

# 1 Reply to Reviewer # 1

We wish to thank the reviewer for this thorough revision of the manuscript and the many helpful and constructive suggestions and corrections, which will help to improve the article substantially. We appreciate the positive evaluation of the manuscript and the recognition of the novelty and usefulness of the approach. The following paragraphs respond to the general comments. Responses to all detailed and technical comments are listed in the table of changes (Supplement).

*1. Actually, the presentation of the AHEAD index and a more detailed analysis of results for the present situation could be an interesting article on its own, even without the consideration of future projections and the role of uncertainties from modelling, which could be dealt with in a follow-up article. The consideration of these additional aspects in one article is ambitious given the limited space.*

In this paper we only briefly present the AHEAD approach, to clarify the basis for the consequent quantification, which focusses on the projections of climate change and associated uncertainties. In addition, we are currently in the revision process of another paper on the background of the AHEAD approach, which should be available soon.

*2. Even though the overall presentation is well structured and the language is fluent, the documentation of results and their calculation partially lacks clearness and preciseness, which makes it difficult for the reader to truly understand the modelled results and associated uncertainties (e.g., see specific comments 16, 20, 24, 25, 33).*

We apologize for not having presented the methods and results in enough detail and much appreciate the specific comments in this regard. We have revised the manuscript along the comments of both reviewers (see table of changes).

*3. Furthermore, the authors present their results ? which derive from a range of models and climate scenarios and refer to several periods ? in an aggregated way without revealing country-specific fuzzy values of the AHEAD index and underlying indicators. A documentation of these values, e.g. in the supplementary material, would allow a more transparent documentation of results.*

We suggest to publish all data as follows:

(1) We will upload a supplementary file containing country-specific fuzzy values for (a) AHEAD elements (b) subindices (c) results of the ensemble mean, where modelled data is involved (water availability, Subsistence, AHEAD).

(2) Additionally, the results of all individual model runs will be made accessible through figshare (<http://figshare.com/>), where it will be linked and accessible with a doi.

Please see the attached table of changes for all other comments.

REVIEWER #1	
Reviewer Comment	Changes made
1 (1) Page 404, lines 24: "( : : ) for 44 out of 111 countries, the water-specific uncertainty ranges are outside relevant thresholds for AHEAD, and therefore do not contribute to the overall uncertainty about climate change impacts ( : : )" – This information is not mentioned in the manuscript. Did you possibly confuse this information with the following result: "In 44 countries ( : : ), uncertainty is relevant to highly relevant" (page 420, lines 27-28)?	Indeed, the numbers seem to be mixed up. We have adjusted the abstract with the correct numbers.
2 (2) Page 405, lines 14-16: "Single aspects of climate change and impacts can be put into context by relating them to other development aspects and needs, allowing for a comparison of impacts across sectors." – Readers can get a wrong expectation when reading this statement, because the application of the AHEAD index, as presented in this paper, addresses only potential changes in 'annual internal renewable water resources' per person and related effects on the resulting AHEAD value. It does not deal with impacts of changed water availability on other sectors, i.e. on the other 15 elements that are included in the AHEAD index. So, the survey is no comparison of impacts across sectors.	We have rephrased this sentence in the introductory part ("Yet, such a framework can provide an important means to assess the consequences of climate change for human welfare and societal systems, allowing to relate impacts of climate change to other development aspects and needs and to compare of impacts across sectors."); also we have added a more specific sentence in the objectives part to clarify the scope of the present paper (" For a first implementation of the approach, we focus on the example of water scarcity which has been identified as a major challenge of the future (Grey et al. 2013)."; "After an initial implementation of the approach on a global scale, we show how climate as well as population change may affect overall fulfilment of AHEAD, focussing on changes in water availability")
3 (3) Page 407, lines 16-26: You state that you have identified the set of 16 elements based on a number of approaches, which are listed subsequently. It does not become clear what element is based on which approach. So, the specific origin of each single element remains unclear. You can solve that easily by adding the underlying approaches in a new column in table 1 (next to the column 'Elements').	A paper on the details and background of the AHEAD elements has just been accepted for publication. Here, a detailed overview of each element is given. We would prefer to direct the reader to this article, instead of adding additional information to the table. We therefore suggest to make sure the doi of the background paper is available before the publication of the final version of this manuscript.
4 (4) Page 408, lines 2-3: "Additional literature devoted to the topic, but not directly applicable for the purpose of defining single elements for the present analysis, further supports this set ( : : )." – If the additional literature is not applicable for the definition of elements, how can it support the set of defined elements?	We have removed this sentence, as the background paper is available shortly and should give all relevant information to understand the development of AHEAD.
5 (5) Page 409, lines 18-19: "Fuzzified data sets take continuous values between 0 ( : : ) and 1 ( : : )." – As the fuzzy data range includes 0 and 1, the formulation should rather be "Fuzzified data sets take continuous values from 0 ( : : ) to 1".	Sentence adjusted.
6 (6) Page 409, lines 19-20: "Upper and lower thresholds for membership (I1, I2)" – As I1 is smaller than I2 (as can be seen from equations 1-4), you should change the beginning of the sentence to "Lower and upper thresholds for membership (I1, I2)"	Order is updated.
7 (7) Page 411, lines 6-8: "Further operators available for the aggregation of variables include average operators, such as harmonic, geometric and arithmetic mean (Mayer et al. 1993)." – As you already introduced the arithmetic mean as an operator of your analysis a few lines above, the arithmetic mean should not be mentioned here as one of the further operators available. Furthermore, the reference to harmonic and geometric means appears unnecessary, because they are not relevant for your survey. So, you can drop the whole sentence.	Sentence dropped.
8 (8) Page 412, lines 10-12: "the lower threshold I1 should reflect a basic level or resource availability, below which survival would be compromised. The upper threshold I2 delineates a level of sufficiency, where basic needs are fully met and conditions are adequate." – This is only true for membership functions with linear/curved increase (equations 1 and 3). It is not the case for linear/curved decrease (equations 2 and 4).	We have rephrased this to: "Fuzzified data sets take continuous values from 0 (conditions are inadequate) and 1 (conditions are adequate). For the purpose of determining the fulfilment of AHEAD, fuzzy values near 0 reflect a basic level of resource availability, below which survival would be compromised. Fuzzy values near 1 indicate a level of sufficiency, where basic needs are fully met and conditions are adequate."
9 (9) Page 412, line 15: "possible satisfiers" – What are satisfiers?	We have added a paragraph to Section 2.1 which briefly discusses the relationship between elements (needs) and satisfiers (data used to represent elements).
10 (10) Page 412, lines 24-25: "limited factors" – Do you mean limiting factors?	Yes, thank you. Changed accordingly.
11 (11) Page 417, line 23: "inter-model spread" – As the spread is one of the key components of your survey, you need to define what this spread is concerned with. If you do not clearly define this term, it will be difficult for the reader to understand the following uncertainty analyses. Does spread refer to each country's difference between minimum and maximum fuzzy value for water availability/person across all model calculations – comprising all climate scenarios and all periods, including the baseline? Or does it refer to each single period separately?	We have extended this paragraph to include a more explicit definition, also including the suggestions in comment #12, #13 and #33 (Figure 2), giving more details of the procedure.
12 (12) Page 418, line 1-2: "the country-specific result range of fuzzified AHEAD conditions" – What are "fuzzified AHEAD conditions"? I assume that you refer to a country's overall AHEAD value, which is calculated on the basis of the 16 elements from table 1, and not to these elements themselves (or their underlying indicators). But this becomes clearer only after further reading. So, for a better understanding, you should explain clearly what you mean with the expression "fuzzified AHEAD conditions".	See comment #11
13 (13) Page 417, line 4: "water is not limited" – What do you mean when stating that water is not limited (or that there is "no water limitation" in figure 2). Do you mean that the fuzzy value for water availability is 1?	See comment #11
14 (14) Page 418, line 18-19: "Using the values of the ensemble mean, global mean AHEAD fulfilment is intermediate (0.48)." – The analysis of the present state of human livelihoods according to the AHEAD baseline assessment, which is presented in this paragraph (i.e. till line 28), is quite short and general. As the AHEAD index is a novel measure that integrates aspects from various sectors, a detailed analysis of current livelihood conditions in the world would be an interesting topic for an article even without the consideration of future developments and related uncertainties. Such an analysis could address regional differences in livelihood conditions and their underlying reasons (i.e. specific limiting factors that may be characteristic for certain regions or types of countries) in more detail. However, I respect the author's choice to choose a broader topic for this article, which is associated with restrictions to the analysis of the current state. Nevertheless, I think that the article would profit from more country-specific results about the present state that illustrate how the elements underlying the AHEAD index act in concert and result in an overall AHEAD value (e.g., is there an indicator that has a particular strong influence on the overall AHEAD value?). This could, for example, help to understand the impact of the water availability indicator on the overall AHEAD value, or the "relative strength" of both water indicators. It would also be helpful to add a table to the annex that documents the fuzzified values for all indicators and dimensions with regard to all countries (with a second table that shows all modelling results for water availability across the various models, climate scenarios, and periods). This would make the calculation of the overall AHEAD value much more transparent.	We have extended the results section here, including more details on the distribution of between the subindices, as well as the single elements. As the focus is on the presentation of the index at global scale, we would like to refrain from providing too much country-specific details. Such an analysis would require more detailed knowledge of the country specific situation, also considering cultural differences and more country-specific data. Like any global model, the present calculation of AHEAD can provide information of the relative distribution of conditions between regions, but it cannot necessarily provide country-specific information. With regard to an overview of all data please see comment # 3 in the general comments.
15 (15) Page 418, lines 13-15: "The fuzzified values can be represented according to the degree of membership to the linguistic category of adequacy, ranging from very high (1-0.8), high (0.8-0.6), intermediate (0.6-0.4), low (0.4-0.2) to very low (0.2-0)". – Class borders are not clear. For example, a value of 0.6 belongs to the classes "high" and "intermediate".	We apologize for this imprecise documentation. We have adjusted all instances of this to reflect accurate class borders, e.g 0 < 0.2
16 (16) Page 418, lines 21-22: "While this differs slightly across models and scenarios" – The mention of scenarios comes as a surprise, because you refer to the baseline assessment in this paragraph (I assume that there are no climate change scenarios for the baseline assessment). It will be helpful for the reader if you divide the results chapter in one section about the baseline assessment and another section about the modelling of future conditions including future uncertainties.	We have divided the chapter into 2 parts: (1) the results of current and future AHEAD and (2) the analysis of uncertainty (see #14). We have rephrased much of the paragraph and expect that this also clarifies this point.

