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An Agent-based Approach for Simulating Transformation Processes of Socio-ecological Systems as Serious Game

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Abstract. The transformation of socio-ecological systems (SES) has accelerated and is driven by a broad range of factors. Consequently, providing resilience in SES became more challenging, as the drivers are influenced by complex interactions between the social actors (i.e., consumers, producers, and influencers of ecosystem services) and their interactions with the ecosystem itself. As the entire society is affected by landscape changes and lasting damage of ecosystems resulting from the interplay of different drivers, a better public understanding of the transformation processes needs to be achieved. Because dynamics of SES are the result of emergent effects caused by complex local interactions of the actors, the comprehensibility is restricted and public communication is challenging. This work aims at making dynamics of SES experienceable by using an agent-based simulation approach as serious game. By modeling the actors as intelligent software agents, differentiated decision-making and individual goals can be implemented and transformation processes can be simulated.

Keywords: Ecosystem Services, Resilience, Socio-Ecological Systems, Agent-based Simulation, Serious Game

1 Introduction

Globalization is a central feature of socio-ecological systems (SES) and determines its dynamics. SES are coupled human–environment systems and consist of an environmental component, human and institutional actors related to it, and interactions between these entities. Thus, the decisions and the behavior of the actors which lead to globalization affect the entire system and accelerate its transformation. The transformation process is driven by different factors (e.g., demographic shift, climate change, and world-wide connectedness) which are operating at different temporal and spatial scales. Yet, these drivers of ecosystem change are results of earlier decisions made by the actors within SES. Due to these complex interactions and dependencies, SES are difficult to predict and providing resilience is challenging [27]. Some of these drivers can be complementary and result in a change of the environment which then becomes visible as changes of the landscape and might influence the well-being of the inhabitants [54,58]. However, lasting damage of ecosystems can often not be identified in time, as the damaging use of the ecosystem has already occurred and thus cannot be prevented [46].

As everybody is affected by lasting damage of ecosystems it is a human desire to understand the ecological effects of decisions and actions of actors in SES and how they will influence its future development and transformation. This is challenging, as SES are complex systems with different types of actors, multi-layered human-environment relations, and uncertain mechanisms. In terms of SES, three types of actors need to be distinguished: (a) consumers: interacting with or reacting to ecosystem services, i.e., adapting activities, work, and life with respect to the environment, (b) regulators: representing public interests and therefore specifying and supervising regulations as well as offering land areas for specific use, and (c) producers: institutional actors in decision-making processes with respect to land-use change, i.e., changing use of their "own" land or the acquisition of new land. Consumers are demanding specific services from the ecosystem, e.g., mobility or high air quality, which are influenced by the producers, e.g., by building new factories. Regulators have to provide land for a specific use and balance opposing interests of social and institutional actors. In consequence, an ecosystem service market emerges, where the participants and providers are interacting or competing with each other when acquiring, maintaining, and trading ecological areas and ecosystem services related to them.

As the components of SES are interlinked at different temporal as well as spatial scales and as complex feedback loops exist between the actors, SES have the ability to self-organize and respond to disturbances and changing conditions. Self-organizing adaptive behavior, however, leads to emergent and non-linear dynamics [21]. Thus, for making these complex mechanisms and resulting emergent effects investigatable, a sophisticated technique is needed for modeling and analyzing individual decision-making processes and interactions between the three groups of actors.

During the last decades, computer simulation has become a standard means for analyzing, planning, and optimizing complex systems like SES. Using computer simulation, artificial systems can be generated as abstraction of real-world systems. Considering SES, the observed meta-behavior results from the local interactions between the actors in the system. Thus, for simulating SES, actor-based computer simulation approaches need to be applied. This enables a more sophisticated analysis of individual behavior and local interactions, which then lead to global transformation of SES, i.e., emergent effects.

