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Research

From local scenarios to national maps: a participatory framework for envisioning the future of Tanzania

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ABSTRACT. Tackling societal and environmental challenges requires new approaches that connect top-down global oversight with bottom-up subnational knowledge. We present a novel framework for participatory development of spatially explicit scenarios at national scale that model socioeconomic and environmental dynamics by reconciling local stakeholder perspectives and national spatial data. We illustrate results generated by this approach and evaluate its potential to contribute to a greater understanding of the relationship between development pathways and sustainability. Using the lens of land use and land cover changes, and engaging 240 stakeholders representing subnational (seven forest management zones) and the national level, we applied the framework to assess alternative development strategies in the Tanzania mainland to the year 2025, under either a business as usual or a green development scenario. In the business as usual scenario, no productivity gain is expected, cultivated land expands by ~ 2% per year (up to 88,808 km²), with large impacts on woodlands and wetlands. Despite legal protection, encroachment of natural forest occurs along reserve borders. Additional wood demand leads to degradation, i.e., loss of tree cover and biomass, up to 80,426 km² of wooded land. The alternative green economy scenario envisages decreasing degradation and deforestation with increasing productivity (+10%) and implementation of payment for ecosystem service schemes. In this scenario, cropland expands by 44,132 km² and the additional degradation is limited to 35,778 km². This scenario development framework captures perspectives and knowledge across a diverse range of stakeholders and regions. Although further effort is required to extend its applicability, improve users' equity, and reduce costs the resulting spatial outputs can be used to inform national level planning and policy implementation associated with sustainable development, especially the REDD+ climate mitigation strategy.

Key Words: *coupled human-natural system; deforestation; ecosystem services; land use and land cover change; REDD+; sustainable development*

INTRODUCTION

Human-induced land use and land cover changes (LULCC) are a major component of global environmental change (Turner et al. 2007, Ellis 2015), with profound consequences for the climate system through land surface feedbacks (IPCC 2007, Ostberg et al. 2015), biodiversity (Barnosky et al. 2011), and human welfare and development (Griggs et al. 2014). Assessing possible future LULCC is a fundamental need if we are to embed sustainability in development strategies, ecosystem management, and land use planning, particularly for developing countries where rates of LULCC are highest (Rounsevell et al. 2012, Verburg et al. 2013).

The complexity of LULCC results from interactions across biophysical, socioeconomic, and governance factors occurring at different scales (Parker et al. 2008, Meyfroidt et al. 2014) and it is increasingly explored and interpreted through the lens of coupled human-natural systems (Binder et al. 2013, Liu et al. 2015). Within these frameworks, scenario analysis has been widely applied to explore future trajectories, at different scales and using different approaches (Alcamo 2008, Amer et al. 2013, Oteros-Rozas et al. 2015). Through a scenarios approach, uncertainty and complexity can be tackled across multiple thematic dimensions (Peterson et al. 2003, Mahmoud et al. 2009), integrating explorative pathways with normative visions that identify a diversity of potential, as well as desired, futures states (Rounsevell et al. 2012) that engage multiple stakeholders (Johnson et al. 2012, Reed et al. 2013).

At a national level, governments elaborate visions for the future that often underpin policies via national development plans and commitments into international mechanisms, such as the Sustainable Development Goals (UNDESA 2015), the United Nations Aichi Targets linked to the Convention on Biological Diversity (UNEP 2010), the United Nations Framework Convention on Climate Change (UNFCCC), and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES; Zisenis 2014). Global or large-scale scenario analyses (e.g., IPCC 2000, UNEP 2012, van Vuuren et al. 2015) have typically been conducted through top-down, expert-driven processes, and are only weakly connected with grassroots initiatives (Leach et al. 2012). These approaches are inappropriate for assessing national policies, for example on land use and sustainable development, against local impacts and locally tailored solutions that are not captured in larger scale narratives.

Leach et al. (2012) emphasized the need to reconnect top-down policy mechanisms with grassroots innovation and knowledge, to identify new pathways toward sustainability from the bottom upward. Such an approach implies enhanced participation of stakeholders, i.e., those who are affected by or can affect a decision or action (Freeman 1984) in the process. Indeed, stakeholder

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participation is a fundamental prerequisite of sustainable development, particularly for understanding the multidimensional interactions between societal and environmental challenges, both in the policy (UNCED 1992, UN 2012) and in the modeling frameworks (Fraser et al. 2006, Reidsma et al. 2011, Grêt-Regamey et al. 2013, Danielsen et al. 2014, Herrmann et al. 2014). The importance of stakeholder engagement has gradually evolved from respect for peoples' right to participate in decision making, to a means of enhancing the sense of ownership, relevance, and legitimacy of the process (Bell et al. 2012, Priess and Hauck 2014), the understanding of its outputs (Sohl and Claggett 2013), the promotion of social learning (Johnson et al. 2012, Castella et al. 2014), and thus the chances of successful implementation of associated policies and interventions (Reed et al. 2013).

A number of challenges remain for integrating stakeholder participation with scenario analyses and quantitative modeling to support decision making at subnational and national scales (Rounsevell et al. 2012, Sohl and Claggett 2013, Verburg et al. 2013, Castella et al. 2014). First, new methods are required to codify varied and sometimes conflicting knowledge held by stakeholders, to inform how different drivers of change may play out in the future scenarios (Reed et al. 2013). Second, there is the challenge of transforming qualitative storylines into sets of coherent quantitative information within the participatory process (Walz et al. 2007), and to use that information in customized spatial models (Swetnam et al. 2011). Toward these ends, recent studies have proposed new approaches that enhance the role of stakeholders in scenario analysis, especially for assessing and modeling future LULCC and their possible impacts (Swetnam et al. 2011, Lamarque et al. 2013, Malinga et al. 2013, Hanspach et al. 2014, Rosenberg et al. 2014). However, such integrated approaches have, so far, been restricted to subnational scales or single units of analysis, with limited scope for synthesis (Stringer et al. 2006) or upscaling to the national level.

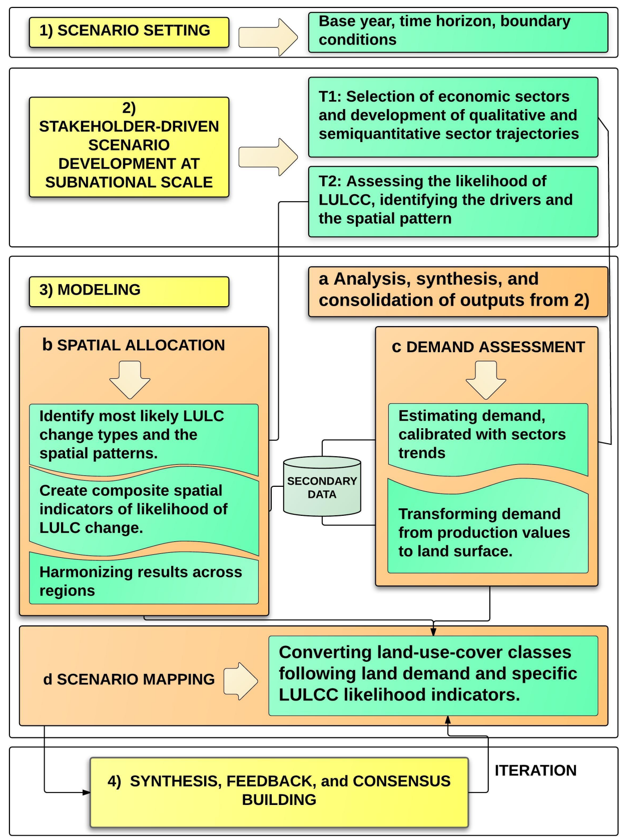
In response to these challenges, we present a methodological framework for participatory development of spatially explicit, integrated socioeconomic and environmental scenarios that reconcile subnational perspectives across a nation. With this framework, we aim to: (1) strengthen the participation of stakeholders in linking socioeconomic trajectories to LULCC; (2) disentangle the complexity of socioeconomic drivers and their causal relations with LULCC; (3) capture and reconcile subnational perspectives at the national scale; and (4) ease the transfer of knowledge to inform decision making at national and subnational scales. We outline our application of the framework to envision future trajectories of LULCC and habitat degradation across mainland Tanzania. We follow with an evaluation of the framework in relation to Tanzania and beyond, and conclude with a discussion on the possible contribution of such a stakeholder-driven approach for elaborating new, achievable sustainable development pathways.

METHODS

Scenario framework

The proposed scenario framework consists of four main steps that involve experts (facilitators and modelers) and stakeholders (those who are affected by or can affect socioeconomic and land dynamics), and guides them to develop scenarios with qualitative, quantitative, and spatially explicit elements (Fig. 1). Scenarios are developed independently at subnational level before being synthetized at national level through a mixed stakeholder-driven and model-based approach.

Fig. 1. Conceptual model of the scenario framework composed of four steps. Setting of initial and future scenario conditions (1) is followed by scenario construction at subnational scale through a mixed stakeholder-driven process (2) and then modeling (3), followed by a synthesis at national scale (4) and by iteration providing feedback to the previous steps.



Step 1: Scenarios setting

In the first step, the focus of the analysis is identified, either by a panel of experts or by a broader group of stakeholders, and key boundary conditions are set including the spatial units of analysis at subnational level, e.g., administrative or management units, base year, and time horizon. Initial and potential future desired or normative conditions are purposely presented as general and synthetic statements to allow stakeholders to develop locally oriented storylines. Scenarios are set while keeping in mind that, in participatory processes, people are able to process a limited number of alternative scenarios at a time, e.g., four or fewer (Reed et al. 2013). Stakeholders are identified (Luyet et al. 2012) to represent relevant segments of the society at subnational (for both subnational- and national-level workshops) and national level (for the national-level workshop only).

Step 2: Stakeholder-driven scenario development at subnational scale
For each subnational unit of analysis, subnational scenarios are developed during multistakeholder workshops. This is achieved through two main tasks (Fig. A1.1a). First, all participants select the economic sectors most relevant to local livelihoods and land use. In parallel focus groups participants discuss the factors driving current situations, envisage alternative futures under scenario conditions, and position the sectors on charts representing economic and environmental axes (from "poor" to "rich" and from "degraded" to "healthy," respectively). These charts are used to exemplify trade-offs between socioeconomic, i.e., income, production, and livelihood, and environmental, i.e., LULCC and resource depletion, interrelationships in sectoral trajectories (Fig. A1.1b). Sectoral trajectories may cut across quadrants, following participants' visions of what environmental and economic changes are likely in their region.

In the second task, participants' groups link the socioeconomic trajectories identified for the future scenarios to specific and spatially defined LULCC, using a reference land use and land cover map (Fig. A1.1c). For each conversion from one land-use-cover class to another (Fig. A1.1d) participants evaluate its likelihood on a scale ranging from 0 ("not possible") to 4 ("very likely"). They rank the specific drivers by their relative importance and report where changes would likely occur in the landscape. Participants are encouraged to report spatial information such as specific sites of potential LULCC, e.g., administrative units or gazetted sites, or biophysical factors associated with them, e.g., "near roads" or "in fertile soils").

For both tasks, participants work in mixed groups across administrative units and sectors to generate consensus and harmonize visions within each subnational unit of analysis. Qualitative descriptions of trajectories, including drivers by sector and scenario, and quantitative LULCC assessments are recorded on open-ended formatted forms by the group, not by individual. Outputs are then compared across groups in plenary sessions where stakeholders discuss their different perspectives until a consensus is negotiated. During the workshops, facilitators take notes and ensure a collective understanding of the objectives (Sandker et al. 2010), but they aim to do so without actively participating in the discussion.