17	(17) Page 419, lines 1-2: "Calculations using the full range of ISI-MIP modelling results (: :)" – I assume that these calculations refer to the future simulations. It would be helpful to the reader if you mention this explicitly.	Thank you, we have rephrased this, indicating the time periods explicitly.
18	(18) Page 419, lines 6-7: "Generally, the distribution of countries between classes is rather even." – The reader can only believe that, because you do not document the modelling results for the future scenarios.	See comment # 3 (general comments) on data documentation.
19	(19) Page 419, line 9: "GCMs and IMs" – Do you refer to global climate models and impact models? This is not clear, because you do not explain these abbreviations.	We have specified the abbreviation where the terms are first mentioned (Section 2.4)
20	(20) Page 420, line 3: "water security" – What exactly do you refer to with this term (also subsequently in the text)? Various definitions of water security exist in the literature, and they can be quite comprehensive. So, you should briefly define water security. Does water security refer to a fuzzy value of 1 for the 'water' variable/element?	Indeed this refers to a fuzzy water availability of 1. We have added this more specifically to the description of the membership function.
21	(21) Page 420, line 6: "seemingly smaller results ranges" – Please drop the word "seemingly", because the results ranges are indeed smaller, even though they do not lead to different fuzzy values.	Word dropped
22	(22) Page 420, lines 19-20: "We use the value range across all models and scenarios for the classification, but differentiate between the four time slices 2000, 2030, 2060 and 2090." – If you have classified the uncertainties for four time periods, why do you only show results for 2000 and 2090?	Changes do not differ significantly between the timeslices, so we chose to illustrate the results with 2 time periods only in order to reduce the amount of figures and information. Indeed, since we focus mainly on this latest timeslice we have adjusted the manuscript and now focus on 2090 changes only. We hope that the reviewers agree with this adjustment.
23	(23) Page 420, lines 22-23: Where changes occur between baseline and 2090 calculations, these are hatched in the respective colour. – (1) It is difficult to recognize the hatched colors in the small printed illustration. (2) As the 2090 projection includes different climate scenarios in the various models, I would have expected that uncertainties are higher than in the baseline assessment. Surprisingly, only five countries differ in their uncertainty classification, and these countries apparently move to "better" classes (I assume that the colors of the thin lines represent the future class). What is the reason for the lack of additional uncertainty from the future scenarios?	We have rephrased and extended this Section, following this and the following comments. The map has been updated and the hatching is replaced with boxes/arrows that indicate the change for better visibility.
24	(24) Page 420, line 24-25: "( : : ) in 67 countries the model spread is outside the thresholds for AHEAD fulfilment." – (1) Please explain what AHEAD fulfilment is. Do you mean an overall AHEAD value of 0.8-1 (class "very good"), or do you refer to AHEAD values of exactly 1? (2) Does the whole sentence mean that at according to all models, the respective country does not achieve a "very good" AHEAD value in a certain period (or a value of exactly 1)?	See #23
25	(25) Page 420, lines 26-27: "( : : ) water security is below all minimum requirements in all RCPs-IM-GCM combinations" – Do "minimum requirements" refer to fuzzy values below 1 for the 'water' variable/element, which indicates that adequate conditions with regard to 'annual internal renewable water resources' or 'access to improved water source' are not achieved (i.e., at least one of both indicators has a fuzzy value below 1)?	See #23
26	(26) Page 421, lines 7-8: "( : : ) the AHEAD approach provides a means to view climate impacts in a wider context." – The studied impacts result also from changes in population size, because the projections of water resources per capita are based on climate scenarios and on population forecasts. Actually, in a range of countries the effects from population changes can be stronger than those from climate change.	We have added a paragraph on this to the discussion: "Both, changes in water resources as well as in population have an effect on the per capita resource availability within a country. By selecting average per capita requirements for a life in dignity as the assessment unit, the various pressures exerted on resources can be represented by the approach. In the case of water availability, it is often the increase in population which reduces the adequacy of per capita water availability, rather than reduction in water resources alone."
27	(27) Page 421, lines 12-15: "( : : ) our approach to combine water resource availability with the access to an improved water resource provides an important way forward to account for the fact that water shortages to some extent can be mitigated by good water infrastructure." – This is not reflected in the AHEAD index: As both indicators are aggregated through a MIN operation (cf. page 421, line 27), water shortages are not compensated by good technical infrastructure.	You are right, the argumentation here is imprecise. The underlying rationale within AHEAD is to reflect that infrastructure is often a limitation to water access in developing countries and is essential additional to resource availability, hence the MIN operator. We have therefore readjusted the paragraph in this regard.
28	(28) Page 422, lines 4-6: "As exemplified with the example of water availability, an assessment of the relevance of changes for the adequacy of conditions becomes possible." – Even though a decline in water availability may have no effects on the overall AHEAD value, it can still have considerable effects on human livelihoods in practice. For example, if water availability drops from "high" to "low" in a country with air quality classified as "low", this will not change the overall AHEAD value, and the decline can therefore be regarded as irrelevant from the AHEAD perspective. However, in practice the decline in water availability can have serious consequences for the population and is definitely relevant. You should address this issue in the discussion section.	The discussion of this aspect may have been too brief in the manuscript. We have extended the respective paragraph in the discussion to reflect the fact that changes in water availability outside water security thresholds are important to other sectors (see below). Additionally, the extended description of results (see comment #23) takes up this point in more detail. However, for changes of water availability within the thresholds of water adequacy, the relevance of these changes is recognised, regardless of their impact on AHEAD (class C.3: AHEAD low to very low, uncertainty range relevant to FW). The decision tree differentiates countries, where AHEAD does not change, as other aspects show limitations, but uncertainty in water data is relevant (class C3). For classes A and B, AHEAD is high and changes of water availability are outside the thresholds of water security. New paragraph: "It is also important to note that uncertainty ranges outside the thresholds relevant to AHEAD remain important for other water-related decisions, e.g. urban water flow management. While such changes may not directly affect water security, nonetheless other effects may negatively affect the adequacy of human livelihood conditions."
29	(29) Page 423, line 11-12: "The use of global data and globally applicable thresholds in a fuzzy logic algorithm adds other types of uncertainties and short-comings." – You should briefly discuss how the spatial scale influences results of the analyses. The key variable of your survey, water availability/person can vary considerably within a country. Moreover, countries with low population density may have high water availability/person even though water scarcity limits agricultural activities. For example, Australia shows very high AHEAD fulfilment (fig. 1), which implies that water availability/person is also very high. However, in practice low water availability limits agricultural activities in large parts of the country.	We have added the following paragraph to the discussion of the limitations of the paper: "The implementation at country-scale also assumes an even distribution of resources as well as population with country boundaries. Especially in large countries with uneven population distributions or diverse climatic conditions, such country-level averages prove to be a limitation for the assessment of water availability. More detailed analyses at finer resolutions, as for example proposed by Lissner (2014), can provide important further information in this regard."
30	(30) Page 433, table 1: (1) According to the explanations on page 415, the lower and upper thresholds for 'solid fuel use' are based on Lillemo and Halvorsen (2013). But in table 1, two other references are documented as sources. (2) The table shows 15 elements, but according to the manuscript (page 404, line 15; page 408, lines 1 and 6; page 421, line 6), the AHEAD index is based on 16 elements.	(1) We have updated the table accordingly. (2) As indicated in footnote 1, page 416, the element 'shelter' cannot be adequately represented with data and is therefore not included in the present analysis. We have specified this again in the caption of the table.
31	(31) Page 434, table A1: (1) You should mention that the table refers to the baseline period. (2) The class borders are not clear (see comment 15). (3) It would be more transparent to provide a table that shows the fuzzy values for all indicators and countries for at least one model. In this way, the reader can see how the various values aggregate to an overall AHEAD value. Such a table would be long, and I leave it to the authors to decide whether they accept the suggestion. But please note that the present article draft shows only aggregated results to the reader. This makes it difficult to track how the various indicators result in an overall AHEAD value (see comment 14).	(1) Added to caption (2) Changed, see also comment #15 (3) Please see comment #3 in general comments
32	(32) Page 435, table A2: (1) There is no reference to this table in the manuscript (applies also to figure A2).	We have made sure these are all referenced – the extended results section also refers to these Tables in more detail now.

