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Research

From stories to maps: translating participatory scenario narratives into spatially explicit information

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ABSTRACT. To understand future land use change, and related ecological and social impacts, scenario planning has become increasingly popular. We demonstrate an approach for translating scenario narratives into spatially explicit land use maps. Starting from four previously developed scenarios of land use change in southwestern Ethiopia we developed a baseline land use map, and rules for how to modify the baseline map under each scenario. We used the proximity-based scenario generator of the InVEST software to model the prospective land cover changes to existing forest (53%), arable land (26%), pasture (11%), and wetlands (7%), under the four future scenarios. The model results indicate that forest cover area would remain essentially the same under the "gain over grain" and "biosphere reserve" scenarios. Coffee plantations would cover almost half the landscape (49%) in the "mining green gold" scenario, whereas arable land would expand and cover more than half of the landscape (57%) in the "food first" scenario. The approach presented here integrates future land use mapping with participatory, narrative-based scenario research to assess the social-ecological outcomes of alternative futures. The translation of narratives onto maps can help researchers and stakeholders better understand and communicate potential land use changes, and facilitate a more spatially nuanced approach to managing or adapting to broad scale socioeconomic changes. Our study constitutes a methodological contribution to the management of land use change, as well as a tool to facilitate transparent policy negotiation and communication at local, government, and NGO levels.

Key Words: *InVEST; landscape; land use and land cover maps; narrative scenarios; plausible futures; spatially explicit land use scenarios; translation rules*

INTRODUCTION

Changes in land use are pervasive in rural areas around the world and impact both ecosystems and people (Millennium Ecosystem Assessment 2005, Haines-Young 2009, Quintas-Soriano et al. 2016). Identifying potential changes in land use helps decision makers to assess the sustainability of alternative future pathways. To assess plausible futures for a particular landscape, many scenario mapping exercises have downscaled regional or global scenarios to a more localized level (Gaffin et al. 2004, Verburg et al. 2006, Frame et al. 2018). Such downscaling provides consistent high-resolution land use and land cover (LULC) for assessing aggregate impacts over large spatial extents. However, the usefulness of such approaches at fine scales may be limited by the lack of context regarding local realities. In contrast, a growing number of social-ecological scenarios are being generated directly in local landscapes together with stakeholders (reviewed by Oteros-Rozas et al. 2015). Localized scenario development facilitates a detailed understanding of the specific dynamics of a place and the contextually relevant drivers of change. However, participatory approaches that generate localized scenarios typically result in the development of narratives. Although such narratives are useful for engaging diverse stakeholders, they lack the spatially explicit, quantitative information provided by downscaled higher level scenarios. To overcome this limitation, in this paper, we demonstrate an approach to translating scenario narratives into spatially explicit LULC maps for four scenarios developed in southwestern Ethiopia. Before presenting our approach, we provide short background reflections on land use change, scenario planning, and existing attempts to turn scenario narratives into maps.

Within a given landscape, LULC change results from a combination of direct and indirect social and ecological drivers (Díaz et al. 2019). Human-driven LULC change is a key driver of the loss of biodiversity and ecosystem services (e.g., Sala et al. 2000, Díaz et al. 2019). From an ecological perspective, LULC change causes biodiversity loss by altering the composition, distribution, abundance and functioning of biological diversity and related processes (e.g. Millennium Ecosystem Assessment 2005, Díaz et al. 2019). LULC change is projected to further intensify, resulting in increasingly higher loss of biodiversity (Sala et al. 2000, Powers and Jetz 2019). The impact of LULC on biodiversity depends on the intensity of change, the configuration of land use patterns, and the spatial distribution of natural biophysical variables (Zebisch et al. 2004). From a social perspective, LULC change and the resulting loss of biodiversity also alter the generation and provisioning of ecosystem services, that is, the benefits that people obtain from the environment (Millennium Ecosystem Assessment 2005).

To understand future LULC change, and related ecological and social impacts, scenario planning has become increasingly popular. Scenario planning can help decision makers to proactively consider uncertainty when choosing among policy alternatives (Peterson et al. 2003, Shoyama and Yamagata 2014, IPBES 2016). Scenario planning combines various tools and techniques to develop plausible and internally consistent descriptions of alternative futures (Peterson et al. 2003, IPBES 2016). Although scenario planning does not eliminate uncertainties about the future, it can provide a means to represent current knowledge in the form of consistent conditional

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statements about the future; thereby providing a rational and reflected basis for improved decision making (Alcamo et al. 2008).

One useful level at which to analyze LULC change is the landscape scale (Wu 2013). Landscapes, in turn, can be analyzed as social-ecological systems, that is, systems in which social and ecological variables are closely interlinked (Fischer et al. 2017). In the context of analyzing landscape-level changes in social-ecological systems, participatory scenario planning has become increasingly popular. Oteros-Rozas et al. (2015), for example, reviewed 23 cases in which participatory scenario planning was used to investigate land use change related futures of social-ecological systems. Participatory scenario planning has been used to explore alternative development trajectories in semi-arid Tanzania (Enfors et al. 2008); to identify changes in ecosystem services in an agricultural landscape in South Africa (Malinga et al. 2013); and to develop plausible scenarios focusing on food security and biodiversity conservation in Ethiopia (Jiren et al. 2020).

Narratives of alternative futures generated in participatory approaches are powerful because they encapsulate the views of diverse stakeholders (Alcamo et al. 2008, Mallampalli et al. 2016, Fischer et al. 2018). This, in turn, can lay the foundation for developing a shared vision for the future (Alcamo et al. 2008, Mallampalli et al. 2016, Nieto-Romero et al. 2016), facilitate social learning, and generate novel ideas for how to achieve a desired and sustainable future (Butler et al. 2014, Booth et al. 2016, Jiren et al. 2020). However, scenario narratives typically result in generalized statements of what the future might look like, rather than quantitatively explicit LULC maps. The precise way in which a given scenario plays out at fine scales, in turn, depends on locally specific social-ecological conditions (Hanspach et al. 2014). The generalized nature of narratives thus makes it difficult to analyze quantitatively the implications of LULC (e.g., on different species and ecosystem services), thereby limiting the extent to which decision makers might engage with such scenarios.

To date, few studies have translated qualitative narrative scenarios at the landscape level into quantitative LULC maps (but see Kok and van Delden 2009, Swetnam et al. 2011, Booth et al. 2016, Kohler et al. 2017). The "story and simulation" approach (Alcamo 2008), in which scenarios are first defined by experts and other stakeholders and subsequently translated into quantitative parameters that can be fed into simulation models, has been most commonly used to couple qualitative and quantitative scenarios (Mallampalli et al. 2016). Given the usefulness of scenario mapping and the growing popularity of participatory scenario planning in social-ecological research (Oteros-Rozas et al. 2015), additional work is needed on how to translate narratives into maps.

Here, we present such an approach. We focus on rural southwestern Ethiopia, for which we had earlier developed four alternative narrative scenarios of social-ecological change (Fischer et al. 2018, Jiren et al. 2020). Our approach combines the extraction of key variables and trends from stakeholder-derived storylines of the future, their translation into quantitative spatial variables, and the subsequent spatial projection of changes to present land cover under different scenarios.

The contribution of our study is twofold. First, from a methodological perspective, our approach is useful to integrate LULC mapping with participatory, narrative-based scenario development. Second, from an applied perspective, our approach helps to better understand plausible LULC change in southwestern Ethiopia, which is valuable for regional-level stakeholders, planners, and policy makers.

METHODS

Study area

The study area consists of three districts or *woredas* (Gera, Gumay, and Setema) in Jimma Zone, Oromia Region, southwestern Ethiopia, with a total area of about 2800 km². Based on Ethiopia's multi-level governance system, woredas are districts that are further subdivided into *kebeles*, where each kebele contains a minimum of 500 households (Fig. 1). Southwestern Ethiopia is a globally recognized biodiversity hotspot (Mittermeier et al. 2011, Bellard et al. 2014), with large areas of Afromontane forests (Hylander et al. 2013a). It is also the place where Arabian coffee (*Coffea arabica*) originates (Senbeta and Denich 2006). Coffee here is traditionally grown in forests under the shade of native trees (Jena et al. 2012). The landscape consists of a forest-agricultural mosaic (Ango et al. 2014, Dorresteijn et al. 2017) that provides multiple ecosystem services to the local population. These ecosystem services are key to local people's livelihoods and well-being (Shumi et al. 2019a).

From narratives to maps: translation steps

Our methodological approach to translating scenario narratives into maps consisted of five key steps, which we outline in detail below. Briefly, first, four narrative scenarios were developed (for details, see Fischer et al. 2018, Jiren et al. 2020). Second, we created a baseline map of current land uses from satellite imagery. Third, based on the scenario narratives, we developed rules for how to modify the baseline map under each scenario. Fourth, we used the proximity-based scenario generator of the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) software (Sharp et al. 2018) to produce maps of the four scenarios. Fifth, we assessed how each of the scenarios affected kebeles of different socioeconomic and biophysical characteristics.