In this work, we are proposing an approach for modeling and simulating actors of SES and their interactions when trading ecological areas for providing a better public understanding by making transformation processes of SES and resulting ecological consequences experienceable. In contrast to conventional simulation studies, which aim at analyzing existing or fictional systems, a serious game approach will be used to simulate real-world processes. Doing so, a comprehensible and interactive approach for understanding complex systems and mechanisms can be provided users of the system can be educated [1].

Instead of defining SES from an economic perspective by describing market behavior using standard decisions, an actor-based perspective enables the differentiated consideration of different types of actors by modeling individual decision behavior. In computer simulation, agent-based simulation approaches have been established for modeling decision-behavior and interactions of actors on a micro level (i.e., consumers, producers, and regulators) leading to emergent behavior on a micro level (i.e., transformation of SES and landscape change). The approach developed in this paper consists of three major components: actor-based models of the participants, ecological models of the environment (i.e. the ecosystem), and a technical simulation core for conducting experiments.

2 Foundations

In order to simulate transformation processes of SES by using a market-oriented approach, domain-specific models are required for modeling the environment, the involved actors, and their behavior. Furthermore, serious games are a special case of a computer simulation, where certain requirements and preconditions need to be considered.

2.1 Socio-ecological Systems and Ecosystem Services

A socio-ecological system consists of both, ecological and social systems which are interdependent and constantly co-evolving. The fact, that human actors within the social system can benefit from the ecosystem is considered as *ecosystem service* (ESS) and provided by the ecosystem itself [40]. This benefit or utility exposes the relationship between nature and economy and enables a quantification of the ecosystem's value for the society while being close to the ecosystem. From an economic perspective, ESS can also be defined as a dividend human beings gain from ecosystems [13] and divided into four kinds of services [46]:

- **Provisioning Services**, characterizing material resources, which are provided by the ecosystem (e.g., food, raw materials or water),
- **Regulating Services**, containing regulating measures by the affected ecosystem (e.g., change of air quality, flood or disease control),
- **Cultural Services**, describing the immaterial and cultural utility (e.g., education value, spiritual/esthetically value or recreational value), and
- **Supporting Services** which are essential for the generation of the other services (e.g., nutrient circulation, photosynthesis or soil development).

Furthermore, each ESS can be described by primary and secondary indicators. As an example, for the provisioning service *food provision* the primary indicator *agricultural production* and the secondary indicator *land use* or *land cover* exist [18]. For each ecosystem, ESS and their primary and secondary indicators need to be identified individually, as each ecosystem is unique and has unique dependencies [46].

2.2 Ecosystem Service Markets

A market is defined as an economic place of negotiation where demand and supply meet and where resources are (re-)allocated between traders [28,29]. Each exchange relationship, also referred to as transaction, is defined as an exchange of an object of exchange (e.g., goods) and a medium of exchange (e.g., money). The transaction process itself can be divided into four phases [45]:

- **Knowledge phase**: In an initial situation, all market participants will be provided with necessary knowledge.
- **Intention phase**: All vendors publish their offer with a detailed product description and all potential purchaser publish their demand.
- **Agreement phase**: Making valid and secure contracts of purchase and specify the settlement phase.
- **Settlement phase**: Execution of the transaction (e.g., exchange of goods).

In terms of environmental management, market-oriented approaches (e.g., for modeling biodiversity conservation, carbon sequestration, and watershed protection) grew in popularity during the last years [28]. By braking down drivers of ecosystem transformation to the side of the market they originate from responsibilities can be distributed among the groups in charge. Doing so, mechanisms for achieving environmental objectives can be searched for and biodiversity of ecosystems can be protected [34].

Certainly for the conservation of ESS and for providing a cost-efficient management, market-based approaches seem to be suitable [33]. According to this, an *ecosystem service market* is defined as:

> "an institution that enables transactions between parties who have an interest in purchasing ecosystem services [...] and other parties who have control over condition of ecosystem services that allows them to supply improved condition if sufficient incentive is provided" [39, p. 4]

By creating ecosystem service markets, a potential for utilizing additional resources arises and more stakeholders can be incorporated into the process of conservation. However, in order to trade ESS on a market and to provide a more efficient environmental outcome, a payment system including an ecosystem-specific monetization is required [13,41].