<p>(33) Page 437. figure 2: This figure is important for the analyses, but it needs clarification, because explanations in the manuscript are scarce. (1) 1st column: What is 'AHEAD spread'? Is it the difference between the maximum and minimum overall AHEAD value across all models and scenarios within a single period? (2) According to the manuscript (page 417), the AHEAD spread in the upper box can also be exactly 0.2, and the AHEAD spread in the lower box can also be exactly 0.5. (3) 2nd column: What does 'AHEAD' refer to? Given the spread of AHEAD values (column 1), how do you arrive at a single AHEAD value for each country? Is it its AHEAD value from the baseline assessment, which represents the mean from all model calculations for that period? (4) 3rd column: Why is class B characterized by "AHEAD low to medium"? Its AHEAD value is between 0.2 and 0.8 (column 2), so it should rather be "low to high", because values from 0.6 to 0.8 are classified as high (page 418, figure 3). (5) 3rd column: Why is the uncertainty range relevant for class C3, but not for classes A and B? In all three cases, the AHEAD spread (which is below 0.2) may make a country pass a class threshold and 33 move to another class.</p>	<p>We have extended the explanation of Figure 2 in text according to these suggestions. Point (3): we differentiate the different spreads 0 - &lt;0.2, 0.2 -&lt; 0.5 and &gt;0.5. Even though class boundaries may be passed for classes A and B, at the most this can be one class. The direction of the results therefore remains the same, making uncertainty less important in these cases.</p>
<p>(34) Page 439, figure 4: The bars are very small in the printed 34 version.</p>	<p>We have revised the figure for better readability. We suggest to also rotate the figure, so the bars become larger (depending on final format of publication).</p>
<p>(35) Page 440, figure 5: (1) Changes between the baseline results and those for 2090 occur for five countries, not four countries as is written below the figure. (2) Obviously, uncertainties do matter less for the 2090 period than for the baseline assessment: Ethiopia and Mongolia move from C.3 to C.2, Hungary from B to A, Syria from D.2 to D.1, and Yemen from D.2 to C.3 (assuming that thin lines depict the 2090 results). How is it possible that the inclusion of five different climate scenarios for 2090 does not lead to significantly higher relevance of uncertainty as compared to the baseline assessment? You should address this in the results or the discussion section (see 35 comment 23).</p>	<p>We have adjusted the figure for better readability and have extended the results section (see comment #23). Briefly, the reduction of uncertainty is due to reductions in water availability, which leads to very high limitations (water availability = 0) under all scenarios in additional countries.</p>
<p>(36) Page 426, lines 15-18: Reference de Crombrugghe et al. (2009) – Apparently, you did not take the data directly from this report, but from the database that is described therein. So, you should add the web database in the reference list 36 and refer to it in table 1.</p>	<p>Reference added</p>
<p>37 Technical comments</p>	<p>All technical comments have been changed in the manuscript</p>

## 1 Reply to Reviewer # 2

We wish to thank the reviewer for recognising the importance of our work and for several important suggestions, which will clarify and improve the manuscript. The following paragraphs respond to the general comments. In the table of changes they are listed again with the according adjustments in the manuscript. All other comments not mentioned here are addressed in the table of changes.

