

Agent-Based Modeling of Large-Scale Land Acquisition and Rural Household Dynamics

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Introduction

Rural systems in most Sub-Saharan African countries are characterized by interdependent relationships between households dependent on subsistence agriculture and the biophysical system to which they are dynamically coupled. Rural households often rely on rain-fed agriculture, with climate variability directly affecting agricultural production. Their livelihood decisions are governed by the availability of and opportunity to use resources (human, social, environmental, or financial).

Recently, the rise in large-scale land acquisitions has become a major public issue altering the dynamics of rural systems and affecting the adaptive capacity of rural communities. Although most rural communities have developed adaptation mechanisms for prolonging their livelihood, the introduction of industrial-scale agribusiness enterprises (both national and international in origins) and the subsequent rapid change in land-use systems are challenging traditional ways of life. As a result, affected communities face a choice of migrating, protesting (including violence), or suffering hardship in situ.

The resilience of such regional systems under future socioeconomic uncertainty, and the complexity of the dynamics (i.e., heterogeneous actors/agents, nonlinear interactions, emergent micro-macro dynamics, and multiple spatio-temporal scales), pose a significant scientific challenge. Understanding the interaction between enterprises and rural communities, as well as the influence of commercialization of land on rural livelihoods and ecosystems, is key to improving policies for

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enhancing the well-being of indigenous rural communities, and improving the prospects for economic development compatible with maintaining the sustainability of the ecosystems's functions and processes.

Rural Systems and Large-Scale Land Acquisition

The current surge in large-scale land acquisition in many developing countries has become a global (or at least a transnational) issue, attracting attention due to the scale and speed of acquisition [52]. The issue is especially felt in Sub-Saharan Africa—the area of the world with the highest hunger indices [53]—where a single enterprise could acquire nearly 500,000 hectares of land in a single purchase [20]. These land acquisitions involve diverse interest groups, both national and international, with diverse sources of investments, including privately owned, government-backed, and sovereign wealth fund investments.

Extent of Large-Scale Land Acquisition

Multiple lines of evidence yield the same overall trend in large-scale land acquisition in developing countries generally, and in particular Sub-Saharan Africa, including Ethiopia. The International Food Policy Research Institute (IFPRI) has estimated that nearly 20 million hectares of farmlands in developing countries have been acquired by enterprises since 2006 [53]. A World Bank study, based on more data sources including media reports, raised the figure to 57 million hectares [20]. Of these, more than two-thirds are in Sub-Saharan Africa [20]. Another empirical study by Cotula et al. [14] has shown that between 2004 and 2008, a total of 2.5 million hectares of land was acquired by national and international enterprises in five African countries: Ghana, Madagascar, Mali, Sudan, and Ethiopia. A recent study by The Oakland Institute, an independent policy think tank, reports that in Ethiopia alone the total amount of lands acquired by foreign and national enterprises increased from about 1.2 million hectares between 2004 and 2008 to nearly 3.6 million hectares as of January, 2011 [40].

Several processes drive large-scale land acquisition, the most common being demand for food and biofuel production. The empirical study by Cotula et al. [14] in five African countries indicated that, of the total 2.5 million hectares that were acquired by different domestic and foreign enterprises between 2004 and 2008, nearly 1.4 million hectares were for food and 1.1 million for biofuel production. In line with this, increased involvement by private enterprises and international organizations in the development of protected areas, nature reserves, ecotourism businesses, and construction of large-scale tourist complexes promote the conversion of productive lands into attractive tourist destinations and cause significant changes to land ownership and the traditional land-use system [54].

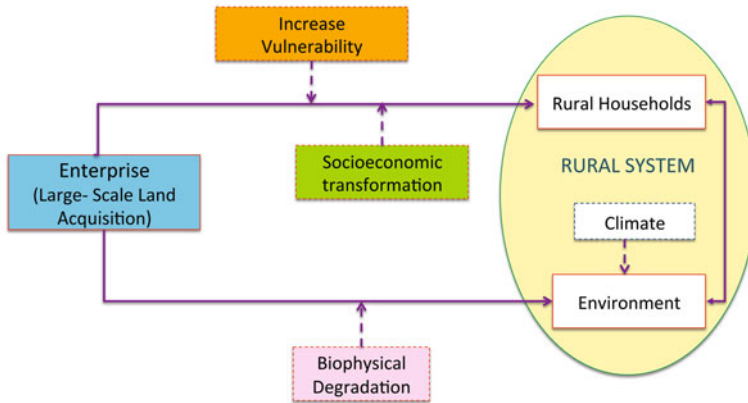


Fig. 1 Influence of large-scale land acquisition on rural systems. *Solid and dashed lines indicate direct and indirect relationships between components, respectively.* Source: adapted from [30]

Implications of Large-Scale Land Acquisition

The expansion of large-scale land acquisition can have various influences on a rural system, as shown in Fig. 1. Earlier studies have linked the activity of such enterprises to significant change in the socioeconomic dynamics of rural systems (e.g., [9, 20, 22, 23, 53], among others), showing that enterprises can contribute to a rural economy by creating jobs, transferring technologies, and developing infrastructure. In many cases, large-scale land acquisitions are oriented toward labor-intensive agriculture, thereby creating opportunities for a wage labor market in rural societies [20]. Wage labor enhances household incomes and diversifies livelihood options. It may also help households minimize dependency on subsistence farming, decrease vulnerability to climate change, and increase economic benefits [5]. Moreover, income growth can lead to a self-sufficient lifestyle and limit rural migration to urban centers [18].

