NASS
NAN YANG ACADEMY OF SCIENCES

Research on World Agricultural Economy

https://journals.nasspublishing.com/index.php/rwae

ARTICLE

Dynamic Integration in Agent-Based Modeling: Strategies for Optimizing Land-Use Change Policies in Peri-Urban Areas through Interactive Simulation

Muhammad Fauzi [1*], ***Yudi Ferrianta*** [1], ***Muhammad Firdaus*** [2]

[1] *Department of Agribusiness/Agricultural Economics, Faculty of Agriculture, Universitas Lambung Mangkurat, Banjarbaru 70714, Indonesia*

[2] *Faculty of Economics and Business, Institut Teknologi dan Sains Mandala, Jember 68121, Indonesia*

ABSTRACT

Land-use conversion in peri-urban areas poses significant social, economic, and environmental challenges, often threatening agricultural livelihoods and community stability. This study aims to analyze the dynamics of land-use change and the interactions among key stakeholders, informing sustainable land management strategies. An agent-based simulation model was developed, integrating social, economic, and environmental variables. The model simulates interactions among farmers, urban developers, NGOs, and government entities in three agricultural regions of South Kalimantan Province, Indonesia. Variables such as social trust, distress levels, economic incentives, policy interventions, and weather conditions were incorporated to reflect real-world complexity. Simulation results indicate that strong social trust and NGO support substantially reduce distress among farmers, thereby fostering greater resilience. Conversely, profit-driven urban developers increase pressure on farmers, especially in scenarios lacking effective government regulation. Participatory and adaptive government policies are shown to balance economic development with environmental and social sustainability. These findings highlight the critical role of social dynamics and policy frameworks in managing land-use transitions and mitigating conflicts. The study

*CORRESPONDING AUTHOR:

Muhammad Fauzi, Department of Agribusiness/Agricultural Economics, Faculty of Agriculture, Universitas Lambung Mangkurat, Banjarbaru 70714, Indonesia; Email: mfauzimakki@gmail.com

ARTICLE INFO

Received: 11 July 2025 | Revised: 20 August 2025 | Accepted: 19 September 2025 | Published Online: 2 February 2026

DOI: https://doi.org/10.36956/rwae.v7i1.2451

CITATION

Fauzi, M., Ferrianta, Y., Firdaus, M., 2026. Dynamic Integration in Agent-Based Modeling: Strategies for Optimizing Land-Use Change Policies in Peri-Urban Areas through Interactive Simulation. Research on World Agricultural Economy. 7(1): 529–545. DOI: https://doi.org/10.36956/rwae.v7i1.2451

concludes that multi-stakeholder engagement and adaptive governance are essential for sustainable peri-urban development. The agent-based model provides a practical tool for policymakers to test policy scenarios safely, enabling evidence-based strategies to protect agricultural communities and promote sustainable land use in rapidly urbanizing regions.

Keywords: Land-Use Change; Agent-Based Simulation; Social Trust; Government Policy; Environmental Sustainability

1. Introduction

In the current global context, land-use conversion, especially in peri-urban areas, represents a significant challenge for both society and governments [1]. The transformation of land, particularly from agricultural areas to urban or industrial zones, has led to substantial social, economic, and environmental impacts [2]. Rapid urbanization, the need for infrastructure development, and economic pressures often drive these changes, yet their effects on local community well-being and environmental sustainability are frequently overlooked [3,4]. This phenomenon not only results in the loss of productive agricultural land but also increases pressure on farmers who feel their livelihoods are threatened [5]. Additionally, land-use change can create tensions between urban developers seeking economic profit and local communities who depend on the land for their daily lives [6]. In many cases, governments attempt to regulate land use through various policies, but the effectiveness of such measures is often questioned [7,8].

Many studies have discussed the impacts of land-use change; however, most focus on a single aspect, such as environmental or economic effects, without considering the dynamic interactions among the actors involved [9,10]. Interactions between farmers, urban developers, NGOs, and government agencies in the context of land-use change have not been widely explored [11]. For instance, how social trust and NGO support influence pressures on farmers, or how the level of government intervention can manage conflicts between economic growth and environmental sustainability.

Most previous studies have not taken into account how agents' decisions and interactions are influenced by external factors such as changing weather conditions or adaptive government policies [12]. Furthermore, research that integrates social, economic, and environmental dimensions into a single agent-based simulation model remains quite limited [13].

This study employs an agent-based modeling (ABM) [14] to simulate the complex interactions among farmers, developers, NGOs, and government agencies in the context of peri-urban land-use change. Agent-based simulation is an effective method for modeling complex systems with many interactive entities. Each agent in this simulation functions as an autonomous entity with unique characteristics and actions, allowing for interaction with other agents and the environment. This approach enables the observation of how changes at the individual level affect the system as a whole [15].

In the context of land-use change, various agents play crucial roles. This study also considers environmental variables such as weather conditions, which can change randomly within the simulation and influence agents' decisions [16]. Thus, the simulation provides a more realistic picture of agent interactions within a dynamic and uncertain environment [17].

The agent-based simulation in this study offers several complex aspects. It adopts a holistic approach by integrating social, economic, and environmental dimensions into a single simulation model, allowing for a more comprehensive analysis of land-use change impacts [18]. The model enables direct observation of how interactions among agents influence the overall system dynamics [13]. It also incorporates external factors such as changing weather conditions and adaptive government policies to illustrate how agents respond to environmental changes [19]. Furthermore, the simulation allows for policy experimentation, making it possible to test various policy scenarios without real-world risk and helping policymakers evaluate potential impacts before implementation [20].

This study aims to address the following research questions:

(1) How do social trust and support influence farmers' responses to the pressures of land-use change?

(2) What are the economic impacts of developer-driven land-use change?

(3) How do government interventions affect outcomes for each stakeholder?

Drawing on prior research, we propose the following theoretical relationships: (a) higher social trust among farmers reduces their stress and distress in facing land-use change pressures [21]; (b) adaptive government policies moderate the impact of developer profit motives, reducing negative consequences for farmers [22,23]; and (c) strong profit orientation by developers increases pressure on agricultural land [24], but this effect can be mitigated by NGO support and social trust [25,26].

The model hypothesizes that collaborative and adaptive policies, particularly those involving NGO support, can reduce pressure on farmers, strengthen community resilience, and balance economic development with environmental sustainability.

2. Literature Review

2.1. Agent-Based Modeling

Agent-based modeling (ABM) has become an essential tool for studying complex systems in social, economic, and environmental contexts [27]. The literature indicates that this approach enables researchers to model individual behaviors and interactions within dynamic environments, thereby deepening the understanding of how macro-level systems emerge from micro-level interactions. A key feature of ABM is its ability to simulate social and economic interactions among agents [28,29], which is particularly relevant for exploring interactions among farmers, urban developers, NGOs, and government entities in the context of land-use change in peri-urban areas.

ABM incorporates agent heterogeneity, capturing diversity in behaviors, properties, and interactions among agents. Such heterogeneity allows realistic modeling of complex systems, where individual differences can lead to emergent system-level patterns [30,31]. Environment representation is another core concept, with spatial structures often modeled as grids or parcels. The choice of spatial representation shapes agent interactions and outcomes, enabling simulations to realistically reflect geographic and urban dynamics [32,33]. Additionally, model validation is critical to ensure that simulations reliably reproduce real-world phenomena. Pattern-Oriented Modeling (POM) is often employed to guide model design and validate ABMs by ensuring that multiple emergent patterns correspond to observed data, increasing confidence in predictive reliability [34,35]. Comparing model outputs with empirical data verifies predictive performance and strengthens confidence in the model's applicability for decision-making [36].

Building on foundational ABM work by Epstein and Axtell [37] and formalized through the ODD protocol [38], ABMs explicitly link heterogeneous agents, spatially explicit environments, and validated interactions to simulate complex system dynamics. This theoretical grounding ensures transparency, reproducibility, and rigor in modeling agent behaviors and emergent patterns.