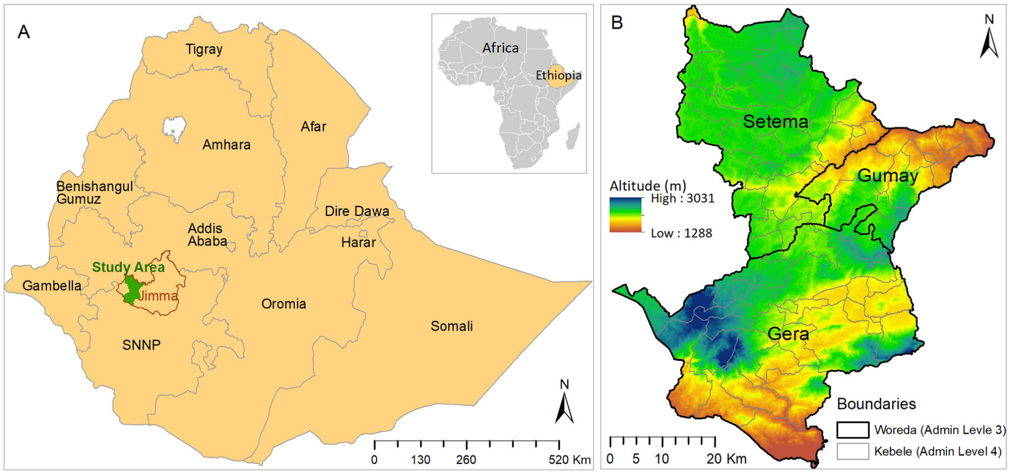
Step 1: Development of the narrative scenarios

Prior to this paper, we had developed four qualitative narrative scenarios (Fig. 2) through participatory scenario planning, which involved 35 stakeholders from different organizations and local community groups (for details, see Fischer et al. 2018, Jiren et al. 2020). Those 35 stakeholders, in turn, were based on an in-depth analysis of the stakeholder network in the study area (Jiren et al. 2018). The scenarios considered a wide range of plausible environmental, social, and economic changes, and are briefly summarized below and in Appendix 1, Table A1.10. The time period for the scenarios was 20 years, from 2020 to 2040.

"A. Gain over grain": local cash crops

This scenario prioritizes farmers' specialization and commercialization to boost development, while traditional food cropping is abandoned in favor of cash crops. The cash crops are coffee, the stimulant drug khat (*Catha edulis*), and fast-growing trees, mostly eucalyptus. The landscape largely consists of intensively managed coffee forests interspersed with khat and tree plantations. Farmers are encouraged to increase coffee production through newly created coffee plantations. Eucalyptus plantations primarily target degraded areas and marginal land. Khat plantations on

Fig. 1. Map of (A) the location of the study area in Jimma Zone, Oromia, Ethiopia; and (B) a detailed view of the three woredas targeted here, including kebeles boundaries and altitude (from ASTER digital elevation model, https://asterweb.jpl.nasa.gov/gdem.asp).



former farmland are intensively managed. Farmland biodiversity is dramatically reduced because of intensive management and habitat simplification. The production of food crops is limited: little space remains for cultivating cereal crops, and only a few farmers maintain small cereal fields. To maximize the limited food production, the most fertile land is preferentially used for farming.

"B. Mining green gold": coffee investors

This scenario is characterized by the intensification and specialization of coffee production through large investors who use modernized production approaches with high external inputs. The landscape consists of intensively managed high-yielding coffee plantations, and relatively little food is produced. Smallholder land, communal land, and forests conducive for coffee investment have been transferred to capital investors for the creation and expansion of coffee plantations. The use of non-native species for coffee shading is common. Local farmers are left to farm marginalized areas unsuitable for large scale coffee plantations, e.g., steep hillslopes.

"C. Coffee and conservation": a biosphere reserve

This scenario is based on a more balanced land use approach. Because of the failure of conventional agriculture and increasing global interest in sustainably grown coffee, a biosphere reserve has been established that combines sustainable agriculture, environmentally friendly coffee production, and tourism. The landscape is a diversified mosaic of forest and farmland and consists of a core zone with unused natural forest; a buffer zone for low-intensity production of local coffee, wild honey, and other forest products; and an outer zone with interspersed cropland, pastures, and tree plantations. Livestock production and communal grazing take place much like at present, and people grow fruits and vegetables as well as grains. Sustainable resource management and improved soil and water conservation are practiced to revert environmental degradation.

Fig. 2. Landscape view at present and in the four scenarios (reproduced from Jiren et al. 2020). The current landscape consists of a mosaic of food crops, cash crops, pasture, forest, and settlements. The "Gain over grain" scenario describes a landscape covered by different cash crops, whereas intensive coffee plantations dominate the landscape in "Mining green gold". The "Coffee and conservation" scenario is similar to the current landscape in that different crops, trees, and settlements co-exist. The "Food first" scenario consists of a landscape dominated by intensively produced food crops, where forest is spared from human activities.

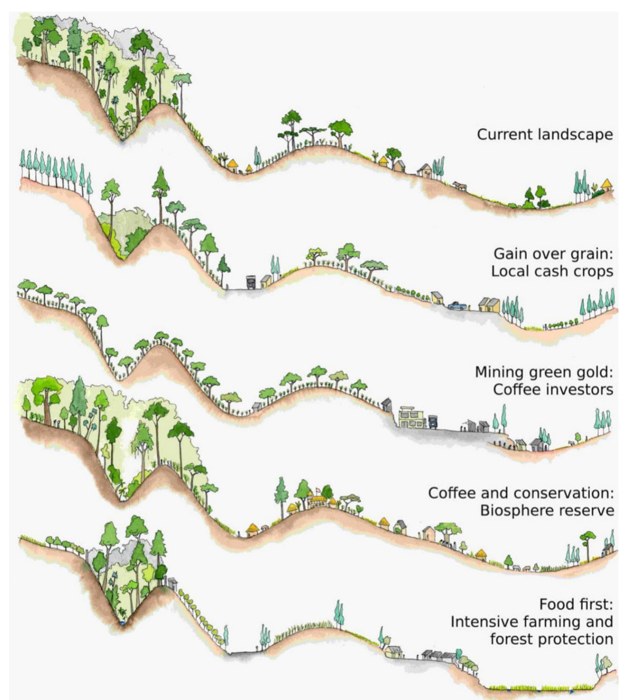


Table 1. Ground control points (GCPs) used for image classification and accuracy assessment with their sources. Out of 159 GCPs from primary fieldwork, 107 GCPs were collected during the previous project called "Identifying Social-Ecological System Properties Benefitting Biodiversity and Food Security (SESyP)" (Shumi et al. 2018, 2019b), and 52 GCPs were collected by the first author of this paper during a short field trip in February 2020.

Land cover	For classification			For verification (accuracy assessment)
	Primary field data	GCPs from Google Earth	Total GCPs	GCPs from Google Earth
Woody vegetation	49	17	66	312
Pasture	46	16	62	120
Arable land	46	20	66	192
Grazed wetland	2	55	57	75
Cultivated wetland	2	40	42	100
Settlement	8	30	38	77
Total	159	178	338	876

"D. Food first": intensive farming and forest protection

This scenario is driven by the impacts of climate change on food and coffee production. Climate change has made coffee production less viable in southwest Ethiopia, and food production has been failing elsewhere in the country. Large amounts of food are now produced in the southwest through intensive, large-scale agriculture, which involves extensive land consolidation, including the clearing of woody vegetation and the expansion of cropland on flatlands and drained wetlands. The landscape is dominated by cereal crop production. Intensified fruit and vegetable plots, as well as pastures for beef fattening and commercial beef production are also present, especially on steep slopes. The remaining patches of natural forest are strictly protected, and the local community is not permitted to access them.

Step 2: Current land cover mapping

In this step, we mapped the current extent of biophysically distinct land use and land cover classes. Characterization of land cover details began with 10 meter Sentinal-2 satellite imagery (channels 2, 3, 4, and 8) (freely downloaded from https://scihub.copernicus.eu/) from January 2019. January 2019 was chosen because it was the latest cloud free image available for the study area to clearly differentiate the different land cover features. This imagery in combination with ground control points were used to produce the current extent of land use and land cover. Over 1000 ground control points (GCPs) were gathered from different sources (Table 1).

We used supervised image classification (Lillesand et al. 2004) to generate six land cover classes of the study area. We used this method of land cover mapping because we had extensive knowledge and data on the area, including having collected many ground control points. Supervised image classification was conducted using ArcGIS Desktop 10.6.1. Signatures from GCPs were taken and analyzed for all primary land cover types identified for mapping, namely woody vegetation, arable land, pasture, cultivated wetland, grazed wetland, and settlement. These signatures were given as input to the maximum likelihood classification method (Lillesand et al. 2004, Gil et al. 2011, Patil et al. 2012). Accuracy assessment of the image classification was done via stratified random sampling (following Olofsson et al. 2014) using 876 points collected from Google Earth. The resulting 10-m pixel classification included fine-scale variation in land covers, e.g. scattered woody vegetation within farmland.

Following the initial classification into six main classes, we increased the thematic resolution of land covers in the landscape. For terrain slope, based on the literature, we used a threshold of 30% in slope to classify flat versus steep areas (Henricksen et al. 1988). To differentiate between levels of farmland heterogeneity, we ran a moving window analysis in Fragstats v4.2.1 to determine the percent woody vegetation within a 200-m radius. We then classified farmland as of low heterogeneity (< 5% woody vegetation), medium heterogeneity (5–20% woody vegetation), and high heterogeneity (> 20% woody vegetation). We classified altitude into five ranges (< 1300 m, 1300–1500 m, 1500–2100 m, 2100–2300 m, > 2300 m), mainly based on the altitudes where coffee growing is viable, both for currently suitable ranges (Senbeta and Denich 2006, Hylander et al. 2013b, Tadesse et al. 2014, Shumi et al. 2018) and a projected future altitudinal shift until 2040 (Moat et al. 2017). Distance from the edge of the forest was used to differentiate between interior forest and edge forest, where forest beyond 150 m from the edge was classified as interior (Shumi et al. 2019b). Combining these different criteria then allowed us to add thematic layering options to the land use map.