The operation of more capital-endowed enterprises in a rural system can also increase rural infrastructure (e.g., roads, irrigation canals, bridges, storage facilities, transportation nodes) as enterprises seek to develop their business for maximum economic return. Infrastructure improvements can expose rural communities to broader opportunities, such as providing new or better links to markets and urban areas, minimizing travel costs, enhancing agricultural productivity, and improving the prospect for greater public services [10, 21]. Enterprises might also contribute to a rural system by increasing the production performance of land through the introduction of modern technology [13].

Although rural households’ welfare might improve from the contributions of enterprises, large-scale land acquisitions also expose rural households to risks to their livelihood [7, 52]. Expansion of industrialized agricultural systems can

deny the customary rights of rural households to utilize communal properties and lands, affecting indigenous adaptive capacity and increasing the vulnerability of households [41]. Considerable expansion of large-scale land acquisition can also cause dispossession and displacement of locals, as most of the lands are already occupied or used by rural households [2]. The policy of changing a rural system to a more modern capital-intensive agriculture system can neglect the social functions of land, which is more than a production-entity in traditional societies.

The environment is also stressed when land is converted to agriculture [29]. The conversion of “marginal” land—currently covered by forest or used for grazing—can accelerate land degradation and loss of biodiversity [37]. Even when large-scale farming is implemented in existing agricultural lands, the change from multi-cropping to mono-cropping causes an increase in vulnerability to drought and disease. Besides degradation and biodiversity loss, increased utilization of chemicals without proper treatment of effluent waters can cause environmental damage and increase health risks for humans, animals, and native vegetation.

Prior Agent-Based Modeling on Traditional Societies in Rural Systems

Several studies have been conducted to analyze the impacts of expansion of large-scale land acquisition in rural systems [45]. Earlier methodologies, such as statistical, equation-based, and systems models have been used to study the complexity of rural systems in different contexts [42]. However, these approaches have been criticized for their inefficiency in capturing complex interactions in human and biophysical systems. Earlier modeling approaches either over-simplify the representation of human actors or fail to capture temporal complexity, spatial complexity, and feedbacks [44].

More recently, understanding a rural system as a complex adaptive system has been a focus of attention, as this approach provides novel insights by capturing the complexity of interactions and dynamic feedbacks among system components [44]. The application of dynamic modeling could also help to explore the impact of climate change and large-scale land acquisition. The application of integrated models—such as agent-based models (ABMs) for capturing interactions among individuals and surrounding environment—is essential for understanding complex, dynamic, and nonlinear challenges faced by rural households when large-scale land acquisitions occur. An ABM provides a powerful computational laboratory for exploring and analyzing interesting scenarios focused on the local people’s adaptive responses to different socioeconomic conditions and the resulting effects on their ecosystem [11, 15].

Several ABMs have examined interactions between rural households and their environments in developing countries, including assessments of consequences of household decisions on land use and land cover change (LUCC) [19, 33–35, 38,

47, 48]; households' migration behavior [24, 26, 32, 50]; vulnerability to climatic factors [1, 8]; adaptation to climate variability [12]; climate risk perception in land markets [25]; and diversification and adoption of new technologies [6, 31].

Although these and other prior models provide insights on complexity in coupled human and natural systems and the impact of human actions on the environment and vice versa, insufficient attention has been paid to the effect of large, industrial-scale enterprise actors, their interaction with local households, and how they affect rural landscape dynamics. Existing models focus mostly on individuals, households, and their interactions with biophysical environments and climate change.

A review of current research on coupled human and natural systems by Rindfuss et al. [47] identified shortcomings in terms of agent typology, scale of applications, and representation of feedbacks. Most of the models use only one type of agent, so agent heterogeneity is typically rendered through variation in household attributes, not in the characteristics of agents (e.g., households vs. enterprises) [43]. However, most systems of households consist of more than one type of agent. Competing actors with diverse objectives and goals interact with each other and with environments at different spatial and temporal scales [3]. The scale of intervention, type of interaction among actors, and factors affecting their decisions are usually different. Rindfuss et al. [47] have suggested that it is essential to consider the influence of diverse actors, their distinct characteristics, and the different factors affecting their decision-making to better understand how human and natural systems function.