ABMs are particularly effective for simulating land-use change because they can link individual decision-making to system-level outcomes. Research demonstrates that ABMs can capture how developers, farmers, and policymakers interact to shape urban expansion, peri-urban conversion, and agricultural land management [39,40]. They can also represent coupled human-natural systems, integrating socio-economic drivers, environmental constraints, and climate variability to predict land-use outcomes [41,42].

In this study, ABM is used to examine how social trust, perceived pressure, NGO support, and government interventions shape interactions among agents and affect peri-urban land-use change dynamics. This approach provides a flexible simulation environment capable of capturing the emergent, context-specific outcomes of agent behaviors, supporting scenario testing for sustainable land-use planning and policy evaluation [29,43].

2.2. Social Capital in Land-Use Change

Social capital refers to networks of relationships, shared norms, and trust that facilitate coordination and collaboration for mutual benefit [44]. The concept of social capital has been extensively explored by scholars such as Bourdieu, Coleman, and Putnam. Bourdieu (1986) emphasizes the relational nature of social capital, showing how networks interact with other forms of capital to shape social advantage and reproduce power dynamics [45,46]. Coleman (1988) highlights the functional benefits of social capital, particularly trust and reciprocity, which enable individuals and communities to achieve personal and collective goals, including enhanced education and lower crime rates [46]. Putnam (2000) focuses on civic engagement and social cohesion, noting that declines in participation in communal activities weaken trust, cooperation, and overall societal well-being [47]. Critiques of these frameworks stress the need for context-specific understanding, as social capital's effects vary across different social interactions [47,48]. Contemporary studies further demonstrate that strong social capital supports public health, economic performance, and effective governance by providing access to resources and supportive networks that mitigate social and economic inequalities [49,50].

In the context of land-use change, social capital is crucial for reducing community distress, strengthening social networks, and supporting environmental sustainability. Strong social capital can help communities manage resources more effectively, respond to environmental changes, and mitigate the negative impacts of land-use change [51]. Previous studies indicate that social trust and NGO support significantly reduce community pressure. Increased trust and social networks can enhance community well-being and strengthen their capacity to cope with environmental changes. In this simulation, social trust is measured through interactions among farmers and the support provided by NGOs [52].

Economic considerations also play a key role in land-use decisions, as described by land rent theory. This theory examines how land values and rents are determined by spatial, economic, and social factors, emphasizing the effects of scarcity, ownership, and market dynamics on land-use choices [53–55]. Indonesian land-use policies further shape these dynamics by regulating access, ownership, and use of land to balance agricultural productivity, urban development, and environmental sustainability. Policies such as the Basic Agrarian Law of 1960, the 2012 Land Acquisition Law, and related regulations aim to protect agricultural land, ensure equitable land acquisition, and integrate customary law practices into formal governance, although implementation challenges remain [56–58]. In peri-urban contexts, urban developers often focus on the economic gains from land-use change, which can disrupt environmental sustainability [59]. Urban development driven by market logic aims to maximize land profits, frequently at the expense of ecological balance [60]. This simulation models how decisions made by urban developers affect community well-being and the surrounding environment.

The government plays a crucial role in regulating land use and implementing policy interventions to balance economic and environmental interests [61]. The success of collaborative resource management often depends on policy frameworks and the level of government involvement [62]. In this simulation, government intervention is measured through the variable "level of intervention," which influences how policies are implemented to reduce pressure and support sustainability.

2.3. External Factors in the Simulation

Weather conditions are an important factor influencing agents' decisions, making the simulation more realistic. Research shows that climate change and weather variability can significantly affect agricultural production and land use [63]. Extreme weather events, such as droughts and floods, have been found to drastically impact agricultural productivity and influence farmers' land management decisions [64]. The conversion of farmland has been linked to intensified regional drought conditions by altering local temperatures and evaporation rates, as farmland often replaces moisture-retaining ecosystems, leading to higher regional temperatures and increased dryness [64].

Flooding also poses a significant challenge, potentially causing substantial economic losses for agricultural areas. Studies have demonstrated that land-use changes, including agricultural expansion and urban development, can increase flood risks, particularly in regions previously occupied by forests or wetlands, which naturally mitigate flooding [65,66]. The reduction in land capacity to absorb rainfall results in higher runoff and more severe flood events[67,68]. Additionally, agricultural practices can contribute to soil compaction and reduced vegetation cover, further impairing natural hydrological functions and elevating flood susceptibility[69].

In this simulation, weather conditions are randomly modeled to observe how agents respond to dynamic environmental changes. Incorporating such external factors provides a more realistic and flexible environment for simulating agents' decisions and interactions under varying conditions.

Several studies have suggested that agent-based simulations can be used for policy experimentation without real-world risk[28]. The ability to test various policy scenarios in a simulated environment enables stakeholders to evaluate potential impacts before implementation[70]. This is highly relevant to this study, where levels of government intervention and NGO support are tested to assess their effects on community well-being and environmental sustainability.

2.4. Hypotheses Development

Drawing on prior research, this study develops the following hypotheses regarding the interactions among developers, farmers, NGOs, and government in peri-urban land-use change:

H1. *Higher levels of social trust among farmers reduce their stress and distress in facing land-use change pressures.*

H2. *Strong profit orientation by developers increases pressure on agricultural land.*

H3. *Support from NGOs mitigates the negative impact of developer profit orientation on agricultural land.*

H4. *Adaptive government policies moderate the relationship between developer profit orientation and farmer well-being, reducing negative consequences.*

3. Methods

This study follows the ODD+D (Overview, Design Concepts, Details + Human Decision-Making) protocol[71,72] to document the agent-based simulation of peri-urban land-use change. The model integrates spatially explicit land parcels, accessibility metrics, and hazard overlays to reflect real-world environmental and social constraints.

3.1. Overview

The purpose of the model is to explore how farmers, urban developers, NGOs, and government entities interact in the context of peri-urban land-use change. The model examines these interactions with a focus on the roles of social trust, perceived pressure, NGO support, and government intervention in shaping community well-being and sustainability. Agents occupy discrete land parcels arranged on a spatial grid representing the study area in South Kalimantan Province, Indonesia. Each parcel is characterized by its land type (agricultural, residential, or urban), accessibility to infrastructure, and susceptibility to hazards such as floods or droughts.

Four agent types are defined, each with distinct attributes, decision rules, and utility functions (**Table 1**). Farmers maximize a utility function that balances income, social trust, NGO support, and perceived pressure. Developers pursue profit maximization considering revenue, land costs, and policy compliance costs. NGOs implement intervention strategies to reduce farmer pressure and enhance trust, while government entities enforce policies aimed at balancing economic development with environmental sustainability.

Agents interact at the community level, with discrete time steps (ticks) representing simulation periods. Social interactions, policy enforcement, and environmental conditions unfold dynamically at each step. Process overview and scheduling at each tick are summarized in **Table 2**.

Figure 1 presents the conceptual framework of this study, illustrating the hypothesized relationships among developers, farmers, NGOs, and government entities in the context of peri-urban land-use change. The framework visually represents how social trust, NGO support, government interventions, and developer profit orientation influence farmers' stress and distress, and how these interactions form the basis for the study's four hypotheses (H1–H4).

Table 1. Agent Types, Attributes, Utility Functions, and Index Formulas.

