Calibration of the Land Uses submodule of the WILIAM-TERRA model

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Contents:

1. Land use change models

Most simulation models of land use changes are based on at least one of the following four core principles of land use changes (LUC) [1], not mutually exclusive:

- Continuation of historical development. Future land use can be predicted by land use historical changes.
- Suitability of land. Suitability covers different aspects, from e.g., maximum market profit (economic suitability) to soil suitability (biophysical suitability) for different uses.
- Neighbourhood interaction. The probability of transition from one use of land to another is dependent on the biophysical or socio-economic drivers conditioning the LU of its surrounding cells.
- Actor interaction. Land use change is the result of interaction between actors according with different socio-economic and political drivers.

It is a common practise for modellers to describe the processes of LUC according to a particular mechanism that can be used to characterise these changes. Main mechanisms found in literature are: cellular automata, statistical analysis, markov chains, artificial neural networks, economic-based models and agent-based systems.

This mechanism of LUC is then codified into algorithms, which lead to different computer simulation models. A huge diversity of model approaches can be found within literature.

From the point of view of the spatial disaggregation, land use models can be classified as spatial versos non-spatial models:

- Spatial models. Spatial models (also called Geographical models) aim at spatially explicit representations of land-use change (LUC) at some level of spatial detail (pixels in a raster model, or other units –administrative, ecological, etc.- in a vector model). They are often associated with Geographical Information Systems (GIS).
- Non-spatial models. Non-spatial models focus on modelling land-use change without specific consideration for its spatial distribution, frequently economic land-use models.

In [2, 3, 4] models are classified in four types:

I. Geographical land-use models. These models allocate land area or land demand based on biophysical and socioeconomic properties, and the resulting suitability of land for a specific use.

II. Economic land-use models. Models that use demand and supply functions as the main drivers of land-use change, giving total areas of specific land-use types within defined geographical regions.

III. Integrated land-use models. These models combine natural and human subsystems. In most cases, these models consist of a combination of separate economic and environmental processes capable of spatially explicit modelling, typically at large (global) scales.

IV. Other type of models. Here, the classification includes Urban growth, Machine learning and agent-based models.

There is a myriad of LUC models, many of them currently used in IAM models, some of the most popular and relevant ones are:

1. The CLUE Framework. Set of models evolved from the original CLUE model [5]. It simulates LUC using empirically quantified relations between land use and several driving factors in combination with dynamic land competition allocated in a raster based system. The extrapolation of trends in land use change is a common technique to calculate land use requirements but, these trends can be corrected for changes in population growth and/or diminishing land resources. It is a spatially explicit model and can be freely downloaded from the model website.
2. The IMAGE modelling [6] is an ecological-environmental model framework that simulates the environmental consequences of human activities worldwide. It represents interactions between society, the biosphere and the climate system to assess sustainability issues such as climate change, biodiversity and human

well-being. Is a spatially explicit model and uses regression-based suitability assessment to determine future land-use patterns. IMAGE has had several versions and has been integrated with other models such as the vegetation growth model LPJmL [7], the CLUMondo [8] for more precise LU representation.

3. The MAgPIE model is a global land-use allocation model [9] which is connected to the grid-based dynamic vegetation model LPJmL, with a spatial resolution of 0.5°x0.5°. It takes regional economic conditions such as demand for agricultural commodities, technological development and production costs as well as spatially explicit data on potential crop yields, land and water constraints (from LPJmL) into account. Based on these, the model derives specific land use patterns, yields and total costs of agricultural production for each grid cell.
4. GCAM [10,11] is a recursive -dynamics partial-equilibrium global IAM that represents the interactions between energy, water, agriculture and land use, economy, and climate. It is a dynamic-recursive model with technology representations of the economy, energy sector, land use and water linked to a climate model that can be used to explore climate change mitigation policies including carbon taxes, carbon trading, regulations and accelerated deployment of energy technology. It is not based on gridded data but the agriculture and land module uses more than 300 subregions and approximately a dozen types of land covers.
5. GLOBIOM [12,13] is a land use model that works with the recursive-dynamic partial-equilibrium MESSAGE model designed to address various LUC related topics (bioenergy policy impacts, deforestation dynamics, climate change adaptation and mitigation from agriculture, long-term agricultural prospect). It is a partial equilibrium economic model that optimizes an objective function defined as the sum of producer and consumer surpluses under a certain number of constraints. LUC are based on a spatially explicit gid based framework.

Most of these models are spatially explicit (all except GCAM). This spatial representation allows them to use very detailed information about the physical suitability of land use changes, but is computationally intensive. These models have a structure that is mainly based on linear flows of information, as described in Figure 1. In a linear flow, information about demand, suitability, and the socio-economic factors that drive land use change is provided in a priori scenarios generated by other models (or parts of the same model), and the model calculates land use changes based on optimization or recursive algorithms. LUCs are then used to provide information on crops or energy production, emissions, and other types of environmental or social impacts. Although some models include feedbacks, grid based data, recursive algorithms and optimizations are not the best tools for representing feedback-rich models with strong interactions, for which system dynamics simulations are the most appropriate tool.

These models use economic drivers for land use changes such as agricultural prices, income, price elasticities or relative land profitability [15]. On the other hand, the most common policies applied are detailed decarbonization policies such as carbon taxes, subsidies, agricultural quotas or land protection policies.

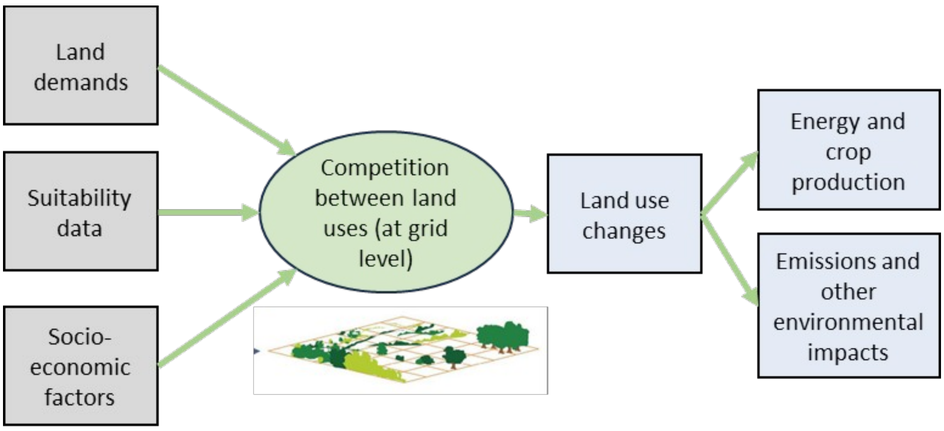

Figure 1: lineal information flows of LUC models

2. General description of the Land Uses submodule of WILIAM-TERRA

WILIAM model is a System Dynamics feedback-rich model that addresses the biophysical limits of the energy transitions, and its spatial scale is global with a division in 9 large regions. Economic indicators such as prices or elasticities are hardly reliable at this level of aggregation, while the huge cultural and sociopolitical differences between world regions make it very difficult estimate the effect of detailed decarbonization policies.

