We thank the anonymous referee #1 for their valuable and constructive feedback. Their detailed and professional review was very useful and important for improving the manuscript. Here below, we provide a point-by-point response letter addressing the comments. Our responses are in blue and the line numbers (L) refer to the manuscript. The cited references are provided at the end of the letter. We thank you for your time and effort. Stay safe and take care.

On behalf of all the authors,
Sincerely,
Vilna Tyystjärvi

This manuscript aims to model methane fluxes over peatlands under different management and climate scenarios. In general, the manuscript is well written and easy to read. It is important to understand variation in methane fluxes considering its potent nature.

However, I would like the authors to discuss one important aspect of such modelling studies. From the manuscript, I can see that this is a quite complex modelling exercise involving lot of coupled models and formulations (e.g. for biomass). A lot of published papers are cited to support the modeling framework that was adopted. In reality, one cannot read all those papers, even to understand the models on a stand-alone basis. Understanding the complex coupling between them is even more challenging. There could be significant uncertainties in model outputs even for a stand alone model. Given this, how confident one can be in the results obtained (given the limited number of observation sites) and further, how others can replicate such studies? Even a minor change in model parameters can lead to some major changes in the results!

This is an excellent point and one that we agree should be discussed in more detail in the paper. It is true that these types of models are very complicated because they aim to describe a vast number of different processes to, more or less, accurately describe the functioning of the whole land surface and atmosphere interactions. Thus, describing even the basic functioning of the main model, JSBACH, here in a way that would help the reader understand all its relevant aspects is not viable. Furthermore, sufficient calibration data to evaluate these models is limited which then also increases the level of uncertainty in the models. On the other hand, simulating possible changes in complex ecosystem processes at large scales and into the future requires these types of models, so they are a necessary tool to help us understand the possible impacts of human actions on ecosystems.

We will add a point about these issues and compromises related to complex modelling systems to section 1. In section 4.3, we will discuss further the uncertainty related to complex modelling systems. Considering the uncertainty, while we haven't calibrated each parameter in this work separately (which indeed would not be possible in this case), the most important aspects of the work have been tested in previous papers which does reduce the risk of increasing uncertainty with poor parameter choices. The forestry-related parameters in JSBACH-FOM have been calibrated against forest measurements in Nordic countries as shown in Appendix B. Methane-related parameters have been tested in Raivonen et al (2017) and further tested in Li et al to better suit these types of peatland forests. Furthermore, research done by Mäkelä et al. (2019) indicates that the largest source of uncertainty in climate scenario driven simulations of carbon balances in LSMs comes from climate-related uncertainty rather than from parameter uncertainty. This we have taken into account by considering multiple climate models and emission pathways. Nonetheless, it is true that replicating this study with for example a different modelling set up could lead to different results as each model describes relevant processes and parameters somewhat differently. This is also an important aspect to consider and highlights the need to use various models and setups to understand model-related uncertainty.

In addition to this, I believe that the peatlands scenarios modelled in this manuscript are hypothetical in nature (please correct me if I am wrong). Then how beneficial this study will be?

These peatlands are hypothetical in the sense that we haven't tried to replicate any existing peatland site but rather tried to estimate the average responses to climate and land management at larger scales. However, the peatland characteristics describe average conditions in northern peatlands and the forestry scenarios are based on management types used in Finland (Juutinen et al. 2021), albeit in a simplified way to allow them to be simulated in the model. In this sense, they are not purely hypothetical and thus provide a way to understand the possible impacts of combined climate change and land use changes on northern managed peatlands. Furthermore, the aim of this paper is not to be a tool for a single forest owner but rather to help us estimate regional changes in the future. Simulating this at site level would make it more challenging to distinguish regional differences from differences created by site-specific characteristics.

In a more generic manner, given the increase in computational resources, anyone can assume some scenarios, model it and try to publish a paper. How such modelling studies will benefit the scientific community as a whole? If such studies are not justified strongly, this can potentially lead to hundreds of modelling papers. (To the authors: This is a more generic comment I have in my mind seeing the proliferation of modelling studies in the scientific literature. Some of the modelling studies do not even consider the uncertainties or performance of the underlying datasets but make strong claims. Please do not take this as a personal comment. You may please provide justifications to show that your manuscript is not just any one modelling study but it makes a real strong case).

We agree that modelling studies should carefully take into account the reasoning and implementation of model simulations and scenarios as well as the reliability and usability of the results. Considering the importance of drained peatlands and their management options in Europe, and particularly in Finland, we consider that it's extremely important to understand the impacts of these options now and in the future. The scenarios we have used are the main management options currently used in Finnish peatland forestry, with one "business as usual" option (clearcutting) and two climatologically better options (restoration and partial harvesting). The model system used is complex enough to simulate all the relevant processes, as well as describe changes in climate and land management. Thus, we consider the reasoning of this modelling study to be well justified. While this doesn't likely provide a complete final answer on the functioning of drained peatlands, it does provide useful information on how these regions may change and what should be considered in future studies of these areas. We will emphasise this point in section 1.