Agent Type	Key Attributes	Decision Rule/Utility Function	Index Formula/Interaction	Behaviors and Interactions
Farmers	Social trust, perceived pressure	$U_f = \alpha.Income + \beta.Trust$ $+\gamma.NGO\ support$ $-\delta.Perceived\,pressure$	$Trust_{t+1}$ $= Trust_t$ $+\alpha.Interaction_{farmers}$ $+\beta.NGO\ support$ $-\gamma.Developer\ pressure$ $Distress_t$ $= \delta.Developer\ pressure$ $-\epsilon.(Trust_t$ $+NGO\ support_t)$ $Opinion_t$ $= \frac{\sum w_i.Response_i}{\sum w_i}$	Interact with other farmers and NGOs to enhance trust or reduce pressure; pressure increases under land-use change pressures from developers.
Urban Developers	Economic profit	Π_d $= Revenue\,from\,land\,conversion$ $-Land\ cost$ $-Policy\ compliance\ cost$	Pressure exerted on farmers is proportional to land-use change activity	Seek to maximize financial returns through land-use change; engage with government and NGOs to secure support or permits.
NGOs	Support capacity	N/A (intervention-based)	$NGO\ support_t =$ $\sum s_i.Intervention_i$	Provide assistance to farming communities, helping reduce pressure and increase trust; interact with government and communities to strengthen social networks and resilience.
Government Entities	Policy intervention	N/A (policy optimization)	Enforces policy; indirectly affects all indices via regulation	Regulate land-use conversion; interact with all agents to implement policies balancing economic interests and environmental sustainability.

Table 2. Process Overview and Scheduling in Each Simulation Tick.

Step	Agent Type	Main Action	Expected Effect
1	Farmers	Interact with other farmers and NGOs to exchange trust or reduce pressure	Trust may increase; perceived pressure may decline
2	Urban Developers	Seek opportunities for land-use change	Increases economic profit; raises pressure on farmers
3	NGOs	Provide support to farmers	Enhances resilience; reduces farmers' pressure
4	Government	Implement policies and regulate land-use change	Balances economic and environmental interests

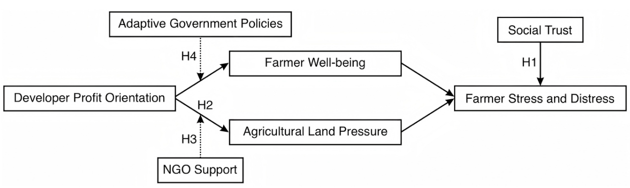

Figure 1. Conceptual Framework and Hypotheses.

3.2. Design Concepts

The model is grounded in social capital theory, land-use conflict dynamics, and policy intervention frameworks. System-level outcomes, including distress index, trust index, and land-use change rate, emerge from micro-level agent interactions.

Agents are adaptive, modifying their behaviors based on social, economic, and environmental cues. Farmers learn from repeated interactions with NGOs and neighboring farmers, adjusting strategies to minimize pressure. Developers target profit maximization constrained by policy enforcement and spatial accessibility. NGOs focus on strengthening community resilience, while government entities aim to enforce sustainability policies effectively.

Stochasticity is incorporated through weather variability, random interaction outcomes, and hazard events, introducing uncertainty across simulation runs. Outputs are captured via indices for trust, distress, profit, NGO support, and opinions.

3.3. Details

At the beginning of the simulation, agent attributes were initialized using empirical survey data collected from 220 respondents in South Kalimantan Province, Indonesia. These respondents included 160 farmers—72 in Banjar, 52 in Batola, and 36 in Tanah Laut—selected through proportional random sampling. Additionally, 30 urban developers were included, comprising 12 from Banjar, 10 from Batola, and 8 from Tanah Laut, stratified by scale of operation. The sample also included 20 NGO representatives and 20 government officials, both selected purposively.

Farmers' initial levels of social trust and perceived pressure were assigned based on regency-level means calculated from the survey (Banjar: mean 0.65, SE 0.05; Batola: mean 0.60, SE 0.04; Tanah Laut: mean 0.58, SE 0.06). Developers' profit orientations were initialized according to strata, with probabilistic ranges reflecting observed variation among respondents. NGO and government intervention levels were parameterized using survey-based estimates, incorporating uncertainties to reflect sampling error. Survey data were also used to calibrate model parameters, ensuring that simulated distributions of trust, perceived pressure, and profit orientation closely matched observed survey statistics. For example, probabilistic ranges for developer profit orientation were adjusted so that the mean and variance in the simulation reflected empirical distributions. These procedures ensured that the model both represents observed agent attributes and produces realistic behavioral dynamics.

The model integrates three categories of input data. Socioeconomic attributes derived directly from survey responses provided initial values for trust, perceived pressure, profit orientation, and NGO support capacity. Environmental data, including local climate information on drought and flood frequencies, informed the stochastic weather module. Policy context was drawn from government regulations and official reports to set baseline levels of policy intervention in the simulation.

The simulation consists of several interconnected submodels. The farmer interaction model simulates changes in trust, which increase when farmers receive support from NGOs or cooperate with fellow farmers, and decrease under developer-induced pressure. The developer model captures profit-seeking behavior constrained by government enforcement. The NGO model represents the provision of support that reduces perceived pressure and strengthens social trust networks. The government model implements policies aimed at reducing illegal land-use change while balancing economic and ecological objectives. Finally, the weather model introduces stochastic drought and flood events, influencing farmer distress and decision-making processes.

3.4. Simulation Procedure

The simulation was implemented in NetLogo 6.4.0 (Northwestern University, USA), with each run consisting of multiple ticks during which agents interact according to their behavioral rules. To reduce stochastic variability and ensure robust estimates, each scenario was standardized to at least 100 replications for all indices, including trust, distress, profit, NGO support, and opinion indices. Outputs from these replications were summarized as mean values with 95% confidence intervals (CI), providing a more rigorous assessment of system-level dynamics.

All simulations were conducted with settings described in the latter two tables. For reproducibility, random seeds used for stochastic elements are provided for each index: trust and distress indices (seeds 101–149), profit and NGO support indices (seeds 201–210), and opinion index (seeds 301–400).

To explore a broader set of conditions, scenarios combined variations in government policy intervention, developer profit orientation, NGO support capacity, and stochastic climate events such as drought and flood. This policy × incentive × climate design enables the assessment of interactive effects on farmers' trust, distress, and overall community resilience.

The simulation also allows for systematic exploration of uncertainty through global sensitivity analysis, in which key parameters such as government intervention, developer profit orientation, NGO support capacity, and environmental shocks are varied simultaneously across their plausible ranges. This analysis identifies the relative influence of each parameter on model outputs and highlights interactions among parameters that significantly affect outcomes.

An example of the simulation application's user interface is shown in **Figure 2**, illustrating how agents and variables are displayed and managed during simulation runs.

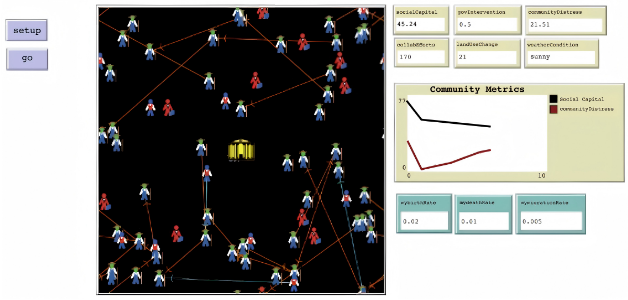

Figure 2. Simulation Application Interface.

3.5. Model Validation

Model validation was conducted through a multi-step process to ensure the reliability and robustness of the agent-based simulation. First, an empirical comparison was performed by aligning simulation outcomes, such as reductions in farmer distress under NGO support, with independent field data from similar peri-urban regions, including East Java. These datasets were not used in model calibration, providing an unbiased benchmark for validation. Quantitative agreement between simulated and observed data was assessed using the Kappa statistic for categorical outcomes (e.g., land-use change classification) and RMSE (Root Mean Square Error) for continuous indices, including trust, distress, profit, and NGO support. These metrics indicated a high level of concordance, confirming that the model accurately reproduces independent observations.

Second, cross-model comparison was conducted by evaluating the simulation outcomes against established land-use change models, such as the IDRISI SELVA Land Use Change Modeller. System-level patterns, including feedback loops between social trust, developer pressure, and distress, were consistent with prior models, reinforcing model credibility.