Step 3: Modeling
The modeling step follows the completion of participatory workshops in every subnational unit. First (Step 3a), subnational workshops outputs are checked, compared, and integrated across groups. This analysis produces intermediate outputs that enhance the interpretation of the final scenario outputs, i.e., national scale LULCC quantification and mapping, providing additional information for decision making and spatial planning. From Task 1 of Step 2, qualitative outputs are integrated and codified focusing on drivers of the future scenarios, and spatial distribution of LULCC. Sector-specific trajectories from charts are translated into numerical vectors that can be used to distribute land demand across subnational units. From Task 2, LULCC likelihood scores are cross-tabulated to compare potential losses and gains for each land-use-cover class, and corresponding drivers and spatial information are identified. The relative importance of drivers is assessed based on frequency, likelihood of change score, and relative ranking.

Second (Step 3b), global and national spatial datasets are selected to represent the spatial information associated with LULCC at subnational and national scales, and are used as single dimensions of spatial composite indicators (CIs) of LULCC likelihood. The CIs can synthetize complex information into a scalar quantity, which can be compared across analysis units and then easily communicated to a nonexpert audience (Saisana and Tarantola 2002). The single dimensions, i.e., spatial datasets, of CIs are tested for collinearity to avoid redundancy and, where necessary, are reduced, taking into account workshop participants' statements. The spatial datasets representing the selected dimensions are reclassified to a common scale following the spatial patterns described by participants, then combined by linear aggregation, and finally multiplied by constraining factors to account for areas where changes are limited or excluded (Fig. A1.1). Composite indicators of LULCC likelihood are created for every LULCC type in each analysis unit. Finally, CIs are rescaled to a common scale (from 1 to 10) using maximum-minimum method and merged at national scale (Fig. A1.1).

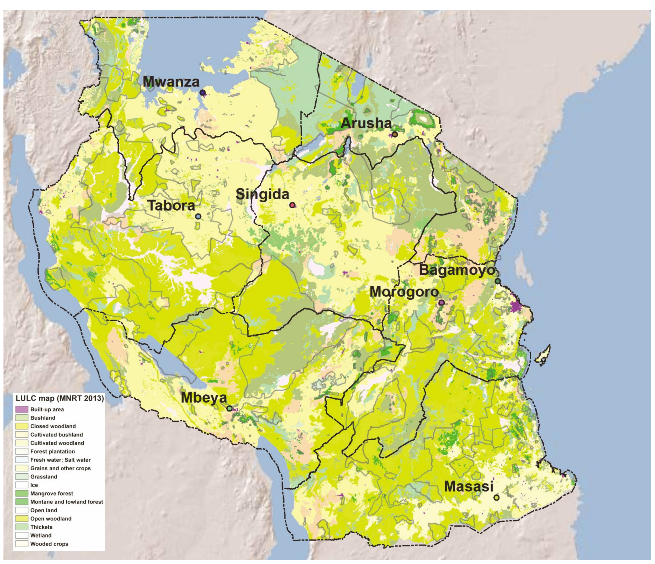
In Step 3c, land demand under the future scenarios is estimated from available data and literature at the national and local level, and according to the trajectories developed by stakeholders. In Step 3d, demand is allocated across subnational units and land-use-cover classes following (1) the relative impacts of the economic sectors assessed by stakeholders, (2) the relative share of land-use-cover classes, (3) the specific likelihood scores associated with each LULCC type, and (4) the specific CIs of LULCC likelihood. Pixels are converted until land demand is fulfilled (Fig. A2.4).

Step 4: Synthesis, feedback, and consensus building
In this step, subnational scenarios and a preliminary quantitative national synthesis are presented in a national-level workshop involving stakeholders representing both the subnational units and the national level. Through the revision of inputs (data, assumptions) and outputs (scenarios trajectories and maps) of the scenario analysis, the workshop aims to receive feedback on the process, to identify and fill in possible gaps, and to reconcile competing perspectives between subnational perspectives and national level harmonization. This is followed by a revision of the modeling step and the same feedback-oriented process, iterating the cycle as required until consensus is reached.

Application of the framework in Tanzania
We applied this step-wise scenario framework across mainland Tanzania (~ 883,600 km²; Fig. 2) within the context of a national readiness initiative for the program Reduced Emissions from Deforestation and Degradation (REDD+). Tanzania's National Development Vision 2025 sets development goals to turn the country into a middle-income economy by 2025 (URT 2005), and has inspired efforts toward sustainable development in conformity with the United Nations Sustainable Development Goals (SDGs). Tanzania's mainland population reached 43.6 mil in 2012 (2.7% annual growth rate since 2002), with the majority (70.9%) inhabiting rural areas and reliant on a semisubsistence economy (NBS and OCGS 2013, 2014). The country's annual GDP growth rate averaged 7% between 2002 and 2014 (World Bank 2014); the headcount ratio for the Multidimensional Poverty Index was 65.6% of the population in 2010 (Alkire and Robles 2015). A diversity of ecosystems (Burgess et al. 2004) provide fundamental services both for local livelihood, e.g., water

and climate regulation, soil protection, timber and wood fuel provision, and grazing land, and for the national economy, e.g., hydro-power for energy production or nature-based tourism (Fisher et al. 2011, Willcock et al. 2016). Globally important biodiversity hotspots (Burgess and Clarke 2000, Myers et al. 2000, Burgess et al. 2007), and core areas for key populations of large mammals (Brooks et al. 2001) are included in a large network of reserved areas with different protection designations, covering almost one third of mainland Tanzania (IUCN and UNEP-WCMC 2015). These areas are facing various pressures from human activities, e.g., encroachment, illegal timber harvesting, or mineral extraction (Lange 2008, Pfeifer et al. 2013, URT 2014). In the unreserved land, ~ 44 million ha is considered potentially available for agricultural expansion (URT 2014), attracting the interest of large-scale investors, e.g., the Southern Agricultural Growth Corridor of Tanzania (SAGCOT). Between 1995 and 2010 the deforestation rate over the country has been estimated at 100,000 to 400,000 hectares per annum (MNRT 2015, Willcock et al. 2016).

Fig. 2. Map of Tanzania showing the units of analysis (black lines), which are the management zones for the Tanzania Forest Service, and terrestrial protected areas (grey line) from the World Database on Protected Areas (IUCN and UNEP-WCMC 2015). Points represent the workshop venues for the zones: Singida for Central; Morogoro for Eastern; Mwanza for Lake; Arusha for Northern; Mbeya for Southern Highlands; Masasi for Southern; and Tabora for Western. The national workshop was held in Bagamoyo. The reference land use and land cover map (MNRT 2013) is visible in the background. Shaded Relief: Copyright © ESRI 2014.



Like other developing countries, Tanzania has endorsed payment for ecosystem services (PES) schemes to support sustainable development pathways of local communities, among which is the REDD+ program (URT 2013*a*), building on existing community-based natural resource management initiatives (Burgess et al. 2010, URT 2013*b*). Although REDD+ has undergone much critical exploration (e.g., Chhatre et al. 2012, Mustalahti et al. 2012) implementing it could trigger a shift toward an economic model that stimulates sustainable resource use and decreased LULCC rates, generating a positive cascade on livelihoods (UNEP 2015). In the application of our scenario framework to Tanzania, we aimed to assess the potential for such a development model and the contribution of PES schemes to its attainment, using a "green economy" scenario (GE), as an alternative to the current development trends, which we refer to as "business as usual" (BAU). Scenarios boundary conditions (Table 1) built on the study conducted by Swetnam et al. (2011) in eastern Tanzania, combined with a literature review (e.g., URT 2005, 2011, NBS-OCGS 2013, URT-MASFC 2013, World Bank 2014). Under BAU, current trends in governance, population growth, deforestation, degradation, and cultivated land expansion continue. The GE scenario includes the normative target of implementing REDD+ and other PES schemes, but it is also partially explorative, i.e., roadmap to be established, of pathways toward sustainable development focused on trade-offs between cultivated land expansion and forest management. The base year was set to 2010, consistent with the baseline reference land use and land cover map (MNRT 2013), while the time horizon was set to 2025, in agreement with Tanzania's National Development Vision (URT 2005) and the SDG timeline.

Table 1. General definitions for business as usual (BAU) and green economy (GE) scenarios proposed to participants of multistakeholder workshops.

	BAU	GE
Population-GDP growth rate	Same as current	Same as current
Governance and regulations	Weak	Enforced
Farmland expansion rate	Same as current	Decreased
Crop yields	Same as current	Increased
Biomass energy dependency	Same as current	Decreased demand
Deforestation rate	Same as current	Decreased
PES and REDD+ mechanisms	Inadequate	Efficiently implemented

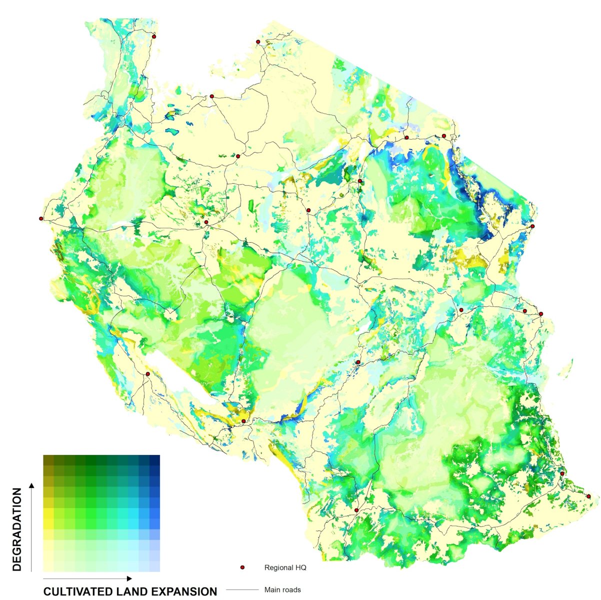
At subnational scale, our analysis units were the seven management zones of the Tanzania Forest Service (TFS; Fig. 3). Between February and June 2014, seven back-to-back multistakeholder workshops were conducted, each lasting two days and involving 180 participants in total (Table A1.1; WWF-TCO 2015). Stakeholder identification and selection for inclusion in the participatory processes (Steps 2 and 4) followed the criteria of representativeness, knowledge at the scale of the analysis, and skills for participating in the process. We invited governmental institutions, private companies, research institutions, and civil society organizations (CSOs) representing land users, land managers (technical and political) at municipal, district, and regional level, with expertise in socioeconomic and development sectors. Local (village-level) communities were represented by farmers and livestock keepers associations, community-based natural resources management and conservation organizations, and women's groups. Participants were asked to complete anonymous questionnaires at the end of the workshops to provide feedback on the process. The synthesis workshop was conducted in October 2014 and gathered 60 stakeholders from public

Table 2. Land use and land cover changes simulated under business as usual (BAU) and green economy (GE) scenarios. In BAU scenario, under two patterns of agriculture sector expansion (BAU1 and BAU2), cultivated land increases by 30% of cropland area in the reference map (MNRT 2013). In the BAU2 pattern, additional expansion of mixed cultivated-wooded land is simulated. For every scenario and pattern, additional degradation of wooded areas occurs to fulfill wood demand, spatially segregated from cultivated land expansion. Surfaces areas are reported in km², and percentages of the original land cover are given in parentheses for each class.