This is the reason why the approach of WILIAM-TERRA differs from that of other IAMS. The policies used in WILIAN-TERRA are not detailed political measures but physical outcomes that can be derived from all kinds of government measures or social changes (similar to those in the World 3 model [16]). Land use changes are driven by the continuation of observed trends and some basic demands plus the application of a wide range of policies. Thus, it is a policy evaluation model, not aimed at predicting the future, but at analysing the dynamic effects and interactions of a wide range of policies.

WILIAM-TERRA can be classified as a model of continuation of historical development with limits to land expansion set by the land suitability and some features of actor interaction. It is a non-spatial model (since the very detailed grid-based models are hardly compatible with system dynamics) and an Integrated model that combines human and natural interactions. It is not an economic model, since it does not use demand and supply functions as the main drivers of land-use changes since their authors do not believe that reliable data for supply, demand and prices can be found to calibrate these exchanges for a global model at the level of aggregation used.

The structure and submodules of WILIAM-TERRA are shown in Figure 2. It incorporates a wide range of policies (in pink in the diagram of Figure 2), including dietary changes, land use changes and land protection, livestock manure management, afforestation, urban density, transition to sustainable agriculture and to industrial agriculture, forest exploitation, crops allocation between regions and uses, and carbon capture in grassland soils. This document describes only the calibration and validation of the Land Uses submodule of this WILIAM-TERRA.

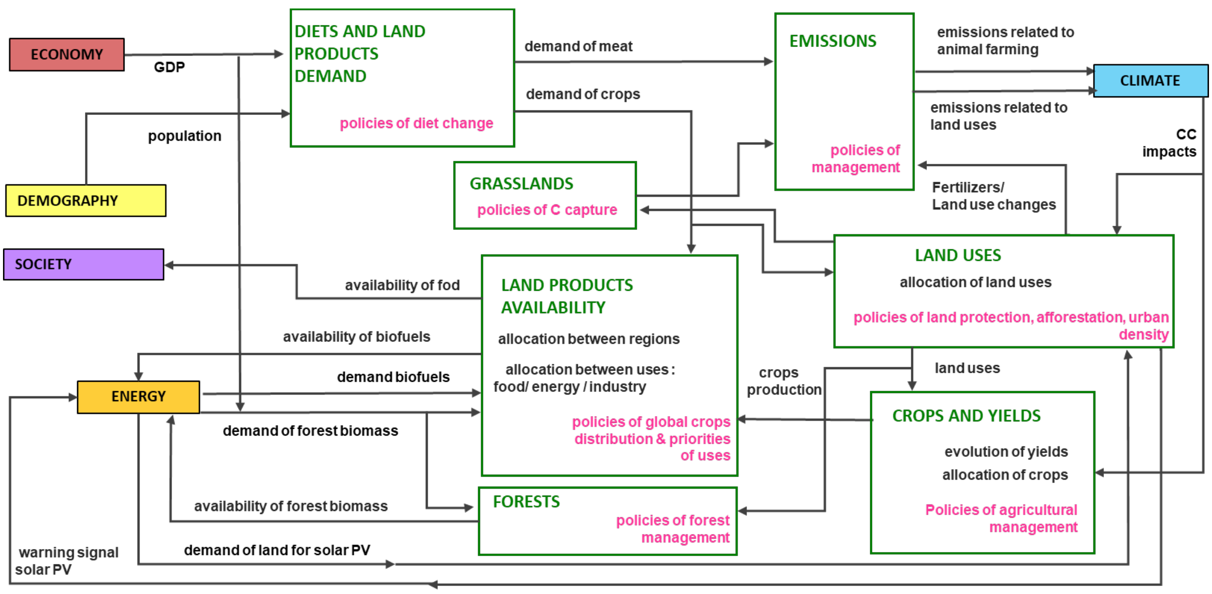

Figure 2. WILIAM-TERRA module and its connection with the rest of WILIAM model modules. White-green boxes are submodules of WILIAM-TERRA, boxes in other colour belong to other modules of WILIAM. Variables in pink are exogenous policies chosen by the user.

The WILIAM-TERRA Land Uses submodule is in charge of allocating the land among 12 uses. The demands of all uses are comprised in a vector named *Vector of land use change demand*s, and it is generated by adding two components:

- Historical trends of land use changes, which are estimated using lineal approximations over the period from 2005 to 2019 (Source FAO).
- Land use changes driven by various demands:
  - urban expansion (driven by population growth)
  - solar energy (driven by the demand of solar electricity)
  - cropland loss due to sea level rise
  - policies of land demand such as reforestations and land protection
  - new cropland (driven by the global physical shortage of crops)

The competition between the demand of different uses takes place within a dynamic of "all against all" competition in which all uses have the same priority when it comes to demand from others and only land for solar energy and cropland have parameters that allow prioritizing their use over the rest.

The expansion of land uses must be obtained from other land uses in order to ensure the physical coherence of the land allocation. This is specified in the matrix of land use change demands (Eq. 1), that describes the demand of changes from land use L_n to another land use L_m:

$$Matrix\ of\ LUC\ Demands\ (R_i, L_n, L_m) = Share\ of\ LUC\ from\ Others\ (R_i, L_n, L_m) \cdot LUC\ Demands\ (R_i, L_m)$$

(1)

Where, $LUC\ Demands\ (R_i, L_n)$, represents the vector of land use change demand by region and land type $L_n\ or\ L_m$; $Share\ of\ LUC\ from\ Others\ (R_i, L_n, L_m)$ and represents the share of land use L_m that is obtained from use L_n. The $Share\ of\ LUC\ from\ Others\ (R_i, L_n, L_m)$ are constant matrices.

The land use changes demanded might not be fulfilled if policies of land use protection are activated. $Matrix\ of\ LUC\ Demands\ (R_i, L_n, L_m)$ is transformed into a $Matrix\ of\ LUC\ changes\ (R_i, L_n, L_m)$ in which those land use changes that are not compatible with the physical boundaries or with the boundaries imposed by the user's policies are discarded.

The $Matrix\ of\ LUC\ changes\ (R_i, L_n, L_m)$ is collapsed into a $Vector\ of\ LUC\ changes\ (R_i, L_n, L_m)$ by adding the changes that are given to each use and subtracting the ones that demand from it:

$$vector\ LUC\ (R_i, L_m) = \sum_n matrix\ LUC(R_i, L_n, L_m) - \sum_n matrix\ LUC(R_i, L_m, L_n)$$

(2)

The loss of agricultural land due to sea level rise is subtracted to this vector. And this loss is determined in our module by adapting the method reported Roson & Sartori [3] to WILIAM-TERRA regions and driven by the temperature change received from the WILIAM Climate module.