In addition to the land uses in Table 1, which were generated by using satellite image and GCPs only, we added four additional land uses (coffee plantations, eucalyptus plantations, khat, and fruits and vegetables) to the baseline map based on their current approximated locations because they were not directly visible from satellite imagery. Although their present location was not precisely known, we made assumptions based on our knowledge of the study area where these land uses were most likely to occur. For coffee plantations, we assumed that current coffee plantations are found at the edges of flat forested areas, in altitude ranges from 1500 to 2100m, within 1 km distance from a road, and only in kebeles confirmed by local administrators as having coffee plantations. For eucalyptus plantations, we assumed these to occur close (within 1 km) to tin roofed houses, and in small patches of woody vegetation measuring less than 0.25 ha. This was based on findings that most villagers plant eucalyptus around their homesteads (Takahashi and Todo 2017) and that eucalyptus is mostly found in woodlot areas outside natural forest (Ango et al. 2014). We further assumed that khat was found very close to

Table 2. Examples of key rules for the conversion of land use and land cover for the translation of qualitative narratives into quantitative rules under different scenarios. Details of the rules of conversion can be found in Appendix 1 (Tables A1.1, A1.2, A1.3, and A1.4, for "Cash crops," "Mining green gold," "Biosphere reserve," and "Food first" scenarios, respectively).

Scenarios	Qualitative rules identified from the narrative scenarios	Quantitative rules that detail the original land use/cover to be converted
Cash crops	Farmers are encouraged to increase coffee production on farmland - arable land.	44% (27,500 ha) of flat, arable land at future coffee-producing altitudes (1500–2300 m) was converted to coffee plantation.
Cash crops	Intensively managed khat plantations are established on former farmland.	21% (13,000 ha) of flat, arable land at below- and above-coffee altitudes (< 1500 m and > 2300 m) was converted to khat plantation.
Cash crops	Fast-growing trees (mainly monocultures of eucalyptus plantations) primarily target degraded areas or marginal land.	85% (9800 ha) of steep, arable land was converted to eucalyptus plantation.
Mining green gold	Large areas of smallholder arable land conducive for coffee investment have been transferred to capital investors for the expansion of large-scale intensive coffee plantations.	75% (47,400 ha) of flat, arable land at future coffee producing altitudes (1500–2300m) was converted to coffee plantation.
Mining green gold	Large areas of farmland woody vegetation were converted into intensively managed shade coffee plantations, often using non-native shade tree species.	60% (2800 ha) of farmland woody vegetation in flat areas at future coffee producing altitudes (1500–2300m) was converted to coffee plantation.
Mining green gold	Large areas of natural forest conducive for coffee investment has been transferred to capital investors for the expansion of largescale intensive coffee plantations.	50% (74,400 ha) of forest at future coffee producing altitudes (1500–2300m) was converted to coffee plantation.
Biosphere reserve	The landscape consists of a core zone of unused natural forest and a buffer zone for low intensity production.	Forests were maintained as in the baseline.
Biosphere reserve	The landscape consists of an outer area to a core and buffer zones of forests with a mosaic of cropland, pastures, and tree plantations.	Flat and steep arable land with high woody vegetation was maintained as in the baseline.
Biosphere reserve	Livestock production and communal grazing are maintained.	Flat and steep pastures with high woody vegetation was maintained as in the baseline
Food first	Large-scale land consolidation, including clearing of woody vegetation and cropland expansion.	Flat, arable land remains as in the baseline.
Food first	Farming has been mechanized as much as possible with government-owned tractors being available for hire to work the large stretches of cropland in the flat areas.	Farmland woody vegetation on flat areas (3900 ha) was converted to arable land.
Food first	Modern agriculture almost completely replaced traditional small-scale farming.	Flat pasture (27,900 ha) was converted to arable land.

homesteads on arable land, and only in kebeles mentioned by local administrators to contain khat. We therefore allocated small patches of arable land (less than 0.25 ha) adjacent to tin roofs to khat. Similar to khat, for fruits and vegetables we allocated small patches (less than 0.25 ha) of cultivated wetland close to homesteads. Woody vegetation was divided into two classes reflecting whether it occurred as part of the forest (where woody vegetation patches > 1 ha) or was dispersed as farmland woody vegetation (where woody vegetation patches < 1 ha). Settlement was assigned to agglomeration of tin roofs in the study area. We divided settlement into towns and rural settlements. Based on the location of the three administrative towns of the three woredas (CSA 2007) agglomerated tin roofs were assigned to towns, whereas the remaining agglomerated tin roofs in the study area were taken as rural settlement. The final baseline map thus generated contained 12 land use and land cover classes: forest, woody vegetation in farmland, arable land, pasture, cultivated wetland, grazed wetland, coffee plantation, eucalyptus plantation, khat, fruits and vegetables, rural settlement, and towns.

Step 3: Translation of narrative rules into qualitative spatially explicit rules

To translate narratives into maps, we defined rules that allowed specific land use/cover types to be converted under the scenarios. For this, we started by extracting and summarizing from each scenario narrative qualitative rules that could be converted into spatially explicit rules. For each land cover class in the baseline map, a set of rules were generated that governed how and where changes could occur. These rules were established using a combination of land cover classes, biophysical elements (such as slope, heterogeneity, and altitude), and distance from forest edge. Thus, the rules were context specific, that is, they were dependent on local conditions and importantly, they were directly linked to the narratives of the scenarios developed with local stakeholders for that specific area. Hence, although our general approach for deriving locally relevant rules is transferable to other places, the specific rules are not transferable.

We developed transition rules so that all land use transitions occurring in the narrative scenarios could be expressed via spatially explicit quantitative rules. The rules were derived via iterative discussions within the author team, with the central aim being that they were plausible based on known dynamics of LULC change and consistent with the scenario narratives (Table 2, Appendix 1 Tables A1.1–A1.4.). In all scenarios, towns and rural settlements expanded at annual rates of 5.4% and 1.8%, respectively (World Bank 2015, Schmidt et al. 2018). In addition, in the "B. Mining green gold" scenario, grazed and cultivated wetlands remained unaltered compared to the baseline because such wet areas are unsuitable for coffee plantations (Teketay 1999).

Step 4: Scenario maps generation

To produce scenario maps, we processed the baseline map into four different spatially explicit scenarios of LULC in the InVEST proximity-based scenario generator based on the established conversion rules. InVEST is a tool designed to inform decisions about natural resource management by providing information about how changes in ecosystems are likely to lead to changes in the flows of benefits to people (Sharp et al. 2018). The proximity-based scenario generator in InVEST is a model that is used to create a set of contrasting LULC maps that convert land cover in different spatial patterns (Sharp et al. 2018). For all scenarios, conversion of the original, to-be-converted land covers started from those edges that were most proximate to the target, newly

Table 3. Percent land use and land cover under the scenarios.

Land cover	Percentage of land cover for baseline and scenarios (in %)				
	Baseline	Cash crop	Mining green gold	Biosphere	Food first
Arable land	26.5	9.3	9.4	12.3	57.4
Coffee plantation	0.3	12.3	49.1	0.3	0.0
Cultivated wetland	4.9	4.6	4.9	4.6	0.0
Eucalyptus plantation	0.1	6.4	0.0	0.0	0.1
Farmland woody vegetation	1.7	1.5	0.7	9.8	0.0
Forest	52.9	52.8	26.4	52.9	35.2
Fruits and vegetables	0.1	0.1	0.1	8.6	2.1
Grazed wetland	0.9	0.9	0.9	0.9	0.0
Khat	0.1	6.0	0.1	0.1	0.1
Pasture	11.1	4.2	6.6	8.5	3.3
Settlement	1.3	1.3	1.3	1.3	1.3
Towns	0.3	0.6	0.6	0.6	0.6

established land cover. For every scenario, we identified the area of the original and target land covers, in hectares, that needed to be replaced. For this, we intersected the spatial layers of land use and land cover, slope, percent woody vegetation, and altitude in ArcGIS ArcMap 10.6.1 version using the “Intersect tool” in “Spatial analysis” that creates an output layer with table columns of those mentioned layers. Then, we calculated the area for this new layer using the “Calculate geometry tool.” When different conversion rules were competing for the same land cover type, we defined priorities based on the logics of the narrative scenarios regarding which conversion was more important. The resulting, altered land cover map was then used to run the next iteration of conversions that were of lower priority. For a single scenario, we thus ran multiple iterations before the final land cover map was completed. The InVEST model outputs were then visualized in a geographic information system (GIS), where we also extracted summaries of area changes for each land cover compared to the baseline map.

Step 5: Contrasting future changes between groups of kebeles

Finally, we clustered kebeles into distinct groups to summarize the changes occurring in the spatially explicit LULC scenario maps. Such summarizing of changes by kebele groups was meaningful because (a) the large number of kebeles (n = 67) rendered the presentation of LULC for each kebele unpractical, (b) many kebeles may share characteristics and therefore might be similar in the changes that occur, and (c) aggregating LULC across a woreda (regardless of the diversity of kebeles within the woreda), or the entire study area, would potentially obscure important spatial patterns of LULC change.