	BAU1 and BAU2	BAU1	BAU2		GE	
	Conversion to cultivated land	Degradation	Conversion to mixed cultivated-wooded land	Degradation	Conversion to cultivated land	Degradation
Bushland	10690 (8.6)	9137 (7.3)	7647 (6.1)	2160 (1.7)	17429 (14.0)	3944 (3.2)
Open woodland	30144 (14.3)	52973 (25.1)	19174 (9.1)	23921 (11.4)	18144 (8.6)	26266 (12.4)
Grassland	1366 (2.2)	-	1267 (2.1)	-	4938 (8.0)	-
Natural forest	422 (2.8)	133 (0.9)	550 (3.6)	63 (0.4)	56 (0.4)	-
Closed woodland	4498 (4.2)	18183 (17.3)	3390 (3.2)	6903 (6.5)	419 (0.4)	5567 (5.2)
Thicket	664 (14.6)	-	876 (19.1)	-	-	-
Wetlands	6015 (19.1)	-	2013 (6.4)	-	3050 (9.7)	-
Mangrove forest	68 (5.6)	-	5 (2.0)	-	95 (7.9)	-
Total	53867	80426	34941	33047	44132	35778

institutions (mainly at national level), research institutions, CSOs, agribusiness, and media (Table A1.b; WWF-TCO 2015).

Fig. 3. Bivariate representation of land use and land cover changes (LULCC) likelihood composite indicators for cultivated land expansion (light yellow-light blue) and degradation (light yellow-green) for all land cover classes, under business as usual (BAU) scenario. Areas where such LULCC were not expected are shown in light yellow, e.g., existing cultivated areas.



Further details on the framework application in Tanzania are included in Appendix 1 for stakeholder-driven steps and Appendix 2 for LULCC and demand modeling steps. Given uncertainties on cultivated land surface at the base year (Appendix 2), we simulated two BAU scenario patterns: BAU1 (expansion of intensively cultivated land only) and BAU2 (additional expansion of mixed cultivated-wooded land). All spatial and quantitative analyses were performed in ArcGIS 10.2 (ESRI 2014) and R (R Core Team 2014).

RESULTS

Framework outcomes

Land use and land cover changes

In the BAU scenario, with the population reaching ~ 62 million by 2025 in the Tanzania mainland and with no productivity gain, cultivated land expands at a rate of ~ 2% per year. Simulated LULCC amounts to 53,867 km² of new cropland and, under BAU2, 34,941 km² of additional mixed cultivated-wooded land by 2025, mainly through the conversion of woodland (Table 2). Estimated wood demand of 1.3 m³/capita/year is not entirely fulfilled by conversion to cultivated land and leads to additional habitat degradation, i.e., loss of tree cover and biomass without replacement from cropland, over 80,427 km² (BAU1) or 33,047 km² (BAU2) of woodland, bushland, and forest (Table 2).

Under the GE scenario, assuming the same population growth as in BAU, a 10% increase of crop productivity and no further expansion of mixed cultivated-wooded areas, cultivated land expands by 44,132 km² (Table 2) and conversion of natural forest and closed woodland is reduced compared to the BAU scenario. In this scenario, assuming a 50% reduction of demand exceeding sustainable annual harvest, an additional 35,778 km² of woodland and bushland are degraded (Table 2).

Spatial pattern of change
Subnational workshop participants reported that spatial patterns of habitat degradation are determined by factors such as proximity to human settlements and roads, but also mismanagement of resources in specific sites, e.g., protected area borders and forest reserves (Fig. 3). Cultivated land is most likely to expand near human settlements, roads, and irrigated sites (Fig. 3). The likelihood of both potential habitat degradation (as a consequence of wood extraction) and of cultivated land expansion is the highest in the northern (Tanga) and southern (SAGCOT) development corridors (Fig. 3). In the BAU scenario (both BAU1 and BAU2), cultivated land expansion rates are highest in the Southern Zone, but the largest conversion is in the Central Zone (Fig. 4), where it was envisaged that lower productivity due to poor agricultural practices would lead to high rates of land conversion. Under the GE scenario, cultivated land expansion rates are highest in the Eastern and Southern Highlands Zones, and degradation (both rates and area) is highest in the Southern Zone (Fig. 4).

Drivers of change
Subnational workshop participants developed storylines composed of qualitative, quantitative, and spatially explicit elements that characterize the scenarios in each zone, synthesized at national level in Fig. 5 and Fig. 6 for BAU and GE scenarios, respectively. Under the BAU scenario stakeholders emphasized population growth, poor governance, inadequate land use planning, lack of know-how, and poor practices in productive activities, low access to alternative energy sources and income generating activities as underlying factors driving sector trajectories (Fig. 5a). Participants generally envisaged economic growth at the expense of the natural environment, but negative economic trends were expected for agriculture, livestock, energy, and mining sectors in the Central Zone and for agriculture in the Lake Zone (Fig. 5b). Participants suggested that economic sector trajectories would be interdependent at individual or community level, e.g., charcoal production as alternative income generation activity to farming during dry season, and that they could be affected by cultural factors. Under the BAU scenario (Fig. 5c), among the direct drivers of LULCC, population growth was perceived to have the highest impact in the Northern Zone, farmland expansion in the Southern Zone, wood fuel production in the Western Zone, livestock keeping in the Central Zone, timber forest product extraction in the Southern Highlands, and human-set fires in the Eastern Zone.

For the GE scenario, participants reported technical improvements, law enforcement, land use planning, and good practices, e.g., in land use and economic activities management to be among the main opportunities for green development (Fig. 6a), leading to reductions in environmental impact and improvements in livelihood (Fig. 6b). However, under this scenario, trajectories did not always cross onto the positive side of the environmental axis, i.e., “healthy environment,” suggesting that participants were not expecting to reach a high level of environmental sustainability within the scenario time frame (Fig. A1.1). In the Eastern Zone participants did not envisage any GE scenario for the livestock sector (Fig. 6b). Among the direct drivers of LULCC reduction in the GE scenario (Fig. 6c), land management, e.g., planning areas for human settlement and cultivated area expansion in respect of sustainable forest management, was perceived most important in the Northern Zone, law enforcement and governance in the Lake Zone, e.g., in reference to participatory forest management, conservation in the Southern Highlands Zone, forest management in the Eastern Zone, financial incentives in the Southern Zone, and afforestation in the Lake Zone.

Fig. 4. Distribution of possible future land use and land cover changes under business as usual (BAU) and green economy (GE) scenarios. Potential cropland expansion is represented in red, expansion of mixed cultivated-wooded land (BAU2 only; see Table 2) in orange, and degradation in shades of blue (BAU2) and green (BAU1 and GE). Areas where land use and cover are not changing under these scenarios are represented in grey, and grey lines delimit terrestrial protected areas from the World Database on Protected Areas (IUCN and UNEP-WCMC 2015).

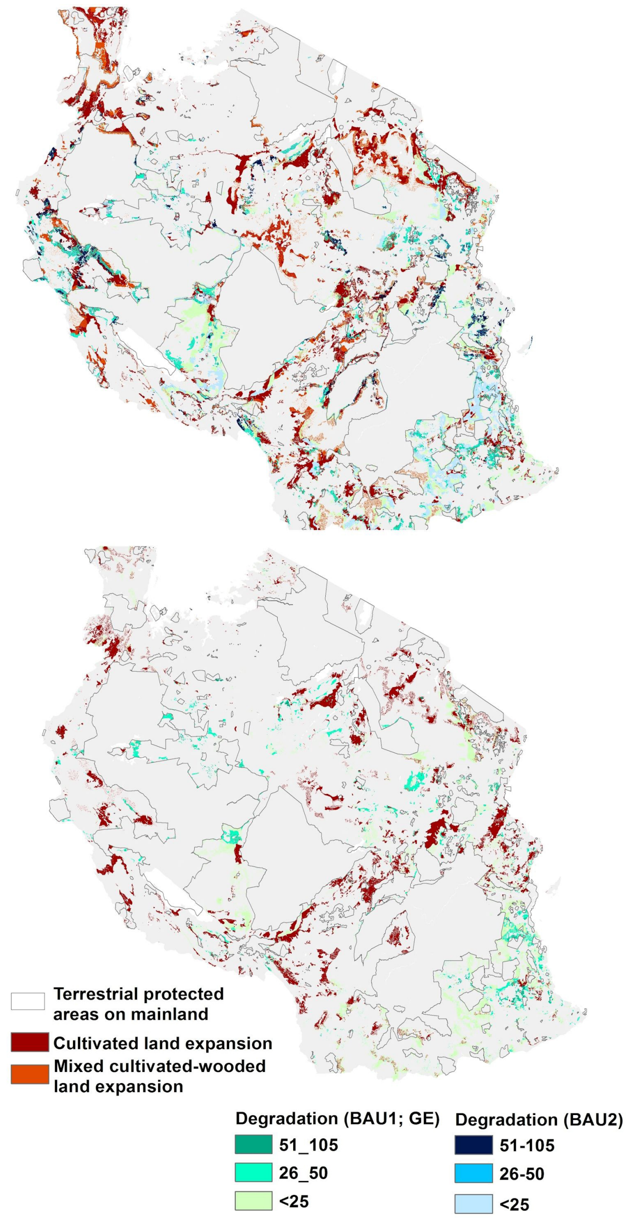


Fig. 5. Synthesis of the qualitative and quantitative outputs from multistakeholder workshops, for the business as usual (BAU) scenario. Socioeconomic-environmental factors drive sectoral trajectories across units (a), determining different rates of changes between BAU scenario and current situation (b). Direct drivers related to socioeconomic trajectories (c) affect land use and land cover changes (d). In (a), top-down positioning symbolizes decreasing recurrence of factors in sectoral trajectories descriptions across zones. In (b), forestry and energy sectors were analyzed together in Central (C), Lake (L), Southern (S), and Western (W) Zones, and separately in Eastern (E), Northern (N), and Southern Highlands (SH) Zones. In (d), Fn = natural forest; Fm = mangrove forest; Wc = closed woodland; Wo = open woodland; Bl = bushland; Gl = grassland; Th = thicket; Cult = Cultivated land; Fp = Forest plantation.