Third, sensitivity and uncertainty analyses were undertaken to assess the robustness of the model to parameter variation and the propagation of input uncertainty. Input uncertainties—including variation in initial trust, perceived pressure, developer profit orientation, and NGO support—were propagated through the model using Monte Carlo simulations, with ≥100 runs per scenario. Output distributions were summarized as means with 95% confidence intervals to quantify the combined effects of input variability on key outcomes. For example, a 20% increase in government intervention reduced illegal land-use change by 35% [95% CI: 31–39%], whereas a 15% decrease in NGO support increased farmer distress by 22% [95% CI: 19–25%] (see **Appendix A Table A1**). These results demonstrate that the model reliably captures the influence of parameter uncertainty on simulation outcomes.

3.6. Parameter Table

Table 3 summarizes key parameters, ranges, sources, and uncertainties, including spatial and hazard-related variables.

Table 3. Model Parameters with Ranges, Sources, and Associated Uncertainties.

Parameter	Range/Value	Source	Uncertainty/Notes
Farmers' social trust	0–1 (normalized)	Survey (160 farmers)	Variation across regencies
Farmers' perceived pressure	0–1 (normalized)	Survey, expert input	Influenced by developer activity
Developer profit drive	Low/High (strata)	Survey (30 developers)	Market variability
NGO support capacity	0–1 (normalized)	Survey (20 NGOs)	Funding fluctuations
Government intervention	0–1 (normalized)	Policy reports, survey (20 officials)	Policy enforcement uncertainty
Weather shocks	Drought/Flood, prob. 0.1–0.3	Climate data	Stochastic variation
Parcel type	Agricultural/Urban/Residential	Land use maps	Land classification uncertainty
Accessibility index	0–1	GIS, survey	Variability in market/road access
Hazard overlay	Flood/Drought probability	GIS, climate data	Stochastic spatial events

4. Results

4.1. Reduction of Pressure on Farmers

As shown in **Figures 3** and **4**, the simulation results demonstrate that interactions among farmers and support from NGOs generally increase trust levels while reducing distress among farmers. These findings reflect positive developments, suggesting that greater trust strengthens the sense of solidarity and enables farmers to unite more effectively in facing pressures related to land-use change. Moreover, lower levels of distress indicate that farmers feel more secure and stable, supported by legal assistance, training, and resources provided by NGOs.

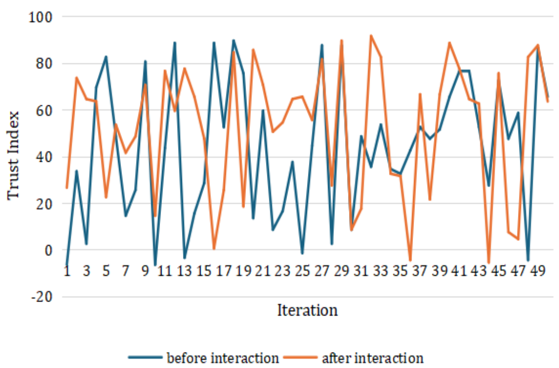

Figure 3. Simulation of Farmers' Trust Levels within the Community.
Note: "Before interaction" shows trust levels before interactions and policy interventions. "After interaction" shows trust levels after interactions with other farmers, NGOs, and government policies.

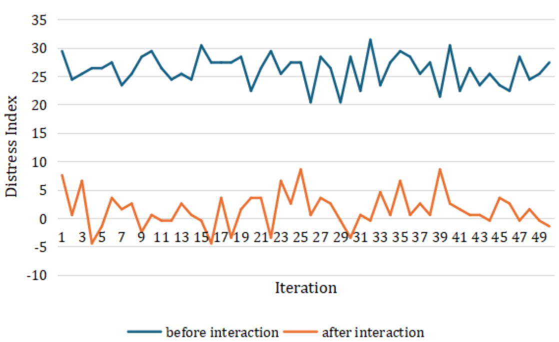

Figure 4. Simulation of Distress Levels Experienced by Farmers.
Note: "Before interaction" shows distress levels before interactions and policy interventions. "After interaction" shows distress levels after interactions with other farmers, NGOs, and government policies.

In this simulation, trust and distress were used as variables to capture two important aspects of farmers' mental and social conditions. Trust represents the level of confidence that farmers have within their community, where higher levels reflect strong social connections, effective cooperation, and adequate mutual support among community members. Conversely, low levels of trust may indicate conflict or a lack of confidence in community mechanisms. Meanwhile, distress measures the degree of anxiety or stress experienced by farmers, with higher distress levels indicating significant pressure and a greater need for support. Simulation outcomes, therefore, suggest that social interactions and NGO involvement play critical roles in mitigating the adverse impacts of land-use change pressures on farmers' well-being.

4.2. Economic Impact of Land-Use Change

As shown in **Figure 5**, government policies that restrict land-use change reduce developers' profit margins, thereby encouraging more responsible development practices. Simulation results indicate that urban developers prioritize economic gains by converting agricultural land into urban areas. This approach often overlooks environmental sustainability and the needs of local communities, aligning instead with market-driven logic. Although developers achieve significant economic profits, these gains come at the expense of farmers' livelihoods and carry the potential to cause environmental degradation.

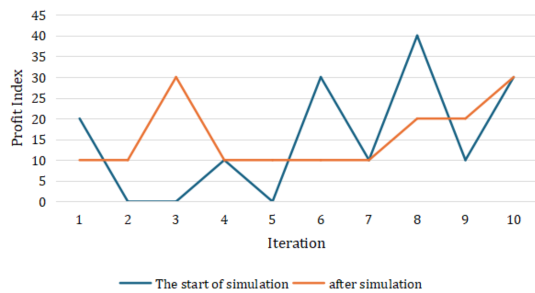

Figure 5. Urban Developers' Profits Under Land-Use Change Limits.
Note: "Start of simulation" shows developers' profits before land-use change restrictions and policy interventions. "After simulation" shows profits after agents have interacted with policies, other developers, and environmental constraints.

The simulation also reveals that economic incentives drive developers to expand projects aggressively, which, in turn, fuels social tensions with farmers. In the absence of government regulation, urban expansion poses risks to social cohesion and ecological balance.

4.3. The Role of NGOs in Supporting Farmers

NGOs play a crucial role in reducing pressure on farmers by providing legal assistance, education on land rights, and economic empowerment initiatives. The simulation results show that support from NGOs increases farmers' trust and strengthens their bargaining position against developers, as illustrated in **Figure 6**. Furthermore, mediation by NGOs helps prevent conflict escalation and preserves social cohesion.

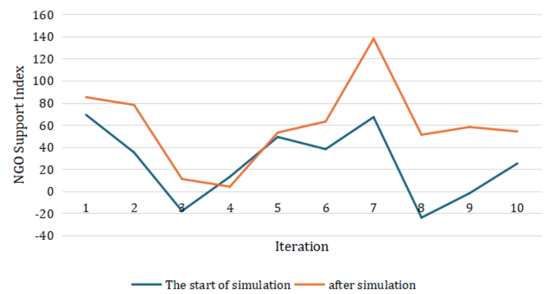

Figure 6. Simulation of the Impact of NGO Support on Farmers.

Note: "Start of simulation" shows the baseline NGO support index for farmers before agent interactions. "After simulation" shows the NGO support index after farmers and NGOs have interacted throughout the simulation iterations.

4.4. Government Response to Social and Environmental Changes

Government interventions, such as restricting land-use change and offering incentives for sustainable agricultural practices, are designed to reduce pressure on farmers and protect agricultural land. In the simulation, negative values represent cumulative net pressure on farmers, with more negative values indicating higher stress or adverse impacts. Interestingly, the cumulative pressure became more negative after intervention (from −1570 to −3087), suggesting that overly stringent policies can initially increase resistance or stress among agents. These results underscore the importance of adaptive and participatory policies that involve all stakeholders (**Figure 7**).

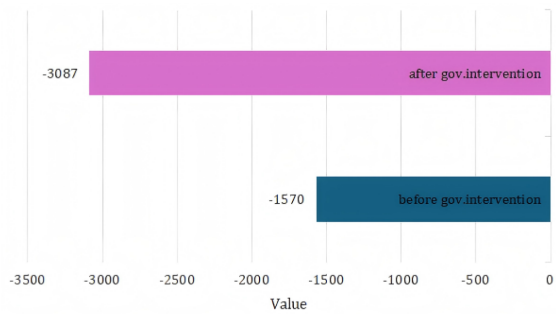

Figure 7. Simulation of Agents' Responses to Government Policies.