We used nine baseline variables, i.e. present conditions, to group kebeles according to their social-ecological characteristics. Three of these variables, the areas of woody vegetation, pastures, and arable land, were used as proxies for their overall agro-ecological makeup and were generated from the satellite imagery. Three other variables, the present levels of khat, eucalyptus, and honey production, were chosen because of their key importance for the livelihoods of the local community and were gathered from interviews with local experts. Khat and eucalyptus were estimated based on their area coverage in hectares, whereas honey production was estimated in kilograms. Two variables, mean altitude and kebele remoteness, were important general variables that might influence a range of social-ecological characteristics. Mean altitude was calculated from ASTER digital elevation model with 30-m resolution (obtained from https://asterweb.jpl.nasa.gov/gdem.asp; NASA/METI/AIST/Japan Spacesystems and U.S./Japan ASTER Science Team 2009). A remoteness index was calculated as the weighted overlay analysis using equal weights of the distance from the nearest town, the distance from the nearest road, and the subjective perception of local stakeholders classifying kebeles into one of five remoteness classes. Last, we considered wealth as an important socioeconomic variable and therefore also calculated a wealth index for the study area based on the ratio of tin roofs (identified from satellite imagery) to households in a kebele.

We used hierarchical clustering of these nine variables to identify distinct groups of kebeles and visualized the resulting groups in a dendrogram, with the number of groups selected based on group interpretability and approximately balanced group sizes (Oberlack et al. 2019, Rocha et al. 2020, Schultner et al. 2021). Specifically, based on the scores in the variables, we calculated a distance matrix using Ward’s method and visualized by “dendextend” package in R. We also visualized the kebeles and groups in two-dimensional non-metric multidimensional scaling (NDMS) to confirm the groupings (Galili 2015).

RESULTS

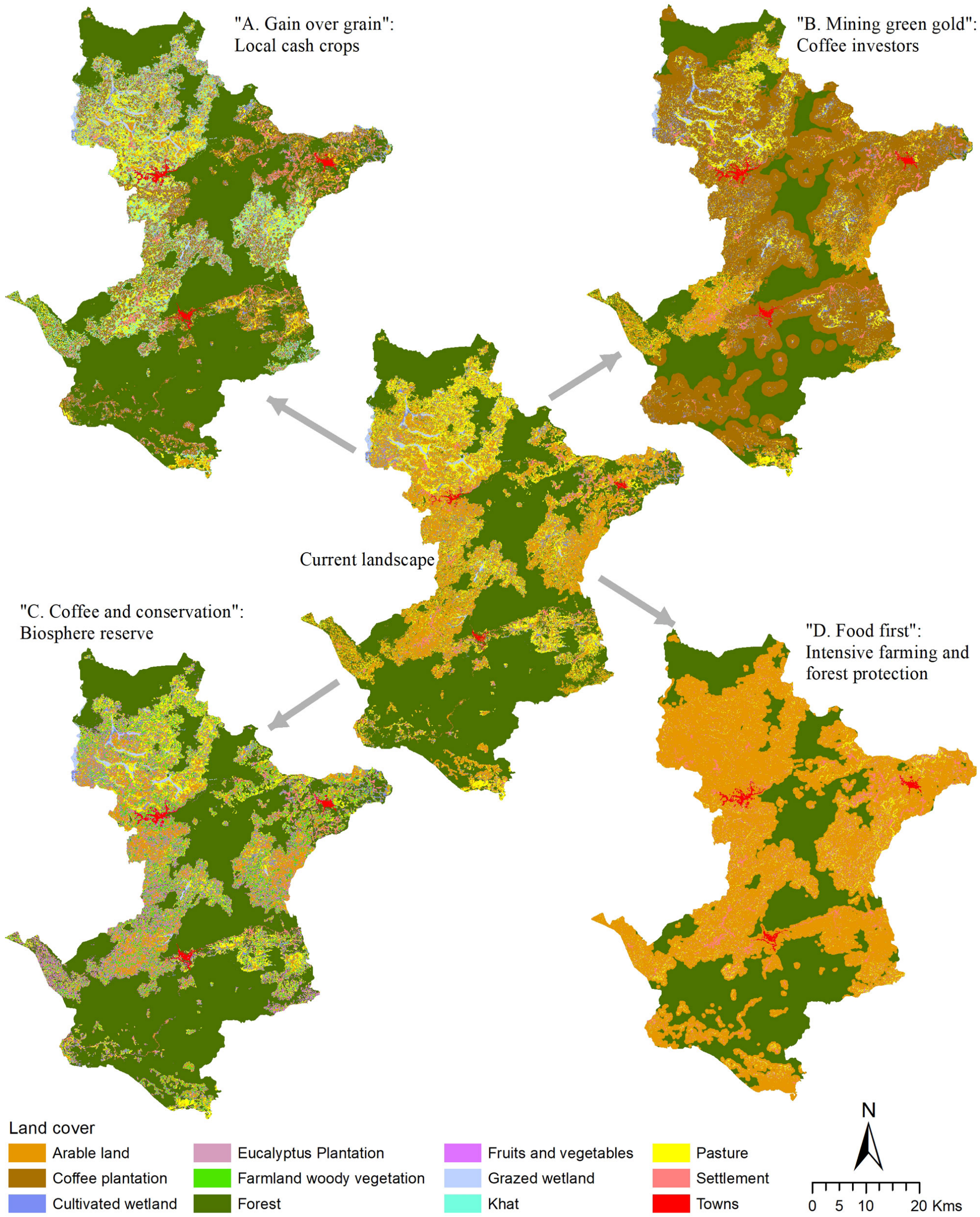
Land cover maps

In the baseline, forests covered more than half (53%) of the study region. Arable land and pasture represented 26% and 11% of the land cover, respectively. Cultivated wetland made up 5%, while grazed wetland, farmland woody vegetation, eucalyptus plantations, coffee plantations, fruit and vegetable plots, khat, and settlements together covered the remaining 5% of the region (Table 3). The result of the overall accuracy assessment for the baseline was 86.3%, and the kappa coefficient was 0.82. Figure 3 presents the map of the baseline together with the four scenarios.

Kebele groups

The kebeles were clustered into four groups based on their baseline social-ecological characteristics. The first cluster of kebeles, the “pasture-cropland group,” contained 17 kebeles and was characterized by the high availability of pasture and arable land. This group had the lowest cover of woody vegetation and low

Fig. 3. Baseline and scenario land cover maps. Arrows in the map indicate the plausibility of land cover change from the current landscape to the four scenarios.

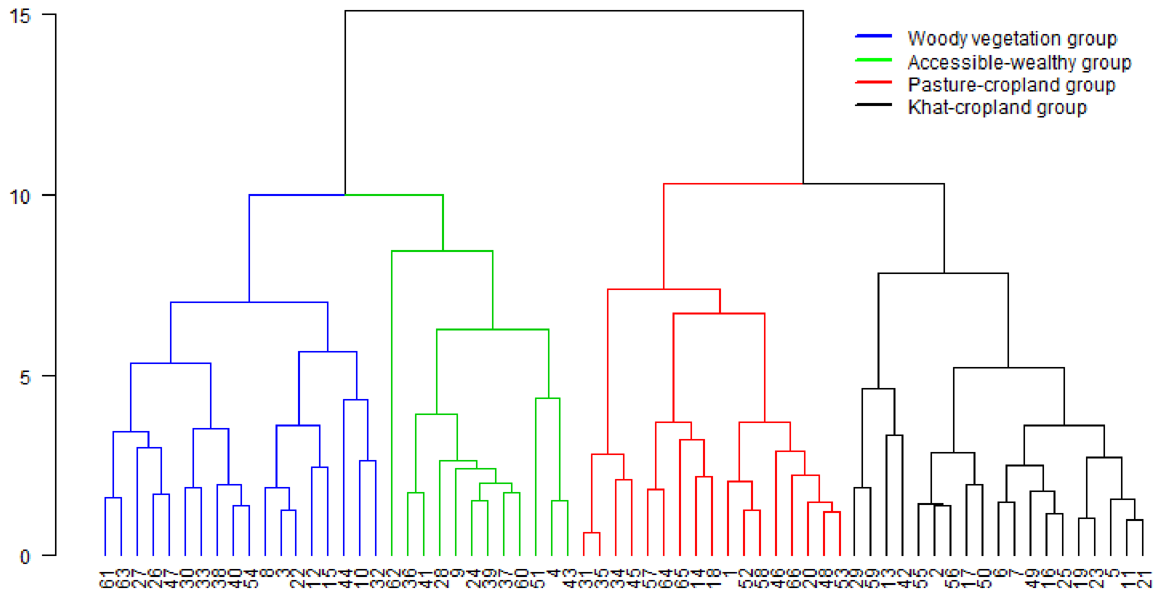


levels of coffee forest, khat, and eucalyptus. A second cluster of 19 kebeles, the "khat-cropland group," had a distinctly high availability of khat and arable land and was located at higher altitudes. This group had low coffee forest availability and the lowest wealth index. A third cluster of 18 kebeles, the "woody vegetation group," had a high extent of woody vegetation cover, high coffee forest availability, high importance of honey production, and was relatively remote. Finally, a fourth cluster of 12 kebeles, the "accessible-wealthy group," had large extents of eucalyptus plantations, and was relatively accessible and wealthy. Figure 4 shows the hierarchical clustering presented as a dendrogram. We cross-checked the dendrogram with NDMS ordination for the groups, but we did not include the graph.

Spatially explicit scenario maps

Land cover changed markedly under the four different future scenarios, with strong distinctions between the individual scenarios. Figure 5 shows the total LULC under each scenario, whereas Table 3 summarizes the LULC proportional to the baseline extent of land covers under each scenario. Notably, however, changes in a given scenario did not occur uniformly across the study region but differed between kebele groups. Along

Fig. 4. Cluster dendrogram of kebeles groups (branch colors indicate the groups: blue = "woody vegetation group," green = "accessible-wealthy group," red = "pasture-cropland group," and black = "khat-cropland group").



with general changes, we therefore also present differences between the kebele groups. Note that all land cover and land cover changes in the following summaries are rounded to the nearest percent(age).