2.3 Serious Games

A computer simulation is defined as the execution of a model which describes the behavior of a real or a fictive system over time [23]. In this paper, an ecological demand-supply-market will be modeled and simulated. Due to the complexity of interdependencies between ecosystem, the variety of market participants, and different market transactions taking place, it is necessary to chose a well-suited abstraction for keeping the simulation and its results comprehensible. For this reason, the application of the *serious game* concept seems feasible.

A serious game is a combination of scientifically relevant questions or problems and an abstract representation of reality by the means of games for making them experienceable. By involving the player using different kinds of interactions with the simulation, knowledge can be transferred in an indirect way and even complex connections or relationships between entities can be communicated [1].

The adaptation of the serious game concept to market simulation described in this paper is meant to provide a better understanding of the impact different ways of ecosystem usage have and support the identification of a balanced state. The player of the serious game can then use the awareness he/she gained and transfer the knowledge to reality.

2.4 State of the Art

When modeling complex actor-based systems for the application of computer simulation, the use of intelligent software agents has been established [31]. Agent-based modeling (ABM) is used for describing and simulating complex and emergent phenomena by using a collection of autonomous entities with individual decision-making and is well suited for simulating human behavior [8]. Each actor is implemented as individual software agent, which can perceive its environment and determine its actions accordingly. Depending on the complexity of the actors' deliberation processes, different types of agent architectures can be applied. The behavior of reactive agents is determined by a static action rules [19,2] in contrast to deliberative agents which use symbolic reasoning for planning its actions [14,42]. In a number of hybrid approaches, these two technologies have been merged [15].

Economic models are abstract representations of ecological systems and can be divided into static and dynamic models. Static models are time-independent and usually differential equation-based [16,48] while dynamic models use more sophisticated numerical techniques for describing the behavior of an ecosystem [4,43]. Furthermore, economic models are used for predicting future scenarios [7,12], yet, in terms of innovative concepts, e.g., *smart environments*, existing models are considered not to be sufficient [24]. For developing more sophisticated economic models, agent-based modeling can be used, too. Here, the process of land use planning is performed by agents representing the residents [11,35]. [38] and [47] describe the simulation of a landscape and ignore the fact that there are ecosystem services. In contrast, the work from [10] includes the changes of ecosystem services and their indicators in ecosystems.

For analyzing and optimizing supply and demand markets, computer simulation has been established as a standard means. Depending on the granularity and focus of the simulation study, it is referred to as macro- or microsimulation.

Markets can either be simulated as a whole on a macro-level for analyzing complex processes without considering the components of the system [56,53] or the single components of the market can be individually simulated on a micro-level resulting in the market meta-behavior to emerge from the local interactions of the components [3,44,57]. Market simulation has also been used for simulating competitive economic scenarios, e.g., land use transitions or valuation of ecosystems, from a market-based perspective [51,25]. But also ABM has been used for simulating individual market participants and their supplies and demands [26]. Another approach is to use *cellular automata* (CA) to model dynamics of ecosystems and ecosystem service markets. [17] and [32] use CA to represent the complex ecological relationships and to enable users to intuitively recognize patterns in a simulation. Yet, both approaches describe a model without the possibility of interaction outside the neighborhood and without a market.

Because of extensive consequence of irreparable ecosystems, it is necessary to develop approaches for increasing the public awareness regarding lasting damage of ecosystems due to misbehavior. In [55] and [49] the serious game concept has proven to be suitable. Both works use an approach where the player is the only entity to make decisions in the system. In contrast to this, a number of frameworks exist for the assessment of SES and the use of artificial intelligence was proven to be suitable [50]. However, these frameworks address professional users such as researchers or political actors for enabling stewardship of SES and are not used for promoting public awareness [5,6,9].