Setting, Situation and Study Area

This study focuses on the South Omo Zone of Ethiopia, where large-scale land acquisition is an emerging public issue. The zone is rich in resources (fertile soils, rivers, irrigable lands) and has significant potential for increased agricultural and livestock production. It is comprised of 2.3 million hectares of arid and semi-arid lands in southern Ethiopia, with low and erratic rainfall, periodic droughts, and different types of vegetative cover and soils. The region borders Kenya in the south and South Sudan in the southwest, as shown in Fig. 2. Regional topography shows a distinct gradient along a northeast-southwest direction. Elevation in the northeast reaches 2500–3500 meters above sea level (MSL), while in the southwest it falls to 400–500 MSL. Vegetation cover varies along the elevation gradient. Lowlands are covered primarily with grasslands and woodlands, while highlands are covered with shrubs and trees. The Omo River dissects the zone running north to south, draining northern, higher-rainfall areas into Lake Turkana. The South Omo Zone is intersected by the Woito River on the southeast side, draining the northeast escarpments into the Chew-Bahir (also known as the “Salt Sea”).

The local population consists of indigenous tribes living in a traditional system of subsistence agriculture. The total population of the zone is 569,448 inhabitants, according to the 2012 census, with 284,781 (50.01%) males and 284,667 (49.9%)

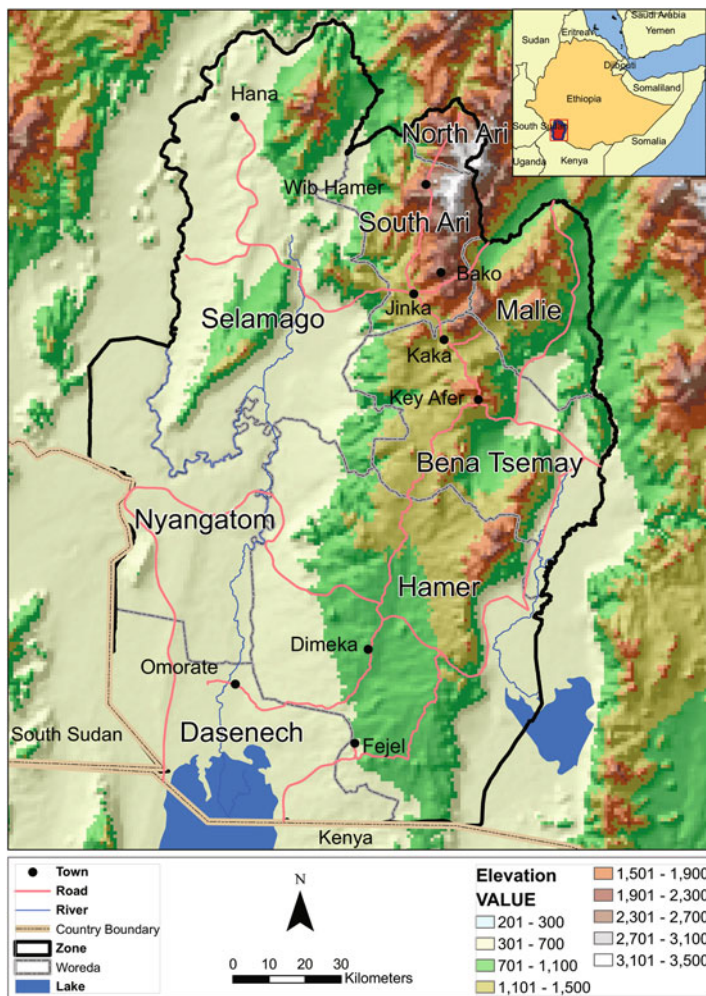


Fig. 2 Geographical location of the South Omo Zone of Ethiopia, also known as Dehub Omo. Source: drawn by the first author, based on [30]

females [17]. The total number of households is 125,009 with an average household size of 4.6 persons, of which about 80% are male-headed households while the remaining 20% are female-headed households. The economic activity of the region is characterized by subsistence agriculture dominated by agro-pastoral and pastoral systems. Subsistence crop production is the traditional system, focused primarily on household consumption needs. Crop production is highly dependent on rain, although there are significant opportunities for irrigation and riverine crops. Livestock production occurs mainly in lowland areas, where moisture is a constraint. Lowland households realize 80% of their income from livestock [28].

South Omo is in the public spotlight due to a rising trend in large-scale land acquisitions. The government of Ethiopia is interested in increasing the socio-economic status of rural traditional communities and improving the agricultural sector by “commodification” of the land. Current policy entails transforming a rural society of many small farmers and subsistence agriculture into capital-intensive production enterprises for feeding a growing urban population [39]. Currently the federal land administration has assigned about 500,000 hectares of land in the South Omo Zone—which is about 20% of the total area of the region—to a variety of investment purposes [40]. The Oakland Institute [40] estimates that the amount of land already provided to large enterprises is 445,500 hectares, mainly along the Omo river, which is a significant ecosystem used by traditional pastoralists for coping and adaptation purposes. This trend in land acquisitions will likely bring major changes to the currently stable rural system—a hypothesis tested by our ABM. Growing pressures from national and foreign enterprises for large-scale agricultural production and ecotourism, and shifts in government policies, generate changes in socio-ecological dynamics, potentially affecting the adaptive capacity of rural households by limiting access to traditional resources.

