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Optimal Control Model for Managing Land Subsidence and GHG Emissions in Peatlands

Dewy Verhoeven
Environmental Economics and Natural Resources Group, Wageningen University & Research, Wageningen, Netherlands (dewy.verhoeven@wur.nl)

Peatlands are crucial carbon reservoirs, containing one-third of global soil carbon. Many peatlands undergo extensive drainage for agriculture, causing land subsidence and substantial greenhouse gas (GHG) emissions. Peatland drainage contributes approximately 5% to global anthropogenic GHG emissions. Rewetting is considered an effective climate and subsidence mitigation strategy, strongly reducing CO_2 emissions. However, this comes at the cost of reduced agricultural productivity and can (temporarily) increase methane emissions. This paper addresses these trade-offs by developing a bio-economic optimal control model for managing subsiding peatlands, incorporating social costs and emission impacts.
Our model integrates water level management, subsidence dynamics, and monetization of effects on agricultural profits, management costs, and GHG emissions. Through numerical simulations, the model optimizes the groundwater level pathway (*g(t)*) over time achieved through drainage, maximizing net societal benefits. We model the relation between drainage intensity and the peat thickness (*S(t)*), and monetize the impacts on agricultural profits (*y(S, g, t)*), water management costs (*m(g, t)*), and climate costs (*c(S, g, t)*), thus considering the objective function:

$$V^* = \max_{g(t),T} V[S,g,t] = \int_0^T (y(S,g,t) - m(g,t) - c(S,g,t))e^{-\delta t}dt - \theta(T) \qquad (1)$$

Subject to land subsidence:

$$\dot{S}(t) = \dot{S}(S,g,t) \qquad (2)$$

Where *t* $\in$ *[0, T]* represents the exploitation period of peat before full rewetting.
We apply our model to the Dutch peat meadows, which suffer from severe subsidence and are responsible for 3% of Dutch yearly GHG emissions. We parametrize our model based on empirical data found in literature, existing physical subsidence models and peatland emission factors. For a welfare analysis, we compare the optimal pathway to a Business-as-Usual (BAU) scenario in which financial net benefits are maximized, ignoring climate costs.
Baseline simulations for a typical peatland plot indicate that it is socially optimal to lower drainage intensity from year 0 and reduce the exploitation period before full rewetting, compared to the

BAU. Sensitivity analysis reveals that optimal pathways are particularly sensitive to changes in agricultural prices and marginal damage costs of carbon. The net social benefit of adopting the optimal drainage path over BAU is around € 46,800 ha^{-1} in the baseline, growing considerably with lower discount rates and higher marginal cost of carbon. Using a spatial soil and subsidence data set of Dutch peat meadows, we are able to analyse spatial differences in optimal pathways and identify key areas where (quick) rewetting would be most beneficial.

This research underscores the efficacy of a bio-economic optimal control model in designing sustainable subsidence and climate mitigation measures for peatlands. Results suggest that (partial) rewetting of peatlands yields significant long-term social benefits, even with reduced agricultural productivity.