Finally, the $Land\ use\ area\ by\ region\ (R_i, L_m)$ is calculated as the integral of $vector\ LUC\ (R_i, L_m)$ although, the module only integrates some of the uses in the stock of $Land\ use\ area\ productive\ uses\ (R_i, L_m)$ and excludes wetlands, snow, ice and waterbodies and shrubland area. These land uses are not calculated via the $vector\ LUC\ (R_i, L_m)$ because they are not driven directly by the policies of the rest of the module and, at present stage, are left constant.

3. Data sources

The Land Uses submodule is mainly based on land use data from FAOSTAT and land cover data from the same source, trying to maintain the consistency of these sources although relevant discrepancies are found between them. Data sources are detailed in Table 1.

Some of the WILIAM categories come from “land uses” categories and others from “land cover”. SHRUBLAND and OTHER LAND are calculated using a mix of land uses and land cover. The categories CROPLAND_RAINFED, CROPLAND IRRIGATED, FOREST MANAGED, FOREST PRIMARY, FOREST PLANTATIONS and GRASSLANDS are taken from FAO “land use”. URBAN, SNOW-ICE-WATERBODIES and WETLAND are obtained from “land cover” data.

SHRUBLAND and OTHER LAND (basically bare areas) are adapted, since taking them from land cover creates incoherences (the sum of all categories is greater or smaller than the total area in some cases, for example). In order to avoid those incoherences, all the uses except SHRUBLAND and OTHER LAND are subtracted from total land and the resulting are is divided between SHRUBLAND and OTHER LAND on the bases of the share obtained with the data of land cover.

Table 2 describes the land use FAO categories. Table 3 describes the FAO land uses and Table 4 the mix of both sources of information used for the categories of WILIAM-TERRA model. The numbers beside the description correspond to FAO codes [18]. As pointed out by Tubiello et al. [19] there are big discrepancies between land use measures of different sources including satellite data, therefore FAO database has been used as the standard data despite these incoherences. All the FAO data has been revised to check those years when countries do not report and the data that appears in tables in zero. In those cases, the data has been interpolated. The historical values of land use area are shown in table 5 and the correspondence of WILIAM regions and countries is in table 6.

Table 1: data sources of the Land Uses submodule

Land use by category	thousand ha	Food and Agriculture Organization of the United Nations (FAO), Statistics Division (ESS), Environment Statistics team	http://www.fao.org/faostat/en/#data/RL
Land cover by land cover class	thousand ha	Food and Agriculture Organization of the United Nations (FAO), Statistics Division (ESS), Environment Statistics team	http://www.fao.org/faostat/en/#data/RL

Table 2. "Land use" FAO categories

<table>
<tr><td rowspan="12">total area</td><td rowspan="10">Land area 6601</td><td rowspan="7">agriculture 6602</td><td rowspan="6">agricultural land 6610</td><td rowspan="4">cropland 6620</td><td rowspan="3">arable land 6621</td><td>L. temporary crops 6630</td></tr>
<tr><td>L. temporary meadows and pastures 6633</td></tr>
<tr><td>L. temporary fallow 6640</td></tr>
<tr><td>L. permanent crops 6650</td><td></td></tr>
<tr><td rowspan="2">L. permanent meadows and pastures 6655</td><td>L. permanent meadows and pastures cultivated 6656</td><td></td></tr>
<tr><td>L. permanent meadows and pastures naturally growing 6659</td><td></td></tr>
<tr><td>Protective cover (buildings in agricultura land) 6649</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">forest land 6646</td><td>primary forest 6714</td><td></td><td></td><td></td></tr>
<tr><td>naturally regenerated forest 6717</td><td></td><td></td><td></td></tr>
<tr><td>planted forest 6716</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">water bodies</td><td>Inland waters 6680</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Coastal waters 6773</td><td></td><td></td><td></td><td></td></tr>
</table>

Table 3. Land cover FAO categories

LAND COVER -FAO	
Item code	**Item**
6970	Artificial surfaces (including urban and associated areas)
6971	Herbaceous crops
6972	Woody crops
6973	Multiple or layered crops
6983	Grassland
6974	Tree-covered areas
6975	Mangroves
6976	Shrub-covered areas
6977	Shrubs and/or herbaceous vegetation aquatic or regularly flooded
6978	Sparsely natural vegetated areas
6979	Terrestrial barren land
6980	Permanent snow and glaciers
6981	Inland water bodies
6982	Coastal water bodies and intertidal areas

Table 4. WILIAM-TERRA land categories

WILIAM CATEGORIES	**From FAO land uses**	**From FAO land cover**	**Mixed (with calculations)**
CROPLAND_RAINFED (FAO land uses)	cropland 6620 - cropland area actually irrigated 6694		
CROPLAND_IRRIGATED (FAO land uses)	cropland area actually irrigated 6694		
FOREST_MANAGED (FAO land uses)	naturally regenerated forest 6717		
FOREST_PRIMARY (FAO land uses)	primary forest 6714		
FOREST_PLANTATIONS (FAO land uses)	planted forest 6716		
SHRUBLAND (mixed calculated)			REST1*SHARE OF SHRUBLAND
GRASSLAND (FAO land use)	L. permanent meadows and pastures 6655		
WETLAND (FAO land cover)		Shrubs and/or herbaceous vegetation, aquatic or regularly flooded 6977 (from land cover)	
URBAN_LAND (FAO land cover)		Artificial surfaces (including urban and associated areas) 970 (from land cover)	
SOLAR_LAND (historical data aprox=0)			zero (before 2015 very low value)
SNOW_ICE_WATERBODIES (FAO land cover)		(from land cover) Inland water bodies 6981 + Coastal water bodies and intertidal areas 6982+Permanent snow and glaciers 6980	
OTHER_LAND (mixed, calculated)			REST1*(1-SHARE OF SHRUBLAND)
	ALL (land+ inland waters) 6680+6601		
REST (other land+shrubland)= ALL-(C.RAINFED+C.IRRIGATED+F.MANAGED+F.PRIMARY+F.PLANTANTIONS+URBAN+GRASSLAND +SNOW ICE WATERBODIES+WETLANDS)	**REST**=6680+6601-(6620 + 6717 + 6714 + 6716 + 6655 + 6977+ 970 + 6981 + 6982+6980)		
SHARE OF SHRUBLAND (from REST) = shrub covered areas 6976 /REST			