Because of that, we use autonomous agents which actively participate on the ecosystem service market and thus influence the progress of the game. The player is not able to influence short-term market transactions, but can affect the market in the long term by adapting the rules of the market. There is no complete approach, which combines all components together in one model. Nevertheless, this approach is an extension of the combination of existing ones.

3 Modeling the Trading of Ecological Areas in SES

An important aspect of the conception of the simulation model is the integration of the player of the serious game into the simulation. The user is able to initialize the simulation and consequently determine the initial status of the ecosystem as well as the actors and the market. After starting the simulation the actor has the ability to influence the execution of the simulation, the ecosystem, and the actors. For providing a visual representation of the computer simulation, the serious game will be implemented in the style of a board game. Symbolically speaking, the landscape will be the game board which is segmented into smaller areas by a grid, the use of land will be represented by playing cards which can be placed on the game board, and ecosystem services and other characterizing indicators of areas are represented as attributes of playing cards.

In the following subsections the technical representation of the ecosystem as a two-dimensional grid as well as the integration of the market and its actors including communication and transactions will be presented.

3.1 Ecosystem modeling

For modeling the interactions within ecosystems, the size of the ecosystem itself does not need to be determined because ecosystems can be arbitrarily scaled (i.e., aggregated or disaggregated) [30]. To simplify the model, the shape of an ecosystem and the shape of the traded area are congruent. The combination of all ecosystems represents the playing field of the *serious game* where each field consists of two layers (see fig. 1): The landscape of the area is represented by the **topographic layer**. This layer contains the topography (e.g., mountains, flat countries or rivers) as well as the indicators of the ecosystem and its services (e.g., biodiversity or the emission of pollutants). The **utility layer** represents the usage of an ecosystem (e.g., agriculture). The usage can be changed each time the user has performed a transaction on the market, i.e., in terms of a serious game the user can place a playing card with the corresponding usage. The options of how an area may be used depends on the nearby areas and their usage.

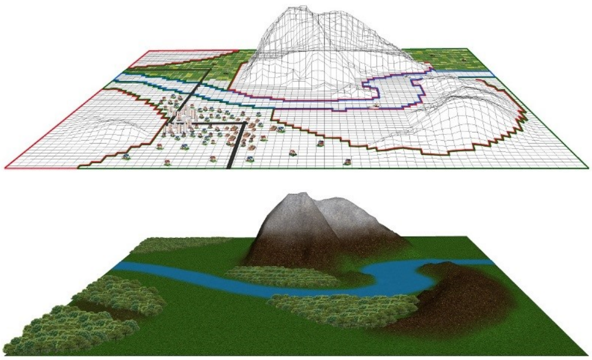

Fig. 1. Topographic layer (landscape) with utility layer (usage of ecosystem) on top

Landscapes and the usage of landscapes can imply a positive or negative influence on the attributes of nearby areas. Considering a game board with a high number of different areas and attributes, complex dynamics may occur. For this reason, a two-dimensional grid is used as a conceptual basis and to structure the dynamics of the system. The grid is defined by arrangement of its cells, the states of the cells, a rule according to which cells change their state, and a definition of each cell's neighborhood [32].

The representation of the real-world landscape is achieved by mapping the land areas to the cells of the grid and the entire playing field to the grid itself. The neighborhoods within the grid depend on the usage of the nearby areas and vice versa. Accordingly, different kinds of neighborhoods are possible, e.g., *von Neumann* or *Moore* neighborhoods [32]. For each specific application of this model, the neighborhoods have to be individually defined. Just like the neighborhoods, the rules for updating the cells depend on the specific application. Each area is represented by an self-governed cell which is updated according to a periodic interval (e.g., daily). When updating, the influence of the neighborhood is apprehended and the changes to the indicators are calculated according to the rules of change.

By modeling ecosystems as reactive agents representing the landscape and the usage of the ecosystems, as well as modeling the game board as a two-dimensional grid, it is possible to model the coherencies of ecosystems and to simulate these coherencies over any desired period of time.

