

Interactive comment on “How to represent human behavior and decision making in Earth system models? A guide to techniques and approaches” by Finn Müller-Hansen et al.

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These are the final author responses to referee comments on our manuscript.

Referee Comment #1

We thank the referee for his valuable comments. Although we do not agree with all the points, we think that they raise important issues that could be clarified in the paper. Furthermore, a productive ongoing discussion about these issues could help in aligning

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forces for the important goal of gaining a more holistic understanding of global human-nature interactions by developing Earth system models that include important social and economic dynamics. In the following, we respond point by point to the comments of the referee.

This paper provides an overview of a broad range of representations of human behaviours that might be considered when attempting to 'people' Earth System Models (ESMs). I found the paper to be well researched and written on the whole and if the aim was to inform the reader as to the range of options on offer in this space it did a relatively good job (with one or two notable exceptions which I detail below). However, the title suggests something more, with the stated aim to also offer some guidance over the way forward in this space. This is very much needed given the likely expansion of research this area will experience. Unfortunately, I found this aspect of the paper a little disappointing given it was rather passive, reserved or limited in any guidance it offered. This was not helped by the structure of the paper which separated out the extensive review of potential methods and the critique of these methods which was largely relegated to the Discussion. If the authors really want to be faithful to their title and stated aims I would suggest some editorial changes. I would start by offering a strong steer on the guiding principles of model framework selection in this space. I would then combine the description of the options with a more hard-hitting critique of the various options assessed against your guiding principles. My reading of the current paper suggest the author team would be more than able to achieve this and the product would be far more valuable than the largely descriptive review currently tabled. The alternative would be to dilute the title and aims to being those of a review of options as I believe this is what is currently being offered. I would like to encourage the former but providing the title and aims were adjusted the paper could go forward without this

reediting. I've ticked the 'major revisions' box but only because I couldn't simultaneously tick the 'minor revisions' box. This depends on which way you chose to jump.

We appreciate the critique of the referee and agree that this work did not deliver on the promise of a general guideline for building ESMs with explicit human decision and behavior components. This is for a specific reason: Such a guideline depends a lot on the concrete research questions that a modeler wants to tackle with the model. Therefore we argue that rather than a concrete guideline, some general principles have to be considered by the modelers and they have to be aware of the various possibilities from the toolbox that the literature provides and we aim to give an overview over. This approach is much in line what researchers from sociology have termed theory of the middle range (Merton, 1957). This approach does not aim at an all-encompassing theory of whole societies, but rather argues for using elements of different theories tailored to a specific problem. The selection of assumptions underlying the modeling approach has to be on the ground of good reasons and empirical evidence. In case of doubt, the validity of assumptions have to be tested for the specific context. Furthermore, we note that an extensive critique of all the different methods would be beyond the scope of a single paper. Where we were aware of such critiques, we provided some references for the readers. However, due to the huge variety of methods, there may be relevant strands of critique which we were not aware of and therefore did not include into the paper. In line with the above considerations, we will change the title and make the aim of the paper clearer in the introduction to avoid misunderstandings. Furthermore, we will make the general point more prominent, that there is not one method and theory that will fit all relevant research questions, which are interesting in the context of global human-nature interactions. Therefore the approach most appropriate for the question at hand has to be selected taking into account various general considerations as listed in the Discussion part of the paper.

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Specific points (in no particular order) 1. I would like to see a full discussion over when ESM peopling might be useful, when it might not and when it might be actively discouraged. Given the huge uncertainties this activity can/will open up researchers need dissuading from the illegitimate and unnecessary hybridisation of social and natural systems models. This paper could offer some guiding principles. For example, although the chosen example of land surface/use parameterisation suggest a useful role for microscopic representations of people, ultimately we are only interested in the structural social dynamics when exploring Earth (i.e. global) scale feedbacks, even if these dynamics arise from the act of an individual. Therefore, at the ESM scale you would have to have a really powerful justification of a highly disaggregated representation of people and there should always be a presumption in favour of the macroscopic representation. The fact that ESMs are spatially disaggregated and therefore we should naturally entertain representations of people at this scale is not sufficient in my view.

We agree with the referee that a discussion about when a “peopling” of ESMs is useful should be added to the paper. We will add some corresponding paragraphs to the paper discussing that this is only relevant if there is a closed loop of interactions with the outcome of relevant decision processes and behaviors changing over the relevant time scales. However, we think that a full-blown discussion of this question could be well suited for a follow-up paper as suggested by the editor. Regarding the example of the macro- vs. micro-description of a human component in ESMs, we want to note that we do not argue that human behavior always has to be included at a micro-level and on the basis of single actors. But, as we are arguing in the paper, a complete picture of humans in ESMs should be well founded in micro-models of decision making, behavior and interaction. Especially when large societal and institutional changes are considered, models purely based on observed macro-dynamics might not be able to rightly capture these changes (this is referred to as the Lucas Critique in the eco-

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conomic literature, see Lucas, 1976). Of course, here again, it depends on the research questions whether a macro model of societal dynamics suffices (assuming that major societal dynamics will not change fundamentally over time) or if a more micro-founded model is needed.

2. The opening text made a big play of the distinction between 'explicit decisions' and 'implicit behaviours'. Close inspection suggests this is a largely arbitrary distinction and some critique of this divide would be a useful addition. Is me typing this response an explicit decision or an implicit behaviour? I'm not sure.

