InSEEDS model ODD+D Protocol

As InSEEDS integrates LPJmL as a biophysical model component, we provide a brief description of the LPJmL model using the “overview” part of the ODD protocol (as agreed on with Volker Grimm). We then describe the InSEEDS model, with a focus on the agent-based component and its interactions with LPJmL, separately and in depth.

LPJmL Overview part of ODD Protocol

A complete, detailed model description, is provided at: Schaphoff et al. (2018), and von Bloh et al. (2018), with subsequent model description papers for individual model extensions, see https://doi.org/10.5281/zenodo.3497212

The overall purpose of our model is to provide global-scale assessments of changes in the terrestrial biosphere, hydrology, and agrosphere in response to climate change, land-use change, and other factors. This is accomplished by gridded simulations of biogeochemical, ecological and hydrological processes.

Specifically, we are addressing the following questions: Among others, climate change impacts on vegetation, carbon cycle, nitrogen cycle, crop yields, and freshwater; adaptation options in agriculture; transgression of planetary and local environmental boundaries.

To consider our model realistic enough for its purpose, we use the following patterns: LPJmL versions are continuously evaluated against reference data for global carbon, nitrogen, and water dynamics (e.g. Schaphoff et al. 2018b, von Bloh et al. 2018) as well as crop yields (e.g. Müller et al. 2017) Individual model feature developments are generally evaluated against relevant reference data. Participation in model intercomparison studies (e.g. AgMIP, ISIMIP) provide the basis for comparing LPJmL simulation results against other state-of-the-art models. .

The model includes the following entities:
LPJmL's core architecture is object-oriented, and the entities and state variables can be described as follows: The LPJmL model consists of several entities and state variables that are used to simulate the dynamics of the Earth system. The entities and state variables can be described as follows: The cell is the top-level entity in the LPJmL model, representing a spatial unit of analysis. The cell is associated with a single state variable, which is land use. Stands are the patches within a cell, where each stand represents a specific Crop Functional Type (CFT) or a combination of natural Plant Functional Types (PFTs). The state variable associated with stands depends on the type of land use. For natural PFTs, the state variable is the natural vegetation distribution, while for agricultural land, it is the CFT realization. PFTs are the plant categories in the LPJmL model, which include Crop Functional Types (CFTs) as subsets. The state variables associated with PFTs are not explicitly defined, but could include Net Primary Production (NPP) or vegetation carbon. The soil entity in the LPJmL model is associated with several state variables, including soil carbon and nitrogen pools, as well as other variables such as NO3 and NH4. The water flows and stocks entity in the LPJmL model is associated with several state variables, including local runoff, river discharge, reservoirs, and withdrawals.

Note that this description is not exhaustive, and other entities and state variables, like carbon and nitrogen pools, freshwater stocks, soil columns distinguished by soil texture classes, river stretches, crop and water management types are included in the LPJmL model.

They are characterized by the following state variables Vegetation is represented by different organs, which have carbon and nitrogen pools in leaves, roots, sapwood, and heartwood (for trees), leaves and roots (for grasses) and leaves, roots, harvestable storage organ, and mobile pools (for crops). Each crop and plant functional type (PFT) is represented with one average individual per simulation unit. Soils are represented as 5 hydrologically active layers (20, 30, 50, 100, 100 cm depth) and a 6th bedrock layer as a heat reservoir for computing soil temperatures per layer. Each soil layer has a water content, organic carbon content, and mineral nitrogen (ammonium and nitrate) and organic nitrogen pools. Organic litter pools are represented per

PFT in above-ground, below-ground, and incorporated (e.g. after tillage, bioturbation) above-ground litter pools. In addition to water in soils, it is also represented as amounts in rivers, lakes and reservoirs.

The spatial and temporal resolution and extent are: spatially flexible, typically at 0.5 x 0.5° globally over land, mostly daily simulation time steps

The most important processes The processes represented in the LPJmL model that are relevant for its use within InSEEDS, are daily simulations of plant photosynthesis and autotrophic respiration, plant growth (including yield formation), and dynamics of soil organic matter from litterfall and decomposition processes. All these processes are affected by nitrogen and water supply, which are also simulated as the result of different input, transformation, and loss processes.