3.2 Market modeling

The ecosystem service market contains a set of land areas which are for sale, market actors, and a communication structure to exchange messages between these market actors. Market transactions will be structured according to the phase model from Section 2.2. The participants of the market will be modeled as autonomous software agents which react to influences and changes of the environment. Every actor is capable to viewing and buying every land area as well as selling own areas on the market. Following, the actors' behavior and the coordination of the message flow between the actors are described to illustrate the market model.

The actions of an actor will be described based on their roles, e.g., sending and receiving of messages, choosing potential buying objects, and selecting a suitable buyer. A sequence of those actions models the actors behavior and is described as follows:

1. Check for received messages
2. Evaluate selling options for each land area and publish an offer on the market
3. Get offers from the market, check buying options, and send offers to vendors
4. Analyze all received offers and select a well-suited buyer

The decision of buying a land area depends on economic and ecological criteria and needs to be defined for every domain of application. Besides that, the process of selecting an adequate buyer is also based on the area of application and needs to be made concrete, too.

The exchange of messages between the actors is used to control individual transaction processes. Buyers can make an offer for land areas by sending a message directly to the vendor or owner. The land owner saves those offers over a certain period of time and notifies the sender whether the offer will be accepted or declined. If an actor's offer is accepted, the land ownership of this area will change, the transaction process is completed, and the buyer is able to change the utilization of the land area. Because of the market and its communication structure, the actors can perform actions on the game board, which results in the dynamics of the system: a change of utilization over time.

4 Example Case: Bioenergy Cropping Systems

After modeling the components of the simulation, a real-world scenario for the serious game needs to be defined. As data are needed for evaluating the scenario, a study conducted by one of the authors is used as example case [20]. In this study, the sustainability of the production of bioenergy is in focus by analyzing the energy output:input ratio of commercial farms when cultivating different energy cropping systems. The study has taken place in the agricultural area of the *Kenner Flur*[1] in Western Germany.

Definition of the landscape: For this example case, the landscape of the *Kenner Flur* (size: 500ha) is divided into agricultural areas of 1ha. According to observations from reality, three types of energy cropping systems (i.e., maize, rapeseed, and miscanthus) can be grown on these areas. Furthermore, the areas can be used for building a farm as origin for cultivation. After buying a land area, the new owner is capable of changing its way of use.

Selection of ESS / indicators: Provisioning and regulating services are modeled in this scenario. Supporting services are assumed to be existent, too, because of their elementary character. Cultural services are not relevant for this case and are not considered any further. The neighbors of an area are defined using the *von Neumann* neighborhood, comprising the four cells which are directly adjacent to a central cell, and the range of the used indicator values is taken from previous research studies conducted by the authors [20].

The specific primary indicators are characterized as follows:

- **Energy of natural resources (provisioning service):** By the use of maize as biogas plant it is possible to gain 91 GJ/ha([2]) of electricity and heat. Contrary to maize, rapeseed is processed to biodiesel with an energy balance of 254 GJ/ha [20].
- **Biodiversity (regulating service):** Biodiversity is defined as the variety of species in flora and fauna [37]. In this scenario, the biodiversity is defined as the ratio of the number of differently cultivated areas in the neighborhood to the maximum diversity of neighbor areas. The overall biodiversity is defined as the mean of the biodiversity of all areas:

$$\left(\sum_{i=1}^{n} \frac{\#\text{ of neighbors of area } i \text{ with different cultivation}}{\text{max. diversity of neighbors areas of area } i}\right)/n \tag{1}$$

- **Carbon dioxide-equivalent savings (regulating service):** By the use of CO_2-equivalent savings, the net reduction of greenhouse gas is quantified: maize (6.276 kg CO_2-eq. savings), rapeseed (3.191 kg CO_2-eq. savings), miscanthus (22.251 kg CO_2-eq. savings).
- **Output/input ratio (regulating service):** This service is the ratio of the energy generated by the crops to the energy needed for cultivation, harvest, and planting: maize (5.5), rapeseed (4.7), miscanthus(47.3).

