Prompt rewetting of drained peatlands reduces climate warming despite methane emissions

Anke Günther[1]*, Alexandra Barthelmes[2,3], Vytas Huth[1], Hans Joosten[2,3], Gerald Jurasinski[1], Franziska Koebsch[1], John Couwenberg[2,3]

[1]University of Rostock, Faculty of Agricultural and Environmental Studies, Landscape Ecology, Rostock, Germany

[2]University of Greifswald, Faculty of Mathematics and Natural Sciences, Peatland Studies and Paleoecology, Greifswald, Germany

[3]Greifswald Mire Centre (GMC), Greifswald Germany

*Corresponding author: anke.guenther@uni-rostock.de

Peatlands are strategic areas for climate change mitigation because of their matchless carbon stocks[1–4]. Drained peatlands release this carbon to the atmosphere as carbon dioxide (CO_2) [5,6]. Peatland rewetting effectively stops these CO_2 emissions[7,8], but also re-establishes the emission of methane (CH_4) [9,10]. Essentially, management must choose between CO_2 emissions from drained or CH_4 emissions from rewetted peatland. This choice must consider the radiative effects as well as the atmospheric lifetimes of both gases, with CO_2 being a weak but persistent and CH_4 a strong but short-lived greenhouse gas[11]. The resulting climatic effects are, thus, strongly time-dependent. Yet, common metrics like global warming potential (GWP) and its 'sustained flux' variants[12,13] fail to account for temporal dynamics and how these relate to expected global warming dynamics.

We used a radiative forcing model to compare forcing dynamics of global scenarios for future peatland management using areal data from the Global Peatland Database[14]. Our results show that CH_4 radiative forcing does not undermine the climate change mitigation potential of peatland rewetting. Instead, postponing rewetting increases the long-term warming effect of continued CO_2 emissions. Unlike CO_2 (and N_2O) from drained peatlands that accumulates in the atmosphere, possible CH_4 emission spikes upon rewetting do not add to expected peak warming when rewetting occurs before 2050. Warnings against high CH_4 emissions from rewetted peatlands[9] are therefore unjustified.

Each year, drained peatlands worldwide emit ~2 Gt carbon dioxide (CO_2) by microbial peat oxidation or peat fires, causing ~5 % of all anthropogenic greenhouse gas emissions on only 0.3 % of the global land surface[3]. Peatland rewetting has been identified as a cost-effective measure to curb these emissions[15], but may be associated with elevated emissions of CH_4 (16–19). In light of the strong and not yet completely understood impact of CH_4 on global warming[20,21] it may seem imprudent to knowingly create or restore an additional source.

The trade-off between CH_4 emissions with and CO_2 emissions without rewetting is, however, not straightforward: CH_4 has a much larger radiative efficiency than CO_2 (11). Yet, the huge differences in atmospheric lifetime lead to strongly time-dependent outcomes, especially regarding the question when the maximum climate effect of various management scenarios will occur and how this will affect peak global warming (i.e. the maximum deviation in global surface temperatures relative to pre-industrial times). Radiative forcing of the long-term GHGs (in case of peatlands: CO_2 and N_2O) is determined by *cumulative* emissions, because they factually accumulate in the atmosphere. In contrast, radiative forcing of near-term climate forcers (in case of rewetted peatlands: CH_4) depends on the contemporary emission *rate* multiplied with the atmospheric lifetime[11,12], because resulting atmospheric concentrations, also in case of sustained emissions, quickly reach a steady state of decay and removal.

Here, we explore how the different lifetimes of CO_2/N_2O vs. CH_4 play out when assessing options for peatland rewetting as a climate warming mitigation practice. We compare the following global scenarios:

- ‘Drain_More’: The area of drained peatland continues to increase from 2020 to 2100 at the same rate as between 1990 and 2017
- ‘No_Change’: The area of drained peatland remains at the 2018 level
- ‘Rewet_All_Now’: All drained peatlands are rewetted in the period 2020-2040
- ‘Rewet_Half_Now’: Half of all drained peatlands are rewetted in the period 2020-2040
- ‘Rewet_All_Later’: All drained peatlands are rewetted in the period 2050-2070

These scenarios represent extreme management options and exemplify the differences caused by timing and extent of rewetting. For our modeling exercise, we assume that the maximum peatland area to be drained during the 21st century equals the area that is already drained in 2018 (505,680 km², Global Peatland Database[14]) plus an additional ~5,000 km² per year (average rate of new peatland drainage between 1990 and 2017[22]). We apply IPCC default emissions factors[23] and test the influence of CH_4 emissions by adding an initial strong CH_4 spike (10 times the natural emissions for the first 3 years), as has occasionally been reported[17,18]. To compare the radiative forcing effects of the different GHGs, we use a simplified atmospheric perturbation model that has been shown to provide reliable estimates of the climatic effects of peatlands[24] (see Methods).