If this comment is based on the reading of our definition that decisions are only explicit and there are no implicit processes involved, we regret the misunderstanding. We reformulated the corresponding paragraph to make it clear that decision-making can be influenced by implicit, unconscious and intuitive processes. In this understanding, the result of a decision process is usually a certain type of behavior. However, not every behavior has to be the outcome of a decision process, and this is why we think the distinction between decision making and behavior is analytically useful and not arbitrary. Although in the end, only the behavior of humans may be observable, many behaviors are highly influenced by semantic considerations as well as inscribed social and individual norms and values. For complex cultural settings, it is therefore often not helpful to reduce humans to a reflex-response scheme as in behaviorist approaches. The only alternative to modeling behavior without explicitly using theory about the decision processes would be to model behavior statistically or at the basis of physiological processes in the brain. Concerning the latter, the science is still in its infancy and it is at least questionable whether such a description is possible at all. Regarding statistical approaches, as explained in the previous point, when looking at strong social changes, statistical correlations might break down calling for the explicit modeling of decision processes. Apart from these more pragmatic considerations, there is a philosophical

argument to be made: From introspection the distinction between behavior as an event of the physical world (i.e., the body) and the decision-making process as at least being influenced by the mind should be clear to every human making conscious decisions. How these different processes interact has been the subject of the age-old debate called the mind-body problem in philosophy. Solving this problem by simply denying the existence of the mind altogether leads to even more serious problems: If we would assume that me typing this response is only a behavioral reaction to a very complex stimulus without any involvement of semantic processing, why should anybody of us care about the semantic content of what we are writing here anyways?

3. Surely the most important distinction in normative framing involving any ESM is whether they adhere to the current socio-economic norm or they represent transitional/ transformative dynamics. Everything else is simply detail. This is not developed at all and yet practically all applications of peopled ESMs will revolve around exploring and contrasting alternatives to business-as-usual. This review is very constrained in this regard, and hardly mentions alternative (and potentially indispensable) economic framings required when investigating, for example, implementation of the Paris Agreement.

We are well aware of the debate between the economic mainstream dominated by neoclassical theory and heterodox schools of economic thought and the different economic framings they involve (see for example Müller-Hansen, 2016). To come up with new models of the economy that build on the work done in heterodox branches such as ecological and institutional economics is actually one of the main challenges when including social dynamics in ESMs. Thus, we agree that such models have to go beyond the currently dominant socio-economic framing. However, we tried to avoid an extensive discussion of this debate in the paper. The main goal of this paper is to compare different approaches to modeling human decision making that could be po-

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tentially useful to Earth system modeling. Therefore, the paper only considers those economic approaches that use mathematical modeling. Because many of the heterodox economic schools are not much engaged with modeling or even reject mathematical modeling as a valid tool to advance knowledge about social processes, this collection, unfortunately, is much biased towards mainstream economic thinking. If we omitted important and formalized economic modeling approaches in the literature, this is due to our knowledge gaps, which are unavoidable for such a comprehensive topic.

4. Other than discussion of flow consistent approaches, this review makes little or no mention of (bio)physical frameworks as covered in say ecological economics. I appreciate they are not mainstream but I think this is a critical omission because perhaps the most consistent scheme for peopling of ESMs is where both the Earth and social systems are both on a sympathetic '(bio)physical' footing. This could be nicely contrasted against the fact that the standard macroeconomic framings are flow/physically inconsistent. Perhaps it's time for the natural sciences to call the macroeconomic emperor on their lack of physically defensible clothing and peopling ESMs appears to be a great place to start. ESD has been central to getting these alternatives into the literature and it is anomalous that they are not considered here.

A discussion of purely biophysical models is neither the goal nor the focus of our article. We agree that a social-metabolic or biophysical description of human activities is crucial for linking classical ESMs and social science approaches and that physically consistent stock-flow or similar approaches should be an essential part of ESMs with explicit human dynamics. This is why we discuss such approaches in Chapter 5.6 "Dynamics at the system level: System dynamics, stock-flow consistent and input-output models". We will complement our account of physical stock-flow consistent modeling in this Chapter and add references to the important work of Nicholas Georgescu-Roegen in this area. We also agree that models of the social metabolism have to take thermodynamic limits into account. However, we doubt that thermodynamic laws alone can account for the complex dynamics of social-metabolic processes as some recent work

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of the referee and others in this Special Issue suggest (Garrett, 2014; Garrett, 2015; Jarvis et al., 2015).

5. Much of the problem space that peopled ESMS would explore would be around precautionary Command and Control type policy such as that offered in the Paris Agreement. Here a formal control representation of 'people' is much more appropriate given it is about compliance or non-compliance with a stated environmental objective such as keeping below 2 K. I would like to see some discussion of this.

Actually, a lot of economic reasoning for environmental policy recommendations builds strongly on the control perspective. But as the failure of some of these policies shows, it is not only important to have the formal framework right but also the micro-model of human behavior and decision making to judge how people will react to changes in institutional frameworks. For example, in some settings monetary incentives for environmental behavior might be counterproductive because they can lead to crowding out effects when moral rules are replaced by economic considerations. Therefore, a successful policy assessment needs to select correct micro-models to identify the right approaches for adjustments that influence individual behavior in the right direction. This applies equally to command and control type policies as to other (e.g., market-based) solutions. As suggested by the referee we will add these considerations to the paper.

Referee Comment #2

This paper provides a very comprehensive review of the application of human behavior in earth system models. I was impressed with the coverage and extensive literature review. The paper is well written and will make a valuable contribution to the field. My main concern, which perhaps is

unavoidable for such a review, is that the paper is very long, bordering on overwhelming. There are parts that are redundant such as page six, which takes three paragraphs to restate a Table. I suggest the authors search for other places to streamline the paper. The table in the Discussion is an excellent summary. I would recommend publication following minor revision.

We thank the referee for the positive response. We will revise the paper, shorten the suggested parts, and aim at an overall reduction of the text.

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