Model dynamics are driven by input data representing daily weather conditions, atmospheric carbon dioxide concentrations and nitrogen deposition, soil texture types, river flow directions, lakes and reservoirs, extent of agricultural land use types, nitrogen fertilization and other crop management.

InSEEDS ODD+D Protocol

Outline (template)		Guiding questions	Own ODD+D Model description
I	I.i Purpose	I.i.a What is the purpose of the study?	The InSEEDS model is developed to foster understanding of the adoption and spreading of regenerative agricultural practices on up-to-global scales. Using InSEEDS simulations, we aim to develop future projections of co-evolutionary, social-ecological transition pathways, and understand their potential social and ecological impacts.
		I.ii.b For whom is the model designed?	The model is primarily targeted at a scientific audience of land system / sustainability transition scientists.
	I.ii Entities, state variables, and scales	I.ii.a What kinds of entities are in the model?	InSEEDS is built using the copan:LPJmL modeling framework and therefore consists of the three taxa the framework prescribes: The socio-cultural taxon (CUL), the metabolic taxon (MET) and the environmental taxon (ENV). These taxa are integrated within two distinct model components; an Agent-Based model component, *Anthroposphere,* covering processes in the CUL and MET taxa; and a Dynamic Global Vegetation Model (LPJmL), *Biosphere,* component, covering processes in the ENV taxon. Entities in the ABM component are two different types of farmer agents: traditionalists and pioneers. Through the DGVM LPJmL, 0.5*0.5 degree grid cells are provided as the spatial model structure. One agent is allocated to each grid cell.
		I.ii.b By what attributes (i.e. state variables and parameters) are these entities characterized?	Characterization of agents: Farmer agents are either part of the *traditionalist* or *pioneer* agent type group. Both of these types have the same basic decision-making structure, resting on the Theory of Planned Behaviour, but differ in their weighting of different attributes within the theory. These are the importance of *Norms* compared to individual *Attitude*; the degree to which information on *soil health* vs. *yield* is considered in decision-making; and the perceived behavioural control (PBC). Characterization of spatial units: A farmer agent is allocated to each model grid cell (that is provided through LPJmL) that has land use.
		I.ii.c What are the exogenous factors / drivers of the model?	Exogenous model drivers mainly stem from the input data provided to LPJmL.
		I.ii.d If applicable, how is space included in the model?	InSEEDS is a spatially explicit model, it uses the global 0.5*0.5-degree LPJmL grid. InSEEDS can also be run on smaller spatial scales, for example, for single countries.
		I.ii.e What are the temporal and spatial resolutions and	Both model components have their own temporal resolution. In LPJmL, the resolution is at up to a daily temporal scale. Monthly and yearly updates are also possible.

		extents of the model?	For the coupled model, one time step represents one year. At each timestep, information between the two components is exchanged bidirectionally: LPJmL provides information about certain biophysical parameters (currently soil organic carbon and yield) to the ABM, this is factored into the farmer decision-making process simulated in the ABM, and the management decisions for the following year (time step) are provided as input to LPJmL. LPJmL, in turn, simulates a year under this chosen management style and, at the next time step, the process is repeated. As the ABM uses the spatial structure provided by LPJmL, there are no differences between the components regarding spatial resolution (both 0.5*0.5 degree).
	I.iii Process overview and scheduling	I.iii.a What entity does what, and in what order?	On a yearly basis, the farmer agents make decisions on their management style. They can choose between conservation tillage or conventional agricultural management. In the decision-making process, the agents evaluate their inclination to switch to a different strategy by considering attitude, norm and perceived behavioural control. The model proceeds in discrete time steps (years). Each year, farmers: 1. Evaluate their soil carbon and crop yield. 2. Compare their performance with that of neighboring farmers. 3. Evaluate their inclination to switch to a different strategy by considering attitude (using information from step 1 and 2), social norm and perceived behavioural control. To update_behaviour: If agent > threshold_for_minimum_duration_between_strategy_switches: Inclination_to_switch = (weight_attitute*attitude + weight_norm*norm) * perceived behavioural control If inclination_to_switch is above 0.5: Switch_behaviour Set_back_counter_for_ minimum_duration_between_strategy_switches Lower_perceived_bahvioural_control If inclination_to_switch is between 0.4 and 0.5: raise _perceived_behavioural_control raise_counter_for_ minimum_duration_between_strategy_switches If inclination_to_switch is below 0.4: raise_counter_for_ minimum_duration_between_strategy_switches
II	**II.i Theoretical and Empirical Background**	II.i.a Which general concepts, theories or hypotheses are underlying the model's design at	LPJmL component submodel: The InSEEDS Biosphere submodel, i.e., the LPJmL model component, rests on the dynamic global vegetation modeling paradigm, that presupposes vegetation as a function of climate and abiotic factors. It globally and dynamically models carbon, nitrogen, water and energy cycles, using a set of different plant functional types. LPJmL endogenously models the composition of vegetation (grassland, trees, …) and how vegetation