Page 3, line 75: What is a nutrient-rich and nutrient poor peatland? How do they differ in terms of functioning?

Nutrient-rich, or minerotrofic, peatlands receive their water, as well as nutrients, from the surrounding land either from groundwater or surface water whereas nutrient-poor, ombrotrophic, peatlands receive water solely from precipitation. This in turn influences vegetation and carbon dynamics in the peatlands with peatland forests on nutrient-poor peatlands possibly staying as carbon sinks (Lohila et al 2011). We will expand on these terms in section 1 to clarify the differences.

Page 4, section 2.1: The JSBACH model uses PFT's to represent the vegetation functions in the model. Since this is a case study specific to Finland, are the vegetation PFTs prescribed in the model correspond to the vegetation found in Finland. For example, a same type of vegetation may exhibit different growing phases/phenology etc. depending on the site. Hence, to learn about how CH4 fluxes vary in Finland, the vegetation types and the peatland characteristics coded in the model should match the ground conditions. How to ensure this?

The PFTs used in this study describe well the average conditions in Finnish peatland forests and wetlands of which a considerable portion is coniferous forests. Therefore, the phenology in the PFT is appropriate for Finnish peatland forests. Furthermore, our implementation takes into account regionally relevant aspects of vegetation properties such as the delayed effect of temperature for photosynthetic activity in spring (Mäkelä et al 2019). The forest growth has been matched to measurements done in boreal forests. The parameters describing soil processes and methane production have been calibrated to match Finnish peatlands. This means that the results may not describe any specific ground conditions in Finland precisely, as fine-scale variation in both vegetation and soil properties is often considerable and unfruitful to consider in this type of study, but they do describe well the average conditions throughout Finland.

Section 2.1.1, line 100 (and several other places): Reference to a paper under preparation is given. Please do not cite a paper under preparation to support your work. How one can check the scientific validity of the work that is under preparation? Technically, all the novelties in the manuscript under preparation must be presented here.

This is completely true. The paper that we cited was submitted in autumn 2023 while we were preparing the manuscript and this has now been corrected in our manuscript. The paper cited is available as a preprint here: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4170450.

Page 7: Line 176: Can you give a mean value of the carbon stock as simulated by the model after the spinup, for different regions in Finland, along with standard deviation?

This is a good suggestion, we will add a table to section 3.1.

Section 2.2: The management practices assumed for the modelling simulations adhere to the actual ground conditions followed in Finland?

While the simulated management practices are somewhat simplified from real-life practices, they do describe currently used management practices in Finland.

Section 2.3: Can you provide a map of Finland with the different regions marked (as the region names are used frequently in the paper, it is difficult to attach a location to them) and showing the location of the flux measurement sites?

We will add the suggested map to section 2.2.

Section 3.1: The first line is too generic and qualitative in describing the model's performance. Please provide some useful numerical metrics to understand the same. From Figure 2, I can see significant differences between the model simulated results and the ground observed fluxes.

The aim of the first line was to be generic and qualitative as it starts a paragraph. However, we will modify it to be more exact. We will also add numerical metrics, median and standard deviation, to either the figure or a separate table to provide more information on the model performance. However, we would like to point out that the aim of this comparison is not to show that the model corresponds precisely to the measurements. That would be impossible as the model has not been trained to describe these exact peatland sites. The useful information in figure 2 is that 1) the simulated and measured fluxes are in the same scale, i.e. the model doesn't drastically over- or underestimate the fluxes, and 2) the dynamics in comparison to changes in soil temperature (2a) and water-table depth (2b) are similar in measurements and the model, e.g. when WTD rises, methane sinks weaken. We will explain this in more detail in section 3.1 and explain in section 4.3 further how the measurements and model results can be compared.

Page 17: line 329: Is the amount of methane contained in the fast decaying pools fixed? Then only an initial overestimation can lead to later underestimation. Won't there be any CH4 cycle to replenish this pool? Also, in the same line, the word 'latter' should be changed to 'later'.

The amount of methane in the fast-decaying pools is not fixed. As explained in 2.1.4., HIMMELI simulates also the production of methane, in addition to oxidation, transport etc. The word "latter" is used to describe for example something related to the end of something or to the second part of two groups, in this case, the second half of the century (https://www.merriam-webster.com/dictionary/latter).

Page 4, line 91: In this work....simulations with only ONE PFT per site (the word one is missing).

Thank you for noticing that!

References:

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Raivonen, M., Smolander, S., Backman, L., Susiluoto, J., Aalto, T., Markkanen, T., ... & Vesala, T. (2017). HIMMELI v1. 0: HelsinkI Model of MEthane buiLd-up and emIssion for peatlands. *Geoscientific Model Development*, 10(12), 4665-4691. https://doi.org/10.5194/gmd-10-4665-2017