The OMOLAND Model

Model Description

The OMOLAND model includes interrelated components of the South Omo Zone rural system. This ABM is designed to explore interactions and decision-making among different actors in the system: (1) rural households, whose livelihood is significantly coupled with climate and biophysical environments; (2) large-scale land enterprises, operating in the rural system; (3) climate, with variability that impacts actors and the biophysical environment; (4) actors, affecting their respective environments; and (5) the environment, producing feedback effects that influence actors’ decision-making processes at different temporal and spatial scales. The representation of entities and their interactions uniquely distinguishes this model from previously implemented agent-based models of rural systems (e.g., [8, 19, 33, 48]). The model is implemented in MASON [36], an ABM simulation toolkit written in the Java programming language and primarily designed to facilitate the development of fast and efficient ABMs. MASON provides extensive libraries to integrate GIS data (vector and raster) [51].

Figure 3 illustrates the main components and relationships in OMOLAND using a UML (Unified Modeling Language) class diagram. The environment is the South Omo Zone, consisting of biophysical components (including natural and built systems) with spatial extent of 146.7 by 224.7 km and comprised primarily of heterogeneous parcels (built environment is minimal in this region, except for some roads). OMOLAND’s spatial resolution is 1 hectare (100 by 100 m), based on the

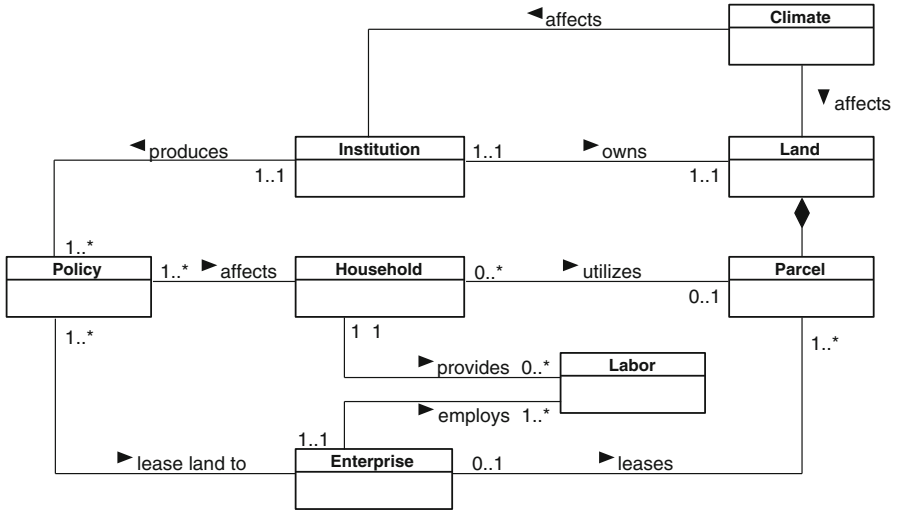


Fig. 3 High-level UML class diagram of the OMOLAND model in MASON. Source: adapted from [30]

average land-holding size of the rural households in the region. Each parcel has quality that is restored or depleted based on actions by households and enterprises. The biophysical system dynamically responds to climate and its variation. Such response will indirectly influence land-use choices by households and enterprise agents.

Climate in OMOLAND is represented by rainfall in terms of precipitation distribution patterns and variations, calibrated to the study area. Climate variation includes significant changes in weather patterns, shifting from normal to extreme events (e.g., drought, flooding). Climate determines the characteristics of biomass in the environment; i.e., type, growth rate, productivity, and annual number and length of growing period(s) or season(s).

Household agents represent individual households that live in a subsistence agricultural system (herding and/or farming) within the study area. Household agents are heterogeneous in their profile, livelihood choices, and decision-making processes. They have bounded rationality [49], lacking full knowledge of the environment, and making decisions based on information they have at hand and on their previous experience. However, households learn, imitate skills and techniques, and make adjustments to their livelihood. They are also social agents, cooperating among themselves and competing with others for resources. Each household has one or more family members. Each family member knows its employment situation.

Enterprise agents represent business actors operating large-scale agricultural production systems. They use much larger tracts of land in their possession and are heterogeneous, based on their land holdings and the number of employees they can hire at a given time. They also create jobs in the rural system and they interact with household agents in a labor market.