[1] Geographic coordinates: $N49°48'22.2''E6°42'33.0''$
[2] gigajoule [GJ] per hectare [ha]

Possible usage: In the context of the serious game approach, the utility of the land will be described by a second layer which is placed on top of the landscape layer. The preconditions for utilizing an area are that the usage requirements are fulfilled and that the area is cultivatable. Usage requirements are defined by indicator thresholds and are depending on the land usage of surrounding areas. The types of usage are specified as follows:

- **Farm:** This usage is part of the primary economic sector for resource production and is defined by growing different kinds of crops on nearby land areas. Every farm belongs to an owner and is defined by related cultivated areas and their usage.
- **Maize cultivation:** Energy maize is a common crop in Germany and is planted in a yearly shift with other crops. Because of legal regulations, only 60% of an area may be covered with maize, to avoid negative effects on the environment. After harvesting the maize, it will be transported to the nearest biogas plant for producing electricity and heat.
- **Rapeseed cultivation:** Rapeseed is a crop, similar to maize, and also planted in a yearly shift. Biodiesel is gained from transesterification of rapeseed oil.
- **Miscanthus cultivation:** Miscanthus, a plant from the family of grasses, is a weatherproof crop and can be cultivated over a long period of time (usually 20 years). Contrary to maize or rapeseed, it is able to gain a higher mean energy balance and a lower mean carbon dioxide balance. It is most commonly used as fuel for heat stations to gain energy.

Indicator change by usages: Every indicator of a land area is dependent on the utilization of the areas in the direct or indirect neighborhood. The different ways of usage have various impacts on the indicators. The influence is either unique or constant. For purposes of simplification, the indicators in this scenario are limited to the influence of the direct neighborhood. This affects most of the *biodiversity* indicators, yet, the energy gained from the crops is not influenced by the nearby areas. Because of the occurrence of scale effects on close-by areas having the same type of utilization, the *carbon dioxide-equivalent savings* as well as the *output/input ratio* are higher.

Selection of market actors: The actors in this scenario are defined according to the parties on the market. Every type of actor is represented by a reactive market agent and multiple instances can exist. An agent is able to buy an area, utilize it, and sell it on the market. Common property as abandoned agricultural land is owned by a communal agent who may to sell these areas, too.

Determination of market behavior: An area-specific market behavior is implemented by a threshold, which is dependent on the usage of the neighboring areas and also permits to buy or to sell a land area. First of all, during the process of purchasing an area, the *Euclidean distance* between the object and the farm is relevant because of the increasing energy effort caused by a longer distance decreasing the attractiveness of a land area. But also the number of equally utilized areas in the direct neighborhood, resulting in a decreasing energy effort and lower CO_2 emissions, is relevant in terms of the buying process. Finally, the increase of biodiversity by the anticipated utilization is important. Still, it is a superior condition not to fall below a defined level of overall biodiversity. If multiple actors are interested in an area, the actor which is going to increase the overall biodiversity most significantly is chosen.

5 Prototypical Implementation and Evaluation

For the implementation of the serious game, specification and implementation of the simulation core are in focus. As a number of agent-based simulation frameworks are available, the implementation of the case study is realized using an existing framework. This reduces the complexity of the model implementation as the framework provides certain facilities. For implementing the scenario described in Chapter 4, the simulation framework needs to be capable of handling a large number of agents. Additionally, it is desirable to use the *FIPA Agent Communication Language* [22] standard for specifying the communication between the actors as defined in Chapter 3.2. Accordingly, the selected framework should support the use of FIPA performatives to avoid the development of an own standard referring to Chapter 3.2.

After comparing a number of existing JAVA-based software agent frameworks, the *Aimpulse Spectrum* framework[3] has been chosen due to its high scalability regarding a large number of agents and the support of the FIPA-ACL standard [36].