		the system level or at the level(s) of the submodel**(s) (apart from the decision model)?** What is the link to complexity and the purpose of the model?	dynamically reacts to shifts in climate and other factors. Through the dynamic set-up, it reflects possibilities of changing land use. Copan:CORE ABM submodel: The model is based on the Theory of Planned Behavior (TPB). More information is provided below. Following agent-based logic, it rests on the assumption that micro-level interactions give rise to macro-level emergent phenomena, like spatial adoption patters. The model also assumes that social-ecological interactions are important to capture farmer decision-making.
		II.i.b On what assumptions is/are the agents' decision model(s) based?	The model is based on the Theory of Planned Behavior (TPB), which suggests that an individual's behavior is influenced by: ● **Attitude**: Attitude towards different agricultural goals is based on the evaluation of ecological performance This rests on both personal experience (soil carbon and crop yield on their land over time) and social learning (comparison with neighbors). ● **Social Norm**: Local descriptive social norm, based on the behaviors of surrounding farmers (moore neighborhood). ● **Perceived Behavioral Control (PBC)**: Farmers' confidence in successfully being able to change their management strategies. Farmers periodically decide whether to change their agricultural strategy based on their TPB score. If the score is high (above a threshold), they switch strategies; if it's near the threshold but remains below, their perceived behavioral control increases slightly.
		II.i.c Why is a/are certain decision model(s) chosen?	The TPB was chosen on the basis of mapping findings from literature on farmer decision-making to the HuB-CC framework (Constantino et al., 2021).
		II.i.d If the model / a submodel (e.g. the decision model) is based on empirical data, where does the data come from?	We are using an input dataset on the distribution of conservation agriculture practices generated by Porwolik et al (2019). This data is used to globally allocate the initial management strategies of our farmer agents.
		II.i.e At which level of aggregation were the data available?	Grid cell level.
	II.ii Individual Decision Making	**II.ii.a What are the subjects and objects of decision-making? On which level of aggregation is decision-making modeled? Are multiple levels of decision making included?**	Subjects of decision-making: farmer agents, one farmer agent per LPJmL grid cell that shows land use. The agents could, given by their large field size, also be perceived as representative agents. ▯ 45064 farmer agents are simulated for a global InSEEDS simulation Objects of decision-making: agricultural management strategy (conservation tillage / conventional management)

		II.ii.b What is the basic rationality behind agents' decision-making in the model? Do agents pursue an explicit objective or have other success criteria?	Using the TPB as our decision-making backbone, agents are still behaving rationally to a certain extent. For example, in the attitude component, agents have certain individual attitudes (e.g., towards reaching soil health or maximizing yield) that they try to improve using certain management strategies. However, this is no classical rational choice approach in the sense of strict profit maximization, for example, as agents are also influenced by social norms.