*1. This paper attempts to systematically assess climate impacts on livelihood via a methodology called AHEAD, which combines the effect of a variety of climate impacts, and the appropriate assessment of model uncertainties. The paper focuses on water availability (as an example) using results from ISI-MIP, and ascertaining when model uncertainty is significant to livelihood predictions and when it is not. The overall goal of the methodology is to digest model results for policymakers, including ascertaining relevance of various uncertainties.*

*The authors approach in doing this is to begin with a long list of subjective elements (listed in Section 2.1), and attempt to quantify them through impact model output and what turns out to be a simple scheme based on fuzzification. However, this translation (from qualitative to quantitative) is necessarily arbitrary. This puts the whole endeavor on thin ice. Such a translation would seem to demand transparent methodology, thorough examination of assumptions, careful justification of every step, and precise language.*

We have carefully revised the manuscript on the basis of the reviewer comments, focussing on more precise language. We have also focussed on extending and clarifying the translation process from qualitative to quantitative and several points in the manuscript, especially in Section 2.1 and 2.2. An additional paragraph added to Section 2.1 elaborates on the differentiation between the identified elements of AHEAD and the representation with data (see comment #3). We will also add a table to the supplementary which outlines in more detail the process from the element definition to quantification. For each element, the table contains:

1. Element: Description/relevance for AHEAD 2. Sources/underlying approaches 3. Indicators/satisfiers (data sources) 4. Motivation for thresholds and membership functions

In this paper we only briefly present the AHEAD approach, to clarify the basis for the consequent quantification. We are currently in the revision process of a manuscript containing further details on the conceptual background, which discusses the choice of elements in detail. This paper should be available online soon.

*2. I feel that the overall goal of this paper, to meaningfully digest impact model results and uncertainties, is important. However, I feel that the methodology presented here is perhaps too qualitative, and the presentation too imprecise, to successfully advance this goal.*

Our choice of fuzzy reasoning specifically focusses on representing imprecisions and vagueness which are associated with the translation from qualitative to quantitative in socio-ecological analyses (please see also comment before). We have extended the discussion of the relationship of qualitative and quantitative aspects in several parts of the manuscript, specifically also with regard to the fuzzy logic method.

With regard to the potential impreciseness in the presentation of the results, we have carefully revised the manuscript on the basis of the suggestions of both reviewers for a more precise presentation.

*3. Furthermore, there seem to be some culturally-specific assumptions underlying this work (e.g. the necessary factors for adequate livelihood), which should perhaps be given explicit consideration.*

As the criticism of culturally-specific assumptions and the choice of indicators is recurrent, we would like to address the issue in detail at this point. The choice of the elements of AHEAD is based on literature, which was chosen according to the focus on generally valid determinants of human livelihood needs (please see also comment #1). According to the underlying concepts, the elements included in AHEAD are not culturally-specific, but generally valid and globally applicable (see e.g. Narayan et al., 2000; Sen, 1985; Alkire, 2002; Max-Neef, 1992). Following the idea put forward by Max-Neef (1992), generally valid needs can be met by different satisfiers, which can vary, for example according development status or culturally-specific preferences. While the identified elements of AHEAD (which are conceptually designed to correspond to needs according to Max-Neef) are non-culturally specific (according to the underlying approaches), the choice of indicators to represent their fulfilment (satisfiers) can vary. For the purpose of a global application, the availability of data sets of sufficient coverage is clearly a limitation. This may lead to some cultural bias, as available data are limited. Data sets are usually raised within a specific cultural frame, mostly by institutions in developed nations, therefore available data on satisfiers is often culturally specific. We agree that this is an essential point, and we have given it much consideration during the development of the approach. The choice of indicators was discussed in an international team of researchers and the cultural bias of available data was an intense topic of debate and reduced where possible (e.g the representation of “social protection”). However, in most cases data coverage proved to be a strong limitation in the choice of indicators.

In the revised manuscript, we have added an additional paragraph in Section 2.1 addressing the issue, and address the topic explicitly in the discussion. To keep the presentation of results concise we have chosen not to discuss each indicator in detail in the text. Detailed accounts of the backgrounds of the used indicators are available in the indicated literature in Table 1. As indicated in comment # 1, we will also add a table to the Supplementary, which providing details on the used data.

*4. I find the acronym "AHEAD" to be awkward.*

We decided to use an acronym because the terms well-being and livelihood have been used in different fields of research as related, but sometimes slightly conflicting concepts.

The concepts are also used at different scales (i.e. individual vs. national/aggregate measures). Such conflicting views on a fundamental concept make the review process difficult, as a keyword may raise expectations that then remain unmet. Therefore, we have chosen an acronym, to reflect the scale and scope of the approach. We are happy to take up alternative suggestions of terms or acronyms in this regard.

5. *“Based on a transdisciplinary sample of influential concepts” sounds vague./ The word “influential” here weakens the presentation. Similar persuasive rhetoric appears often in the paper, and is not helpful.*

Thank you for your comments in this regard. We have carefully screened the manuscript to reduce instances vague and persuasive language of the paper.

6. *“However, the idea of adequacy is easily presented in linguistic categories, for example sufficient water is available. I find this sentence to be too simple, and also tautological (i.e. “sufficient” is a synonym for “adequate” here). Does “sufficient” mean “sufficient to drink”? Or “sufficient for subsistence agriculture”? Or “sufficient for non-native landscaping”? This sentence highlights the fundamental tension between the qualitative and the quantitative in this paper. A more sophisticated and precise treatment of this tension might be needed.*

We agree that this is a major challenge of our paper and hence follow your suggestions to address the tension more explicitly. As indicated in the previous comments, we have revised the manuscript in this regard at several points (specifically Section 2.1, discussion, Supplementary table) and hope that this makes the presentation precise. Please see also specific comment #4 for details on this paragraph.

For the purpose of this first global implementation, we refer to the cumulative water needs for all sectors, as proposed by Falkenmark (1997) and Falkenmark and Rockström (2004). The detailed representation of “sufficient water availability”, is an important question and we have given this more detailed attention in a paper currently under review for HESS (doi:10.5194/hessd-11-4695-2014).

7. *Equations 1-4. I would be interested to see how results would change if every variable swapped shape of membership function. Im not convinced that the level of precision implied by the use of two classes of shape is relevant to the results. / How much uncertainty is introduced by use of these idealized functions? / Gamma = 0.6 seems arbitrary.*

Every exact number used in the framework is associated with vagueness, which is the reason for using a fuzzy logic approach. The order of magnitude, and likely ranges, of the thresholds and gamma values are motivated by the properties of elements and literature; the specific choices of these values are arbitrary only within these ranges.

We have prepared several figures to illustrate the effects of changed membership functions and gamma. With regard to using a gamma value, we have prepared comparison plots of gamma-values of 0.4 and 0.8 (see Figures 1a and 1b), compared to the original value of 0.6. While differences are visible, values within this range yield the same message as the standard choice.

Figures 2a through 2d show how different membership functions would affect the result. Figures 2a and b show how fuzzified values of water and calorie availability vary with different membership functions, which illustrate the effect of such different assumptions. Figures 2c and d show changes in AHEAD values, if only linear (c) and exponential (d) membership functions are used.

*8. What are "micro credits"?*

Micro credits generally refer to the access to low (or no) interest loans, available informally or through institutions (e.g. governments or NGOs). The indicator provided by the Institutional Profiles Database is an aggregate of informal and institutional access to micro-lending schemes, as well as the quality of the micro-lending guarantees (see de Crombrughe et al. (2009)). As discussed in comments #2 and #3, the representation of AHEAD elements with data in the present manuscript focusses on global applicability and comparability. We feel that a detailed discussion of each indicator would go beyond the scope of the paper and we would refer the reader to the original sources.