We find that immediate rewetting of all drained peatlands quickly leads to climatic benefits compared to keeping the *status quo* (Figure 1, break-even point ~6 years after last peatland rewetting). Before the break-even, CH_4 emissions including the strong emission spike assumed for the first years after rewetting create a warming overshoot. Peatlands should, therefore, be rewetted before 2050 to prevent the CH_4 overshoot to exacerbate peak warming, which AR5 climate models expect to occur after ~2060[25] (Figure 1).

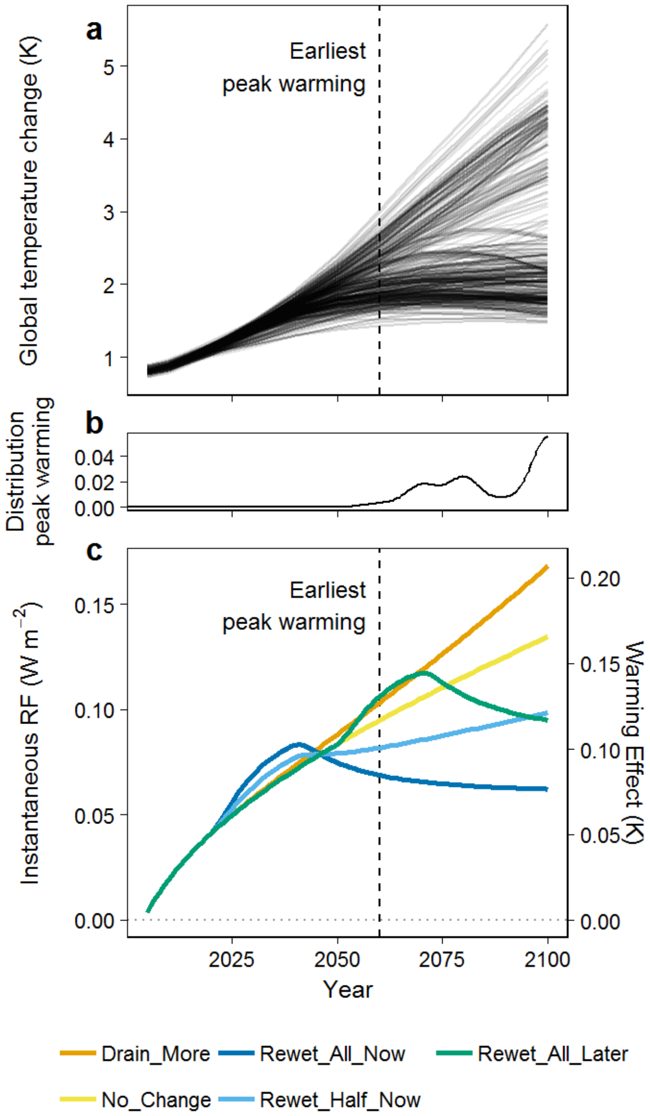

Figure 1 Climatic effects of peatland management in relation to global warming. Mean global temperature change relative to 2005 (a) and frequency distribution of the timing of peak warming (b) according to AR5 (MAGICC) models[25] are shown compared to radiative forcings (RF) and estimated warming effects of global peatland management scenarios (panel c, own calculations). Please note that panel c) does not include forcing of peatlands that remain pristine.

The overall climatic effect of peatland rewetting is indeed strongly determined by the radiative forcing of sustained CH_4 emissions (Figure 2). However, because of the negligible or even negative emissions of CO_2/N_2O of rewetted peatlands and the short atmospheric lifetime of CH_4, radiative forcing of all three GHGs combined quickly reaches a plateau after rewetting. Meanwhile, differences in radiative forcing between the scenarios are mainly determined by CO_2. Rewetting only half of the currently drained peatlands ("Rewetting_Half_Now") is not sufficient to establish stable radiative forcing. Instead, CO_2 from peatland drainage keeps accumulating in the atmosphere and warming the climate.

Comparing the scenarios "Rewet_All_Now" and "Rewet_All_Later" shows that timing of peatland rewetting is not only important in relation to peak temperature, but also with respect to the resulting total long-term forcing of CO_2 and N_2O emissions (Figure 2). The sooner drained peatlands are rewetted, the better it is for the climate.