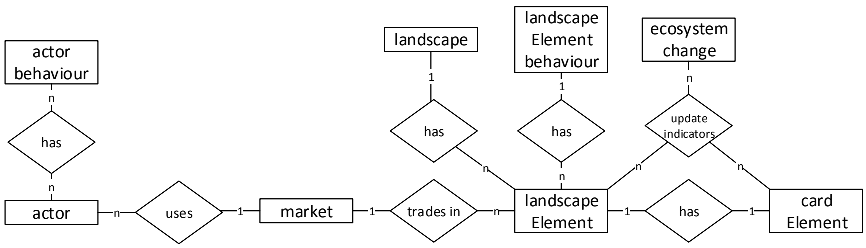

Fig. 2. Entity-relationship model of the prototypical implementation

The implementation is based on the data model shown in figure 2. At the right side, it illustrates the interrelationships between the landscape, its usage, and its changes. The market, as a central component, serves as a connection between the actor and ecological components of the model, i.e., the landscape and other ecosystem-related entities. Actors as well as landscape entities are implemented

[3] Web: http://www.aimpulse.com (visited: Jan. 2016)

as software agents and have an own behavior. In contrast to an actor, a landscape entity, which is part of the overall landscape, only has a shared behavior.

To provide a user friendly visualization of the simulation, the graphical user interface is inspired by a game board. In figure 3, an example of the combination of the topographic layer, consisting of agricultural land, and of the utility layer, consisting of the cultivation of maize, rapeseed, miscanthus, and farms, is shown.

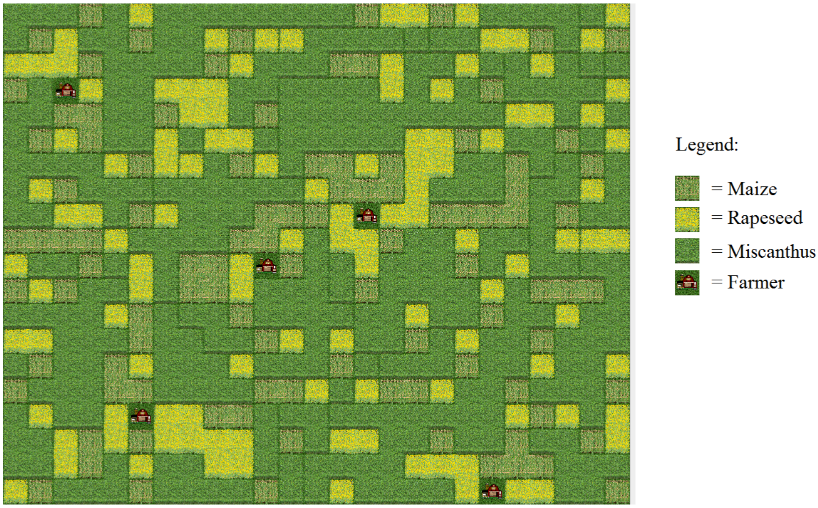

Fig. 3. The game board, illustrating the agricultural land-use

After the prototypical implementation, the next step is the evaluation of this implementation. The aim of this step is to evaluate the system using a sensitivity analysis, a reproducibility analysis, and a plausibility check of the simulation's results.

The **sensitivity analysis** of the developed system is defined by the sensitivity of the simulation results when altering the control variables (i.e., parameters) of the simulation model, e.g., the position of the farms on the game board. Another parameter is the biodiversity of the entire landscape as a superior condition when an actor is choosing which land area to buy.

A large difference in the results can be observed when varying the number of farmers and their positions. This might be explained by the increasing number of competitors at the market and the advantages of a position close to unallocated land areas. When intending a biodiversity between 75% and 100% and when simulating a long period of time (minimum 50 years), the results are almost identically and converge to a limiting value between 70% and 75%. The lower the intended biodiversity (<75%), the stronger the variation of the results at the change of the areas with miscanthus.