		II.ii.c How do agents make their decisions?	Utility function
			
			self.tpb = (self.weight_attitude * self.attitude
			+ self.weight_norm * self.social_norm) * self.pbc
			
			if self.tpb > 0.5:
			# switch strategy
			self.behaviour = int(not self.behaviour)

		II.ii.d Do the agents adapt their behavior to changing endogenous and exogenous state variables? And if yes, how?	Adaptation of behavior to changing endogenous state variables: Farmers adapt by changing their behavior based on their perceived success (crop yield and soil carbon) and the behavior of their neighbors. They switch strategies when their TPB score exceeds a certain threshold.
		II.ii.e Do social norms or cultural values play a role in the decision-making process?	Local descriptive social norms are evaluated as part of the TPB by the farmer agents.
		II.ii.f Do spatial aspects play a role in the decision process?	Through the LPJmL grid, farmers are allocated on a spatially explicit network. Geographic proximity is therefore decisive for both social norm evaluation, as well as social learning from neighboring agents.
		II.ii.g Do temporal aspects play a role in the decision process?	Farmer agents have a memory of past levels of soil carbon and yield to compare their current observations. Furthermore, the agents have a counter tracking the duration since their last strategy switch to account for the fact that frequent (e.g., yearly) switching is unrealistic.
		II.ii.h To which extent and how is uncertainty included in the agents' decision rules?	For switching probabilities close to the switching threshold, the farmers' perceived behavioural control is raised. This way, if the following decision-making evaluation results in a similar inclination to switch based on attitude and norm, farmers account for the fact that they were already close to switching (i.e., they considered an uncertain situation before) and are more inclined to actually switch.

	II.iii Learning	II.iii.a Is individual learning included in the decision process? How do individuals change their decision rules over time as consequence of their experience?	Farmers engage in **individual learning** by comparing their current with their past performance. They adjust their attitude based on the development trends of ecological parameters over time.
		II.iii.b Is collective learning implemented in the model?	Farmers engage in **social learning** by comparing their performance with their neighbors. They adjust their attitude toward their current strategy based on whether they observe an improvement on their own land (individual learning), and whether their neighbors using different strategies are more successful (social learning).
	II.iv Individual Sensing	II.iv.a What **endogenous** and **exogenous** state variables are individuals assumed to sense and consider in their decisions? **Is the sensing process erroneous?**	Farmers can "sense" their soil carbon, crop yield, and the strategies and performance of their neighbors. These variables are endogenous to the InSEEDS model, they are calculated within the LPJmL and ABM components of InSEEDS. They use this information to update their attitudes and social norms.
		II.iv.b What state variables of which other individuals can an individual perceive? **Is the sensing process erroneous?**	Farmers can non-erroneously perceive behaviour, soil carbon and crop yield of their direct neighbors.
		II.iv.c What is the spatial scale of sensing?	Local grid-based network (the farmer's 8 neighboring cells – moore neighborhood).
		II.iv.d Are the mechanisms by which agents obtain information modeled explicitly, or are individuals simply assumed to know these variables?	Obtaining information on biophysical variables is modeled through the information exchange with LPJmL (LPJmL simulation of the current year provides the agents with yield/soil values). Other processes are modeled within the agent-based InSEEDS component only: The evaluation of social norms is done by calculating the average management behaviour during decision-making.
		II.iv.e Are costs for cognition and costs for gathering information	Currently, these are not considered.

		included in the model?	
	II.v Individual Prediction	**II.v.a Which data uses the agent to predict future conditions?**	Farmers do not directly predict future environmental conditions but rely on past performance (previous year's soil carbon and crop yield) and social learning for decision-making.
		II.v.b What internal models are agents assumed to use to estimate future conditions or consequences of their decisions?	No assumption of future conditions is made within this current model version.
		II.v.c Might agents be erroneous in the prediction process, and how is it implemented?	Prediction is currently not modeled.
	II.vi Interaction	II.vi.a Are interactions among agents and entities assumed as direct or indirect?	Farmers interact indirectly through social learning and social norms. In the social learning component of attitude formation, they compare their crop yields and soil carbon with those of neighbors who use different strategies, adjusting their own attitude accordingly. For the social norm evaluation, agents evaluate the average behaviour of their direct neighbors.
		II.vi.b On what do the interactions depend?	Spatiality is the foundation for both social and social-ecological interactions: For social interactions, it manifests in the grid-based neighborhood network (only 8 direct neighbors constitute the neighborhood agents can learn from and perceive the descriptive norm of). Social-ecological interactions also solely take place within the agents' own (individual learning) and adjacent (social learning) cells.
		II.vi.c If the interactions involve communication, how are such communications represented?	No communication is represented explicitly.
		II.vi.d If a coordination network exists, how does it affect the agent behaviour? Is the structure of the network imposed or emergent?	No coordination network exists in the current model version.