*9. I am not inclined to agree with the implication (by inclusion in the same dimension group) that cell phones and the internet are equivalent in importance to the other infrastructure factors such as shelter or health care. I think there is an underlying assumption in this work as to what is necessary for adequate livelihood, which is critically culture-dependent.*

Please see comment #3 with regard to the culture-dependence. The grouping of the three subindices follows their According to the underlying literature, no hierarchies exist between elements exists, except for the Subsistence elements (see e.g. Max-Neef (1992)). For the global implementation of AHEAD, we follow this reasoning and further distinguish between tangible (Infrastructure) and intangible (Societal Structure) aspects. In terms of the specific indicators, the distinction between the element 'communication' and the representation with data has to be noted (see comment #3). The relevance of access to communication for adequate livelihoods has been shown (see e.g. Horner et al., 2010; Figueroa et al., 2002; Urry, 2003) and at global scale we can measure this aspect with the two indicators.

*10. Why is it necessary to use a political grid in this study?*

The use of countries as the spatial scale of reference is motivated by the availability of data, as societal aspects are usually assessed at national resolution.

*11. Table 1. For the "communication" category, why are the lower and upper bounds 0% to 100% respectively?*

It was not possible to identify specific threshold values from the literature. As there is no information regarding the needed levels of access to communication, we have included the full range of values here.



12. Table 1. I find the implicit claim that 0.5 cap-1 motor vehicle density is necessary for "adequate livelihood" to be a conundrum in a paper about climate change, and another culturally-specific assumption.

As indicated, a global analysis relying on available data faces some constraints and more detailed representation of many indicators would be preferable in many cases. This is indeed a very important point that has been insufficiently addressed throughout the manuscript so far. As indicated, we have added this aspect at several points of the paper and very specifically address it in the discussion.

In the case of representing mobility, data availability is limited at present. Many different ways of satisfying the need for mobility are possible, however, only data on motor vehicle density is currently available with a comprehensive global coverage. The methodological approach of calculating the adequacy of each element would allow to change this representation, if additional or more suitable indicators become available. With regard to the relation between motor vehicles and climate change it must be noted, that the present analysis does not suggest mitigation or sustainability goals, but aims to depict the present situation of livelihood conditions with the currently available data.

Please see the attached table of changes for all other comments.

## References

- Alkire, S. (2002). Dimensions of Human Development. *World Development* 30(2), 181–205.
- de Crombrughe, D., K. Farla, N. Meisel, C. de Neubourg, J. O. Aoudia, and A. Szirmai (2009). Institutional Profiles Database III: Presentation of the Institutional Profiles Database 2009 (IDP 2009). Technical report, DGTPE, Paris, France.
- Falkenmark, M. (1997). Meeting water requirements of an expanding world population. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences* 352(1356), 929–936.
- Falkenmark, M. and J. Rockström (2004). *Balancing water for humans and nature. The new approach in ecohydrology*. London UK: Earthscan.
- Figuroa, M. E., D. L. Kincaid, M. Rani, and G. Lewis (2002). *Communication for Social Change: An Integrated Model for Measuring the Process and Its Outcomes*. Number 1. New York, USA: Communication for Social Change Working Paper Series. The Rockefeller Foundation.
- Horner, L., D. Hawtin, and A. Puddephatt (2010). Information and Communication Technologies and Human Rights. *Directorate-General for External Policies - Policy Department. EXPO/B/DRO*.
- Max-Neef, M. (1992). Development and human needs. In P. Ekins and M. Max-Neef (Eds.), *Real-Life Economics: Understanding Wealth Creation*, pp. 197–213. Routledge, London.
- Narayan, D., R. Chambers, M. K. Shah, and P. Petesch (2000). *Voices of the Poor. Crying Out for Change*. New York: Oxford University Press for the World Bank.

Sen, A. (1985). *Commodities and Capabilities*. Oxford University Press.

Urry, J. (2003, June). Social networks, travel and talk. *The British journal of sociology* 54(2), 155–75.

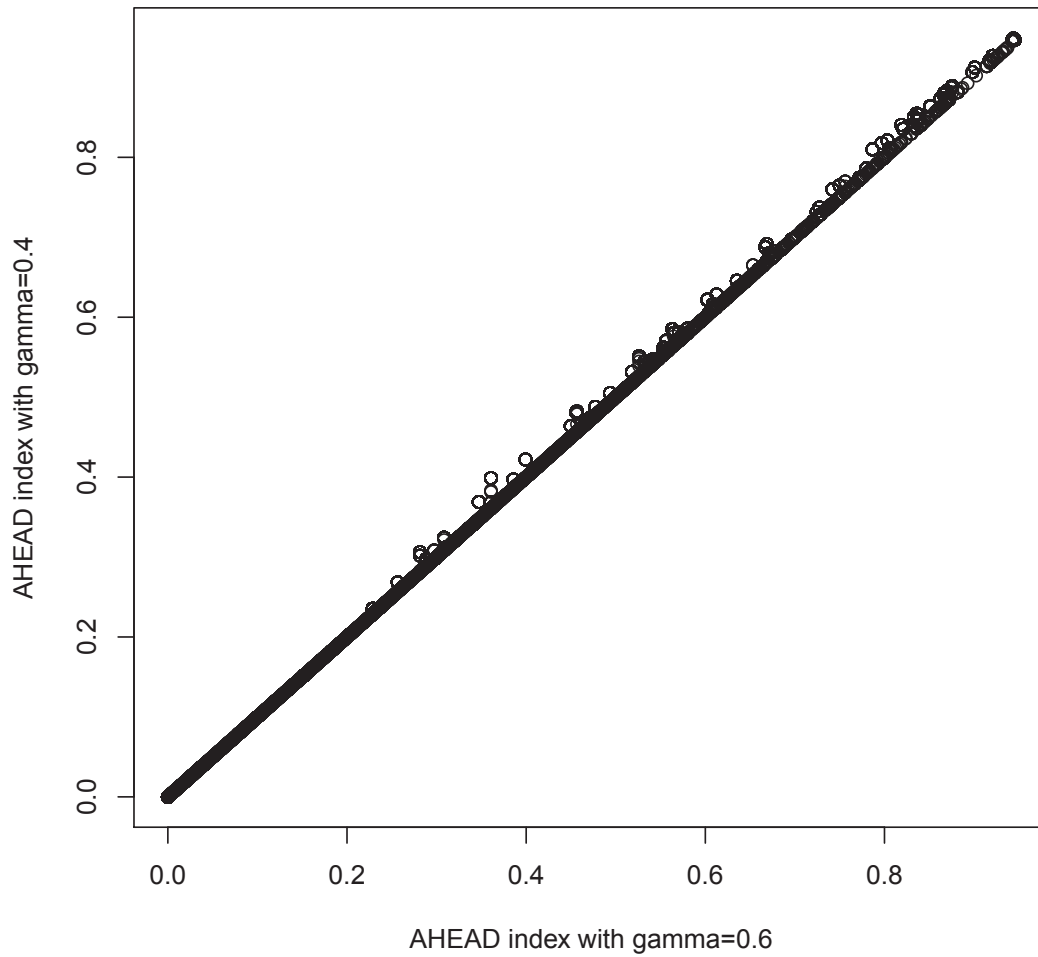


Figure 1a: Comparison of AHEAD results with  $\gamma=0.6$  (original value) vs.  $\gamma=0.4$  (water data: ensemble mean, baseline)