Note: Negative values indicate the cumulative net pressure on farmers, with more negative values representing higher stress or adverse impact on agricultural sustainability.

4.5. Farmers' Opinions on Government Policies Limiting Land-Use Change

The simulation results shown in **Figure 8** indicate that farmers' opinions toward government policies on land-use change tend to improve when such policies align with their interests, particularly in protecting agricultural land and promoting sustainable land-use practices. Farmers generally support policies that prevent uncontrolled land-use change, as these provide a sense of security and help safeguard their livelihoods. When farmers' perspectives are taken into account during policy formulation, their trust in government institutions increases, thereby strengthening social cohesion within the community.

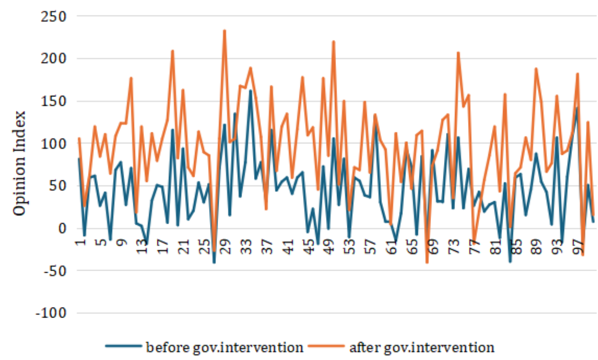

Figure 8. Simulation of Farmers' Opinions on Government Land-Use Change Policies.

Note: "Before government interaction" shows the baseline opinion index of farmers prior to interactions with government policies. "After government interaction" shows the updated opinion index after farmers have responded to government interventions throughout the simulation iterations.

As shown in **Figure 8**, the simulation illustrates that farmers are more likely to support participatory and adaptive policies, particularly those that involve community stakeholders in the decision-making process. This participatory approach allows farmers to provide input on land management, fostering a sense of ownership over the policies. Conversely, top-down policies that lack transparency often provoke resistance. Flexible policies that consider community needs also help maintain positive perceptions among farmers, as they are seen as safeguarding long-term well-being.

Farmers' support for inclusive policies strengthens collaboration in protecting agricultural land and creates a united front against pressures from developers. The simulation demonstrates that participatory policies generate higher levels of social capital, which enhances farmers' collective capacity to cope with land-use change pressures. These findings underscore the importance of adaptive and responsive policy frameworks for achieving socio-ecological sustainability in peri-urban areas.

5. Discussion

This study investigated the complex dynamics of land-use conversion in peri-urban areas using an ABM approach. The model captured the interactions among diverse stakeholders—including farmers, urban developers, NGOs, and government entities—in response to the pressures of rapid urbanization. The use of ABM, as described by Parker et al.[73], enables a nuanced representation of heterogeneous agents whose decisions collectively shape systemic outcomes. The findings underscore the value of ABM as a policy simulation tool, aligning with Crooks et al.[74], who emphasized its capacity to explore real-world scenarios without associated risks.

One of the most significant findings from the simulation is the feedback loop between social trust and farmers' distress levels. Farmers who actively engage in social networks and build trust experience a noticeable reduction in distress, confirming the results of Awaworyi and Mishra[75], who found that strong trust and social capital enhance community well-being. This relationship aligns closely with Ostrom and Ahn's[76] theory on the crucial role of social capital in managing common resources.

NGOs emerged as essential actors in this dynamic, not only mediating conflicts but also strengthening community resilience through advocacy, support, and information-sharing. This aligns with Haase[77], who highlighted the effectiveness of NGOs in facilitating dialogue among stakeholders and mitigating land-use conflicts.

The simulation also revealed tensions between economic and environmental priorities. Urban developers, driven by market logic and the goal of maximizing economic profits, often pursue aggressive land-use change strategies, leading to conflicts with farmers and NGOs. Without effective government intervention, this dynamic threatens both social cohesion and ecological balance. This finding reinforces Termorshuizen and Opdam's[78] argument that adaptive and balanced policies are critical to maintaining community resilience in peri-urban contexts.

Moreover, the integration of dynamic variables such as weather conditions and adaptive policy responses reflects the complex human-environment interactions described by Seto et al.[79]. The model demonstrates that changes in a single variable—such as government intervention levels—can produce cascading effects throughout the system. For instance, excessively lenient policies may accelerate urban sprawl, whereas overly restrictive measures might constrain economic development. Overall, the simulation provides valuable insights into the systemic complexity of peri-urban land-use change and emphasizes the necessity of a holistic approach that incorporates multidisciplinary perspectives for sustainable land management.

The study's findings also resonate with local research, notably the work of Ferrianta and Makki[80] in Banjar Regency, which identified several drivers of land-use change, including rising land prices, declining agricultural productivity, and inheritance factors. High land values near urban centers incentivize farmers to sell their land for urban development, while stagnating productivity—exacerbated by increasing input costs such as fertilizers and pesticides—reinforces the economic rationale for land-use change. Furthermore, inheritance often leads to land fragmentation, reducing operational efficiency and discouraging younger generations from continuing farming. These socioeconomic and cultural factors highlight the importance of designing land-use policies that consider local realities alongside broader systemic dynamics.

The simulation results suggest that participatory and adaptive policy frameworks may contribute to balancing economic development with social and environmental objectives in the study area. Scenarios in which community stakeholders were actively involved in decision-making showed higher levels of trust and reduced conflicts in the model. Incentive-based mechanisms for land conservation were associated with better maintenance of agricultural land and slower urban expansion within the simulation. Similarly, simulated support for NGOs and community networks strengthened social trust and improved resilience against rapid land-use changes. These findings indicate that ABM can be a useful tool to explore potential policy options in a controlled, context-specific environment, though real-world applicability may vary depending on local conditions and institutional capacities.

6. Conclusion

This study employed an agent-based model to explore the complexity of land-use conversion in peri-urban areas of South Kalimantan Province, Indonesia, focusing on the interactions among farmers, developers, NGOs, and government policies. The key findings indicate that balanced and adaptive government policies, supported by NGO interventions, are important for reducing farmers' distress, strengthening community resilience, and promoting sustainable land management within this specific local context. Model validation against empirical data from the study area and comparisons with established models confirm the simulation's reliability in replicating local dynamics.

However, the model has several limitations. Agent behaviors and environmental variables were simplified and are not yet fully dynamic, and socio-cultural factors were only partially represented. The simulation scenarios were bounded by the assumptions described in the Methods, including policy interventions, stakeholder behaviors, and environmental conditions. Extreme counterfactual scenarios—such as drastic or simultaneous policy shifts, multi-agent shocks, or long-term market collapse—were not explored and could lead to different system dynamics. Future research should focus on concrete model enhancements. Agent learning processes could be incorporated using reinforcement learning or adaptive decision rules to capture dynamic behavioral responses over time. Market dynamics could be modeled through probabilistic price fluctuations and economic shocks to reflect realistic developer behavior. Climate projections, including stochastic drought and flood scenarios based on historical and predicted data, could be added to evaluate long-term environmental impacts. Expanding the model's geographic scope could help test its applicability in diverse peri-urban contexts and contribute to a deeper understanding of local dynamics. In addition, due to small sample sizes for developers and institutional agents, the model's results may not fully represent broader population behaviors, and caution is warranted when generalizing findings beyond the study region.

Based on the findings, several recommendations emerge. Effective collaboration among governments, NGOs, farmers, and urban developers is essential for designing realistic and widely accepted policies, where participatory forums can facilitate dialogue and help reduce conflicts of interest. Governments could utilize simulation models to test the impacts of policy alternatives before implementation, exploring scenarios such as sustainable agricultural incentives or protective zoning measures. Moreover, NGOs and educational institutions should increase farmers' awareness of land rights, negotiation techniques, and sustainable farming practices through training and capacity-building programs. Future research should adopt multidisciplinary perspectives, drawing from sociology, ecology, and economics, to better understand the holistic impacts of land-use change.