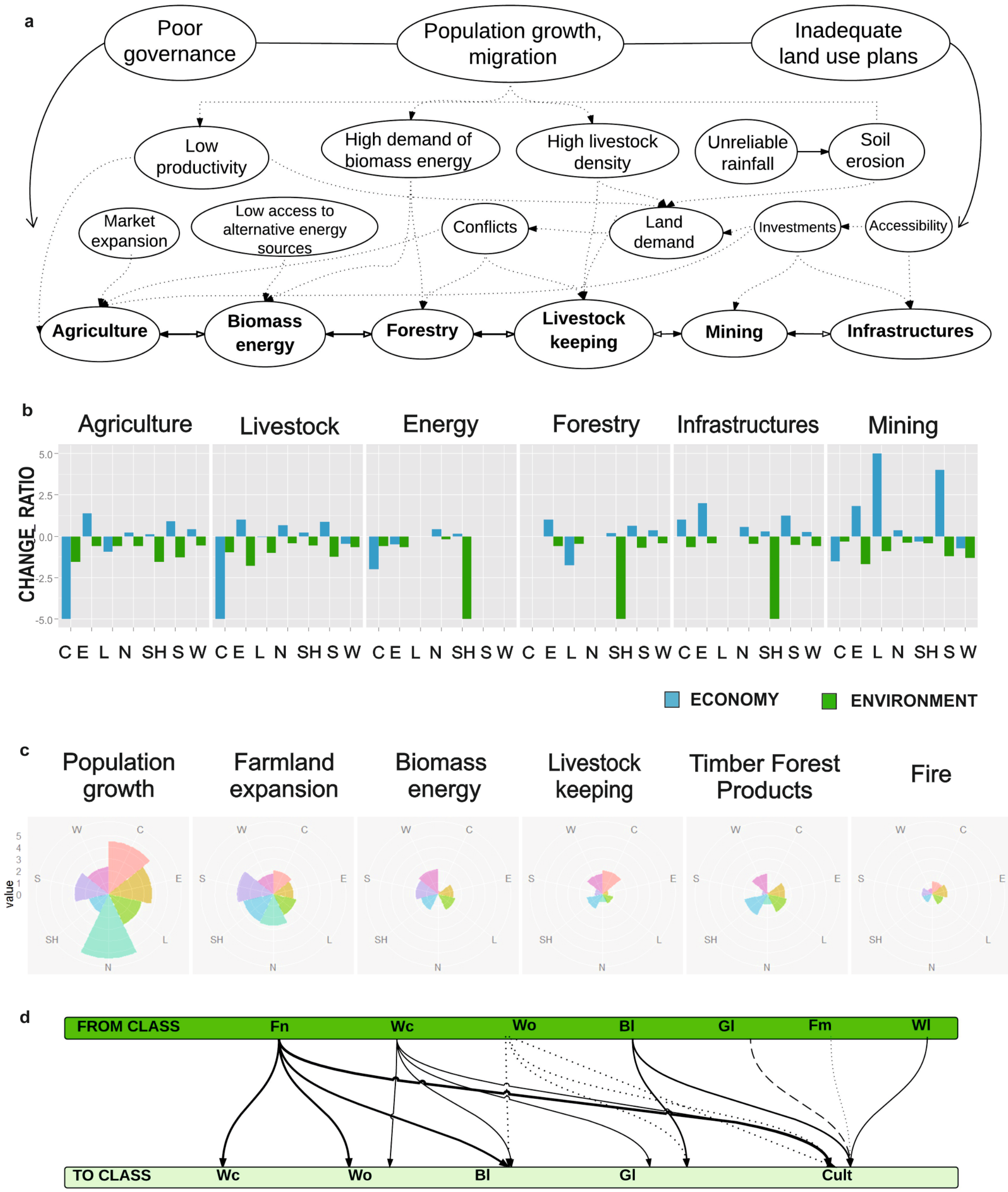
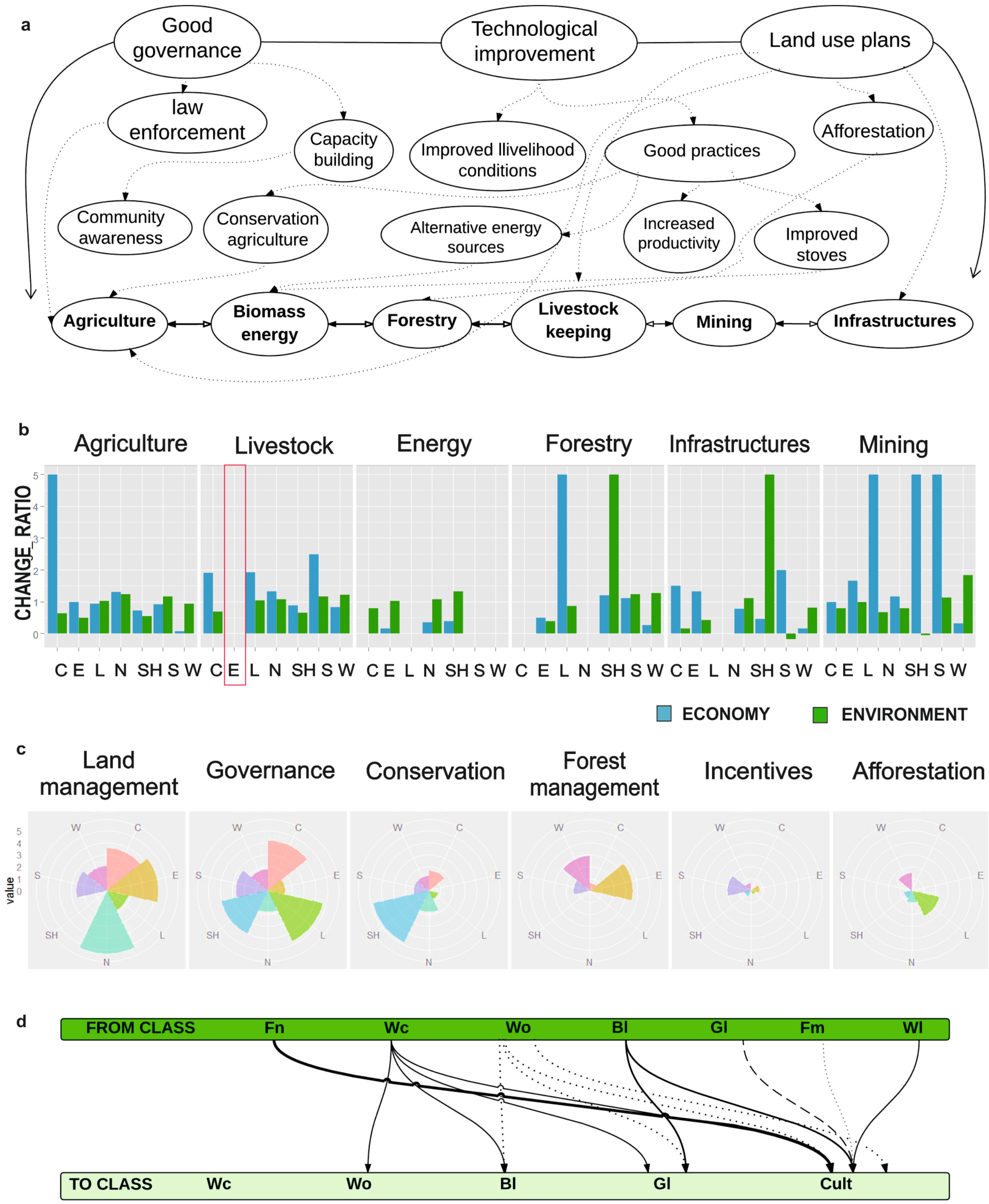


Fig. 6. Synthesis of the qualitative and quantitative outputs from multistakeholder workshops, for the green economy (GE) scenario. Socioeconomic-environmental factors drive sectoral trajectories across units (a), determining different rates of changes between GE scenario (b). Direct drivers related to socioeconomic trajectories (c) reduce degradation and deforestation (d). Legend and symbols as in Figure 5. The red rectangular frame indicates the lack of envisaged GE scenario for the livestock sector in the Eastern Zone, symptomatic of challenges for coexistence between traditional and modern ways of living.



DISCUSSION

Evaluation of the framework

The proposed scenario framework enhances the role of stakeholders in scenarios development, particularly in (1) envisioning future socioeconomic-environmental trajectories and (2) quantifying their impacts as specific LULCC. In our application in Tanzania, one or both objectives were reported as challenging by most individual participants at subnational workshops (82% of 125 respondents to feedback questionnaires), particularly the LULCC analysis (70%). Nonetheless all focus groups were able to complete the assigned tasks. Facilitators faced the challenges of eliciting participation of group members and collaboration within the group without imposing any personal bias, and of objectively guiding participants to converge from comprehensive discussions to specific impacts. Participants generally reported increased understanding of landscape dynamics following the workshop, suggesting a potential for capacity building despite the technical complexity (Johnson et al. 2012, Oteros-Rozas et al. 2015). Overall engagement and understanding of the participatory tasks proved similarly high across the seven zones in Tanzania, though different communication tools and timing may be considered when applying the framework at a different scale, depending on education and experience of the participants (Reed et al. 2013, Butler and Adamowski 2015).

This framework does not limit the type of information stakeholders can provide on the spatial patterns of LULCC, nor are there compulsory indicators to be used in the modeling step. Instead, there is a targeted effort to obtain and process the relevant spatial datasets after the workshops. In this way, it is possible to capture perspectives on factors other than biophysical or economic properties, e.g., "LULCC will happen where people need land or where there is corruption," as opposed to "LULCC will happen at forest edges or where land rent is high." Although this approach may increase the complexity of the modeling steps, it ensures that stakeholders are free to express any information they deem to be important. In cases where the required spatial datasets prove to be unavailable or of poor quality, this can guide future efforts to fill such gaps in knowledge, while in the meantime focusing on the most relevant indicators for which data are available.

Important advances of this framework beyond the related methodology of Swetnam et al. (2011) include the identification and quantification of region-specific patterns of causality behind LULCC, and the differentiation of processes and extent of habitat degradation versus whole-scale conversion. The resulting composite indicators and LULCC likelihood maps facilitate communication of scenario outputs to decision makers in a way that explicitly accounts for uncertainty, e.g., "likelihood of LULCC equal to 4 on a 1-10 scale," and captures either overlaps or spatial segregation of different LULCC pressures that assists in the planning of spatially distinct actions (Riedler et al. 2015). Even though the proposed framework has a clear directional flow toward the defined alternatives, it allows us to explore how different factors and drivers can contribute to a range of alternative pathways, and investigate less likely options. Competing perspectives are also easily identified and may be used to generate focus when transferring lessons learned from scenarios to decision makers (Castella et al. 2014).

The framework aims to ensure consistent applications to multiple areas. By capturing stakeholders' perspectives through explicit and standardized means, e.g., likelihood scores, it permits reproducibility across subnational units while maintaining representation of local subjective perspectives in the upscaling process (Stringer et al. 2006). Shared visions at subnational level were negotiated within each unit of analysis by workshop participants, and often proved consistent across the zones. Reconciling visions between subnational and national governance levels, however, was sometimes challenging because of the different roles covered by stakeholders (implementers versus decision makers). For example, subnational and national level stakeholders expressed different levels of confidence regarding the success of existing policies being implemented effectively. When interpreting scenario outputs we consulted secondary information to validate one or other stakeholder perspectives. Such divergences were pointed out in the synthesis workshop, and were further discussed in the iteration step.

In capturing subnational and national perspectives in Tanzania, we also faced challenges in terms of representativeness and replicability (Oteros-Rozas et al. 2015). Participant selection for stakeholder workshops was made by organization rather than by invitation of specific individuals. This limited our control over participants' characteristics, and may have reduced the range of voices heard in the construction of our scenarios (Luyet et al. 2012, Butler and Adamowski 2015). One example was the low level of attendance by women, especially within governmental organizations, and in particular at national compared with subnational levels. Women are reported to have limited opportunities in the public sector in Tanzania (Strachan 2015), and tend to be excluded from official land use decision making or planning processes in other developing countries (World Bank 2008, Bourgoin et al. 2012). Furthermore, we could not ensure repeat attendance of all stakeholders at both subnational- and national-level workshops (Reed et al. 2013).

Despite our effort to design a stakeholder-driven process, experts' facilitation and modeling skills were still required to generate and communicate the final outputs. In addition to the logistical cost of the participatory step, this commitment in time and resources limited the number of scenarios we could develop, as well as feedback opportunities with stakeholders. Local resources should increasingly be employed to abate the implementation cost. Investing in the capacity and feasibility of (more) autonomous application of tools such as this framework at local scale, and at lower cost, is then a critical challenge for enhancing bottom-up engagement in sustainable development processes (Tschakert and Dietrich 2010), along with improving accessibility to data and decentralization of information sources, and developing platforms for continuous feedback exchange among stakeholders.

In our application, we presented a green economy alternative to the business as usual, to stimulate discussions and emphasize contrasts in the final outcomes (Carpenter et al. 2015). This facilitates understanding of the scenario concept for those who are not accustomed to it, but may give the impression that there is just one comprehensive alternative to the business as usual. Participants in the process did not develop purely bad or purely good alternative scenarios, as could be to some extent suggested by the initial definitions, and they carefully evaluated possible trajectories. However, they pointed out that the real future could be a mix of the two scenarios. In the proposed framework, the disaggregated analyses of economic-environmental trade-offs contributes to an understanding of competition or synergies among different drivers and policy objectives, and so provides a starting point for hybrid scenario analyses. Policy trade-offs should be addressed directly in further scenario exercises to ensure their relevance in policy debates and buy-in of decision makers.

