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Transforming agriculture under climate change: A coupled framework of process-based, optimization and agent-based models

Andrea Kaim[a], Bartosz Bartkowski[b], Malin Gütschow[b], Irina Heiß[a], Johannes Linde[b]

[a]Helmholtz Centre for Environmental Research – UFZ, Department Computational Landscape Ecology, Permoserstr. 15, 04318 Leipzig, Germany; [b]Helmholtz Centre for Environmental Research – UFZ, Department Economics, Permoserstr. 15, 04318 Leipzig, Germany, E-Mail: andrea.kaim@ufz.de

Abstract: Agriculture in Germany and across Europe remains largely monofunctional, prioritizing high yields of food, fodder, and biomass, while other ecosystem services (ESS) such as climate regulation, drought protection, or habitat for biodiversity are often neglected. At the same time, climate change is intensifying the call for a transformation towards multifunctional agricultural landscapes that balance productivity with resilience and sustainability.

We present a coupled modelling framework to explore ecological and societal trade-offs in this transformation. The framework integrates (i) a spatial multi-objective optimization algorithm (Hildemann et al., 2023) linked with the Agricultural Production Systems sIMulator (APSIMx, https://www.apsim.info/) and a habitat connectivity model to identify Pareto-optimal management allocations, and (ii) an agent-based model (ABM) that simulates farmers' management decisions as a response to different policy incentives.

The Optimization algorithm allocates management bundles (comprising fertilization, soil management, crop rotations, and linear landscape elements) across fields to maximize the objectives agricultural yield, climate regulation, water quality, and biodiversity potential. To reduce computational effort, APSIMx simulations are pre-computed and applied through a look-up table during the optimization while the habitat connectivity model is integrated directly into the optimization process. The ABM incorporates APSIMx outputs to evaluate farmers' decisions on management bundle allocation and policy impacts. Both the optimization and the ABM generate spatially explicit land-use maps of field-level management bundles, enabling direct comparison and trade-off analysis.

By contrasting these results (Bartkowski et al., 2020), we identify solutions that are both ecologically optimal and socially feasible, allowing preferences for ESS to be explicitly considered. The framework will be demonstrated in an intensively farmed region in Northwest Saxony, Germany, under alternative climate scenarios. Beyond this case, the approach is transferable to other regions and scales, supporting policy and planning processes that seek to reconcile ecosystem services, agricultural production, and climate adaptation.

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