	II.vii Collectives	II.vii.a Do the individuals form or belong to aggregations that affect, and are affected by, the individuals? Are these aggregations imposed by the modeller or do they emerge during the simulation?	No groups exist in the current model version.
		II.vii.b How are collectives represented?	No collectives exist in the current model version.
	II.viii Heterogeneity	**II.viii.a Are the agents heterogeneous? If yes, which state variables and/or processes differ between the agents?**	The current model version includes two different agent types: pioneers and traditionalists. Both have the same state variables and structure of decision-making, but differ in their parametrization (i.e., weighting of different dimensions of the decision-making function). Exchanging agent types would affect the simulation.
		II.viii.b Are the agents heterogeneous in their decision-making? If yes, which decision models or decision objects differ between the agents?	Yes. Both agent types make their decisions on the basis of the TPB, but vary in their weighting of certain parameters: Within the attitude component of the decision-making function, the traditionalist places a focus on yield success, while the pioneer more strongly considers soil health. This is done through a relatively higher weighting of information on crop yield (traditionalist) or soil carbon (pioneer) for attitude formation. Furthermore, while for both agent types own attitudes are more strongly weighted than social norm, pioneers place an even larger emphasis on own attitudes and weigh norm very little. Compared to pioneers, traditionalists weigh norms more (Casagrande et al., 2016). PBC varies in the initialization of the agents; pioneers are assumed to have a higher PBC than traditionalists.
	II.ix Stochasticity	II.ix.a What processes (including initialization) are modeled by assuming they are random or partly random?	1) Allocation of agent types (initialization) 2) Initial strategy_switch_time counter to prevent synchronization (initialization)
	II.x Observation	II.x.a What data are collected from the ABM for testing, understanding, and analyzing it, and how and when are they collected?	The model tracks variables such as: ● The proportion of farmers using conservation / regenerative versus conservative strategies. ● Soil carbon and crop yield at the farm and landscape levels. ● Farmers' TPB scores and PBC values. ● The contributions of different factors of the decision-making function to a behavioural switch This information is collected for each timestep (year) of the simulation, and is evaluated using sensitivity analyses.