Author Contributions

Conceptualization, M.F. (Muhammad Fauzi) and Y.F.; methodology, M.F. (Muhammad Firdaus); software, M.F. (Muhammad Fauzi); validation, M.F. (Muhammad Fauzi), Y.F. and M.F. (Muhammad Firdaus); formal analysis, M.F. (Muhammad Fauzi); investigation, M.F. (Muhammad Fauzi); resources, M.F. (Muhammad Fauzi); data curation, M.F. (Muhammad Fauzi); writing—original draft preparation, M.F. (Muhammad Fauzi); writing—review and editing, Y.F. and M.F. (Muhammad Firdaus); visualization, M.F. (Muhammad Fauzi); supervision, Y.F. and M.F. (Muhammad Firdaus); project administration, M.F. (Muhammad Firdaus); funding acquisition, M.F. (Muhammad Firdaus). All authors have read and agreed to the published version of the manuscript.

Funding

This work was funded by Universitas Lambung Mangkurat for the 2023 fiscal year, following Rector's Decision Letter No. 61.5/UN8/PG/2023, dated May 31, 2023.

Institutional Review Board Statement

The study was conducted in accordance with ethical standards, and formal Institutional Review Board approval was not required for this type of survey-based research.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Acknowledgement

The authors would like to express their gratitude to Universitas Lambung Mangkurat for providing research funding. The authors also wish to thank the Institute for Research and Community Service (LPPM) of Universitas Lambung Mangkurat for the facilities and support provided during the research.

Conflicts of Interest

The authors declare no conflict of interest.

Appendix A

Table A1. Sensitivity Analysis of Key Parameters on Simulation Outcomes.

Parameter Variation	Illegal Land-Use Change (%)	Farmer Distress (%)
Government Intervention		
−20%	50 [46–54]	30 [27–33]
−15%	48 [44–52]	28 [25–31]
−10%	46 [42–49]	27 [24–30]
0% (baseline)	45 [41–49]	27 [24–30]
+10%	43 [39–46]	26 [23–29]
+15%	40 [37–43]	26 [23–29]
+20%	35 [31–39]	25 [22–28]
NGO Support		
−20%	36 [32–40]	23 [20–26]
−15%	35 [31–39]	22 [19–25]
−10%	34 [31–38]	21 [18–24]
0% (baseline)	33 [30–36]	20 [17–23]
+10%	32 [29–35]	19 [16–22]
+15%	31 [28–34]	18 [15–21]
+20%	30 [27–33]	17 [14–20]

References

[1] Basuki, Y., Rahayu, S., 2022. Land use and trip production model in central and peri-urban Semarang to anticipate land use conversion in post pandemic era. IOP Conference Series: Earth and Environmental Science. 1082(1), 012015. DOI: https://doi.org/10.1088/1755-1315/1082/1/012015

[2] Mazumder, S., Saha, J., Nandi, G., et al., 2021. Long-term monitoring of cropland transformation in Kolkata Metropolitan Area, India using open-source geospatial technologies. SN Applied Sciences. 3(1), 98. DOI: https://doi.org/10.1007/s42452-020-04064-4

[3] Cinderby, S., Archer, D., Mehta, V.K., et al., 2021. Assessing inequalities in wellbeing at a neighbourhood scale in low-middle-income-country secondary cities and their implications for long-term livability. Frontiers in Sociology. 6. DOI: https://doi.org/10.3389/fsoc.2021.729453

[4] Anderson, V., Gough, W.A., Agic, B., 2021. Nature-based equity: An assessment of the public health impacts of green infrastructure in Ontario, Canada. International Journal of Environmental Research and Public Health. 18(11), 5763. DOI: https://doi.org/10.3390/ijerph18115763

[5] Sullivan, C.A., Meigh, J. R., Fediw, T. S., 2002. Derivation and testing of the Water Poverty Index Phase 1. Final Report May 2002. Centre for Ecology and Hydrology: Wallingford, UK.

[6] Seto, K.C., Fragkias, M., Güneralp, B., et al., 2011. A meta-analysis of global urban land expansion. PLoS ONE. 6(8), e23777. DOI: https://doi.org/10.1371/journal.pone.0023777

[7] Harnaha, O., Savina, N.B., Hrytsiuk, V., 2023. Environmental and economic assessment of the land use regulation effectiveness. Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska. 13(4), 139–141. DOI: https://doi.org/10.35784/iapgos.5604

[8] Amani Fard, F., Riekkinen, K., Pellikka, H., 2023. Evaluating the effectiveness of land-use policies in preventing the risk of coastal flooding: Coastal regions of Helsinki and Espoo. Land. 12(8), 1631. DOI: https://doi.org/10.3390/land12081631

[9] Temesgen, H., Wu, W., Legesse, A., et al., 2021. Modeling and prediction of effects of land use change in an agroforestry dominated southeastern Rift-Valley escarpment of Ethiopia. Remote Sensing Applications: Society and Environment. 21, 100469. DOI: https://doi.org/10.1016/j.rsase.2021.100469

[10] Alijani, Z., Hosseinali, F., Biswas, A., 2020. Spatio-temporal evolution of agricultural land use change drivers: A case study from

Chalous region, Iran. Journal of Environmental Management. 262, 110326. DOI: https://doi.org/10.1016/j.jenvman.2020.110326

[11] Gomes, E., Abrantes, P., Banos, A., et al., 2019. Farming under urban pressure: Farmers' land use and land cover change intentions. Applied Geography. 102, 58–70. DOI: https://doi.org/10.1016/j.apgeog.2018.12.009

[12] Lawyer, C., An, L., Goharian, E., 2023. A review of climate adaptation impacts and strategies in coastal communities: From agent-based modeling towards a system of systems approach. Water. 15(14), 2635. DOI: https://doi.org/10.3390/w15142635

[13] Kasargodu Anebagilu, P., Dietrich, J., Prado-Stuardo, L., et al., 2021. Application of the theory of planned behavior with agent-based modeling for sustainable management of vegetative filter strips. Journal of Environmental Management. 284, 112014. DOI: https://doi.org/10.1016/j.jenvman.2021.112014

[14] Bonabeau, E., 2002. Agent-based modeling: Methods and techniques for simulating human systems. Proceedings of the National Academy of Sciences. 99(suppl_3), 7280–7287. DOI: https://doi.org/10.1073/pnas.082080899

[15] Macal, C.M., North, M.J., 2010. Tutorial on agent-based modelling and simulation. Journal of Simulation. 4(3), 151–162. DOI: https://doi.org/10.1057/jos.2010.3

[16] Gasparini, F., Giltri, M., Bandini, S., 2021. Safety perception and pedestrian dynamics: Experimental results towards affective agents modeling. AI Communications. 34(1), 5–19.