Table 5: historical values of land use per region

LANDS_I	CROPLAND RAINFED									
		EU27	UK	CHINA	EASOC	INDIA	LATAM	RUSSIA	USMCA	LROW
Year		1.064	0.056	0.695	1.186	1.105	0.982	1.191	2.055	4.358
2005	[Mm2]	1.053	0.060	0.701	1.162	1.086	1.007	1.189	2.030	4.487
2006	[Mm2]	1.026	0.060	0.707	1.176	1.065	1.023	1.190	2.006	4.520
2007	[Mm2]	1.034	0.059	0.713	1.201	1.071	1.010	1.192	1.991	4.530
2008	[Mm2]	1.034	0.060	0.719	1.259	1.061	0.999	1.192	1.971	4.528
2009	[Mm2]	1.026	0.059	0.718	1.251	1.073	1.034	1.192	1.948	4.562
2010	[Mm2]	1.021	0.060	0.718	1.323	1.058	1.042	1.192	1.922	4.617
2011	[Mm2]	1.023	0.062	0.717	1.333	1.041	1.053	1.192	1.915	4.729
2012	[Mm2]	1.011	0.063	0.717	1.337	1.033	1.050	1.192	1.918	4.758
2013	[Mm2]	1.011	0.062	0.705	1.345	1.013	1.038	1.192	1.922	4.759
2014	[Mm2]	1.011	0.060	0.691	1.358	1.010	1.027	1.192	1.927	4.764
2015	[Mm2]	1.005	0.060	0.678	1.377	1.020	1.014	1.192	1.929	4.772
2016	[Mm2]	1.002	0.061	0.671	1.403	1.020	1.064	1.192	1.918	4.784
2017	[Mm2]	0.997	0.060	0.666	1.404	1.020	1.052	1.192	1.917	4.773
2018	[Mm2]	1.001	0.061	0.662	1.406	1.020	1.050	1.192	1.912	4.761
2019	[Mm2]									

CROPLAND IRRIGATED

Year		EU27	UK	CHINA	EASOC	INDIA	LATAM	RUSSIA	USMCA	LROW
2005	[Mm2]	0.105	0.002	0.635	0.056	0.592	0.073	0.045	0.291	0.609
2006	[Mm2]	0.107	0.002	0.635	0.057	0.608	0.073	0.044	0.291	0.476
2007	[Mm2]	0.111	0.001	0.635	0.051	0.627	0.076	0.044	0.290	0.477
2008	[Mm2]	0.109	0.001	0.635	0.051	0.623	0.078	0.042	0.286	0.479
2009	[Mm2]	0.107	0.001	0.635	0.051	0.636	0.080	0.042	0.287	0.479
2010	[Mm2]	0.104	0.001	0.635	0.052	0.619	0.082	0.042	0.291	0.485
2011	[Mm2]	0.105	0.001	0.635	0.053	0.636	0.084	0.042	0.298	0.480
2012	[Mm2]	0.108	0.001	0.635	0.055	0.653	0.088	0.042	0.291	0.484
2013	[Mm2]	0.111	0.000	0.635	0.058	0.661	0.091	0.042	0.294	0.481
2014	[Mm2]	0.109	0.001	0.645	0.058	0.681	0.094	0.042	0.297	0.491
2015	[Mm2]	0.107	0.001	0.659	0.056	0.684	0.096	0.042	0.299	0.496
2016	[Mm2]	0.108	0.001	0.671	0.056	0.673	0.098	0.042	0.300	0.501
2017	[Mm2]	0.110	0.001	0.678	0.057	0.673	0.100	0.042	0.302	0.498
2018	[Mm2]	0.111	0.001	0.683	0.057	0.673	0.100	0.042	0.302	0.507
2019	[Mm2]	0.113	0.001	0.687	0.054	0.673	0.100	0.042	0.302	0.511

FOREST MANAGED

Year		EU27	UK	CHINA	EASOC	INDIA	LATAM	RUSSIA	USMCA	LROW
2005	[Mm2]	1.065	0.003	1.247	3.146	0.575	7.084	7.947	6.855	10.933
2006	[Mm2]	1.064	0.003	1.252	3.140	0.573	7.034	7.949	6.851	10.885
2007	[Mm2]	1.064	0.003	1.258	3.134	0.572	6.984	7.950	6.847	10.837
2008	[Mm2]	1.063	0.003	1.263	3.128	0.570	6.934	7.952	6.842	10.789
2009	[Mm2]	1.063	0.003	1.268	3.122	0.569	6.885	7.954	6.838	10.741
2010	[Mm2]	1.063	0.003	1.273	3.116	0.567	6.835	7.955	6.833	10.692
2011	[Mm2]	1.062	0.003	1.281	3.107	0.569	6.810	7.954	6.829	10.639
2012	[Mm2]	1.061	0.003	1.289	3.099	0.572	6.785	7.953	6.824	10.586
2013	[Mm2]	1.060	0.003	1.297	3.090	0.574	6.760	7.953	6.820	10.532
2014	[Mm2]	1.059	0.003	1.305	3.081	0.576	6.735	7.952	6.815	10.479
2015	[Mm2]	1.058	0.003	1.313	3.073	0.578	6.710	7.951	6.811	10.426
2016	[Mm2]	1.061	0.003	1.322	3.075	0.580	6.688	7.958	6.805	10.374

2017	[Mm2]	1.061	0.003	1.330	3.067	0.582	6.665	7.964	6.784	10.322
2018	[Mm2]	1.061	0.003	1.337	3.060	0.585	6.644	7.964	6.778	10.272
2019	[Mm2]	1.060	0.003	1.345	3.052	0.587	6.624	7.964	6.772	10.220

FOREST PRIMARY

Year		EU27	UK	CHINA	EASOC	INDIA	LATAM	RUSSIA	USMCA	LROW
2005	[Mm2]	0.037	0.000	0.116	0.770	0.157	2.812	2.727	3.158	3.238
2006	[Mm2]	0.038	0.000	0.116	0.767	0.157	2.803	2.727	3.155	3.223
2007	[Mm2]	0.038	0.000	0.116	0.765	0.157	2.794	2.727	3.153	3.208
2008	[Mm2]	0.039	0.000	0.116	0.763	0.157	2.785	2.727	3.150	3.194
2009	[Mm2]	0.040	0.000	0.116	0.760	0.157	2.776	2.727	3.148	3.179
2010	[Mm2]	0.040	0.000	0.116	0.758	0.157	2.767	2.727	3.145	3.164
2011	[Mm2]	0.040	0.000	0.116	0.756	0.157	2.768	2.727	3.145	3.144
2012	[Mm2]	0.040	0.000	0.116	0.754	0.157	2.770	2.727	3.144	3.125
2013	[Mm2]	0.040	0.000	0.116	0.752	0.157	2.771	2.727	3.144	3.105
2014	[Mm2]	0.040	0.000	0.116	0.751	0.157	2.773	2.727	3.143	3.085
2015	[Mm2]	0.041	0.000	0.116	0.749	0.157	2.774	2.727	3.143	3.066
2016	[Mm2]	0.041	0.000	0.116	0.749	0.157	2.774	2.727	3.143	3.066
2017	[Mm2]	0.041	0.000	0.116	0.749	0.157	2.774	2.727	3.143	3.066
2018	[Mm2]	0.041	0.000	0.116	0.749	0.157	2.812	2.727	3.143	3.066
2019	[Mm2]	0.041	0.000	0.116	0.749	0.157	2.812	2.727	3.143	3.066