An enterprise agent is designed to capture two of the main influences of real-world enterprises in the rural systems. First, enterprises agents influence a biophysical environment by occupying a large tract of land and changing the land property from grazing land to farmland as lands are used for production of commercial crops through mechanized farming. The occupation and conversion of land has direct effects on the amount of vegetation production in the system. Conversion of grazing land to commercial farming reduces the total grazing area. This, in turn, has implications for livestock production, which solely depends on grazing. Moreover, occupation of land can also affect herding movements from place to place by fragmenting grazing areas. Second, enterprises affect the system by introducing a new livelihood option for rural households. These employment opportunities can diversify household income options. OMOLAND is designed to implement these two concepts.

Enterprises individually determine labor needs and announce openings to the public. Employment positions remain open until filled. When a position is filled, it is no longer searchable by the public and the enterprise does not employ additional labor. Positions are temporary. When a task reaches its time limit, the enterprise dismisses all employees and determines when to start a new task.

It is critical to point out that workers can also resign and leave an enterprise. A household may abandon off-farm activity at any given time and decide to return to agricultural activities, since in most rural systems off-farm activity is subsidiary to traditional farming and herding [27]. If a household member decides to leave an off-farm position, the enterprise will assess labor needs and immediately publicize employment positions as necessary [46].

In the OMOLAND model, each enterprise pays each worker an equal amount each day. Although skill or experience may affect the amount of money a worker can earn, this is not considered in the model. We believe that prior skill or experience are not yet valued in off-farm activity in South Omo, because the main opportunity is related to short-term labor activities.

The institution agent in Fig. 3 represents the government and is responsible for generating policies related to land use. This agent has overall knowledge of the entire area, assessing and designating land for different uses. For instance, the institution agent assigns lands to enterprises based on land quality. The allocation to enterprises can be either on lands that are occupied or unoccupied by rural households. The institution agent can also relocate household agents depending on demand for more lands from enterprise agents.

The temporal resolution of OMOLAND is a discrete time step, where 1 step = 1 day. Although such a temporal resolution is relatively fine, some processes occur only when necessary conditions are satisfied. For instance, crops can only instantiate and grow when a household agent sows crop seeds on his farmland. Similarly, a household member's age increases only once in a year. A full description of the OMOLAND model can be found in Hailegiorgis [30].

Model Sequence

The model sequence includes all components involved in the scheduling routine. Each procedure is activated by its generating actor or entity, and similar procedures are activated in the same order at each time step. The first routine concerns how climate affects land. This is updated by having rain fall on each parcel, which is followed by each parcel updating its soil moisture level. Equal amounts of rainfall generate equal amounts of soil moisture. In OMOLAND there is no overflow, inflow of water, or accumulation of soil moisture, as a simplifying assumption, so the updating mechanism is simple. If there is no rain on a given day, the amount of soil moisture added to a parcel is assigned as zero; otherwise, a parcel's soil moisture equals the amount of rainfall on the parcel. After updating rainfall, the vegetation subroutine is executed. Vegetation grows or decreases depending on a parcel's moisture, for each parcel where there is vegetation.

The second routine concerns household agents. In each time step, each household agent engages in livelihood activities, updates profiles, and assesses the success or failure of actions. The main sequential procedures of the household are predicting future climate conditions, analyzing adaptive response, selecting potential livelihood options, allocating resources for implementing livelihood-related activities, monitoring wealth status, updating profile, and updating memory. Routines are only executed at times when appropriate conditions are fulfilled. For instance, sequential procedures from predicting future climate conditions to determining livelihood options are executed once in a season. Each household predicts a date and amount of rainfall for the upcoming season. Based on the outcome of their action, each household makes an appropriate decision to either adapt or fail to adapt in response to the anticipated climatic condition of the season. Depending on the adaptation decision, each household determines the best livelihood or combination of livelihoods (herding, farming, or off-farming) that yields highest return. The household then allocates resources necessary for each livelihood in proportion to the share value of each livelihood. The household remembers its decision and allocation of resources for each livelihood option throughout the implementation of each activity. Implementation of an activity is carried out until each has either been discarded or completed. Memory update is executed at the end of each season.

The livelihood activity sequence of a household is scheduled in the following order: herding, farming, and off-farming. If a household engages in only one of the three livelihood options, it only implements the corresponding activity sequence. For instance, herding activities are invoked if the household has livestock. A household with livestock looks for high-quality grazing areas for its herds. A herder household also monitors its herd income in this sequence. Households with farmland implement farming activities, which include land preparation, planting, weeding, and harvesting. The implementation date of each activity is determined by when its necessary conditions are met. For instance, after the onset of rain, a household assesses if there is sufficient moisture to perform planting. Likewise, when a crop is ready for harvest, a household executes harvesting. At harvest

time, each farmer household updates its income in proportion to yield harvested. Household agents can execute off-farm activities to earn extra income by seeking employment in one of the enterprises.

After the household routine, the herd sequence is invoked. Herds consume grass from their current location and move to an assigned location. They update their metabolic rate, food level, and size based on grass consumption.