		II.x.b What key results, outputs or characteristics of the model are emerging from the individuals? (Emergence)	Emergent phenomena in the model include: ● Patterns of agricultural management strategies across the landscape. ● The impact of attitude (social and individual learning), PBC, and social norms on the distribution of conservation and conservative farming strategies. ● Changes in overall soil carbon and crop yield patterns as farmers adjust their behaviors.
II	**II.i Implementation Details**	**III.i.a How has the model been implemented?**	InSEEDS is the first model built with the copan:LPJmL framework, which is available on github: https://doi.org/10.5281/zenodo.14246191 (Breier et al., 2025). This framework integrates LPJmL, a dynamic global vegetation model, as a model component within the copan:CORE framework (Donges et al., 2020). The integration of LPJmL into copan:CORE technically is done through a technical coupling using different software items: The extension of LPJmL by sockets, the pycoupler tool, and a "virtual LPJmL" component in copan:CORE. Copan:CORE, a python-based modeling framework developed to built World-Earth Models of different kinds (agent-based, equation-based, etc.).
		III.i.b Is the model accessible and if so where?	Breier, J., Schwarz, L., Prawitz, H., & Hotz, R. (2024). Model of integrated social-ecological resilient land systems (InSEEDS) (v0.2.3). Zenodo. https://doi.org/10.5281/zenodo.14265856
	III.ii Initialization	III.ii.a What is the initial state of the model world, i.e. at time t=0 of a simulation run?	Before the simulation of the coupled model dynamics (t=0) begins, a set of spin-up runs of the LPJmL submodel is conducted. These spin-ups serves to simulate the land system prior to the coupled simulation. During a first "*natural vegetation spinup*", usually running from about 1000 B.C. until the year 1500 A.D., natural vegetation and soils are equilibrated without human input. Afterwards, a *social-ecological spinup* is conducted. In a first step, for about 300-400 years, land use is slowly externally introduced into the simulation. In a second step, during the so-called historic run, this is continued (where's the difference to the land use spinup again?) until the year of the model coupling. In this year (t=0), the dynamic social-ecological simulation with the InSEEDS model begins. At t=0, one farmer agent is initialized for each LPJmL cell in which landuse is possible. Their current behaviour at that time is determined by the aforementioned dataset by Porwolik et al (2019). Farmers are randomly assigned as either conservative or progressive, with probabilities defined in the configuration (progressive_probability). Neighbors are assigned based on the spatial configuration of cells.
		III.ii.b Is initialization always the same, or is it allowed to vary among simulations?	The farmer type assignment at initialization of the coupled model is random, so there is variation among simulations.

		III.ii.c Are the initial values chosen arbitrarily or based on data?	The initial values of agent parametrization are chosen on the basis of different literature results (e.g., regarding the different weighting of attitude and norms).

	III.iii Input Data	III.iii.a Does the model use input from external sources such as data files or other models to represent processes that change over time?	For the LPJmL model, various external inputs are used:
			- The LandInG 1.0 Toolbox (Ostberg et al., 2023)
			- ISIMIP athmospheric climate input data (Lange et al., 2022)
			
			The standard inputs used for LPJmL simulations are:
			`"temp" : { "id" : 1, "fmt" : "clm", "name" : "ISIMIP3av2/obsclim/GSWP3-W5E5/tas_gswp3-w5e5_obsclim_1901-2019.clm"},`
			`"prec" : { "id" : 2, "fmt" : "clm", "name" : "ISIMIP3av2/obsclim/GSWP3-W5E5/pr_gswp3-w5e5_obsclim_1901-2019.clm"},`
			`"lwnet" : { "id" : 4, "fmt" : "clm", "name" : "ISIMIP3av2/obsclim/GSWP3-W5E5/lwnet_gswp3-w5e5_obsclim_1901-2019.clm"},`
			`"lwdown" : { "id" : 43, "fmt" : "clm", "name" : "DUMMYLOCATION"},`
			`"swdown" : { "id" : 3, "fmt" : "clm", "name" : "ISIMIP3av2/obsclim/GSWP3-W5E5/rsds_gswp3-w5e5_obsclim_1901-2019.clm"},`
			`"cloud": { "id" : 0, "fmt" : "clm", "name" : "DUMMYLOCATION"},`
			`"wind": { "id" : 15, "fmt" : "clm", "name" : "ISIMIP3av2/obsclim/GSWP3-W5E5/sfcwind_gswp3-w5e5_obsclim_1901-2019.clm"},`
			`"tamp": { "id" : 11, "fmt" : "clm", "name" : "DUMMYLOCATION"}, /* diurnal temp. range */`
			`"tmax": { "id" : 10, "fmt" : "clm", "name" : "ISIMIP3av2/obsclim/GSWP3-W5E5/tasmax_gswp3-w5e5_obsclim_1901-2019.clm"},`
			`"tmin": { "id" : 9, "fmt" : "clm", "name" : "ISIMIP3av2/obsclim/GSWP3-W5E5/tasmin_gswp3-w5e5_obsclim_1901-2019.clm"},`
			`"humid": { "id" : 14, "fmt" : "clm", "name" : "ISIMIP3av2/obsclim/GSWP3-W5E5/huss_gswp3-w5e5_obsclim_1901-2019.clm"},`