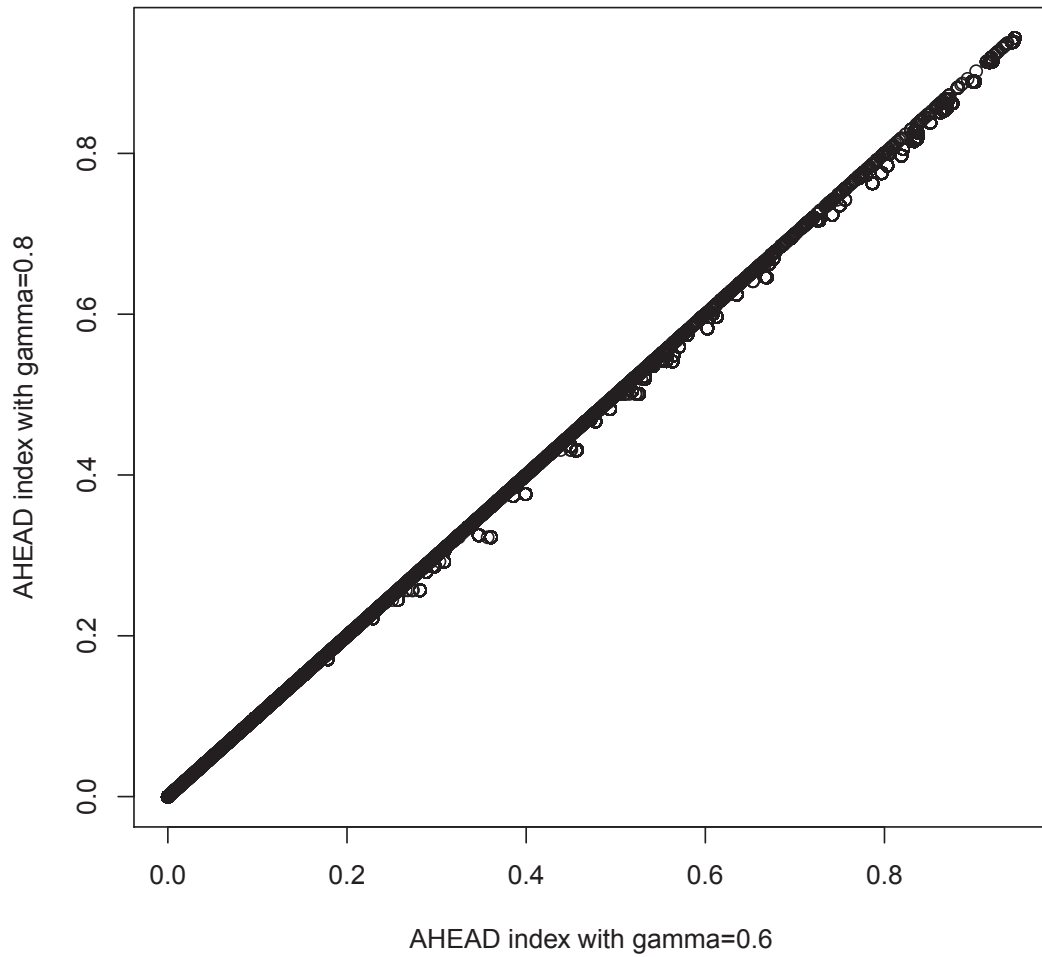


Figure 1b: Comparison of AHEAD results with  $\gamma=0.6$  (original value) vs.  $\gamma=0.8$  (water data: ensemble mean, baseline)

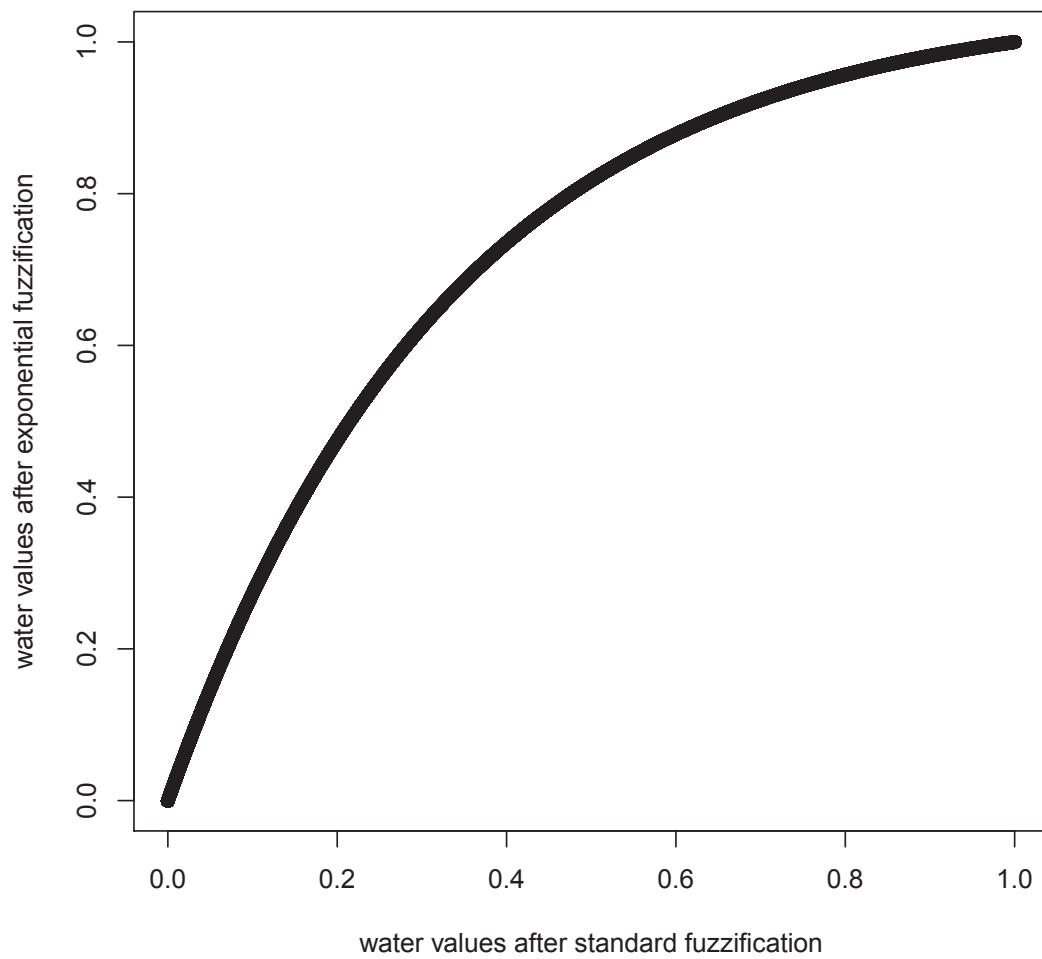


Figure 2a: Comparison of differences in fuzzified values of water availability between a linear (standard) and exponential membership function.