"A. Gain over grain": local cash crops

The "A. Gain over grain" scenario was characterized by strong changes in arable land and pasture, which decreased by 17% and 7%, respectively. Coffee plantations increased by 12%, and eucalyptus plantations and khat plots by 6% each (Fig. 5 and Supplementary Table A1.5). Forest cover, farmland woody vegetation, and cultivated wetland all showed slight decreases due to settlement (both rural and urban) expansion. Under this scenario, forest cover remained essentially unchanged, accounting for approximately half of the landscape (53%). Outside the forest, the landscape was covered by coffee plantations (12%), followed by arable land (9%), eucalyptus plantations (6%), and khat (6%; Table 3).

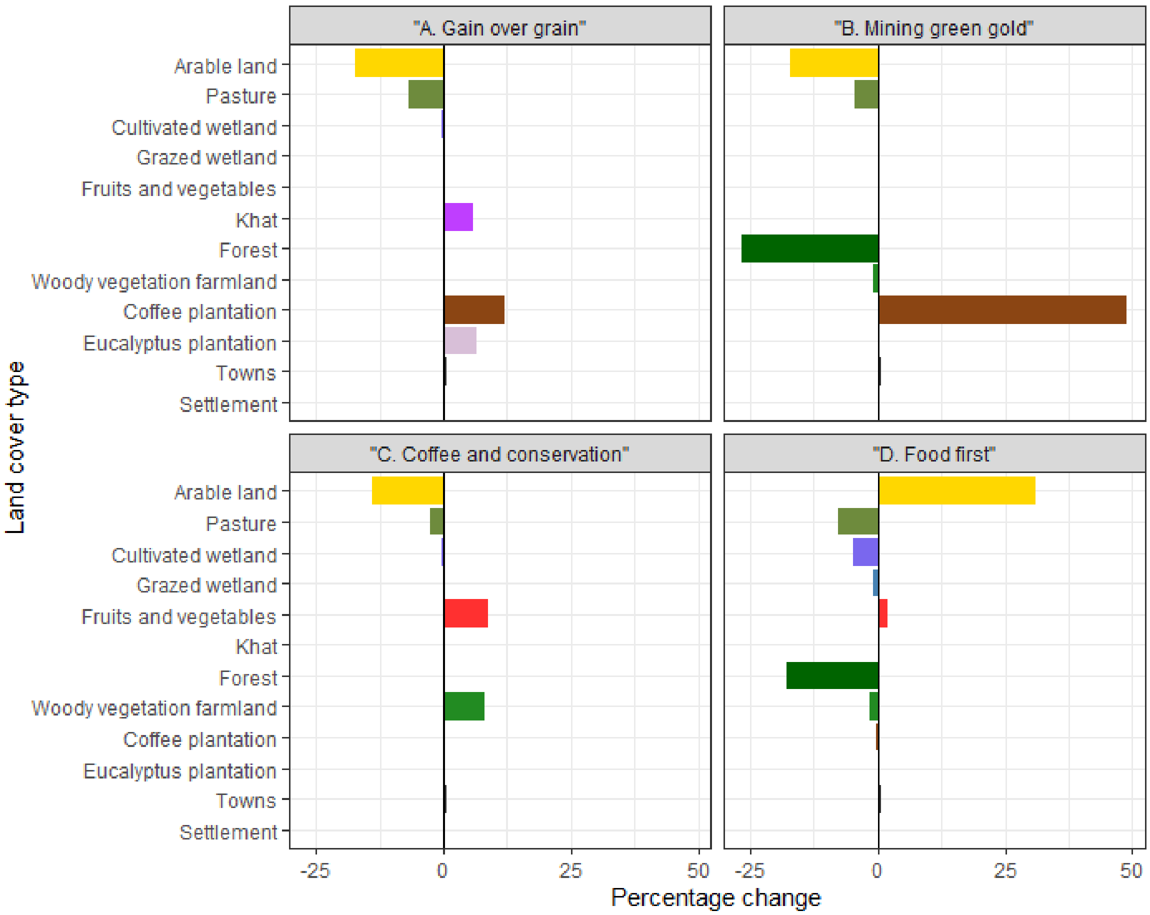
Under the "A. Gain over grain" scenario, the greatest changes occurred in the khat-cropland kebeles, which were originally characterized by a large extent of arable land and relatively high altitude. As indicated in Figure 6 and Table A1.6, arable land decreased by 46%, whereas it decreased by 34%, 25%, and 17% in the pasture-cropland, accessible-wealthy, and woody vegetation kebeles, respectively. Coffee plantations increased by 20% in both the khat-cropland and accessible-wealthy kebeles, whereas they increased by 15% and 12% in pasture-cropland and woody vegetation kebeles, respectively. Eucalyptus plantations increased by 12% in both the pasture-cropland and khat-cropland kebeles, while they increased by 5% in woody vegetation and accessible-wealthy kebeles. Similarly, khat increased by 14% and 12% in pasture-cropland and khat-cropland kebeles, respectively. There was a small increase in khat in the woody vegetation accessible-wealthy kebeles groups of 2% and 3%, respectively. Details of percentage changes by kebele groups are provided in a Supplementary Table A1.6.

"B. Mining green gold": coffee investors

Because this scenario promoted large-scale coffee investment, almost half of the landscape (49%) was converted to intensive coffee plantations. Twenty-seven percent of forest, 17% of arable land, 5% of pasture, and 1% of farmland woody vegetation most suitable for coffee growing were converted to plantations (Fig. 5 and Table A1.5). These conversions took place not only in the current coffee growing altitudes up to 2100 m but up to 2300 m reflecting the predicted shift in suitable areas due to climate change (Moat et al. 2017). In contrast, lower altitudes (1300–1500 m) lost coffee because of increasing climatic unsuitability. Under this scenario, the remaining land cover mainly constituted forest cover (26%), followed by arable land (9%), and pasture (7%; Table 3). Forest, arable land, and pasture decreased by 27%, 17%, and 5%, respectively (Table A1.5).

All kebele groups experienced significant increases in coffee plantations. However, the accessible-wealthy kebeles and woody vegetation kebeles saw the strongest increases in coffee plantations by 72% and 61%, respectively. The khat-cropland kebeles saw an increase in coffee plantations by 41% (Table A1.7 and Fig. 6). Arable land decreased in all kebele groups. However, the strongest decrease occurred in pasture-cropland kebeles of 33%, whereas there was a smaller decrease in the woody vegetation kebeles of 14%. Similarly, forest showed a strong decrease in both the woody vegetation and accessible-wealthy kebeles (41%), with a smaller decrease in the pasture-cropland kebeles (8%). Details of changes of LULC by kebele groups are presented in Table A1.7 and Figure 6.

Fig. 5. Percentage change of land cover types under scenarios.



"C. Coffee and conservation": a biosphere reserve
Here, there were relatively few changes in the landscape from the baseline compared to the other scenarios. Forest cover remained stable, occupying more than half of the landscape (53%) followed by arable land (12%). Farmland woody vegetation increased and constituted 10% of the landscape, followed by fruits and vegetables (9%) and pasture (8%; Table 3). This scenario saw an increase in landscape heterogeneity (Fig. 3). Arable land and pasture decreased by approximately 14% and 3%, respectively. In contrast, fruits and vegetables and farmland woody vegetation increased by 9% and 8%, respectively (Table A1.5).

All kebele groups experienced slight changes under this scenario. However, the khat-cropland kebeles and the pasture-cropland kebeles saw strong increases in farmland woody vegetation of 13% and 14%, respectively. Similarly, fruits and vegetables increased by 12% and 20% in the khat-cropland and pasture-cropland kebeles, respectively. Details are presented in Figure 6 and Table A1.8.