Integrated socioeconomic and environmental scenarios in Tanzania

Our scenarios outputs represent two plausible interpretations of the many possible divergent futures for Tanzania. The presented LULCC quantification is limited to some of the most relevant economic sectors discussed during the workshops. We deem our scenario assumptions valid within the 2025 time frame, while in the longer term other emerging processes could significantly affect socioeconomic and environmental trajectories, in particular natural gas and oil extraction, rural-to-urban migration, introduction of PES schemes, IT development, climate change, and capacity building. Our outputs should be interpreted jointly as an expression of a large, though limited, number of stakeholders, at the time (2014) and at the scale (macro-regions) of the workshops, and should be used along with, and not in replacement of, other analytical approaches, particularly those that harness representation at local scales (e.g., Enfors et al. 2008, Tschakert and Dietrich 2010, Brammer et al. 2016).

When considering the envisaged trends in the BAU scenario, Tanzania seems unlikely to achieve its National Development Vision goals by 2025. This would require high growth and structural transformation sustained by large productivity gains (Moyo et al. 2012). In the BAU scenario, lack of improvement in productivity and agricultural practices is expected to affect local food security in the next decades (MAFAP 2013, URT-MAFSC 2013) and/or induce vast LULCC, with commensurate impacts on water and climate regulation, biodiversity (Green et al. 2013, Kideghesho et al. 2013, Caro and Davenport 2015) and livelihoods (URT 2011). Expansion of large-scale international commercial farming may play a critical role in the next decade (Rulli et al. 2013, Laurance et al. 2015). A review of investment policies in Tanzania (OECD 2013) largely confirmed the regional stakeholders' vision that land tenure insecurity and a heavy bureaucratic burden have discouraged foreigner investors to date, and thus slowed the implementation of development corridors championed at national scale. The Southern Agriculture Growth Corridor of Tanzania (SAGCOT, a public-private partnership) was considered by regional stakeholders either as an opportunity for boosting the agriculture sector, e.g., in the Southern Zone, or as a risk if benefits do not reach the local communities but remain with international corporations, e.g., Eastern and Southern Highland Zone. National stakeholders considered SAGCOT part of the GE scenario (Milder et al. 2013), though they warned that "the impacts could be different than expected."

Farmland expansion and charcoal production are often associated LULCC drivers, though causality relations between them vary across Tanzania. As a consequence, in the GE scenario productivity gains in the agriculture sector contribute to reduced habitat degradation along with the implementation of more efficient and sustainable fuel production, the creation of alternative employment, and the acknowledgment of political responsibilities in mismanagement of local forest resources (Burgess et al. 2010, Sander et al. 2013). For this scenario, PES schemes were expected to support changes in the development pathway by eliciting policies enforcement, e.g., on sustainable forest management, conservation, and reforestation, and integration, e.g., between poverty reduction and environmental policies, and to a lesser extent by direct benefit of financial incentives.

Stakeholders expected that emerging mining and infrastructure sectors could positively support a green economy if benefit sharing mechanisms and environmental safeguards were in place. Infrastructure development in the near future, e.g., road improvement and rural electrification, could lead to livelihood changes and business development, and in turn to a decreased dependency on natural resources and further development of the tourism sector. On the other hand, increased accessibility, often associated with large-scale agriculture and mining development rather than local demand, could spread degradation and deforestation to currently remote areas (Weng et al. 2013, Jew et al. 2016).

In Tanzania, the complex historical background of land policies has created a dualism between customary and institutional land use rights (USAID 2011). Land rights enforcement and land tenure security would be critical elements for the successful implementation of land use plans, which remain inadequate (URT 2014). In the GE scenario, land use planning was expected to optimize land uses and reduce conflicts among land users. However, this approach may not apply to nomadic communities like pastoralists. The absence of a GE scenario for the livestock sector in the Eastern Zone exemplifies the difficulty of envisaging coexistence between traditional and modern ways of living, and thus of overcoming current conflicts in this region. In the other zones, stakeholders envisaged a cultural change from pastoralism toward modern sedentary ranching, including improved breeds and zero grazing systems, or toward arable farming. These results raise questions on the future of traditional livelihood systems and the associated ecosystems (savannah woodlands) in the country (Hesse and MacGregor 2006) and in the policy debate for alternative development pathways. The absence of discourse between traditional communities and other sections of society, particularly in the explorative GE scenario, is a shortcoming of the framework. Future participatory processes could focus on how the problem of dualism can be addressed in the policy making process and targeting under-represented groups such as pastoralists and other traditional communities. This would require greater direct engagement with those communities, and tuning the spatially oriented approach to capture different perspectives on land uses.

CONCLUSIONS

Faced with rapid changes and trade-offs between socioeconomic development goals and environmental sustainability targets, countries such as Tanzania require new frameworks for envisioning and planning desired futures that combine bottom-up perspectives with top-down data sets and policy. In this study, we presented a novel methodological framework for developing scenarios of LULCC through a stakeholder-driven process from subnational to national scale. The proposed framework produces qualitative, quantitative, and spatial outputs that can be jointly used to support ex-ante assessment of development trajectories and policy implementation and of the impacts of consequent LULCC, e.g., on ecosystem services or livelihoods, and to inform decisions for setting spatial priorities for specific interventions. The framework has wide applicability in developing countries, where local communities increasingly participate and create collaborative actions for sustainable management of natural resources and livelihood improvement. However, some important challenges remain:

- exploring how to address competing perspectives (for instance between customary and ordinary rules, traditional and modern ways of living, subsistence and modern economy, subnational and national governance), and elicit buy-in from minorities without excluding them from the visions of majorities;
- tackling socioeconomic and environmental trade-offs directly in the scenario formulation;
- reducing implementation costs and improving self-assessment capacity to support more localized, repeated, and extended applications of the framework.

A greater integration of this framework with local scale scenarios work is a way to pursue these objectives.

Such challenges notwithstanding, the framework proved successful in engaging a wide range of Tanzanian stakeholders in the quantitative assessment of LULCC dynamics. It is the first step towards building a tool that has broad ownership and consensus around future development pathways and policy interventions. The scenario national maps of Tanzania represent the first country-wide, stakeholder-driven assessment of potential socioeconomic and environmental trajectories.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/8565

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Appendix 1. This Appendix contains details on the multi-stakeholders workshops conducted at sub-national and national level in Tanzania.

Step 2

Between February and June 2014, back-to-back multi-stakeholder workshops were conducted, each lasting two days and involving180 participants in total (Table A1.1 and WWF-TCO 2015). Exceptionally, the workshop in the Eastern unit lasted one day only, and involved the largest proportion of academics. A team of experts in forestry, environmental sciences, conservation and community based natural resource management amongst the authors facilitated each of the seven workshops. During the workshops, discussions were mainly conducted in the national language (Kiswahili); nominated group members filled the output forms in English. At the end of each workshop participants were requested to complete feedback questionnaires on the level of engagement and understanding of the process.

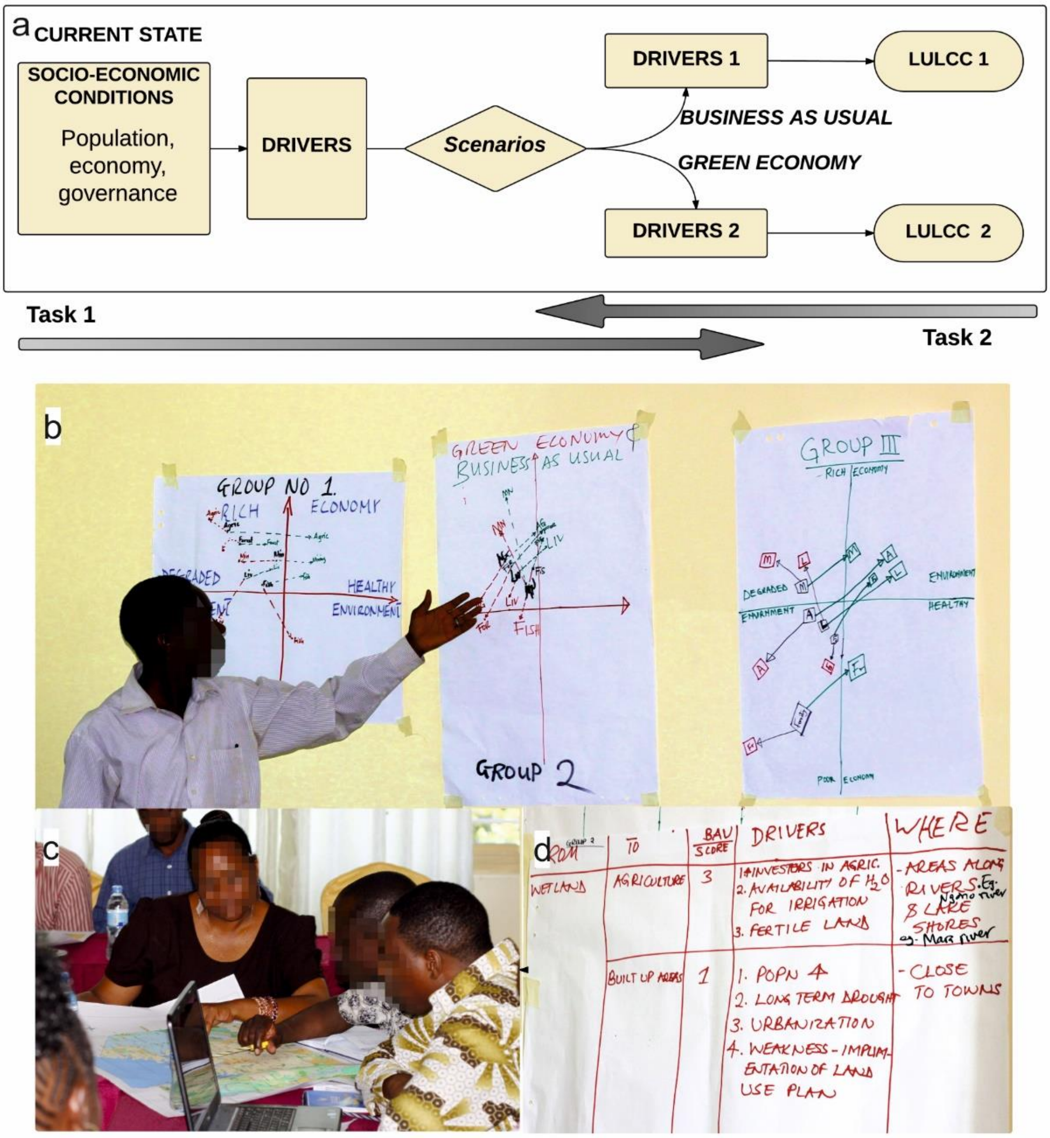
Table A1.1: Stakeholders' composition in regional a) and national b) workshops in Tanzania. Frequency (%) of participants is reported by institution categories and gender (women) by regions. Women were more represented in research institutions and civil society organisations (38.5 and 32.5 %, respectively) than in governmental institutions (5.2%).

a)	Central	Eastern	Lake	Northern	Southern highland	Southern	Western	Total
District government officers	42.9	25.0	30.8	37.0	42.3	25.0	47.8	35.6
Civil society organisations	28.6	20.0	28.2	22.2	23.1	29.2	21.7	25.0
Regional government officers	14.3	10.0	15.4	11.1	15.4	12.5	17.4	13.9
Private sector	9.5	0.0	5.1	11.1	3.8	25.0	4.3	8.3
Government officers (TANROADS, TFS, TCCIA)	4.8	5.0	10.3	7.4	7.7	8.3	4.3	7.2
National* Research Institutes and Universities	0.0	40.0	2.6	11.1	3.8	0.0	0.0	7.2
Media	0.0	0.0	7.7	0.0	3.8	0.0	0.0	2.2
Religious Institute	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.6
Women	4.8	20.0	12.8	20.0	19.2	20.8	8.7	14.9

* One participant from the University of Florida and affiliated to the Sokoine University of Agriculture in Morogoro, Tanzania.