[17] Nassar, M.R., Wilson, R.C., Heasly, B., et al., 2010. An approximately Bayesian delta-rule model explains the dynamics of belief updating in a changing environment. The Journal of Neuroscience. 30(37), 12366–12378. DOI: https://doi.org/10.1523/JNEUROSCI.0822-10.2010

[18] Fischer, A., Glenk, K., 2011. One model fits all? — On the moderating role of emotional engagement and confusion in the elicitation of preferences for climate change adaptation policies. Ecological Economics. 70(6), 1178–1188. DOI: https://doi.org/10.1016/j.ecolecon.2011.01.014

[19] Hoyos, D., Mariel, P., Hess, S., 2015. Incorporating environmental attitudes in discrete choice models: An exploration of the utility of the awareness of consequences scale. Science of The Total Environment. 505, 1100–1111. DOI: https://doi.org/10.1016/j.scitotenv.2014.10.066

[20] Mosler, H.-J., Martens, T., 2008. Designing environmental campaigns by using agent-based simulations: Strategies for changing environmental attitudes. Journal of Environmental Management. 88(4), 805–816. DOI: https://doi.org/10.1016/j.jenvman.2007.04.013

[21] Deegan, A., Dunne, S., 2022. An investigation into the relationship between social support, stress, and psychological well-being in farmers. Journal of Community Psychology. 50(7), 3054–3069. DOI: https://doi.org/10.1002/jcop.22814

[22] Amolegbe, K.B., Adewumi, M.O., 2022. Agribusiness firms and rural dairy development: A case of FrieslandCampina Dairy Development Programme in Nigeria. Agris On-Line Papers in Economics and Informatics. 14(1), 3–18. DOI: https://doi.org/10.7160/aol.2022.140101

[23] Rong, Y., Hou, Y., 2022. Farmers' willingness to participate in voluntary field water management greenhouse gas emission reduction projects based on a context–attitude–behavior framework. Sustainability. 14(23), 15698. DOI: https://doi.org/10.3390/su142315698

[24] Skog, K.L., Bjørkhaug, H., 2020. Farmland under urbanization pressure: Conversion motivation among Norwegian landowners. International Journal of Agricultural Sustainability. 18(2), 113–130. DOI: https://doi.org/10.1080/14735903.2020.1719774

[25] Guliyev, O., Liu, A., Endelani Mwalupaso, G., et al., 2019. The determinants of technical efficiency of hazelnut production in Azerbaijan: An analysis of the role of NGOs. Sustainability. 11(16), 4332. DOI: https://doi.org/10.3390/su11164332

[26] Ekpodessi, S.G.N., Nakamura, H., 2022. Impact of insecure land tenure on sustainable agricultural development: A case study of agricultural lands in the Republic of Benin, West Africa. Sustainability. 14(21), 14041. DOI: https://doi.org/10.3390/su142114041

[27] Brugière, A., Nguyen-Ngoc, D., Drogoul, A., 2022. Handling multiple levels in agent-based models of complex socio-environmental systems: A comprehensive review. Frontiers in Applied Mathematics and Statistics. 8. DOI: https://doi.org/10.3389/fams.2022.1020353

[28] Antelmi, A., Cordasco, G., D'Ambrosio, G., et al., 2022. Experimenting with agent-based model simulation tools. Applied Sciences. 13(1), 13. DOI: https://doi.org/10.3390/app13010013

[29] Zhao, S., Jiang, Y., 2022. Heterogeneous effects of rural–urban migration and migrant earnings on land efficiency: Empirical evidence from China. Land Use Policy. 115, 106003. DOI: https://doi.org/10.1016/j.landusepol.2022.106003

[30] Frijns, B., Lehnert, T., Zwinkels, R.C.J., 2010. Behavioral heterogeneity in the option market. Journal of Economic Dynamics and Control. 34(11), 2273–

2287. DOI: https://doi.org/10.1016/j.jedc.2010.05.009

[31] Mazzoli, M., Morini, M., Terna, P., 2017. Business cycle in a macromodel with oligopoly and agents' heterogeneity: An agent-based approach. Italian Economic Journal. 3(3), 389–417. DOI: https://doi.org/10.1007/s40797-017-0058-y

[32] Dritschel, D.G., Böing, S.J., Parker, D.J., et al., 2018. The moist parcel-in-cell method for modelling moist convection. Quarterly Journal of the Royal Meteorological Society. 144(715), 1695–1718. DOI: https://doi.org/10.1002/qj.3319

[33] Li, Z., Guan, X., Wu, H., et al., 2017. A novel k-means clustering based task decomposition method for distributed vector-based CA models. ISPRS International Journal of Geo-Information. 6(4), 93. DOI: https://doi.org/10.3390/ijgi6040093

[34] Peckham, J., Lloyd, S.J., 2003. Integrating patterns into CASE tools. In Practicing Software Engineering in the 21st Century. IGI Global Scientific Publishing: Hershey, PA, USA. pp. 1–10. DOI: https://doi.org/10.4018/978-1-93177-750-6.ch001

[35] Katzke, U., Vogel-Heuser, B., 2005. UML-Pa as an engineering model for distributed process automation. IFAC Proceedings Volumes. 38(1), 129–134. DOI: https://doi.org/10.3182/20050703-6-CZ-1902.01063

[36] Schneiderbauer, S., 2018. Validation study on spatially averaged two-fluid model for gas-solid flows: II. Application to risers and fluidized beds. AIChE Journal. 64(5), 1606–1617. DOI: https://doi.org/10.1002/aic.16141

[37] Epstein, J.M., Axtell, R.L., 1996. Growing Artificial Societies: Social Science from the Bottom Up. The MIT Press: Cambridge, MA, USA. DOI: https://doi.org/10.7551/mitpress/3374.001.0001

[38] Grimm, V., Railsback, S.F., Vincenot, C.E., et al., 2020. The ODD protocol for describing agent-based and other simulation models: A second update to improve clarity, replication, and structural realism. Journal of Artificial Societies and Social Simulation. 23(2), 7. DOI: https://doi.org/10.18564/jasss.4259

[39] Hinojoza-Castro, G., Gómez-Delgado, M., Plata-Rocha, W., 2022. Real estate developers as agents in the simulation of urban sprawl. Sustainability. 14(15), 8994. DOI: https://doi.org/10.3390/su14158994

[40] Mohammed, A.M.S., Ukai, T., 2023. Agent-based modelling for spatiotemporal patterns of urban land expansion around university campuses. Modeling Earth Systems and Environment. 9(1), 1119–1133. DOI: https://doi.org/10.1007/s40808-022-01551-y

[41] Zeng, Y., Huang, W., Jin, W., et al., 2016. Multi-agent based simulation of optimal urban land use allocation in the middle reaches of the Yangtze River, China. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XLI-B8, 1089–1092. DOI: https://doi.org/10.5194/isprs-archives-XLI-B8-1089-2016

[42] Truong, Q.C., Drogoul, A., Gaudou, B., et al., 2023. An agent-based model for land-use change adaptation strategies in the context of climate change and land subsidence in the Mekong Delta. Sustainability. 15(6), 5355. DOI: https://doi.org/10.3390/su15065355

[43] Gilbert, N., 2008. The Idea of Agent-Based Modeling. In Agent-Based Models. SAGE Publications, Inc.: Thousand Oaks, CA, USA. pp. 2–21. DOI: https://doi.org/10.4135/9781412983259.d5

[44] Berger, J., 2024. Social capital is associated with cooperation and indirect norm enforcement in the field: behavioural evidence from Switzerland. European Sociological Review. 40(3), 511–522. DOI: https://doi.org/10.1093/esr/jcad039

[45] Akhavi Zadegan, R., Pirnajmuddin, H., 2019. Forms of capital in F. Scott Fitzgerald's "Winter Dreams." Miscelánea: A Journal of English and American Studies. 60, 33–50. DOI: https://doi.org/10.26754/ojs_misc/mj.20196286

[46] Portes, A., 1998. Social capital: its origins and applications in modern sociology. Annual Review of Sociology. 24(1), 1–24. DOI: https://doi.org/10.1146/annurev.soc.24.1.1

[47] Bjørnskov, C., 2008. Social capital and happiness in the United States. Applied Research in Quality of Life. 3(1), 43–62. DOI: https://doi.org/10.1007/s11482-008-9046-6

[48] Luiz Coradini, O., 2010. The divergences between Bourdieu's and Coleman's notions of social capital and their epistemological limits. Social Science Information. 49(4), 563–583. DOI: https://doi.org/10.1177/0539018410377130

[49] Cox, K.C., Lortie, J., Dheer, R.J.S., 2022. Influence of national and regional level social capital on entrepreneurial activity. Cross Cultural & Strategic Management. 29(1), 195–218. DOI: https://doi.org/10.1108/CCSM-07-2021-0129

[50] Villalonga-Olives, E., Kawachi, I., 2015. The measurement of social capital. Gaceta Sanitaria. 29(1), 62–64. DOI: https://doi.org/10.1016/j.gaceta.2014.09.006

