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)

Zones From class	To cultivate land						
	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.

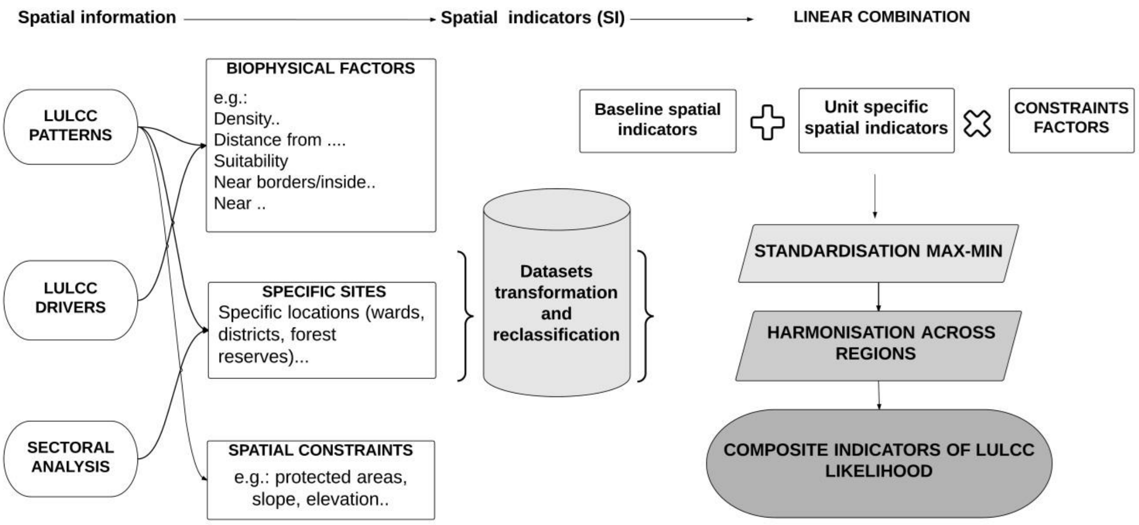

Fig.A2.1: Schematic model for building composite indicators of change likelihood from spatial information collected during multi-stakeholders workshops.

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.

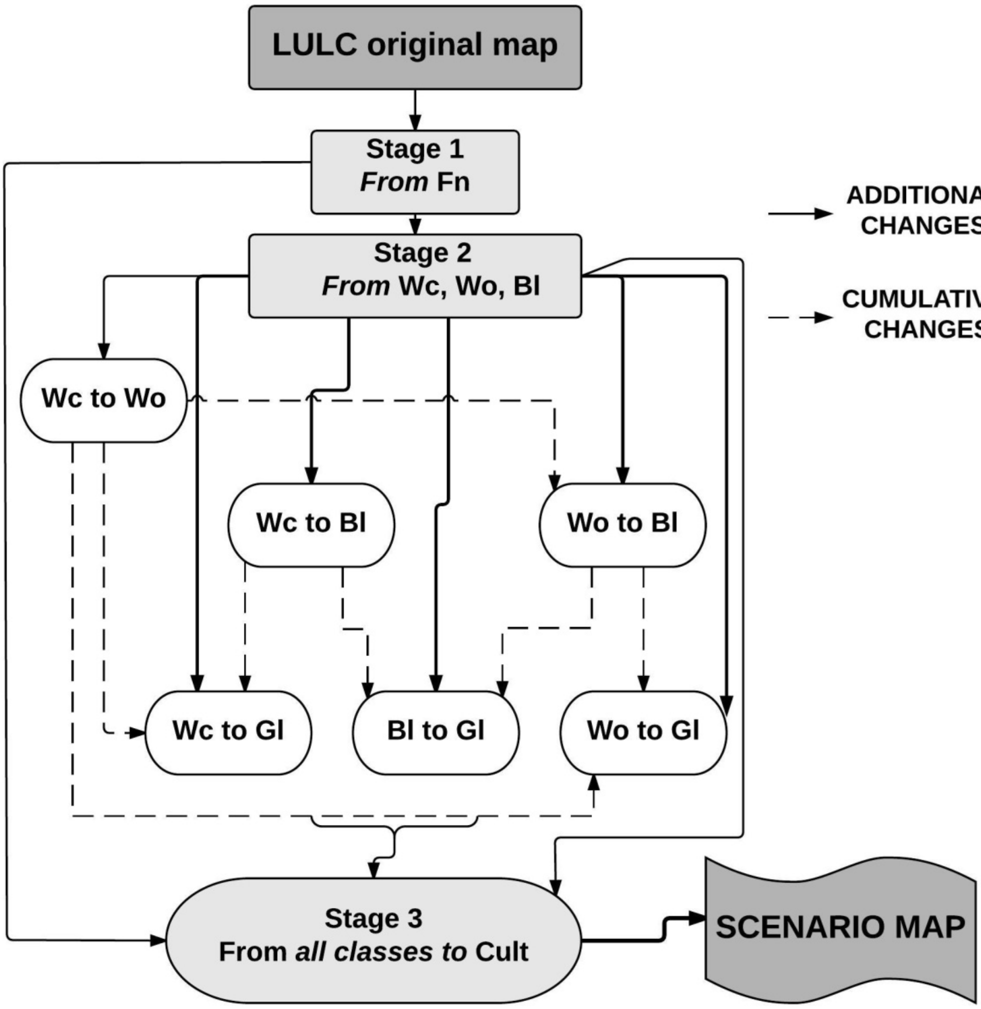

Figure A2.4: Stepwise spatial allocation of land cover changes following land demand and composite indicators of likelihood of change. Symbols: Fn = natural forest (mountain and lowland forest); Wc = closed woodland; Wo = open woodland; Bl = bushland; Gl = grassland; Cult = cultivated land.

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