Following the herd sequence, the crop sequence is invoked. A crop is activated only when it is planted. Similar to vegetation, crops respond to available moisture in their parcel, by either growing or decreasing. A crop updates its growth and production level at each time step.

The enterprise routine comes next. In each time step, enterprise agents manage the labor force by deciding whether to recruit or dismiss workers (daily laborers) and acting on their decisions. Each enterprise determines its labor requirements and allocates the resource to the task. If the current labor is more than required, the enterprise agent reduces the labor force to the required minimum level by dismissing excess workers. Conversely, if there is a need for labor, the agent searches for extra labor and hires to fill the labor gap.

The institutional sequence is invoked after the enterprise routine. The institution agent, which represents government, selects potential households needing capacity-building training or relief support, and provides such benefits as necessary.

Finally, an observer object, for managing data collection and statistics, is invoked and all the output is written to disk.

Policy Scenarios

The main aim of our scenario analysis is to explore and better understand impacts of large-scale land acquisitions on rural households by changing the scale and intensity of intervention of enterprise agents. Policy relevance is high, given the stakes and complexity of dynamic interactions among enterprises, households, climate, and environmental entities.

Scenario analyses using OMOLAND examine the impacts of enterprises on rural households. Analysis focuses on exploring whether enterprises increase the vulnerability of rural households or provide households an opportunity to diversify their livelihood options through off-farm activities. The following two main scenarios are analyzed: large-scale land acquisition without and with off-farm opportunities, corresponding to Scenario 1 and Scenario 2, respectively.

The main goal of scenario analysis is to assess issues related to commercial enterprises' contributions to providing additional off-farm opportunities to rural households. Although commercial enterprises increase employment opportunities, the probability that an individual person in a rural community will participate in such employment opportunities is not significant due to high competition (i.e., excess supply of labor). Moreover, such jobs are often short-term or seasonal and usually poorly paid [46]. Such factors discourage the engagement of rural households in off-farm activities, affecting their off-farm opportunities.

Scenario 1 depicts large-scale land acquisition with diverse spatial intensity and no opportunity for off-farm activity by rural households. In Scenario 2, enterprises offer labor employment opportunities to rural households [14], recruiting and dismissing employees depending on their labor requirements. Rural households search for such nearby off-farm opportunities and engage if they have extra time available from herding or farming, or if either of these two activities fails to provide sufficient household income.

Two trends in enterprise growth rates, “slow” and “fast,” are explored in each scenario, corresponding to 2% and 5% annual growth rates, respectively—with the latter representing the current rate for the South Omo Zone.

Rural households and enterprises are considered as main agents in each scenario. The simulation runs for 18,250 steps. Since each step corresponds to a day, then 18,250 iterations are about 50 years. Monthly rainfall data from 1949 to 2009 is used as climate input. A set of 30 simulation runs is conducted for each scenario, using the same initial (default) parameter settings.

Results

It is important to discuss model verification before presenting results, following current standards in quality control. Verification is the process of ensuring that a simulation is implemented as intended by the conceptual model [4, 11, 16]. Verification of OMOLAND was performed by conducting code walkthroughs, debugging, profiling, and parameter sweeps. These tests insured that we made no logical errors in the translation of the model into code and there were no programming errors. No anomalies have been detected since the above verification procedures were carried out, so we feel confident that the model behaves as it is intended and it matches its design.

In this section we present results from simulation analysis of the two scenarios described in Section “Policy Scenarios”.

Scenario 1: Without Off-Farm Opportunities

Figure 4 shows Scenario 1 (“no off-farm opportunity”) results, assuming slow (2%) and fast (5%) rates in land acquisition expansion. As can be seen, the two figures are very similar, the only difference being a slightly lower final value for household totals in the figure on the right (b). When we explore the number of people that emigrate from the region, results in Fig. 5 also show that there is a significant difference between the 2% and 5% expansion rates, especially during the last 10 years of the simulation. However, emigration change is not linearly related to change in the expansion rate of large-scale land acquisition.

As shown in Fig. 5, at the end of the simulation, the number of emigrants reached 1 person per 9.7 hectares of land acquired by enterprises at a 2% (“slow”) expansion

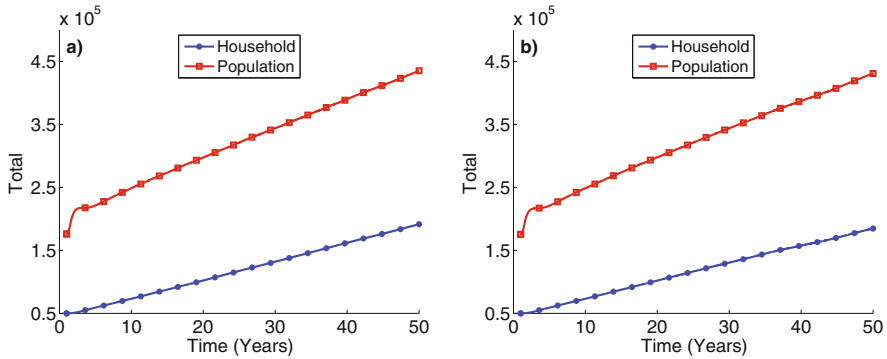


Fig. 4 Scenario 1 results: household and population growth without off-farm opportunities, assuming slow (a) and fast (b) rates of expansion in land acquisition, corresponding to 2% and 5% annual rates