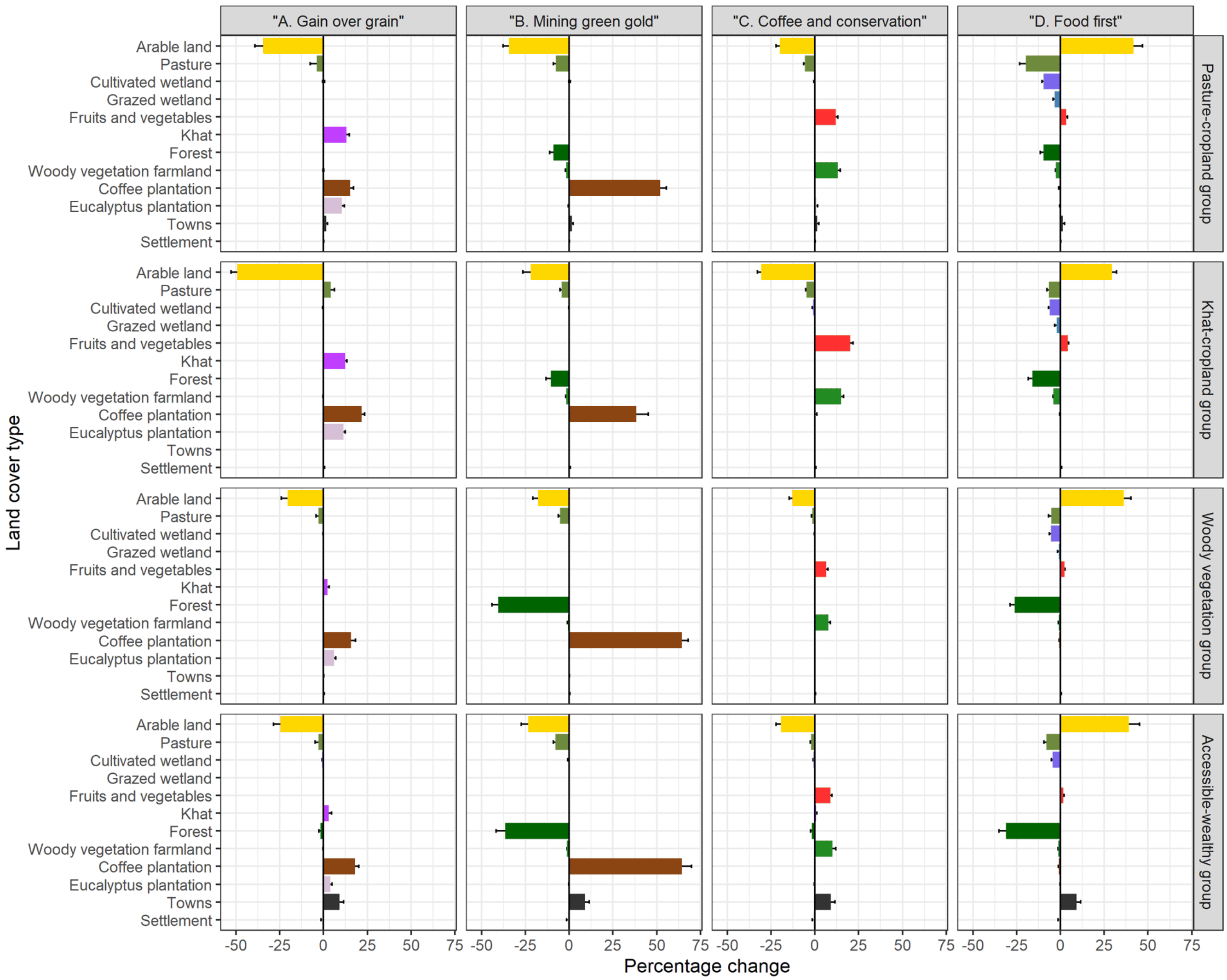
"D. Food first": intensive farming and forest protection
The "D. Food first" scenario was characterized by a strong change to most of the land covers in the landscape. Arable land expanded and covered more than half of the landscape (57%). The remaining proportion of the landscape was mainly covered by forest (35%), followed by pasture (3%) and fruits and vegetables (2%). Wetlands, farmland woody vegetation, and coffee plantations were lost to arable land (Table 3). This scenario created a more homogenous landscape dominated by arable land and patches of forest (Fig. 3). Arable land increased by 31%. Contrary to this, forest and pastureland decreased by 18% and 8%, respectively (Fig. 5 and Table A1.5). Pasture in this scenario was mostly restricted to steep slopes.

All kebele groups experienced increases in arable land. However, pasture-cropland and accessible-wealthy kebeles saw a stronger expansion of arable land by 40% and 44%, respectively, whereas both the khat-cropland and woody vegetation kebeles saw an increase of 32%. There were strong decreases in forest area in the accessible-wealthy kebele group (33%), while there was a smaller decrease (19%) in forest cover in the khat-cropland kebeles (Fig. 6 and Table A1.9).

DISCUSSION

We presented a structured approach for translating narrative scenarios of future landscape changes into maps. Based on key variables that we extracted from the alternative narration lines of four future scenarios that were previously developed in a participatory scenario planning process, we established quantitative rules that made future landscape changes spatially

Fig. 6. Comparison of the results of percentage changes showing means and standard errors of changes in land covers by scenarios and kebele groups. Kebele groups are listed on the right side as the pasture-cropland group, khat-cropland group, woody vegetation group, and accessible-wealthy group.



explicit. Starting from a baseline map of present land uses, we applied a set of rules to generate land use maps for the scenarios. Below, we reflect on our approach, explore some of the general and specific insights we gained from the mapping, and discuss the plausibility of each of the generated maps.

The objective of scenario research is “to move away from the reactive mode of decision making” (IPBES 2016:3). In many cases, however, scenario development stops with the generation of narrative scenarios. The approach presented here integrates future land use mapping with participatory, narrative-based scenario research as a way to assess alternative future social-ecological scenario outcomes. Although narratives may speak well to some stakeholders, e.g., local people, some stakeholders are likely to find maps more useful. Turning scenario narratives into maps thus provides additional opportunities for stakeholders and decision makers to proactively manage plausible LULC changes, biodiversity, and ecosystem services rather than simply allowing for their ongoing degradation. Crucially, the generation of context specific, but still spatially explicit maps of LULC change may help facilitate more nuanced and spatially differentiated approaches to managing or adapting to broad scale socioeconomic changes occurring at the landscape scale.

The results of our spatially explicit land use scenario maps revealed the contrasts of narratives that resulted from participatory scenario planning. As Peterson et al. (2003) argued, the central idea of scenario planning is to consider a variety of possible futures that include many of the important uncertainties in the system rather than to focus on the accurate prediction of a single outcome. The maps can also lend key support to societal envisioning processes by sketching out the land use realities of alternative objectives, and quantifying the trade-offs associated with specific changes in land use and land cover (Verburg et al.

2015). In our study, such changes and the plausibility of the generated maps were assessed at the landscape level as well as, for each scenario, for groups of kebeles with different characteristics.

One scenario focused on cash crops (coffee, khat, and fast-growing trees) grown by local smallholders ("A. Gain over grain"). Under this scenario, the map showed decreases in arable land and pasture by 17% and 7%, respectively (Table A1.5). Land use change impacted arable land and pasture in particular, because the local community focused on producing cash crops instead. At the national level, such changes are plausible; existing evidence indicates that cash crops such as coffee and khat are increasingly being produced by smallholder farmers. Coffee is the country's back bone in earning foreign exchange. About 44% of the coffee produced is exported, and about 98% of coffee in Ethiopia is produced by smallholder farmers (Dharmendra Kumar et al. 2014). Khat is an evergreen tree grown for the production of leaves that are used as a stimulant (Feyisa and Aune 2003), and it is mainly cultivated by smallholder farmers (Feyisa and Aune 2003, Gessesse Dessie 2013, Gebrehiwot et al. 2016). Land used for khat production in Ethiopia has increased rapidly in recent years (Cochrane and O'Regan 2016) replacing cereal production (Feyisa and Aune 2003), and increasingly dominating homegardens (Gebrehiwot et al. 2016). The main reasons for khat expansion are diminishing land availability, land fragmentation, declining soil productivity, a decrease in government subsidies to buy fertilizer and quality seeds for food crop production, high cash return, and low risk of theft and wildlife damage (Gessesse Dessie 2013, Gebrehiwot et al. 2016). Fast growing trees, especially eucalyptus, are also increasingly popular among smallholder farmers to generate cash. Several studies in Ethiopia have indicated that there is a recent uncontrolled expansion of eucalyptus in the country (FAO 2011, Zegeye 2010, Jaleta et al. 2016, 2017), including into smallholder croplands (FAO 2011, Jaleta et al. 2016). Multi-purpose use, fast growth, and high rates of return have made eucalyptus a preferred species by smallholder farmers (Teketay 2000, Jagger and Pender 2003). In combination, strong expansions of coffee, khat, and eucalyptus into farmland are thus highly plausible in general; our map shows one particular way in which such expansion could realistically play out in southwestern Ethiopia.

The "C. Coffee and conservation" scenario focused on sustainable land management in the context of a newly created biosphere reserve. Here, the map showed an increase in farmland woody vegetation by 8% (Table A1.5). Degraded steep slopes became restored by native woody vegetation as well as fruit trees, resulting in a highly diversified farmland mosaic. Forest cover remained stable compared to the current situation. Geographically, our study area is located in a biodiversity hotspot area (Mittermeier et al. 2011) in between two biosphere reserves, the Yayu and Kafa reserves. In the north, the study area borders onto the Yayu coffee forest biosphere reserve, which was registered by UNESCO in 2010. It covers 167,021 ha and has a similar land cover composition to our study area (Gole et al. 2009). Similarly, in the south, our study area borders onto the Kafa biosphere reserve. This was also registered in 2010, and covers an area of 744,919 ha with habitat types also similar to our study area (NABU 2017). In approximate terms, our modeled LULC map of the biosphere scenario thus showed a similar profile as the two existing biosphere reserves in the region. Placing an additional biosphere reserve in the region is especially plausible because aggregations of biosphere reserves are recognized as important "clusters" by UNESCO (for example, Gouritz Cluster Biosphere Reserve located in South Africa; Urban and Beswick 2018). By considering general well-established factors underpinning the success of biosphere reserves (Van Cuong et al. 2017), as well as by learning from the challenges and opportunities facing the Yayu and Kafa biosphere reserves, a new biosphere reserve with diverse land cover types seems to stand good chances of successful implementation.

The other two scenarios, "B. Mining green gold" and "D. Food first," were both based on large-scale agricultural investment and involved large-scale land acquisition or consolidation. Under the "B. Mining green gold," which seeks to produce coffee for export to increase foreign exchange (Jiren et al. 2020), about half of the landscape (49%) was covered by coffee plantations, resulting from the conversion of about 27%, 17%, 5% of forest, arable land, and pasture, respectively (Table 3 and Table A1.5). Similarly, in the "D. Food first" scenario map, more than half of the landscape was covered by intensive cereal crop production. Under this scenario, strictly protected forest covered about 35% of the landscape, whereas about 5% of the remaining landscape was covered by pasture, fruits and vegetables, and settlements (Table 3).