FOREST PLANTATIONS

Year		EU27	UK	CHINA	EASOC	INDIA	LATAM	RUSSIA	USMCA	LROW
2005	[Mm2]	0.480	0.027	0.641	0.274	0.111	0.103	0.175	0.358	0.283
2006	[Mm2]	0.485	0.027	0.659	0.277	0.114	0.108	0.179	0.366	0.288
2007	[Mm2]	0.490	0.027	0.678	0.280	0.118	0.113	0.183	0.373	0.292
2008	[Mm2]	0.495	0.027	0.696	0.284	0.121	0.118	0.188	0.381	0.297
2009	[Mm2]	0.500	0.027	0.715	0.287	0.124	0.123	0.192	0.389	0.301
2010	[Mm2]	0.504	0.027	0.733	0.290	0.128	0.128	0.196	0.396	0.305
2011	[Mm2]	0.508	0.027	0.745	0.296	0.128	0.134	0.197	0.402	0.309
2012	[Mm2]	0.512	0.028	0.756	0.302	0.129	0.140	0.197	0.408	0.313
2013	[Mm2]	0.516	0.028	0.767	0.307	0.129	0.146	0.197	0.413	0.317
2014	[Mm2]	0.520	0.028	0.779	0.313	0.130	0.152	0.198	0.419	0.321
2015	[Mm2]	0.524	0.028	0.790	0.318	0.130	0.158	0.198	0.425	0.325
2016	[Mm2]	0.524	0.028	0.802	0.328	0.131	0.160	0.194	0.429	0.327
2017	[Mm2]	0.526	0.028	0.814	0.320	0.131	0.158	0.189	0.445	0.327
2018	[Mm2]	0.528	0.028	0.825	0.320	0.132	0.166	0.189	0.449	0.328
2019	[Mm2]	0.530	0.028	0.836	0.320	0.132	0.170	0.189	0.454	0.331

SHUBLAND

		EU27	UK	CHINA	EASOC	INDIA	LATAM	RUSSIA	USMCA	LROW
Year		0.558	0.017	0.227	0.949	0.531	0.000	1.570	2.484	0.202
2005	[Mm2]	0.567	0.012	0.223	0.956	0.531	0.000	1.568	2.488	0.215
2006	[Mm2]	0.578	0.013	0.219	0.993	0.531	0.000	1.566	2.489	0.223
2007	[Mm2]	0.568	0.013	0.216	1.024	0.527	0.000	1.564	2.525	0.232
2008	[Mm2]	0.571	0.015	0.212	1.034	0.522	0.041	1.562	2.543	0.240
2009	[Mm2]	0.578	0.015	0.209	1.063	0.524	0.061	1.560	2.563	0.230
2010	[Mm2]	0.583	0.015	0.206	0.983	0.520	0.080	1.560	2.580	0.239
2011	[Mm2]	0.586	0.015	0.204	1.015	0.516	0.083	1.560	2.594	0.332
2012	[Mm2]	0.586	0.015	0.201	1.072	0.512	0.087	1.560	2.594	0.337

2013	[Mm2]	0.595	0.015	0.199	1.063	0.507	0.115	1.560	2.592	0.353
2014	[Mm2]	0.593	0.015	0.196	1.160	0.505	0.144	1.561	2.587	0.365
2015	[Mm2]	0.599	0.014	0.194	1.166	0.503	0.175	1.559	2.584	0.378
2016	[Mm2]	0.597	0.013	0.191	1.049	0.499	0.172	1.558	2.591	0.386
2017	[Mm2]	0.599	0.014	0.188	1.103	0.496	0.202	1.558	2.593	0.397
2018	[Mm2]	0.589	0.013	0.186	1.092	0.493	0.213	1.557	2.594	0.413
2019	[Mm2]									

GRASSLAND

		EU27	UK	CHINA	EASOC	INDIA	LATAM	RUSSIA	USMCA	LROW
Year		0.581	0.112	3.928	4.105	0.105	3.368	0.921	3.465	16.538
2005	[Mm2]	0.574	0.117	3.928	4.114	0.104	3.343	0.921	3.479	16.543
2006	[Mm2]	0.575	0.115	3.928	4.016	0.104	3.334	0.921	3.499	16.537
2007	[Mm2]	0.577	0.116	3.928	3.916	0.104	3.326	0.921	3.459	16.545
2008	[Mm2]	0.569	0.112	3.928	3.835	0.103	3.316	0.921	3.447	16.578
2009	[Mm2]	0.564	0.112	3.928	3.770	0.103	3.305	0.921	3.432	16.633
2010	[Mm2]	0.558	0.111	3.928	3.907	0.103	3.286	0.921	3.421	16.615
2011	[Mm2]	0.544	0.109	3.928	3.815	0.103	3.284	0.921	3.407	16.178
2012	[Mm2]	0.550	0.109	3.928	3.664	0.103	3.295	0.921	3.397	16.196
2013	[Mm2]	0.534	0.110	3.928	3.684	0.103	3.283	0.921	3.390	16.188
2014	[Mm2]	0.534	0.111	3.928	3.427	0.103	3.270	0.921	3.388	16.191
2015	[Mm2]	0.530	0.113	3.928	3.380	0.103	3.257	0.921	3.387	16.196
2016	[Mm2]	0.529	0.113	3.928	3.666	0.103	3.232	0.921	3.387	16.201
2017	[Mm2]	0.529	0.113	3.928	3.533	0.103	3.217	0.921	3.386	16.203
2018	[Mm2]	0.536	0.114	3.928	3.571	0.103	3.219	0.921	3.387	16.183
2019	[Mm2]									