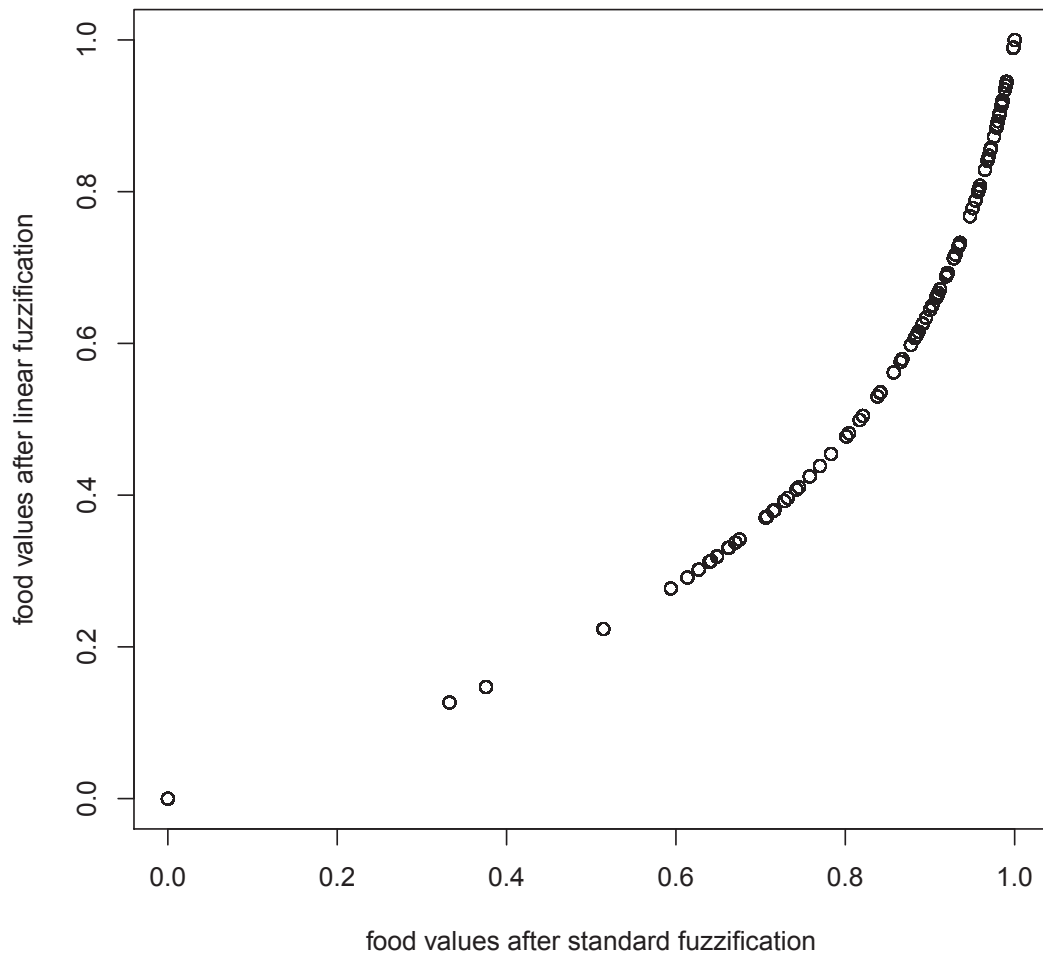


Figure 2b: Comparison of differences in fuzzified values of calorie availability between a linear and exponential (standard) membership function.

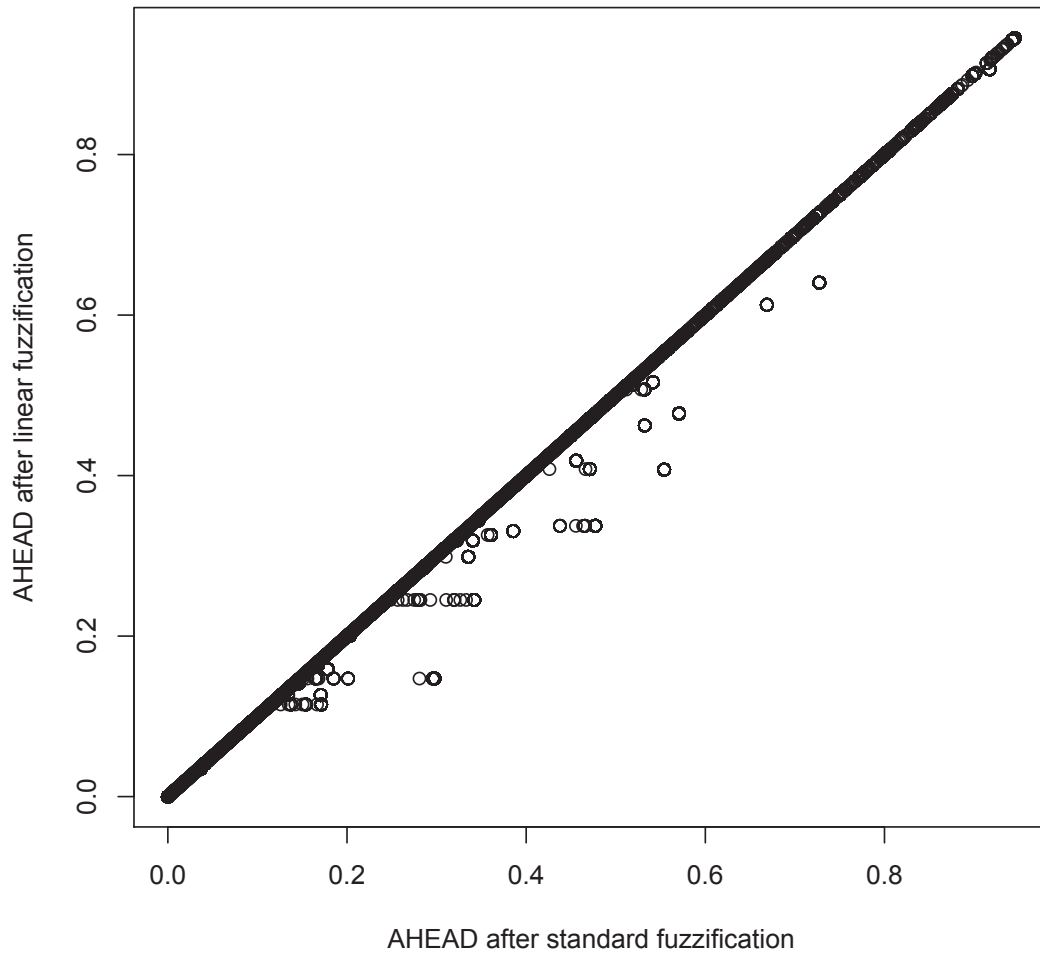


Figure 2c: Comparison of differences in AHEAD values between the standard fuzzification procedure and fuzzification using only linear functions.