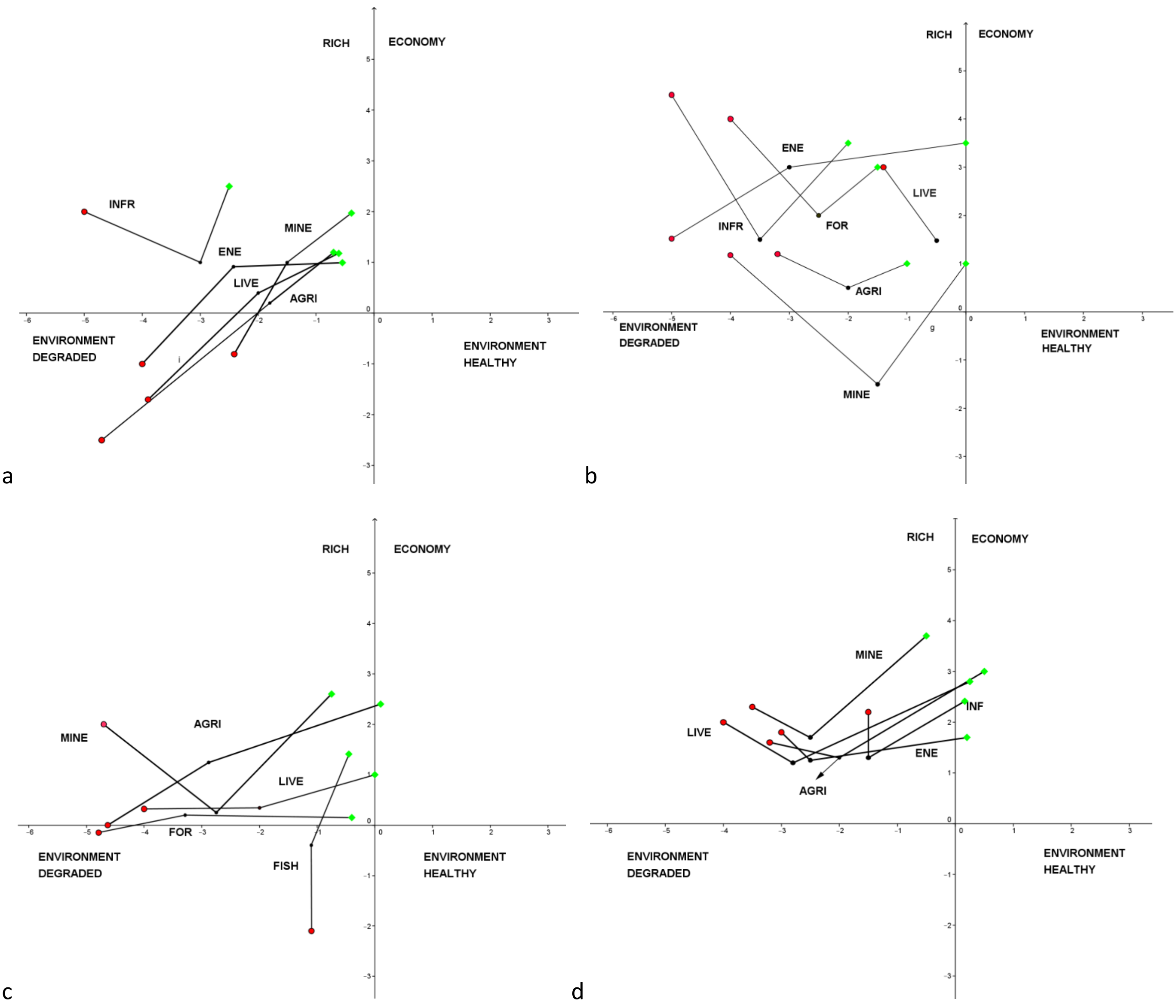
Stakeholder-driven scenario development (Fig. A1.1) followed the logic flow from current socioeconomic conditions to future land changes (Fig. A1.1a). In the first participatory task, stakeholders developed possible future economic sector trajectories by using economy-environment axes charts as reference (Fig. A1.1b) and qualitatively described them. In the second task, using a reference land use and land cover map (Fig. A1.1c), stakeholders evaluated the likelihood of various land use and land cover changes (LULCC), their direct drivers and the spatial distribution (Fig. A1.1d).

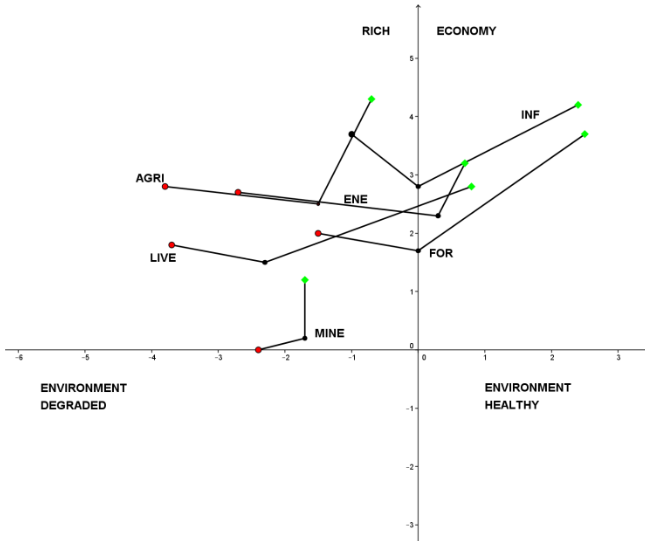
Figure A1.1. Stakeholder-driven scenario development logic flow (a) and step by step representation (c-d).



Overall, participants identified agriculture, energy (mainly charcoal and firewood), forestry, livestock keeping, mining (e.g. minerals, gems, gas or oil), infrastructures (e.g. transport, construction) as the core economic sectors determining future socio-economic and environmental trajectories, though to different extents across Zones. In addition, wildlife management, tourism, and fishing sectors were identified in Eastern unit, Southern and Lake unit, respectively (Fig. A1.2).

Fig. A1.2. Economic sectors positions and trajectories in current situation and business as usual and green economy scenarios in the units of analysis: a) Central, b) Eastern, c) Lake, d) Northern, e) Southern highlands, f) Southern, g) Western. Stakeholders analysed agriculture (AGRI), livestock (LIVE), energy (ENE), forestry (FOR), mining (MINE), infrastructure (INF) and fishery (FISH) sectors. Black, red and green dots represent positions in current situation, business as usual and green economy scenarios respectively.

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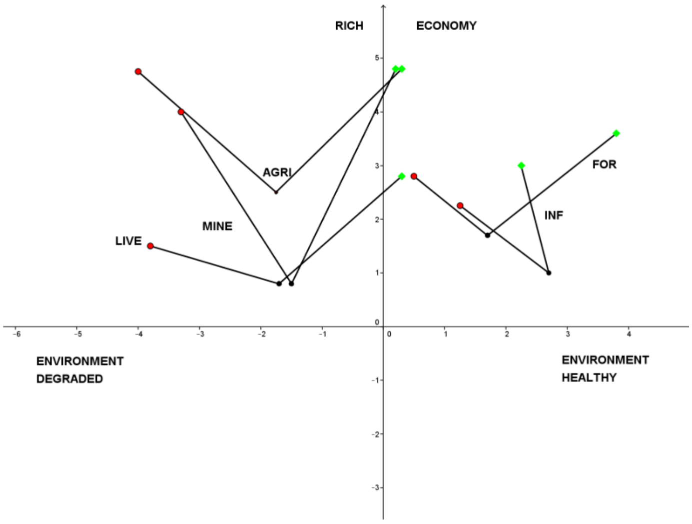
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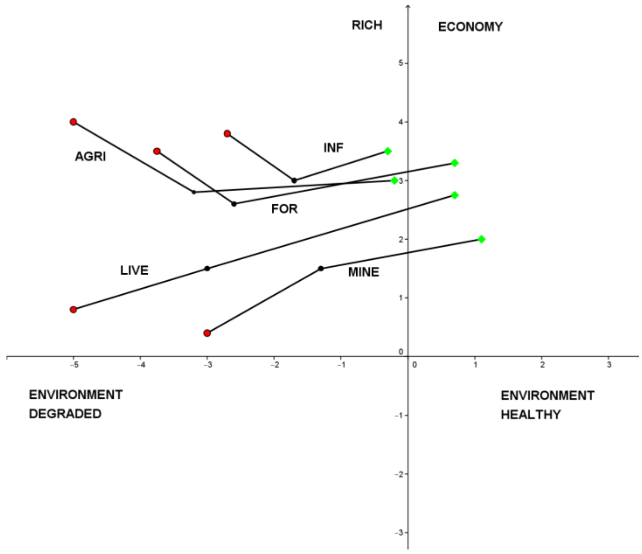
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Step 4

The synthesis workshop gathered 60 stakeholders from public institutions (mainly at national level), research institutions, CSOs, agribusiness and media (Table A1.2, WWF-TCO 2015). Following the presentation of results from regional workshops, participants visually validated the preliminary scenarios output maps, in particular the spatial pattern of farmland expansion. Guided by specific questions, separate groups discussed the main assumptions drawn from the regional workshops focusing on crop suitability and productivity, charcoal production, industry and infrastructures development. In particular, participants highlighted accessibility to markets and land suitability for cash crops as factors determining expansion of commercial farming (Table A2.1c). As for crop productivity, they suggested an average increase of 10% under GE scenario. Participants also provided useful inputs on datasets for roads, irrigation sites and mining activities. A revision of the spatial indicators and quantitative rules used in the modelling step followed the workshop.

Table A1.2. Stakeholders' composition in national workshops in Tanzania.

	Total (%)
Civil society organisations	25.0
Government officers (VPO,TANROADS, TFS, TMA, TIC)	21.7
National Research Institutes and Universities	18.3
Ministry officers	11.7
Media	10.0
Regional government officers	5.0
District government officers	3.3
Private sector	3.3
Women	15.6

Appendix 2. This Appendix contains details on step 3 of the scenario framework implementation in Tanzania.

Step 3

Spatial information provided by workshops participants during sub-national (Table A2.1a and b for biophysical factors affecting land use and land cover changes, LULCC) and national-level workshops (Table A2.1c for crop suitability) corresponded to 18 spatial indicators. These were then simulated by the modellers using national and global datasets (Table A2.2).