URBAN

		EU27	UK	CHINA	EASOC	INDIA	LATAM	RUSSIA	USMCA	LROW
Year		0.076	0.010	0.052	0.039	0.012	0.024	0.022	0.101	0.084
2005	[Mm2]	0.077	0.010	0.056	0.040	0.013	0.025	0.022	0.104	0.086
2006	[Mm2]	0.078	0.010	0.060	0.042	0.014	0.025	0.022	0.107	0.089
2007	[Mm2]	0.079	0.010	0.064	0.043	0.014	0.026	0.023	0.109	0.091
2008	[Mm2]	0.080	0.010	0.068	0.045	0.015	0.026	0.023	0.111	0.093
2009	[Mm2]	0.080	0.010	0.072	0.046	0.015	0.027	0.023	0.112	0.095
2010	[Mm2]	0.081	0.010	0.075	0.048	0.016	0.027	0.024	0.114	0.097
2011	[Mm2]	0.082	0.010	0.079	0.049	0.017	0.028	0.024	0.116	0.100
2012	[Mm2]	0.083	0.010	0.084	0.052	0.018	0.029	0.024	0.119	0.104
2013	[Mm2]	0.084	0.010	0.089	0.054	0.019	0.030	0.025	0.122	0.109
2014	[Mm2]	0.085	0.010	0.092	0.056	0.020	0.030	0.025	0.123	0.112
2015	[Mm2]	0.085	0.010	0.092	0.056	0.020	0.030	0.025	0.126	0.114
2016	[Mm2]	0.085	0.010	0.098	0.057	0.021	0.031	0.026	0.128	0.117
2017	[Mm2]	0.086	0.010	0.103	0.057	0.021	0.032	0.026	0.130	0.120
2018	[Mm2]	0.086	0.010	0.106	0.058	0.022	0.033	0.027	0.131	0.124
2019	[Mm2]									

SOLAR

		EU27	UK	CHINA	EASOC	INDIA	LATAM	RUSSIA	USMCA	LROW
Year		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2005	[Mm2]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2006	[Mm2]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2007	[Mm2]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	[Mm2]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	[Mm2]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

2010	[Mm2]	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2011	[Mm2]	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2012	[Mm2]	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2013	[Mm2]	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2014	[Mm2]	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
2015	[Mm2]	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.000
2016	[Mm2]	0.002	0.000	0.002	0.000	0.000	0.000	0.000	0.001	0.000
2017	[Mm2]	0.002	0.000	0.002	0.000	0.000	0.000	0.000	0.001	0.000
2018	[Mm2]	0.002	0.000	0.002	0.000	0.000	0.000	0.000	0.001	0.000
2019	[Mm2]									

SNOW_ICE_WATERBODIES

Year		EU27	UK	CHINA	EASOC	INDIA	LATAM	RUSSIA	USMCA	LROW
2005	[Mm2]	0.119	0.005	0.187	0.110	0.057	0.271	0.661	1.490	15.302
2006	[Mm2]	0.119	0.005	0.187	0.109	0.057	0.270	0.660	1.490	15.300
2007	[Mm2]	0.118	0.005	0.187	0.109	0.057	0.270	0.659	1.490	15.297
2008	[Mm2]	0.118	0.005	0.187	0.109	0.057	0.269	0.657	1.490	15.295
2009	[Mm2]	0.118	0.005	0.187	0.108	0.057	0.269	0.655	1.490	15.289
2010	[Mm2]	0.118	0.005	0.187	0.109	0.057	0.269	0.653	1.491	15.292
2011	[Mm2]	0.118	0.005	0.187	0.109	0.057	0.269	0.653	1.492	15.290
2012	[Mm2]	0.118	0.005	0.187	0.109	0.058	0.269	0.652	1.493	15.289
2013	[Mm2]	0.118	0.005	0.187	0.109	0.058	0.269	0.652	1.495	15.288
2014	[Mm2]	0.119	0.005	0.188	0.108	0.059	0.269	0.653	1.495	15.288
2015	[Mm2]	0.119	0.005	0.188	0.108	0.059	0.269	0.653	1.495	15.288
2016	[Mm2]	0.119	0.005	0.189	0.109	0.059	0.269	0.653	1.496	15.266
2017	[Mm2]	0.119	0.005	0.189	0.109	0.059	0.269	0.653	1.496	15.266
2018	[Mm2]	0.119	0.005	0.189	0.109	0.059	0.269	0.653	1.496	15.266
2019	[Mm2]	0.119	0.005	0.189	0.109	0.059	0.270	0.654	1.498	15.271

OTHER_LAND

Year		EU27	UK	CHINA	EASOC	INDIA	LATAM	RUSSIA	USMCA	LROW
2005	[Mm2]	0.175	0.012	1.835	1.469	0.044	-0.050	1.840	1.418	0.635
2006	[Mm2]	0.177	0.009	1.805	1.480	0.044	-0.036	1.838	1.421	0.678
2007	[Mm2]	0.181	0.009	1.776	1.537	0.044	-0.024	1.835	1.421	0.701
2008	[Mm2]	0.178	0.009	1.746	1.586	0.044	-0.004	1.833	1.442	0.731
2009	[Mm2]	0.179	0.011	1.716	1.602	0.043	0.015	1.830	1.452	0.754
2010	[Mm2]	0.181	0.011	1.693	1.647	0.043	0.022	1.828	1.463	0.723
2011	[Mm2]	0.182	0.011	1.672	1.522	0.043	0.029	1.829	1.473	0.751
2012	[Mm2]	0.183	0.011	1.652	1.572	0.043	0.030	1.829	1.481	1.046
2013	[Mm2]	0.183	0.011	1.630	1.661	0.042	0.032	1.829	1.481	1.061
2014	[Mm2]	0.186	0.011	1.608	1.646	0.042	0.042	1.829	1.480	1.109
2015	[Mm2]	0.186	0.011	1.589	1.797	0.042	0.052	1.829	1.477	1.150
2016	[Mm2]	0.187	0.010	1.569	1.806	0.041	0.064	1.827	1.475	1.188
2017	[Mm2]	0.187	0.009	1.545	1.625	0.041	0.063	1.826	1.479	1.213
2018	[Mm2]	0.187	0.010	1.523	1.709	0.041	0.074	1.826	1.480	1.249
2019	[Mm2]	0.184	0.009	1.503	1.691	0.041	0.078	1.825	1.481	1.301