Both the scientific literature and Ethiopian government documents indicate the plausibility of these two scenarios, which show two different types of large-scale agricultural investment. Since 2005, through its Growth and Transformation Plan (GTP), the Ethiopian government has promoted large-scale agricultural investment as a major part of its overall development strategy to make Ethiopia a food-secure, middle-income country by 2025 (Keeley et al. 2014, Bachewe et al. 2018) through foreign exchange earnings from agricultural exports, generating increased food availability, improved incomes via employment on commercial farms, and better infrastructure (Keeley et al. 2014, Moreda 2018). Case studies have been conducted on large-scale agricultural investment in different parts of the country, such as in Gambella region (Keeley et al. 2014, Baumgartner et al. 2015), in Benishangul Gumz region (Moreda 2017), and in Bakko Tibbe of Oromia region (Wayessa 2020). These case studies found that, contrary to the government's expectation, the investments have often threatened both ecosystems and livelihood of local communities, depriving local communities from accessing vital common property land resources, causing land dispossession, displacement of farmers, and environmental destruction. Notably, some of the high profile cases of agricultural investment such as the Karuturi Global Ltd. farm project in Bakko Tibbe have already failed (Wayessa 2020); here, however, the land has been returned to the federal land bank for other potential investors (Moreda 2018). Thus, despite the limited success, official commitment to supporting agricultural investment projects appears to be unchanged (Rahmato 2014, Moreda 2018). Extensive land cover change to support more industrial land use practices, as indicated in our scenario maps, thus seems entirely plausible.

At the landscape level, substantial changes were associated with large-scale investment scenarios ("B. Mining green gold" and "D.

Food first"), where about half of the landscape was covered by intensively managed coffee plantations or arable land, respectively. In contrast, under the "A. Gain over grain" and "C. Coffee and conservation" scenarios, LULC changed less. In both of these scenarios, wetlands and forest cover were sustained, while arable land and pasture showed a slight decrease in both scenarios. Smallholder coffee plantations, khat, and fast-growing trees increased in the "A. Gain over grain," while farmland woody vegetation and fruits and vegetables increased under the biosphere scenario. A gain in farmland woody vegetation in the "C. Coffee and conservation," in turn, would likely have major positive effects on biodiversity and ecosystem services.

The impact of scenarios differed significantly across the different types of social-ecological systems within the study area, as identified by the four kebele groups. Our results show that the four types of kebeles experienced differentiated changes under each scenario. For instance, as indicated in Figure 6, pasture-cropland kebeles were least affected by the "C. Coffee and conservation" scenario. The khat-cropland kebeles were more sensitive to the changes under the "A. Gain over grain" scenario, while the changes for these kebeles under the other three scenarios were less sensitive. Woody vegetation kebeles were most affected by the "B. Mining green gold" scenario, while they were relatively less altered by the "A. Gain over grain" and "C. Coffee and conservation" scenarios. Similar to the woody vegetation, the accessible-wealthy kebeles showed pronounced change under the coffee investment scenario. The combined use of spatial mapping and of social-ecological systems characteristics (Oberlack et al. 2019, Rocha et al. 2020) to identify spatially differentiated changes within each scenario, is therefore potentially a very useful tool. It allows consideration of both the sensitivity to, and the (un) desirability of, different scenarios based on localized social-ecological conditions. Based on such assessment, spatially differentiated polices may be developed to mitigate or encourage certain LULC change trajectories.

Notwithstanding the benefits and usefulness of translating narrative scenarios into maps (discussed above), there are also limitations. Most importantly, we acknowledge that our maps in their present form cannot capture important changes in ecological aspects, such as biodiversity loss, or social aspects such as social cohesion, equity, and food security. Other authors have noted similar challenges resulting from simplification of quantitative scenarios during translations (e.g. Kok and van Delden 2009, Booth et al. 2016), such that narratives and maps should best be consulted in combination.

The method introduced in this paper could be improved further by including stakeholders in the definition of the rules of land cover change. This, in turn, may further increase buy-in by stakeholders into the final outputs. In our case, we acknowledge that we were not able to involve stakeholders in setting the translation rules, and this could be a possible limitation of our work. However, the original narratives were co-generated with stakeholders; and the translation rules used were based on in-depth iterative discussions within the project team, who had collectively worked for multiple years (and with local stakeholders) in the study area. Finally, future research could link spatially explicit maps of plausible LULC change (such as those generated here) to spatially explicit models of biodiversity loss or resource appropriation and their impacts on issues of equity and food security.

CONCLUSION

Our spatially explicit land use scenario maps were highly effective in visualizing land use and land cover components related to the previously generated scenarios, and as such, they underline the internal consistency of any given scenario. The maps thus can be used as a valuable input to help stakeholders weigh the pros and cons of different development trajectories, which is a key benefit of using scenarios in general. Developing an approach that translates narrative scenarios into maps further advances scenario research toward being a proactive tool, because it provides spatially explicit information that can help stakeholders and decision makers plan for the future.

Until this work, to the best of our knowledge, within Ethiopia, no studies have translated narrative storylines into spatially explicit land use scenarios. Our study thus represents a methodological development that can be used as a starting point or proof of concept to be replicated in different landscapes elsewhere, and that could also be scaled up to the regional or national level. Through the generation of spatial maps of plausible futures of southwestern Ethiopia, our study also constitutes a useful practical contribution for stakeholders in management and policy, as well as a tool to facilitate transparent negotiation and communication at local, government, and NGO levels. Last, the results can also be used for further research to model ecological and social outcomes in spatially explicit ways across the four scenarios.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/13200

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Data Availability:

The data/code that support the findings of this research are available on request from the corresponding author, [DWD].

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Appendix 1

Table A1.1 Rules for conversion of land uses/covers under Scenario I: Cash crops

Qualitative rules identified from the narrative scenarios	Quantitative rules that detail the original land use/cover to be converted
Farmers are encouraged to increase coffee production on farmland – arable land	44% (27,500 ha) of flat, arable land at future coffee-producing altitudes (1500-2300m) was converted to coffee plantation.
Farmers are encouraged to increase coffee production on farmland – (pasture) and new coffee plantations may stabilize local climate	25% (7,000 ha) of flat, pasture at future coffee-producing altitudes (1500-2300m) was converted to coffee plantation.
Intensively managed khat plantations are established on former farmland	21% (13,000 ha) of flat, arable land at below- and above-future coffee altitudes (<1500m and >2300m) was converted to khat plantation.
Intensively managed khat plantations are established on former farmland	13% (3,600 ha) of flat, pasture at below- and above-future coffee altitudes (<1500m and >2300m) was converted to khat plantation.
Fast-growing trees (mainly monocultures of eucalyptus plantations) primarily target degraded areas or marginal land	85% (9,800ha) of steep, arable land was converted to eucalyptus plantation.
Tree plantations are mostly monocultures of eucalyptus, but also other fast-growing trees	85% (5,400 ha) of flat, pasture of medium heterogeneity (5%-20%) and at above-future coffee altitudes (>2300m) was converted to eucalyptus plantation.
Tree plantations are mostly monocultures of eucalyptus, but also other fast-growing trees	85% (2,800 ha) of steep, pasture was converted to eucalyptus plantation.
To ensure that sufficient food is still grown (and not only cash crops), the most fertile land should be used for farming	Flat, arable land of low heterogeneity (< 5%) and at high altitude (>2300m) remains the same as in the baseline.
To ensure that sufficient food is still grown (and not only cash crops), the most fertile land should be used for farming	Flat, pasture with low heterogeneity (<5%) and at above-coffee altitudes (>2300m) remains the same as in the baseline.
To ensure that sufficient food is still grown (and not only cash crops), the most fertile land should be used for farming	Cultivated and grazed wetlands remain the same as in the baseline.
Forest degradation slowed down because farmland can provide important tree-related ecosystem services	Farmland woody vegetation remains the same except those affected by settlement expansion.

Table A1.2 Rules for conversion of land uses/covers under Scenario II: Mining green gold

Qualitative rules identified from the narrative scenarios	Quantitative rules that detail the original land use/cover to be converted
Large areas of smallholder arable land conducive for coffee investment has been transferred to capital investors for the expansion of largescale intensive coffee plantations.	75% (47,400 ha) of flat, arable land at future coffee producing altitudes (1500-2300m) was converted to coffee plantation.
Large areas of farmland woody vegetation were converted into intensively managed shade coffee plantations, often using non-native shade tree species.	60% (2,800 ha) of farmland woody vegetation in flat areas at future coffee producing altitudes (1500-2300m) was converted to coffee plantation.
Large areas of natural forest conducive for coffee investment has been transferred to capital investors for the expansion of largescale intensive coffee plantations.	50% (74,400 ha) of forest at future coffee producing altitudes (1500-2300m) was converted to coffee plantation.
Endemic trees and shrubs might be lost, including wild coffee and traditional shade tree species	Forest remains in altitude ranges not suitable for future coffee producing (<1500m, and >2300m).
Endemic trees and shrubs might be lost, including wild coffee and traditional shade tree species	Farmland woody vegetation in steep areas and on altitudes not suitable for coffee (<1500m, and >2300m) remains as farmland woody vegetation.
The landscape is largely transformed to a coffee production zone, with monocultures of high yielding improved coffee cultivars.	45% (12,600 ha) of flat, pasture at future coffee producing altitudes (1500-2300m) was converted to coffee plantation.
Local farmers are left to farm marginalized areas unsuitable for largescale coffee plantation such as on steep hills	Flat, arable land but on low altitude (<1500m) and very high altitude (>2300m) remain as arable land as in the baseline.
Local farmers are left to farm marginalized areas unsuitable for largescale coffee plantation such as on steep hills	Flat, pasture but on low altitude (<1500m) and very high altitude (>2300m) remain as pasture as in the baseline.
As intensified coffee plantations have expanded into farmland, very little land is left for crop production.	Steep, arable land remain arable land as in the baseline.
As intensified coffee plantations have expanded into farmland, very little land is left for crop production.	Steep, pasture remain as in the baseline.