Another result of this sensitivity analysis is that at a lower biodiversity results in an increasing cultivation of miscanthus. Miscanthus is preferred because of its good energy ratio in compared to maize and rapeseed. A further consequence of the lower biodiversity are large structures of the same crops in the neighborhood, due to the fact that the biodiversity is decreased and consequently the importance of the same usage in the neighborhood increases.

For the **reproducibility analysis**, the parameters are set to real-world values or to values close to reality and multiple simulation runs are performed and analyzed in terms of similarities and accordances. For this evaluation, five farmers were analyzed and have been arranged according to figure 3. Overall, ten simulation runs covering a time period of 30 years and an intended biodiversity of 70% were executed. The similarity was measured based on the standard deviation (σ) of the amount of purchased land areas, the distribution of the usage as well as the biodiversity of each farmer's areas and each simulation run (see tab. 1). The results of the reproducibility analysis show that farmers own the same amount of land areas in all simulation runs and the distribution of maize, rapeseed, and miscanthus is similar. According to this experiments, simulation experiments are reproducible using identically parameters.

Table 1. Results of the reproducibility analysis

	Amount of land areas (σ)	**Amount of Maze (σ)**	**Amount of Rapeseed (σ)**	**Amount of Miscan. (σ)**	**Biodiversity (σ)**
Farmer 1	20,32% (0,22%)	14,01% (2,29%)	18,98% (1,60%)	67,01% (3,15%)	61,54% (2,53%)
Farmer 2	18,93 % (0,40%)	14,42% (3,35%)	17,17% (3,12%)	68,41% (1,68%)	61,55% (2,46%)
Farmer 3	18,89% (0,77%)	11,33% (1,78%)	16,13% (3,11%)	72,54% (3,64%)	58,37% (3,59%)
Farmer 4	20,48% (0,77%)	14,38% (2,11%)	16,08% (2,47%)	69,54% (2,29%)	61,33% (2,05%)
Farmer 5	21,43% (0,42%)	16,84% (4,06%)	20,85% (2,83%)	62,30% (2,27%)	64,14% (1,94%)

The **plausibility check** implies an inspection of the simulation with respect to its correctness. By comparing the results from the simulation runs to the results of the field study conducted by the authors, we can consider the results of the reproducibility analysis to be plausible (see tab. 1).

6 Conclusion

Transformation processes of SES are complex mechanisms, as they are influenced by a number of different factors, e.g., interactions between human actors, dependencies between the components of the system, and other global drivers. Due to the complexity of these interactions and dependencies, SES are difficult to predict and providing resilience became more challenging. The approach introduced in this paper aims at modeling and simulating actors of SES and their interactions when trading ecological areas as serious game for providing a better public understanding. By making transformation processes of SES experienceable, multi-layered human-environment relations and ambiguous mechanisms causing the dynamics of SES can be communicated in an comprehensible way. The developed serious game approach uses the association of a board game, for communicating the impact of decisions on land use and its change in a playful way.

It was shown that the results of the simulation study are sensitive regarding the control variables of the model. Furthermore, with the control variables remaining unchanged, constant and repeatable results could be generated and the plausibility of the results was confirmed according to a real-world field study. By granting land use rights in a well-controlled way, a balancing of the cultivation of maize, rapeseed, and miscanthus was achieved.

The simulation model developed in this paper is a first step towards increasing the public awareness of transformation processes in SES and how lasting occurs and how it can be prevented using a serious game approach. For providing prognoses regarding the long-term damage of ecosystems, an extension of the simulation model is necessary. For one thing, the use of more sophisticated software agent architectures enabling a more human-like decision behavior, e.g., deliberative agents, can be used for modeling individual goals [52]. For another thing, by extending the model according to a real-world financial system and integrating the Common Agricultural Policy of the European Union, the economic behavior of the actors, e.g., due to agricultural subsidy of climate protection, biodiversity, and preservation of nature, can be modeled and analyzed, too. Finally, to support inventory of ecosystems, it is necessary to include real-world information and data into the simulation model.

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