Table A2.1: Biophysical factors reported by stakeholders associated with (LULCC): a) from and to different wooded land-use-cover classes, and b) from the indicated classes to cultivated land. Crop suitability criteria were ranked by stakeholders during the national-level synthesis workshop (c, ranks in ascending order). Abbreviations: Fn, natural forest; Wc, closed woodland; Wo, open woodland; Bl, bushland; Gl, grassland.

a)

		To class					
Zones	From class	Near border/ inside PAs/FRs	Near human settlements	Distance from roads	Distance from farmland	Livestock density	Distance to charcoal market*
S	Fn	Wo	Wo	Wo	Wo		
C	Fn	Bl		Bl			
C	Wc	Bl					
E	Wc	Wo, Bl, Gl	Wo, Bl, Gl				
L	Wc	Gl	Wo	Wo, Bl		Wo	
S	Wc	Wo	Wo	Wo	Wo		
W	Wc	Wo	Wo	Wo			
E	Wo		Bl, Gl	Bl			Bl, Gl
L	Wo	Bl,Gl					
N	Wo						
SH	Wo						
S	Wo		Bl	Bl	Bl		
W	Wo	Bl	Gl				
C	Bl		Gl				
S	Bl				Gl	Gl	
W	Bl						

(*)Distance to charcoal market and distance to roads replaced by distance to Dar es Salaam for Eastern unit b)

	To cultivate land						
Zones From class	Near border/ inside PAs/FRs	Near human settlements	Distance from roads	Distance from farmland	Distance from main food market sites	Fertile soil	Distance from irrigated sites
Central		Bl, Th	Bl	Th		Bl	
Eastern	Wo	Fn, Wc, Wo	Fn, Wo, Gl		Fn, Wo, Gl		Fn, Wo, Gl
Lake	Wc, Wo	Wc, Bl	Wc, Wo	Wc, Wo		Wc	Wo
Northern		Bl	Bl	Gl			Bl
Southern Highlands	Fn	Wo, Bl	Bl			Bl	Bl
Southern		Fn, Wo	Fn, Wo			Fn, Wo	
Western	Wo	Wo	Gl			Gl	Wo

c)

Criteria	Small producers	Commercial farming
Population density	1	
Soil fertility	4	4
Length of rainy season		
Reliability of rainfalls		
Accessibility	2	5
Water availability		3
Market		2
Distance to markets	3	
Suitability to staple crops	5	
Suitability to cash crops	6	1

Table A2.2: Indicators of spatial distribution of potential future LULCC identified during stakeholders workshops and the spatial datasets selected to represent them. Stakeholders reported biophysical factors (SI1 - SI11) favouring LULCC and specific sites where those were most likely to occur (SI12 - SI14). Factors limiting changes were also simulated (SI14 - SI18), in particular for protected areas. Participants acknowledged the role of those sites in habitat conservation, but they also expected LULCC occurring near or inside their borders under BAU scenario, especially forest reserves.

ID	Spatial indicator description	Reference dataset
SI1	Population density	AfriPop Alpha version 2010, http://www.worldpop.org.uk/data, produced July 2013; Tanzania National Census 2012 (NBS-OCGS 2013)
SI2	Proximity to/inside all protected areas borders	WDPA 2014 (UNEP-WCMC) http://www.protectedplanet.net
SI3	Proximity to/inside forest reserves borders	Same as SI2
SI4	Distance to roads	Global roads dataset (CIESIN-SEDAC), http://sedac.ciesin.columbia.edu/data/; TANROADS (URT), http://www.tanroads.org
SI5	Cost distance to Dar es Salaam, related to charcoal consumption	Same as SI4
SI6	Distance to major food markets	Same as SI4
SI7	Distance from cultivated areas	NAFORMA LULC map (MNRT 2013)
SI8	Grazing impact	Gridded Livestock of the World v2.0(Robinson et el. 2014) http://www.livestock.geo-wiki.org; National Census 2012 (NBS-OCGS 2013), http://www.nbs.go.tz
SI9	Distance to mining sites	Geological map of Tanzania, http://www.gmis-tanzania.com, ACP Mining Data Bank, http://mines.acp.int/html/TZ_geog_en.html
SI10	Crop suitability related to soil condition, rainfall pattern and altitude	Crop suitability, Agricultural Research Institute Mlingano, URT
SI11	Distance to irrigated sites	MIRCA2000, Global monthly irrigated and rainfed crop areas around the year 2000 http://www.uni-frankfurt.de/45218031
SI12	Protected areas identified as specific sites of LULCC	Same as SI4
SI13	Potential distribution of Sagcot clusters	SAGCOT clusters, http://www.sagcot.com/

SI14	Specific wards and districts in Tanzania mainland identified as sites of LULCC	Wards 2012 (Tanzania National Bureau of statistics) http://www.nbs.go.tz/
SI15	Legal protection constraint factor	Same as SI3
SI16	Elevation constraint range (Low, medium, high)	SRTM 90m Digital Elevation Model, http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1
SI17	Elevation constraint mask for farming suitability	Same as SI16
SI18	Slope constraint mask for farming suitability	Same as SI16

To create the indicators dimensions, datasets were transformed to comply with local statistics and projected future conditions whenever the information was available, and then reclassified into LULCC likelihood classes following workshops participants' knowledge of spatial patterns of LULCC and literature data (Table A2.3). Stakeholders expressed the likelihood of change in classes from 0 to 4, and so a consistent approach was followed in the reclassification of spatial indicators. However, for biophysical factors we extended the classes from 0 to 8, so to better represent gradients over the distribution range. This way, spatial locations were given a different weight than the other indicators (where the maximum likelihood of change value would be 8), because spatial location information may be incomplete (due to limited knowledge of stakeholders). However, rather than considering this information redundant, we valued it as additional "local knowledge". In fact, the location information seemed to be related to factors different than the bio-physical rules, which we could not otherwise map (e.g. local governance, private interests).

For distance indicators, we assumed that likelihood of cover change would be maximum in the range of 5 km and then gradually decrease moving farther, reaching the minimum (likelihood = 1) within a maximum distance of 20 km. This threshold was set on the basis of reported travel distances from roads to harvest timber or fuelwood (Kilahama 2008), and on information from stakeholders' consultations (this study, Swetnamet al. 2011). The relation between distance and likelihood of change was described as non-linear by stakeholders, and simulated accordingly through an arbitrarily set sigmoid function.

Stakeholders reported encroachment or illegal harvesting likely to occur under business as usual scenario on the borders and inside protected sites. This behaviour could sometimes be a consequence of ambiguity on boundaries extension or lack of knowledge from local communities. Following observed data, we assumed that the likelihood of change would gradually decrease moving from the border inwards, and that protection degree would vary across the different designations (Hansen et el. 2011, Pfeifer et al. 2012).

Table A2.3: Transformation and reclassification criteria for the spatial indicators of likelihood of LULC change. All datasets were converted to raster layers, adopting as common standard the Coordinate Reference System (CRS) and spatial resolution (sr) of Tanzania AfriPop dataset (CRS: WGS1984, sr= 0.000833333 decimal degrees). The transformed spatial indicators were then projected to UTM37 South (sr = 93.319 m at the equator) and clipped to the extent of the reference LULC map (MNRT 2013).

Spatial indicator	Transformation
SI1 Population density	AfriPop dataset for Tanzania was used as proxy for the indicator "human settlement proximity" because at the time of the study it was the most accurate representation of human settlements distribution. Population for Tanzania mainland was projected to 2025 based on regional annual growth rates estimated from National Census 2012 and 2002 (NBS-OCGS 2014). This way we accounted for possible future migration trends towards Dar es Salaam and other urban centres. To simulate localised impacts from the population "dispersion capacity" when looking for resources (stakeholders' information, Preston 2012), population density per cell was recalculated by using focal statistics function on a moving window of ~5 km. Population density was Log-transformed to account for skewedness in the data, and reclassified in categories from 1 to 8 using Natural breaks method.
SI2 Proximity to/inside all protected	Sites polygons rasterised according to common standards. Reclassified according to designation category.

Spatial indicator	Transformation
areas (PAs) borders	
SI3 Proximity to/inside forest reserves (FRs) borders	Sites polygons rasterised according to common standards. Reclassified according to designation category.
SI4 Distance from roads	Global dataset clipped to Tanzania, revised and reclassified according to Tanroads information with up to date information on planned improvements. Distance to roads calculated for 4 main road categories (Paved trunk, Unpaved trunk, Paved and Unpaved Regionals, Other roads), and then weighted by different factors (1, 1.2, 1.3, 1.4 respectively) which simulate effects of roads conditions on travel time (based on empirical evidence). For each raster cell the distance from any road calculated by the minimum value among all the weighted distance layers (Cell statistics, Minimum). Minimum distance to any road reclassified in categories from 1 (farthest) to 8 (closest). (See text)
SI5 Cost distance from Dar es Salaam, main market for charcoal	Cost distance from Dar es Salaam calculated using the Distance to roads as cost factor, so that the actual distance from Dar was weighted by the presence/absence of roads and their condition. Cost distance from Dar es Salaam reclassified in categories from 1 (farthest) to 8 (closest), assuming that the influence of Dar es Salaam is reported to decrease after 250km (Kilahama 2008).
SI6 Distance from major food markets	Cost distance from major food market cities (namely Arusha, Mwanza, Mbeya, Dar es Salaam) calculated using as cost factor the distance to roads calculated from the category Paved trunk and Unpaved trunk only. Cost distance from major food market reclassified in categories from 1 (farthest) to 8 (closest see text for more details).
SI7 Distance from cultivated areas	Cultivated areas (classes: Grain and other crops, Cultivated woodland, Cultivated bushland) extracted from reference LULC map (MNRT 2013). Distance from cultivated areas calculated by Euclidean distance tool. Distances reclassified in categories from 1 (farthest) to 8 (closest, see text for more details).
SI8 Grazing impact	Cattle, goats and sheep datasets clipped to Tanzania, and summed up transforming the values in Tropical livestock units equivalent (Cattle = 1, Goats and sheep = 0.6). Livestock density multiplied by the ratio between regional census statistics and the raster dataset (Zonal statistics, Map Algebra) to comply with the regional livestock statistics from the National Census 2012 (URT, 2012), and with the reported trends of migration of livestock keepers to southern regions. Livestock density resampled at common resolution adopting nearest neighbour method. (The potential inaccuracy introduced with this procedure is minimised by the following reclassification steps, and by the patchy nature of the data reflecting administrative statistics). Correction on livestock impact in the southern zone adopted based stakeholders mapping. Livestock density reclassified in categories from 1 to 8 based on a TLU carrying capacity of 30TLU/ha, and setting: 1-10 = 1; 10-20 = 2; 30 – 40 = 3; 40 – 50 = 4; 50 – 60 = 5; 60 – 70 = 6; 70 – 80 = 7; >70 = 8.
SI9 Distance to mining sites	Current mining sites identified by different data sources merged on a point dataset. Distance to mining sites calculated by Eclidean distance. Distance from mining sites reclassified in categories of likelihood of change from 1 (farthest) to 8 (closest).

Spatial indicator	Transformation
SI10 Crop suitability	Rasterised according to common standards. Reclassified according to likelihood based on criteria (discussed during the workshops): rainfall amount, length of rainy season, type of crop (staple/cash).
SI11 Distance to irrigated sites	Irrigated areas extracted from MIRCA 2000 dataset. Dataset resampled at common resolution adopting nearest neighbour method. Distance from irrigated sites calculated by Euclidean distance. Distance from irrigated sites reclassified in categories of likelihood of change from 1 (farthest) to 8 (closest), in agreement suitability assessed in a previous study (United Republic of Tanzania (URT). 2002. The study on National Irrigation Master Plan in United Republic of Tanzania. Dar es Salaam, URT. unpublished report)
SI12 PAs identified as specific sites of LULC changes	Specific polygons extracted for LULC change type and zone, reclassified according to likelihood of change values reported by stakeholders and rasterised following the common standard.
SI13 Potential distribution of Sagcot clusters	Digitalisation of SAGCOT clusters and conversion to raster according to common standard. Reclassified according to likelihood of change reported by stakeholders.
SI14 Specific wards and districts in Tanzania mainland identified as sites of LULC changes	Wards and district polygons extracted and rasterised according to common standards. Reclassified according to likelihood of change reported by stakeholders.
SI15 Legal protection constraint factor	Internal distance from the border calculated by Euclidean distance tool. Distances from the border converted to a factor varying from 1 to 0.1 over a distance range varying with PAs categories, following findings from Pfeifer et al 2012 and Hansen et al. 2013.
SI16 Elevation constraint range (Low, medium, high)	Dataset resampled at common resolution by nearest neighbour method. Maximum and minimum elevation calculated by zone and reclassified by Equal breaks into low, medium and high elevation range. Reclassified according to likelihood reported by stakeholders.
SI17 Elevation mask for farming suitability	Dataset resampled at common resolution by nearest neighbour method. Dataset reclassified to 0 and 1 data for elevation above and below 3600 m respectively (threshold based on crop suitability map).
SI18 Slope mask for farming suitability	Slope calculated and resampled at common resolution by nearest neighbour method. Dataset reclassified to 0 and 1 for slope above and below 20°respectively.