[51] Wang, J., Zhang, J., Xiong, N., et al., 2022. Spatial and temporal variation, simulation and prediction of land use in ecological conservation area of western Beijing. Remote Sensing. 14(6), 1452. DOI: https://doi.org/10.3390/rs14061452

[52] Hartmann, D., Arata, A., Bezerra, M., et al., 2023. The network effects of NGOs on social capital and

innovation among smallholder farmers: a case study in Peru. The Annals of Regional Science. 70(3), 633–658. DOI: https://doi.org/10.1007/s00168-019-00944-9

[53] Bradley, Q., 2023. Artificial scarcity in housebuilding and the impact on affordability: the return of absolute rent. Antipode. 55(4), 1110–1127. DOI: https://doi.org/10.1111/anti.12925

[54] Das, D., 2023. Marxist rent theory and its applications in developing countries. Science & Society: A Journal of Marxist Thought and Analysis. 87(4), 531–555. DOI: https://doi.org/10.1521/siso.2023.87.4.531

[55] Schwerhoff, G., Edenhofer, O., Fleurbaey, M., 2020. Taxation of economic rents. Journal of Economic Surveys. 34(2), 398–423. DOI: https://doi.org/10.1111/joes.12340

[56] Suartining, N.K., Djaja, B., 2023. Land rights in the land law system in Indonesia according to the basic agrarian law number 5 of 1960. Journal of Social Research. 2(6), 1775–1785. DOI: https://doi.org/10.55324/josr.v2i6.903

[57] Adhisukmawati, I.G.A.K.H., Handayani, I.G.A.K.R., Karjoko, L., 2023. Fairness aspects of compensation arrangements in the acquisition of land for development for the public interest. International Journal of Educational Research & Social Sciences. 4(1), 186–194. DOI: https://doi.org/10.51601/ijersc.v4i1.606

[58] Bedner, A., Arizona, Y., 2019. Adat in Indonesian land law: a promise for the future or a dead end? The Asia Pacific Journal of Anthropology. 20(5), 416–434. DOI: https://doi.org/10.1080/14442213.2019.1670246

[59] Bai, Y., Wu, S., Zhang, Y., 2023. Exploring the key factors influencing sustainable urban renewal from the perspective of multiple stakeholders. Sustainability. 15(13), 10596. DOI: https://doi.org/10.3390/su151310596

[60] Martellozzo, F., Amato, F., Murgante, B., et al., 2018. Modelling the impact of urban growth on agriculture and natural land in Italy to 2030. Applied Geography. 91, 156–167. DOI: https://doi.org/10.1016/j.apgeog.2017.12.004

[61] Akiruddin, A., 2022. Legal protection of land use in the context of opening and development of agricultural land for public interests. International Journal of Community Service (IJCS). 1(1), 105–110. DOI: https://doi.org/10.55299/ijcs.v1i1.205

[62] Adhikari, S., Kingi, T., Ganesh, S., 2014. Incentives for community participation in the governance and management of common property resources: the case of community forest management in Nepal. Forest Policy and Economics. 44, 1–9. DOI: https://doi.org/10.1016/j.forpol.2014.04.003

[63] Kotir, J.H., 2011. Climate change and variability in Sub-Saharan Africa: a review of current and future trends and impacts on agriculture and food security. Environment, Development and Sustainability. 13(3), 587–605. DOI: https://doi.org/10.1007/s10668-010-9278-0

[64] Yu, W., Zhang, L., Zhang, H., et al., 2020. Effect of farmland expansion on drought over the past century in Songnen Plain, Northeast China. Journal of Geographical Sciences. 30(3), 439–454. DOI: https://doi.org/10.1007/s11442-020-1736-5

[65] Craig, H., Paulik, R., Djanibekov, U., et al., 2021. Quantifying national-scale changes in agricultural land exposure to fluvial flooding. Sustainability. 13(22), 12495. DOI: https://doi.org/10.3390/su132212495

[66] Caldas, A.M., Pissarra, T.C.T., Costa, R.C.A., et al., 2018. Flood vulnerability, environmental land use conflicts, and conservation of soil and water: a study in the Batatais SP municipality, Brazil. Water. 10(10), 1357. DOI: https://doi.org/10.3390/w10101357

[67] Yu, M., Li, Q., Lu, G., et al., 2015. Investigation into impacts of land-use changes on floods in the upper Huaihe River basin, China. Proceedings of the International Association of Hydrological Sciences. 370, 103–108. DOI: https://doi.org/10.5194/piahs-370-103-2015

[68] Gholami, F., Li, Y., Zhang, J., et al., 2023. Quantitative assessment of future land use changes' impact on flood risk components: integration of remote sensing, machine learning, and hydraulic modeling [Preprint]. Research Square. DOI: https://doi.org/10.21203/rs.3.rs-3632802/v1

[69] Yang, D., Yang, A., Qiu, H., et al., 2019. A citizen-contributed GIS approach for evaluating the impacts of land use on Hurricane-Harvey-induced flooding in Houston area. Land. 8(2), 25. DOI: https://doi.org/10.3390/land8020025

[70] Chen, W., Wang, Q., Zhou, H., 2022. Digital rural construction and farmers' income growth: theoretical mechanism and micro experience based on data from China. Sustainability. 14(18), 11679. DOI: https://doi.org/10.3390/su141811679

[71] Grimm, V., Berger, U., DeAngelis, D.L., et al., 2010. The ODD protocol: a review and first update. Ecological Modelling. 221(23), 2760–2768. DOI: https://doi.org/10.1016/j.ecolmodel.2010.08.019

[72] Müller, B., Bohn, F., Dreßler, G., et al., 2013. Describing human decisions in agent-based models – ODD+D, an extension of the ODD protocol. Environmental Modelling & Software. 48, 37–48. DOI: https://doi.org/10.1016/j.envsoft.2013.06.003

[73] Parker, D.C., Manson, S.M., Janssen, M.A., et al., 2003. Multi-agent systems for the simulation of

land-use and land-cover change: a review. Annals of the Association of American Geographers. 93(2), 314–337. DOI: https://doi.org/10.1111/1467-8306.9302004

[74] Crooks, A., Malleson, N., Manley, E., et al., 2019. Agent-Based Modelling and Geographical Information Systems: A Practical Primer, 1st ed. Sage Publications: London, UK.

[75] Awaworyi Churchill, S., Mishra, V., 2017. Trust, social networks and subjective wellbeing in China. Social Indicators Research. 132(1), 313–339. DOI: https://doi.org/10.1007/s11205-015-1220-2

[76] Ostrom, E., Ahn, T.K., 2009. The meaning of social capital and its link to collective action. In Handbook of Social Capital. Edward Elgar Publishing: Cheltenham, UK. DOI: https://doi.org/10.4337/9781848447486.00008

[77] Haase, D., 2021. Integrating ecosystem services, green infrastructure and nature-based solutions—new perspectives in sustainable urban land management. In: Weith, T., Barkmann, T., Gaasch, N., et al. (eds.). Sustainable Land Management in a European Context: A Co-Design Approach. Springer International Publishing: Cham, Switzerland. pp. 305–318. DOI: https://doi.org/10.1007/978-3-030-50841-8_16

[78] Termorshuizen, J.W., Opdam, P., 2009. Landscape services as a bridge between landscape ecology and sustainable development. Landscape Ecology. 24(8), 1037–1052. DOI: https://doi.org/10.1007/s10980-008-9314-8

[79] Seto, K.C., Güneralp, B., Hutyra, L.R., 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceedings of the National Academy of Sciences. 109(40), 16083–16088. DOI: https://doi.org/10.1073/pnas.1211658109

[80] Ferrianta, Y., Makki, M.F., 2015. Risk analysis and strategy of rice farmers in swamp land in the face of climate change impact (case in South Kalimantan Province-Indonesia). International Journal of Agricultural Management and Development (IJAMAD). 5(2), 131–139. DOI: https://doi.org/10.22004/ag.econ.262504