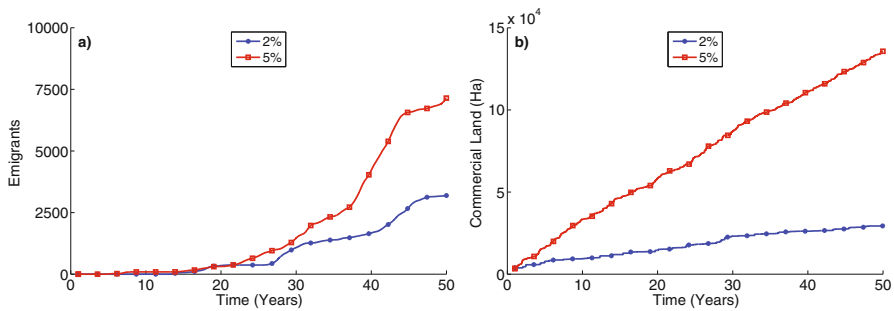


Fig. 5 Scenario 1 results: migration and land expansion without off-farm opportunity: (a) total number of emigrants and (b) area of land acquired by enterprise in hectares

rate, while at a 5% (“fast”) rate of expansion the number of emigrants decreases to 1 person per 18.9 hectares. Note that, as a quantitative measure of social impact caused by enterprise expansion, this emigration effect is akin to a density measured in [persons]/[hectare]. This can also be interpreted as a displacement flow when time is added, or [persons]/[area][time].

The impact of expansion of large-scale commercial farming over time on crop and livestock production is shown in Fig. 6. Interestingly, increasing the rate of expansion of large-scale commercial enterprises does not significantly affect the per capita level of livestock and crop production in the region. Trends in livestock and production for the simulated period are similar under both rates (2% and 5%). However, in both cases, livestock production shows a slightly downward trend, whereas crop production ends with an opposite, slightly upward trend. This could be caused by the fact that most land assigned to enterprises is located in areas where livestock production is the dominant production system, such as in proximity to rivers.

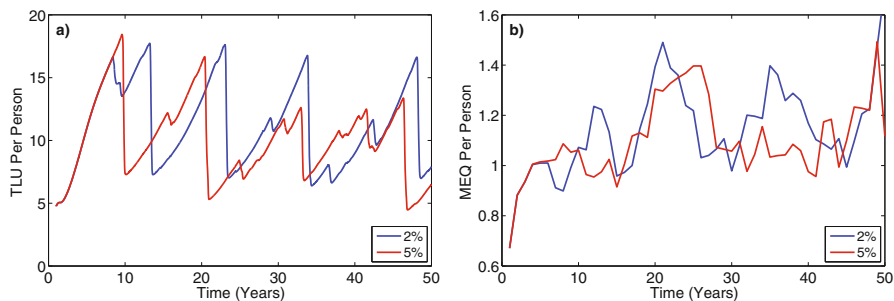


Fig. 6 Scenario 1: livestock and crop production with no off-farm opportunity: (a) number of livestock (TLU) per person and (b) crop (Maize Equivalent-MEQ in kilograms) per person

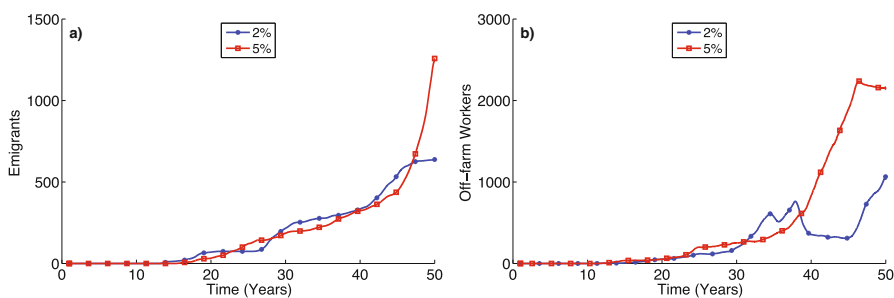


Fig. 7 Scenario 2: migration and off-farm activity with off-farm opportunity: (a) number of emigrants from the region and (b) number of persons engaged in off-farm jobs

Scenario 2: With Off-Farm Opportunities

In the second scenario, enterprises offer employment opportunities to rural households. In this case the OMOLAND simulation model provides different results in terms of the number of emigrants from the region and in patterns of livestock and crop production. Specifically, the total number of emigrants decreases significantly as compared to Scenario 1 as shown in Fig. 7a. This is mainly due to the number of people employed in off-farm jobs increasing as a function of time, following the expansion of large-scale commercial farming (Fig. 7b).