Table 6: correspondence of countries and WILIAM regions

COUNTRY	REGION	COUNTRY	REGION
Austria	EU27	Rest of Oceania	LROW
Belgium	EU27	Mongolia	LROW
Bulgaria	EU27	Rest of East Asia	LROW
Croatia	EU27	Rest south East Asia	LROW
Cyprus	EU27	Bangladesh	LROW
Czech Republic	EU27	Pakistan	LROW
Denmark	EU27	Shri Lanka	LROW
Estonia	EU27	Rest South Asia	LROW
Finland	EU27	Rest of North America	LROW
France	EU27	Ecuador	LROW
Germany	EU27	Paraguay	LROW
Greece	EU27	Uruguay	LROW
Hungary	EU27	Venezuela	LROW
Ireland	EU27	Rest South America	LROW
Italy	EU27	Guatemala	LROW
Latvia	EU27	Honduras	LROW
Lithuania	EU27	Nicaragua	LROW
Luxembourg	EU27	El salvador	LROW
Malta	EU27	Panama	LROW
Netherlands	EU27	Rest central America	LROW
Poland	EU27	Republica dominicaDa	LROW
Portugal	EU27	Jamaica	LROW
Romania	EU27	Puerto Rico	LROW
Slovakia	EU27	Trinidad y Tobago	LROW
Slovenia	EU27	rest Caribe	LROW
Spain	EU27	Norway	LROW
Sweden	EU27	Rest of EFTA	LROW
United Kingdom	EU27	Albania	LROW
Canada	USMCA	Ucrania	LROW
Mexico	USMCA	Rrest of eastern europe	LROW
United States	USMCA	Georgia	LROW
Argentina	LATAM	Iran	LROW
Brazil	LATAM	Israel	LROW
Chile	LATAM	Jordania	LROW
Colombia	LATAM	Kuwait	LROW
Costa Rica	LATAM	Oman	LROW
Peru	LATAM	Qatar	LROW
China (People's Republic of)	China	Saudi Arabia	LROW
Taiwan		Turkey	LROW
Hong Kong SAR	China	United Arab Emirates	LROW
India	India	Rest wester Asia	LROW
Russian Federation	Russia	Egipt	LROW
Australia	EASOC	Marocco	LROW
Brunei Darussalam	EASOC	Tunisia	LROW
Cambodia	EASOC	Rest north Africa	LROW
Chinese Taipei	EASOC	Benin	LROW
Indonesia	EASOC	Burkina faso	LROW
Japan	EASOC	Camerun	LROW

Korea	EASOC	C'ote D'Ivoire	LROW
Malaysia	EASOC	Ghana	LROW
New Zealand	EASOC	Ginea	LROW
Philippines	EASOC	Nigeria	LROW
Singapore	EASOC	Senegal	LROW
Thailand	EASOC	Togo	LROW
Viet Nam	EASOC	Rest west Africa	LROW
		Rest central Africa	LROW
		Rest south central Africa	LROW
		Etiopia	LROW
		Kenya	LROW
		Madagascar	LROW
		Malawi	LROW
		Mauritius	LROW
		Mozambique	LROW
		Rwanda	LROW
		Tanzania	LROW
		Uganda	LROW
		Zambia	LROW
		Zimbawe	LROW
		aafricaRest East Africa	LROW
		Botwana	LROW
		Namibia	LROW
		South Africa	LROW
		Rest of south Africa cu	LROW
		Rest	LROW

4. Calibration of the Lad Uses submodule

This section describes the obtention of the trends of the vector of trends of $LUC\ Demands\ (R_i, L_n)$ and the matrices of shares of land uses from other, $Share\ of\ LUC\ from\ Others\ (R_i, L_n, L_m)$, described in previous section based on historical data and model calibration.

The model is based on the hypothesis that there are some land use changes that are driven by demands, since they are economically or socially interesting (croplands, forests, grasslands, solar land, urban, etc.) and other that are not demanded and only absorb the demand of the rest (other land and shrubland). In any case, all the land demands compete with each other and absorb the demand of other uses. Trend demands are calculated on the basis of historical land use trends, and in some cases have been adjusted to take account of evident changes in trends that cannot be extrapolated into the future (such as the sharp loss of agricultural land in the EU in recent decades due to agricultural policies, which does not appear to be continuing).

In future releases of the model, a GIS-based analysis is planned to be used to determine based on historical data, the real shares of land use from other. This would determine what have really been the actual flows of land from one use to another and improve a lot the calibration of this model. In the meantime, this adjustment aims to stablish the most relevant trends of past land use changes for the most relevant uses.

It is assumed that the primary forest cannot be increased, since it is defined as very mature forests whose creation goes back to centuries ago. When forest primary increases in the historical data, we assume it is due to changes in definition and assume the greatest value as the initial one. Solar land is the land under photovoltaic and concentrated solar power electricity appliances, since its historical values are very low, we do not take it into account in the calibration. For solar land, the initial shares have been obtained applying Geographic Information Systems (GIS) techniques analyzing the allocation of current solar power capacity. This analysis has been done for each of the 9 regions of WILIAM-TERRA module and it is based on data processed from the “Global Database of Power Plants” combined with land cover data (see [22] for a complete description).

These hypothesis of land use trends are used to calculate the land use changes taken from other uses in each simulation time step according to equation 1 using initial values of the matrices of shares of land uses from other, ($Share\ of\ LUC\ from\ Others\ (R_i, L_n, L_m)$) obtained by the analysis of the literature described in [20, 21] (see Table 7) and the resulting land use changes are confronted to historical data. The discrepancy between estimated and historical data is used to accommodate the matrix $Share\ of\ LUC\ from\ Others\ (R_i, L_n, L_m)$. An initial computer calibration of these shares was done with Vensim Software calibration tools, but the final adjustment was made by hand, since the complexity of the task made automatic calibration worse than the human-made. The main efforts have been dedicated to the calibration of the most relevant and conflictive uses (croplands and forests), therefore the errors accumulate in shrubland and other land, whose historical data was not properly found (as described in section 3). Snow, ice and waterbodies and wetlands have not been calibrated at this stage of the model and they are left constant in the model.

Table 7: Initial shares of land use changes from other as stated in Campano 2021 [21]

INITIAL_SHARE_OF_CROPLAND_RAINFED_FORM_OTHER_LANDS_BY_REGION (REGIONS_I,LANDS_I)

LANDS_I	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
REGIONS_I	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]		[%]
EU27	0	0	0.8	0	0	0.12	0.06	0	0	0	0	0.02
UK	0	0	0.8	0	0	0.12	0.06	0	0	0	0	0.02
CHINA	0	0	0.44	0	0	0.16	0.25	0	0	0	0	0.16
EASOC	0	0	0.19	0.66	0	0.15	0.01	0	0	0	0	0.01
INDIA	0	0	0.18	0.3	0	0.24	0.18	0	0	0	0	0.11
LATAM	0	0	0.18	0.63	0	0.18	0.01	0	0	0	0	0
RUSSIA	0	0	0.2	0	0	0.52	0.25	0	0	0	0	0.04
USMCA	0	0	0.11	0.38	0	0.23	0.27	0	0	0	0	0
LROW	0	0	0.18	0.28	0	0.38	0.1	0	0	0	0	0.07

INITIAL_SHARE_OF_GRASSLAND_FORM_OTHER_LANDS_BY_REGION (REGIONS_I,L pondremos que grassland no tiene demanda salvo en LATAM

