is also too restrictive in accounting total water usage and also to take indirect water consumption.

> *Indeed, indirect / embedded trade with agricultural commodities such as soy embedded in livestock products (and eventually the resulting total water footprints) requires input/output type analysis, and hence we mention MRIO as a way forward.*

Pg 2610. I find comparison of relative prices of goods(as basis of trade) missing while explaining table 1.

Of course, comparative advantages of different production regions – expressed in terms of prices of goods – drive commodity flows. That includes climate, labour (see next point below) and many others. But looking at all production inputs and explaining trade patterns would go beyond the scope of the paper, which is to illustrate and quantify the links between food consumption to (non-) sustainable resource exploitation.

Pg 2612 The author should consider other factors like labor, which may influence the terms of trade. One cannot just look at one resource only.

See previous comment.

Pg 2624 line 17.. There are obvious constraints for cities to grow, may be water , land. Saying that, I find the authors projections about growing cities are quite unrealistic.

We will provide sources for the growth figures.

Pg 2615 line 10- The authors talks about consumption of luxurious agr goods (diets), and gave no justification using income elasticities.

Luxurious goods are primarily consumed by higher income groups. Income elasticities specify the increase in consumption with growing income, for which Lundqvist et al show an upper income limit, after which consumption levels out. However our point here was that the WF not only depends on income-driven consumption levels, but also on the generally higher agricultural water productivity in high income countries/source regions. We will reformulate this to clarify the point.

Pg 2616 line 17. I wonder if green and blue water scarcity conditions could be related, and what will be its implications in the context.

We refer in our analysis to Gerten et al 2011 (and Rockström et al 2009) who integrate green and blue water scarcities / availabilities towards an overall water scarcity in terms of food self-sufficiency. That approach is used in table 3. We will make this more explicit in the revision.