	III.iv Submodels	III.iv.a What, in detail, are the submodels that represent the processes listed in 'Process overview and scheduling'?	**Attitude Calculation** The farmer's attitude is calculated based on the weighted combination of: • **Attitude toward own land**: Based on the comparison between current and previous soil carbon and crop yield. • **Attitude through social learning**: Based on the comparison between the farmer's performance and the performance of neighbors using different strategies. **Social Norm Calculation** Social norm is calculated as the proportion of neighbors using the same farming strategy. If the majority of neighbors use a different strategy, the farmer feels pressure to conform. **TPB and Strategy Update**

				Each farmer calculates their TPB score based on their attitude, social norm, and PBC. If the TPB score exceeds a threshold (0.5), the farmer switches strategies. The PBC value is adjusted over time based on the farmer's experience with switching strategies.
			III.iv.b What are the model parameters, their dimensions and reference values?	# Analogous to LPJmL pftpar, define the AFT parameters for the two different # farmer types aftpar: # AFT for conservative/traditional values following farmer tending to stay # with conventional agriculture traditionalist: pbc: 0.75 weight_attitude: 0.6 weight_yield: 0.8 weight_soil: 0.2 weight_norm: 0.4 weight_social_learning: 0.05 weight_own_land: 0.95 # duration of waiting time before switching to another strategy strategy_switch_duration: 10 # years # AFT for progressive farmer who more likely tends to switch to # regenerative agriculture pioneer: pbc: 0.95 weight_attitude: 0.8 weight_yield: 0.3 weight_soil: 0.7 weight_norm: 0.2 weight_social_learning: 0.1 weight_own_land: 0.9 # duration of waiting time before switching to another strategy strategy_switch_duration: 10 # years
			III.iv.c How were submodels designed or chosen, and how were they parameterized and then tested?	The components of the submodels were chosen to represent the components of the theory of planned behaviour: attitude, norm and perceived behavioural control (Ajzen, 1985). To endogenously, within model dynamics, determine the values of the norms and attitude components, certain design choices were made. For the evaluation of social norms, a local descriptive norm was chosen (Bicchieri, 2016). This choice rests on the local network structure provided by LPJmL. Descriptive norms (compared to other types of norms, like injunctive norms) were chosen as a first norm implementation that was simple to formalize and implement. In following model versions, we aim to implement a combination of descriptive and injunctive norms (Bechthold et al., in review). The attitude submodel was chosen to be the most suited entry point for the biophysical information (crop yield/soil carbon) provided by LPJmL. The two agent types are conceptualized to have different attitudes. The pioneers' positive attitude towards soil health makes them more inclined towards prioritizing information on soil organic carbon. The traditionalists' positive attitude towards yield maximizing, in turn, makes them factor in information on crop yield more strongly.

				The implementation of attitude is split in two parts: a comparison of one's strategy's success to neighboring farmers (social learning) and a comparison of one's own land's performance (own land) over time (individual learning). As the social learning part comprises a comparison of the success of different strategies across the neighborhood, it presupposes gaining knowledge about possible outcomes of one or the other action strategy: if agent x, who is a pioneer, observes their neighbors using regenerative agriculture performing much better in terms of soil health, they associate that outcome with the management strategy "*regenerative agriculture*". If they, themselves, currently practice *conventional farming*, the social learning component makes them more likely to switch to *regenerative agriculture*. In contrast, the comparison based on the farmers' own land is not based on such beliefs directly connected to a given management strategy. Here, performance is compared over time. If performance worsens over time, based on the own_land comparison submodel, farmers are more likely to switch strategy without explicitly considering the directionality of switching. The differentiation of weighing within the two presented agent types rests on conceptualizations of farmer decision-making heterogeneity, such as Casagrande et al (2019) or Malek et al (2019). To test the model, a global sensitivity analysis was conducted, systematically varying model parameters in the agent-based modeling component to test the model's sensitivity to changes in to the different parameters. The sensitivity analysis is, in depth, described in the paper.

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