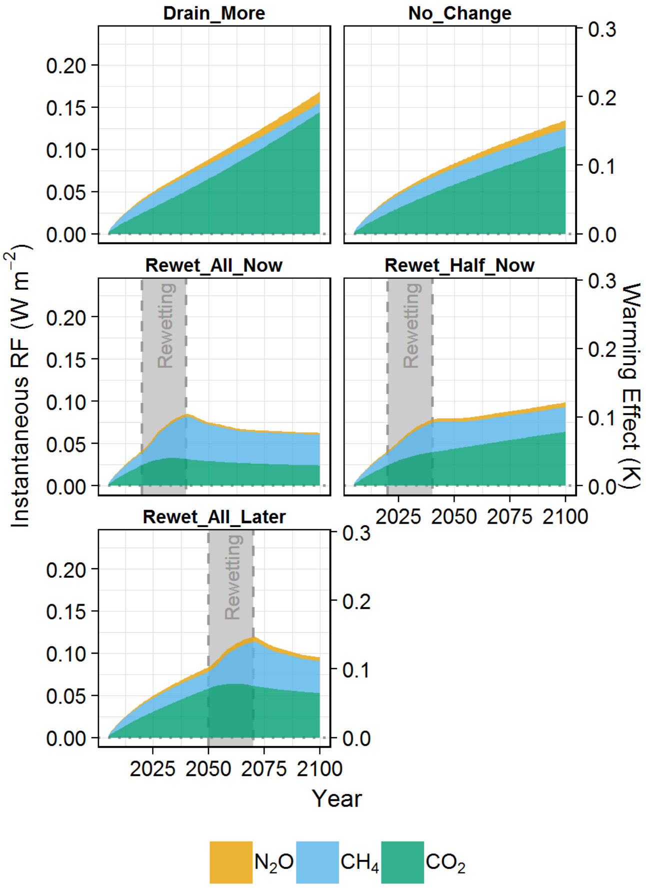

Figure 2 Contributions of the different GHGs (N_2O, CH_4, and CO_2) to total radiative forcing ("RF") and estimated warming effects in the modeled scenarios. The grey area shows the period of rewetting. Note that the figure does not include forcing of peatlands that remain pristine.

Our simulations highlight three general conclusions:

- The baseline or reference against which peatland rewetting has to be assessed is the drained state with its large CO_2 emissions. For this reason, rewetted peatlands that are found to emit more CH_4 than pristine ones[19] are no argument against rewetting.
- The climate effect is strongly dependent on timing of rewetting. This fact is insufficiently recognized and remains hidden when using metrics that involve predetermined time horizons (like GWP or sustained flux variants of GWP).
- In order to stabilize global climate, it is insufficient to focus rewetting efforts on selected peatlands only: CO_2 emissions from (almost) all drained peatlands have to be stopped by rewetting.

Limiting global warming requires immediate reduction of global GHG emissions. It has been suggested that the negative climate effects of drained peatlands could be offset by growing highly-productive bioenergy crops[26] or wood biomass[27] as substitute for fossil fuels. In this study, we did not include this option because wet cultivation methods ('paludiculture') could provide similar substitution benefits without CO_2 emissions from drained peat soil[28].

In conclusion, without rewetting the world's drained peatlands will continue to emit CO_2, with direct effects on the magnitude and timing of peak global warming. These CO_2 emissions can effectively be stopped by rewetting. Especially if we expect large CH_4 emission spikes upon rewetting, we should rewet as soon as possible, so that these CH_4 emissions contribute as little as possible to peak warming. Although the CH_4 cost of rewetting may temporarily be substantial, the CO_2 cost of inaction will be much higher.

Methods

Scenarios

Drained peatland area was taken from the Global Peatland Database (GPD)[14]. We used data separated by climate zone (boreal, temperate, and tropical) and assigned land use categories. Available land use categories were "Forest", "Cropland", "Deep-drained grassland", "Shallow-drained grassland", "Agriculture" (i.e. either grassland or cropland), and "Peat extraction" (see Extended Data Table 1). Because of their only small area and uncertain emission factors, arctic drained peatlands (~100 kha) were neglected. New drained/rewetted area in the scenarios is distributed across the climatic zones (and land use classes) according to the relative proportions of today's drained peatland area. For information on how variations in the assumed drainage rate and duration of the CH_4 peak affected the displayed radiative forcing effects of the scenarios please see Extended Data Fig. 1.

Emissions

Emission factors for each climate zone and land use category were taken from the IPCC Wetland supplement[23]. Emission factors were averaged for IPCC categories that were given at a higher level of detail (e.g. nutrient-poor vs. nutrient-rich boreal forest) than the available land use categories from the GPD (see Extended Data Table 1). Equally, we averaged the supplied emission factors for grassland and cropland in order to obtain emission factors of the land use class "Agriculture". We included emissions from ditches and DOC exports by using emission factors and default cover fraction of ditches given by the IPCC[23]. Since the IPCC Wetlands Supplement does not provide an emission factor for tropical peat extraction sites, we assumed the same emissions as for temperate/boreal peat extraction.

Radiative forcing model

The model uses simple impulse-response functions[29] to estimate radiative forcing effects of atmospheric perturbations of CO_2, CH_4 and N_2O fluxes[13]. For CO_2, we adopted the flux fractions and perturbation lifetimes used by ref[24]. In the model, we assume a perfectly mixed atmosphere without any feedback mechanisms but include indirect effects of CH_4 on other reagents and aerosols[11]. We estimated the approximate effects of radiative forcing on global mean temperature as˜1.23 K per 1 W/m² radiative forcing[30].

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Author contributions

A. G., J. C., G. J. and V.H. conceived the study. A. G., A. B., J. C., H. J. assembled input data. A. G. implemented the simulation model with contributions from J. C. All authors discussed the results and implications. A. G. led writing of the manuscript with comments/edits from all authors.

Author information

The authors declare no competing interests.