Table A1.3 Rules for conversion of land uses/covers under Scenario III: Biosphere reserve

Qualitative rules identified from the narrative scenarios	Quantitative rules that detail the original land use/cover to be converted
The landscape consists of a core zone of unused natural forest, a buffer zone for low intensity production of local coffee, wild honey and other forest products.	Forests were maintained as in the baseline.
The landscape consists of an outer area to a core and buffer zones of forests with a mosaic of cropland, pastures, and tree plantations.	Flat and steep arable land with high woody vegetation was maintained as in the baseline.
Livestock production and communal grazing are maintained	Flat and steep pasture with high woody vegetation was maintained as in the baseline.
People grow Fruits and vegetables in their home gardens	1/3rd (33% or 24,670 ha) of flat, arable land with low and medium heterogeneity was converted to fruits and vegetables.
Diversified landscape: diversification involving crops, forest products and ecotourism	1/3rd (25% or 2,706 ha) of steep, arable land with low and medium heterogeneity was converted to fruits and vegetables.
Sustainable resource management and improved soil and water conservation can revert environmental degradation	1/3rd (33% or 1,800 ha) of steep, arable land with low and medium woody vegetation remaining from fruits and vegetables was converted to farmland woody vegetation.
Forest cover and trees in farmland mitigate negative aspects of climate change	1/3rd (33% or 11,200 ha) of flat, arable land with low and medium woody vegetation remaining from fruits and vegetables was converted to farmland woody vegetation.
Farmland biodiversity recovered and high forest biodiversity	1/3rd (33% or 7,600 ha) of pasture with low and medium woody vegetation were converted to farmland woody vegetation.

Table A1.4 Rules for conversion of land uses/covers under Scenario IV: Food first

Qualitative rules identified from the narrative scenarios	Quantitative rules that detail the original land use/cover to be converted
Large scale land consolidation, including clearing of woody vegetation and cropland expansion	Flat, arable land remain as in the baseline.
Farming has been mechanized as much as possible with government owned tractors being available for hire to work with the large stretches of cropland in the flat areas	Farmland woody vegetation on flat areas (3,900 ha) was converted to arable land.
Modern agriculture almost completely replaced traditional small scale farming	Flat, pasture (27,900 ha) was converted to arable land.
Flat areas including drained wetlands are dominated by large cereal fields	Grazed and cultivated wetlands were converted to arable land.
Hills and steeper slopes used for intensified fruits and vegetables, commercial bee keeping and beef fattening	50% (5,600 ha) of steep, arable land was converted to fruits and vegetables.
Hills and steeper slopes used for intensified fruits and vegetables, commercial bee keeping and beef fattening	50% (360 ha) of steep, farmland woody vegetation was converted to fruits and vegetables.
Hills and steeper slopes used for intensified fruits and vegetables, commercial bee keeping and beef fattening	50% (5,600 ha) of steep, arable land was converted to pasture.
Hills and steeper slopes used for intensified fruits and vegetables, commercial bee keeping and beef fattening	50% (360 ha) of steep, farmland woody vegetation was converted to pasture.
Hills and steeper slopes used for intensified fruits and vegetables, commercial bee keeping and beef fattening	Steep, pasture (around 3,290 ha) remain as in the baseline.
Remaining patches of natural forest are put under strict protection	50% (74,400 ha) of forest remain as forest under strict protection.
Growing coffee is unviable in most parts of southwestern Ethiopia	No coffee plantation, those available was converted to arable land.

Table A1.5 Percentage of LULC changes by scenarios (in %).

LULC	Scenarios			
	Cash Crop	Mining the green Gold	Biosphere reserve	Food First
Arable land	-17.1	-17.0	-14.1	30.9
Coffee plantation	12.0	48.8	0.0	-0.3
Cultivated wetland	-0.3	-0.1	-0.3	-4.9
Eucalyptus Plantation	6.3	0.0	0.0	0.0
Farmland woody vegetation	-0.2	-1.0	8.1	-1.7
Forest	-0.1	-26.5	0.0	-17.7
Fruits and vegetables	0.0	0.0	8.6	2.1
Grazed wetland	0.0	0.0	0.0	-0.9
Khat	5.9	0.0	0.0	0.0
Pasture	-6.9	-4.5	-2.6	-7.9
Settlement	0.1	0.1	0.1	0.1
Towns	0.6	0.6	0.6	0.6

Table A1.6 LULC changes by kebele groups for Cash crop scenarios (in %).

LULC	Kebele groups			
	Pasture-cropland	Khat-Cropland	Woody vegetation	Accessible-wealthy
Arable land	-33.9	-45.7	-16.7	-24.6
Coffee plantation	14.7	20.0	12.3	20.1
Cultivated wetland	-0.5	-0.4	-0.2	-0.6
Eucalyptus Plantation	11.6	11.2	5.0	4.7
Farmland woody vegetation	-0.3	-0.4	-0.1	-0.2
Forest	-0.1	-0.1	-0.1	-0.8
Fruits and vegetables	0.0	0.0	0.0	0.0
Grazed wetland	0.0	0.0	0.0	0.0
Khat	13.7	11.9	2.4	2.5
Pasture	-5.5	3.1	-2.7	-3.8
Settlement	0.0	0.3	0.2	-0.6
Towns	0.3	0.0	0.0	3.3

Table A1.7 LULC changes by kebele groups for Mining green gold scenario (in %).

LULC	Kebele groups			
	Pasture-cropland	Khat-Cropland	Woody vegetation	Accessible-wealthy
Arable land	-33.2	-22.0	-14.5	-23.4
Coffee plantation	50.6	40.6	60.8	72.1
Cultivated wetland	-0.3	-0.2	-0.1	-0.5
Eucalyptus Plantation	0.0	0.0	0.0	-0.2
Farmland woody vegetation	-2.1	-1.7	-0.7	-1.0
Forest	-7.8	-12.2	-41.2	-41.4
Fruits and vegetables	0.0	0.0	0.0	0.0
Grazed wetland	0.0	0.0	0.0	0.0
Khat	0.0	0.0	0.0	0.0
Pasture	-7.5	-4.7	-4.4	-8.3
Settlement	0.0	0.3	0.2	-0.6
Towns	0.3	0.0	0.0	3.3

Table A1.8 LULC changes by kebele groups for Biosphere reserve scenario (in %).

LULC	Kebele groups			
	Pasture-cropland	Khat-Cropland	Woody vegetation	Accessible-wealthy
Arable land	-19.8	-29.0	-10.7	-18.4
Coffee plantation	0.0	0.0	0.0	-0.1
Cultivated wetland	-0.5	-0.4	-0.2	-0.6
Eucalyptus Plantation	0.0	0.0	0.0	-0.2
Farmland woody vegetation	14.4	13.3	6.3	10.6
Forest	0.0	0.0	0.0	-0.6
Fruits and vegetables	11.9	20.2	5.8	8.4
Grazed wetland	0.0	0.0	0.0	0.0
Khat	0.0	0.0	0.0	0.0
Pasture	-6.3	-4.3	-1.4	-2.0
Settlement	0.0	0.3	0.2	-0.5
Towns	0.3	0.0	0.0	3.3

Table A1.9 LULC changes by kebele groups for Food first scenario (in %).

LULC	Kebele groups			
	Pasture-cropland	Khat-Cropland	Woody vegetation	Accessible-wealthy
Arable land	39.8	32.3	32.3	43.5
Coffee plantation	-0.2	-0.2	-0.5	-1.2
Cultivated wetland	-5.9	-5.9	-4.2	-4.4
Eucalyptus Plantation	-0.1	0.0	0.0	-0.2
Farmland woody vegetation	-3.8	-3.8	-0.9	-1.2
Forest	-23.7	-18.5	-23.3	-32.6
Fruits and vegetables	3.2	4.0	1.8	1.7
Grazed wetland	-1.1	-1.1	-0.2	0.0
Khat	-0.1	0.0	0.0	0.0
Pasture	-8.0	-7.0	-5.1	-8.3
Settlement	-0.5	0.3	0.2	-0.6
Towns	0.4	0.0	0.0	3.3

Table A1.10 Narrative scenarios with key indicators.

	Scenarios			
Indicators/main crops	“A. Gain over grain”	“B. Mining green gold”	“C. Coffee and conservation”	“D. Food first”
Food crops (mainly maize, wheat, barely, teff, sorghum)	Remain in very limited space such as cultivated wetlands	Little food is produced on marginalized areas	Food crops are grown interspersed with pasture and tree plantations	Food crops expanded over the landscape mainly by large-scale farming
Local cash crops (mainly coffee, khat, fast-growing trees, mainly eucalyptus)	Farmers increase cash crops by reducing food crops	Not widespread, limited to unsuitable areas for large-scale coffee plantation	Traditional coffee remains in forest, coffee plantations are not favoured.	Coffee is not grown, other cash crops remain on steep slopes and hills
Large-scale coffee plantations	No large-scale coffee plantations	Landscape mainly consists of monocultured large-scale coffee plantation by investors	No large-scale coffee plantations, but traditional coffee remains in natural forests	No coffee plantations due to climate change
Livestock production and communal grazing	Pasture for livestock remains in very limited areas such as grazed wetlands	Pasture for livestock remains in very limited areas such as grazed wetlands	Pastures for livestock and communal grazing are well maintained	Remains on steep slopes
Woody vegetation	Mostly maintained, no clearing of woody vegetation	Woody vegetation conducive for coffee cultivation is converted to plantations by investors	Woody vegetation is maintained; landscape is diversified with mosaic of forest and farmland	Woody vegetation is cleared for cropland expansion