Although off-farm jobs offer additional income to households, such an opportunity does not entirely eliminate emigration, even under the “fast” rate of expansion (5% growth rate). This is because there are still persons who cannot sustain their livelihood under current climatic conditions and are forced to emigrate.

Scenario 2 also shows that off-farm opportunities affect livestock and crop production in opposite ways, as shown in Fig. 8. These results show that in Scenario 2 livestock production (TLU/person) and crop production (MEQ/person) show decreasing and increasing trends, respectively.

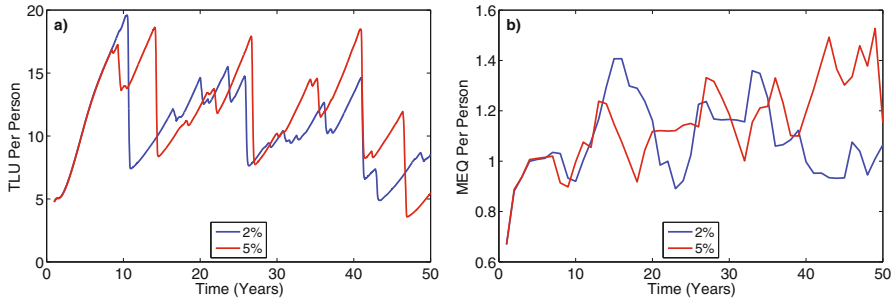


Fig. 8 Scenario 2: livestock and crop production with off-farm opportunity: (a) number of livestock (TLU) per person, (b) crop (Maize Equivalent-MEQ in kilograms) per person

Comparing the two scenarios, trends in both livestock and crop production are more pronounced in Scenario 2. Livestock production levels (20 TLU/person) reached 10 years from the start of the simulation in Scenario 1, decreased to less than 5 TLU/person by the end of the simulation in Scenario 2, while the same level was >7 TLU/person in Scenario 1. Similarly, crop production increased from 1 to 1.6 MEQ/person by the end of the simulation in Scenario 2, almost a 20% increase compared to Scenario 1.

Discussion and Conclusion

The OMOLAND model demonstrates two important points regarding the impact of large-scale land acquisition in the South Omo case, which can be comparable to other regions in developing countries. First, it suggests that land acquisition without providing new employment opportunities to local communities of herders or farmers can lead to catastrophic outcomes—potentially humanitarian disasters and crises—as more people are forced to migrate from the system [41]. Such events can create flows in internally displaced persons (IDPs) and, when national boundaries and border crossings are also involved, transnational refugee flows are another potential disaster. Although migration of rural households can occur simply as a result of extreme climate events (e.g., droughts or floods, both common in the region), results from the model clearly demonstrate that migration rates can be exacerbated as lands utilized by rural households are given to large-scale commercial enterprises.

OMOLAND also contributes to our understanding of the effect of off-farm employment opportunities on rural household livelihood. At first glance, it seems that simulation results align with the aspiration of government development policies or with those who highlight the economic contribution of enterprises in rural communities [52]. The emergence of additional sources of income influences the way in which rural people react to climate change and variability. As more persons work in off-farm jobs, particularly during times of drought, their vulnerability is

reduced by the additional income they can generate through such jobs. However, close observation of these results indicates that emigration and displacement persist as more lands are controlled by enterprises.

Another result demonstrated by the model is the gradual transition of dominant rural livelihood from herding to farming as large-scale enterprises spread throughout the region. Galvin [27] argues that pastoral transitions in most East African countries are attributed to two major factors. First, grazing land is fragmented, due to numerous socioeconomic factors, such as changes in land tenure, agriculture, and institutions. Second, extreme weather events such as droughts are more common than elsewhere, due to climate change and variability. Although the OMOLAND model requires further development and analysis, the simulation results agree with real-world trends in terms of more households engaging in farming than in livestock production as grazing lands are converted into commercial farming.

Current trends of large-scale land acquisition are likely to continue over the next decade in most of Sub-Saharan Africa. Exploring the implications of commercially oriented farming enterprises, not only on rural households but also on the biophysical environment, is a promising potential extension of the model. For example, large tracts of rural lands recently have been given to a variety of enterprises with competing interests. These range from those interested in commercial farming (food crops and biofuel production) to others engaged in ecotourism. Greater demand for rural land will likely increase land value and, consequently, land marketing. It is important and feasible to further explore the dynamics of competition for land among different entities by incorporating into OMOLAND a more comprehensive land marketing mechanism. Such an integration of land markets or land transactions into the model could advance our understanding of rural land-use changes, socioeconomic transformations, and issues related to short- and long-term rural-urban dynamics. Although many future research directions are possible and arguably fruitful, this study contributes to investigating these basic and applied research questions by laying foundations for further rigorous work on complex dynamics in coupled human and natural systems.

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