Composite indicators of LULCC likelihood for different conversion types were developed at sub-national scale and then harmonised at national scale (Fig. A2.1). Spatial indicators common to every unit and across similar LULC change types composed the baseline indicators. Other indicators were combined with the baseline according to unit-specific stakeholders' indications. Standardised composite indicators were merged across regions by adopting distance-weighted mean values over 40km-buffers across the region boundaries. This follows the approach adopted for indicators of distance from spatial elements, for which likelihood of change decrease to minimum (1) above 20km of distance (see Table A1.3). Distance from roads and distance from Dar es Salaam (the business capital for the country) were the only significantly correlated indicators, and were not used in combination.

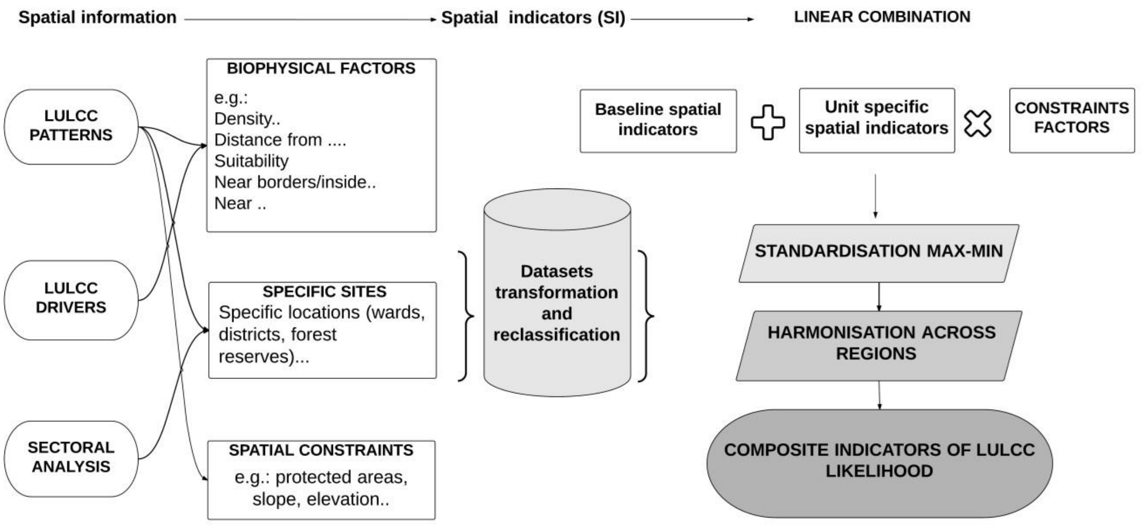

Fig.A2.1: Schematic model for building composite indicators of change likelihood from spatial information collected during multi-stakeholders workshops.

Demand estimate

Following the analysis of sectors trajectories reported by stakeholders, we estimated annual demand for wood and food crops based on exogenous fixed per capita consumption rates, and then we projected it to 2025 according to population growth. We adopted a fixed population growth rate of 2.7/yr estimated from 2012 and 2002 census data (NBS-OCGS, 2013), aligned with the low variant projection for population growth rate estimated in 2010-2025 period by UNDESA (http://esa.un.org/unpd/wpp/index.htm).

Based on literature review (Table A2.4) and following official statistics (MNRT 2015), total wood volume demand was estimated to 1.3 m3/capita/yr. Wood demand is mostly represented by domestic consumption, and the remaining part (industrial, timber, charcoal) is indirectly contributing to household's income. For each year, we estimated total wood demand and compared with available annual cut (AAC), set to 42.7 M3in 2010 (MNRT2015). AAC was decreased each year proportionally to forest and woodland loss, adopting a minimum value of 1000 km2 cover loss per year (Pekkarinen et al. 2014 in MNRT2015). Wood volume demand exceeding the AAC was deemed to degrade wood stocks, and was converted to degraded surface by adopting fixed biomass values per area unit for each land-use-cover class (MNRT 2013), net of wood biomass produced during farmland expansion. This surface was spatially allocated across regions and cover classes following three criteria: 1) the relative proportion of total wood stock and 2) the relative impacts of the forestry and energy sectors assessed by stakeholders, and 3) the specific likelihood of changes scores. For the GE scenario sectorial trajectories drawn by stakeholders suggested a more efficient, but not fully sustainable, use of wood resources. We interpreted this target assuming 50%reduction of wood demand above the AAC, assuming sustainable forest management when harvesting rate is lower or equal to the AAC.

According to sectors trajectories, farmland expansion would follow population growth without gaining in productivity. Accordingly, we estimated possible increase of 1) + 47.28% of production according to per capita daily calories intake and the food balance sheet (EAGCG2010), 2) +39.2% of staple food production and harvested area according to FAOSTAT 1999-2013 statistics, http://faostat3.fao.org/home/E), and 3) +58% of production for staple and cash crops following improved production rates or +69% at current rates (FAO-BEFS 2010) by 2025. However, these growth rates were based on agriculture statistics reported in the National agriculture census for 2007 (small holdings extending ca. 112,663 km^2, out of which ca.88,088 km^2 for annual crops, and large farms extending 11,139 km^2, URT-NBS-MF-OCGS-MFEA 2009), which differ from total surface of cultivated classes in our reference LULC map ("grains and other crops" = ca. 174,325 km^2, mixed cultivated-wooded categories = ca. 117,237km^2, "paddy rice in wetlands" = 2699 km^2, MNRT2013) or from the extrapolation of inventory data (222,480 km^2 MNRT 2015). Differences between spatial and census statistics can be partly explained by the fact that LULC classes for cultivated areas also includes woodlots and human settlements. However, estimates of agricultural area are not consistent even amongst datasets derived from different satellite products (Exner et al. 2015) and from the NAFORMA inventory extrapolation (MNRT 2015). Other sources of uncertainties in our estimates were about: 1) biomass content of mixed cultivated-wooded categories (i.e. cultivated bushland and woodland); 2) loss of biomass during slash and burn practice to open new areas for farming.

Considering the trajectories developed by stakeholders for agriculture sector, the reported estimates and uncertainties, for our scenarios we set potential cropland increase to 30% by 2025, aligned with the estimated area of potential cropland expansion without productivity gain in FAO-BEFS (2010). For the BAU scenario, we assumed two possible patterns of expansion of agricultural land: 1) only actual cropland expands by 30% (BAU1, implies replacement of original cover by cropland, and maximum biomass loss) and 2) additionally to cropland expansion, encroachment and partial biomass loss following shifting cultivation occurs at the same rate (30% of the mixed cultivated-wooded land categories). In GE scenario, following the workshops participants' expectations, we assumed 10% increase of yield, and no further expansion of shifting cultivation.

Given the level of uncertainties on per capita demand, we adopted conservative, minimum, estimates. However, since those were consistent between the two scenarios, this is not affecting the marginal difference.

Table A2.4: Estimate of wood demand (m3/capita/yr) for for biomass energy and timber reported in literature.

CHARCOAL m^3/capita/yr	**TOTAL BIOMASS ENERGY m^3/capita/yr**	**OTHER USES (by households) m^3/capita/yr**	**TIMBER m^3/capita/yr**	**References**
	0.96			Kichonge et al. 2014
0.24 (FAO Forest Products Yearbook 2011)	**0.96 = 0.87 + 0.09** by households and rural factories (FAOSTAT 2014)	0.05 (FAOSTAT 2014)	Import-export balance in roundwood = **0.0025** (FAOSTAT 2014). Illegal harvesting estimate= **0.05**	MNRT 2015
	0.47-1.14 (for 12 villages, mean **0.65**)			Treue et al. 2014
		0.0367 in rural households and **0.0515** in Dar households	Commercial extraction: volume of 54,280–6,355,008 m^3/yr	Schaafsma et al. 2014
0.75				Peter et al. 2009
	1		.	Ngaga 2011

In agreement with the composite indicators of LULCC likelihood, changes were applied to the reference national map to fulfil the demand through the step-wise process described in Fig. A2.4.

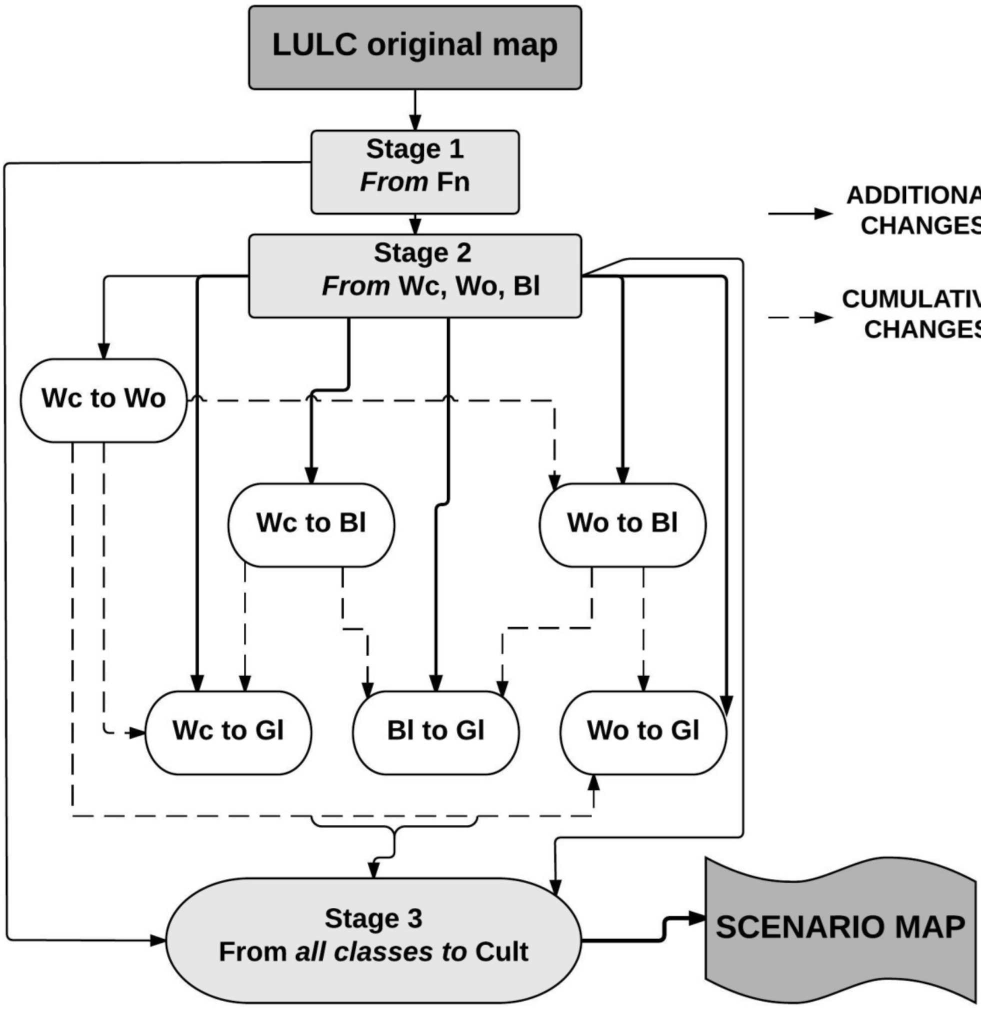

Figure A2.4: Stepwise spatial allocation of land cover changes following land demand and composite indicators of likelihood of change. Symbols: Fn = natural forest (mountain and lowland forest); Wc = closed woodland; Wo = open woodland; Bl = bushland; Gl = grassland; Cult = cultivated land.

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