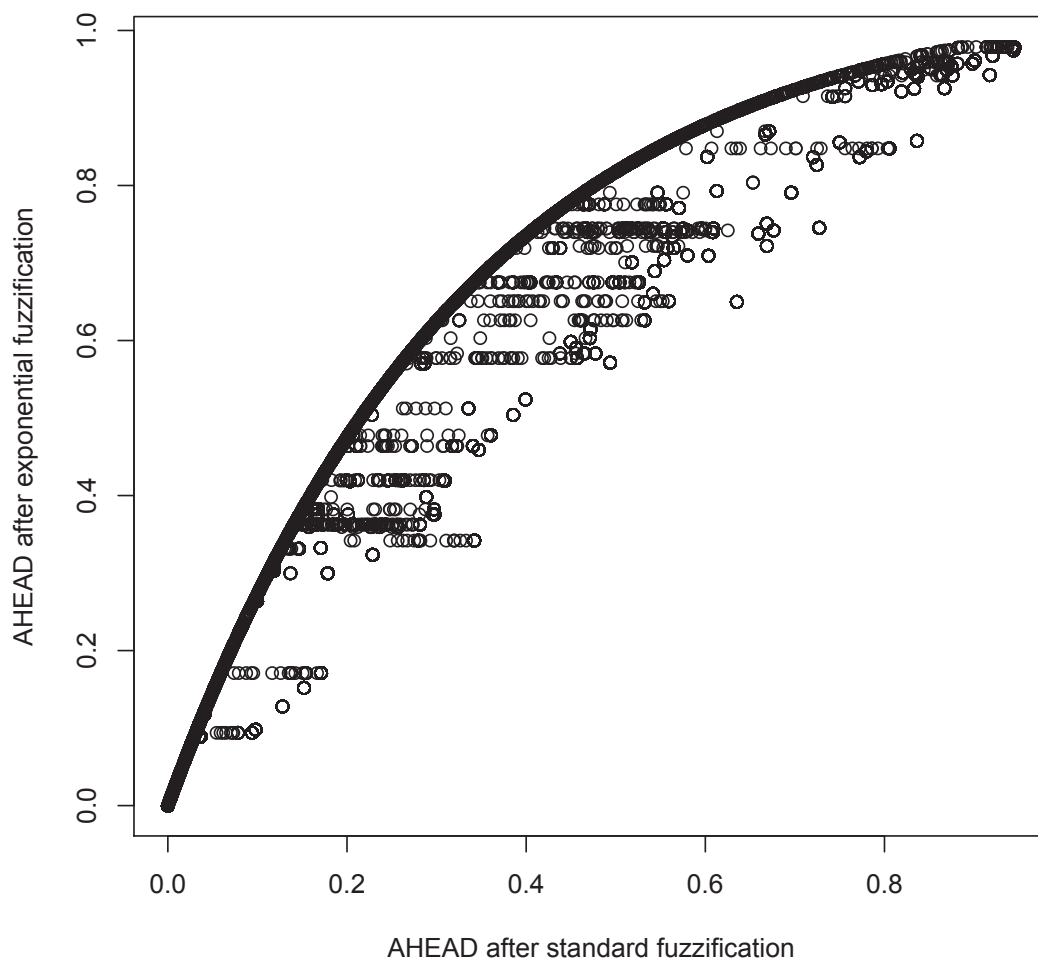


Figure 2d: Comparison of differences in AHEAD values between the standard fuzzification procedure and fuzzification using only exponential functions.

REVIEWER #2	
Reviewer Comment	Changes made
1 404.13 "Based on a transdisciplinary sample of influential concepts" sounds vague.	Sentence changed to: "AHEAD is based on 11 representative concepts of human well-being and livelihoods and measures the adequacy of conditions of 16 elements."
2 404.13 The word "influential" here weakens the presentation. Similar persuasive rhetoric appears often in the paper, and is not helpful.	We have removed the word influential here and in other instances – please see comments #6 in the general comments.
3 408.6. I do not understand the clause, "To measure the fulfilment AHEAD." Dividing the 16 elements into 3 categories may be a prerequisite to measurement, but is not the act of measurement.	We have rephrased the sentence to reflect this more clearly: "To facilitate the measurement of AHEAD, we group the 16 elements into three categories."
4 409.7. 'However, the idea of adequacy is easily presented in linguistic categories, for example "sufficient water is available". I find this sentence to be too simple, and also tautological (i.e. "sufficient" is a synonym for "adequate" here). Does "sufficient" mean "sufficient to drink"? Or "sufficient for subsistence agriculture"? Or "sufficient for non-native landscaping"? This sentence highlights the fundamental tension between the qualitative and the quantitative in this paper. A more sophisticated and precise treatment of this tension might be needed.	We have rephrased the paragraph, in order to more clearly reflect the concept of fuzzy logic and linguistic categories. This paragraph generally introduces the fuzzy logic concept, a detailed discussion of membership functions and thresholds is given in the following Section 2.3. . With regard to the tension of qualitative and quantitative aspects please refer to the general comments. We have added a more detailed outline of the conceptual basis of AHEAD in Section 2.1, also specifying more clearly what is meant by 'sufficient', as this is an aspect that relates to all elements, not only water. "For the purpose of measuring the fulfilment of AHEAD, we want to assess whether the availability of each element is adequate to meet human livelihood needs. Adequacy in this context refers to a situation, where elements are sufficiently available in quantity and quality to meet basic needs and permit a life in dignity (Wicks2012) as recognized for example in the Universal Declaration of Human Rights (BHR 1948). "
5 412.10. These definitions of $\iota_1$ and $\iota_2$ should be moved to where the variables are first introduced.	Thank you for the suggestion, we have moved this to the introduction of the fuzzy logic algorithm
6 412.16. Applied fuzzification methods for each variable are motivated by scientific findings." This is vague. What "scientific findings"?	We suggest to rephrase this to "Applied fuzzification methods for each variable are motivated by results from literature as presented in Table 1."
7 414.1. "Thresholds $\iota_1$ , $\iota_2$ , as well as the shape of the membership function (Eqs. 1–4) to fuzzify each input dataset are motivated by relevant findings." Again, this is too vague. If I wanted to apply this methodology, this sentence would not help me.	Changed to: "Thresholds $\iota_1$ , $\iota_2$ , as well as the shape of the membership function (Eq.1-4) to fuzzify each input dataset, which are discussed in the following paragraphs, are motivated by results from literature (for an overview of all membership functions as well as the frequency distribution of the input data see Figure A1, Appendix)."
8 419. I feel that the discussion of the relevance of uncertainty (an important point) is needlessly complicated. The basic idea is simple: if uncertainty in the best-estimate value causes it to cross a threshold, the uncertainty is relevant.	We have revised the paragraph to convey the main principle (which is clearly simple) first. Nonetheless, we feel that the detailed discussion of this aspect is relevant to the message of the paper. If there are specific aspects which seem to be complicated, we would be very grateful for more specific comments in this regard.
9 421.8. "The approach builds upon influential concepts..." The claim here that the concepts are influential does not add to the argument, but rather detracts.	Please see comment #2
10 421.10. "The selection of indicators and data for the purpose of quantification focusses on a holistic representation of important aspects." Again, statements like this do nothing to advance the discussion.	We rephrased and reworked this paragraph in order to be more precise.
11 424.6. "Uncertainty has often been blamed for inaction in terms of climate mitigation and adaptation." Please add a reference.	Reference added
12 Table 1. What does $200/(1000 \text{ cap})^{-1}$ mean? Do you mean $0.2 \text{ cap}^{-1}$ ? (This applies to similar units within the table.)	We have checked all units and denominators and will make sure they are correct in the proof-reading version. With regard to cancelling down, we have chosen the units of the original data publications.
13 Table 1. Some explanation for "country-specific MDER" is needed.	We have added a footnote with the definition.
14 Fig. 4. This figure is difficult to parse. I assume the middle column is meant to use the right y-axis? Why do some countries and columns have a wide vertical range of values (I assume due to different RCPs) while others have a small range? Why do the cells with a small range also have identical values for each impact model? What is the takeaway message from this figure?	We have revised the paragraph related to this figure in the results section along the remarks and questions. We have also revised the figure itself for better interpretation and will make sure that the figure is sideways or full page in the final version (depending on the format of the final paper).
15 Fig. 5. I don't understand what the hatching signifies, "changes towards the 2090".	We have revised this figure for better readability and have adjusted the caption to more precisely state the content.
16 Tables A1 and A2. It's not clear to me what these tables contribute to the paper. Consider explaining their significance in the captions.	We have updated the captions and refer to these numbers explicitly in the extended results section.
17 Table 1. Font is too small. Please use multi-page table.	We will make sure that the table is sideways or full page in the final version (depending on the format of the final paper).
18 Figure A1 too small to read.	We will make sure that the figure is sideways or full page in the final version (depending on the format of the final paper).