LANDS_I	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
REGIONS_I	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]		[%]
EU27	0	0	0	0	0	0	0	0	0	0	0	0
UK	0	0	0	0	0	0	0	0	0	0	0	0
CHINA	0	0	0	0	0	0	0	0	0	0	0	0
EASOC	0	0	0	0	0	0	0	0	0	0	0	0
INDIA	0	0	0	0	0	0	0	0	0	0	0	0
LATAM	0.34	0	0.12	0.44	0	0.04	0	0	0	0	0	0.05
RUSSIA	0	0	0	0	0	0	0	0	0	0	0	0
USMCA	0	0	0	0	0	0	0	0	0	0	0	0
LROW	0	0	0	0	0	0	0	0	0	0	0	0

INITIAL_SHARE_OF_FOREST_PLANTATIONS_FORM_OTHER_LANDS_BY_REGION (REGIONS_I,LANDS_I)

LANDS_I	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
REGIONS_I	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]		[%]
EU27	0.23	0	0.61	0	0	0.1	0.6	0	0	0	0	0
UK	0.23	0	0.61	0	0	0.1	0.6	0	0	0	0	0
CHINA	0.23	0	0.61	0	0	0.1	0.6	0	0	0	0	0
EASOC	0.23	0	0.61	0	0	0.1	0.6	0	0	0	0	0
INDIA	0.23	0	0.61	0	0	0.1	0.6	0	0	0	0	0
LATAM	0.23	0	0.61	0	0	0.1	0.6	0	0	0	0	0
RUSSIA	0.23	0	0.61	0	0	0.1	0.6	0	0	0	0	0
USMCA	0.23	0	0.61	0	0	0.1	0.6	0	0	0	0	0
LROW	0.23	0	0.61	0	0	0.1	0.6	0	0	0	0	0

INITIAL_SHARE_OF_NEW_URBAN_FORM_OTHER_LANDS_BY_REGION (REGIONS_I,LANDS_I)

LANDS_I	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
REGIONS_I	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]		[%]
EU27	0.75	0	0.08	0	0	0.04	0.06	0	0	0	0	0.06
UK	0.75	0	0.08	0	0	0.04	0.06	0	0	0	0	0.06
CHINA	0.76	0	0.03	0	0	0.06	0.14	0	0	0	0	0.02
EASOC	0.82950502	0	0.06475246	0	0	0.06306926	0.01297029	0	0	0	0	0.03
INDIA	0.84	0	0.03	0	0	0.07	0.05	0	0	0	0	0.01
LATAM	0.45	0	0.11	0	0	0.35	0.08	0	0	0	0	0.02
RUSSIA	0.67	0	0.08	0	0	0.12	0.09	0	0	0	0	0.04
USMCA	0.40465181	0	0.17046426	0	0	0.24418755	0.16313836	0	0	0	0	0.01244197
LROW	0.53574826	0	0.09093677	0	0	0.19739033	0.06602194	0	0	0	0	0.10978433

INITIAL SHARE_OF_NEW_SOLAR_FORM_OTHER_LANDS_BY_REGION (REGIONS_I,LANDS_I)

LANDS_I	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
REGIONS_I	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]		[%]
EU27	0.125	0	0	0	0	0.125	0.125	0	0	0	0	0.625
UK	0.125	0	0	0	0	0.125	0.125	0	0	0	0	0.625
CHINA	0.125	0	0	0	0	0.125	0.125	0	0	0	0	0.625
EASOC	0.125	0	0	0	0	0.125	0.125	0	0	0	0	0.625
INDIA	0.125	0	0	0	0	0.125	0.125	0	0	0	0	0.625
LATAM	0.125	0	0	0	0	0.125	0.125	0	0	0	0	0.625
RUSSIA	0.125	0	0	0	0	0.125	0.125	0	0	0	0	0.625
USMCA	0.125	0	0	0	0	0.125	0.125	0	0	0	0	0.625
LROW	0.125	0	0	0	0	0.125	0.125	0	0	0	0	0.625

EU27

In Table 8 one can see the historical trends of land use change in EU. EU27 has had a decrease of rainfed cropland that shows a stagnation in the last years and a similar growth of irrigated cropland that have been maintained. Forest primary grows in the historical data and has been accommodated to be zero, as explained in previous section. Shrubland, snow ice and waterbodies and other land are assumed to have no demand. The historical demand of plantations and urban is maintained. Managed forest demand is set equal to the value of annual deforestation recorded in FAO data. Grassland shows a significant loss that is coherent with the abandonment of extensive farming seen in the EU and is maintained with a small increase to adjust the rest of the uses. Table 9 shows the calibrated shares.

The error between the historical and the simulated land use areas after the calibration are shown in Figure 3. The average error is less than 0.4% and, although some land uses such as cropland rainfed and forest managed reach 4% in some years, this result is considered to be acceptable taking into account the big discrepancies that are always present in land use data at this level of aggregation.

Table 8. EU27 initial and calibrated land use trend demands

	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
EU27 Initial trends of land demand (km2/Year)	-4471.5	517.9	-303.2	233.6	3515.1	749.0	-3280.0	0.0	691.9	0.0	23.6	2323.4

	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
EU27 calibrated trends of land demand (km2/Year)	-4471.5	517.9	1127.0	0.0	3515.1	0,	-4000.0	0,	691.9	0.0	0.0	0.0

Table 9. EU27 calibrated matrices of shares of land use changes from others

Calibrated shares of land use changes from others (EU27)												
share of --> that comes from:	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
RAINFED	0.00	1,	0.3,	0,	0.23	0,	0,	0,	0.75,	0.13,	0,	0;
IRRIGATED	0.00	0,	0,	0,	0.00	0,	0,	0,	0,	0,	0,	0;
FOREST_MANAGED	0.06	0,	0,	0,	0.61	0,	0,	0,	0.08,	0,	0,	0;
FOREST_PRIMARY	0.00	0,	0,	0,	0.00	0,	0,	0,	0,	0,	0,	0;
FOREST_PLANTATIONS	0.00	0,	0,	0,	0.00	0,	0,	0,	0,	0,	0,	0;
SHRUBLAND	0.80	0,	0.3,	0,	0.10	0,	0,	0,	0.04,	0.13,	0,	0;
GRASSLAND	0.12	0,	0.4,	0,	0.06	0,	0,	0,	0.06,	0.13,	0,	0;
WETLAND	0.00	0,	0,	0,	0.00	0,	0,	0,	0,	0,	0,	0;
URBAN	0.00	0,	0,	0,	0.00	0,	0,	0,	0,	0,	0,	0;
SOLAR	0.00	0,	0,	0,	0.00	0,	0,	0,	0,	0,	0,	0;
SNOW_ICE_WATERBODIES	0.00	0,	0,	0,	0.00	0,	0,	0,	0,	0,	0,	0;
OTHER_LAND	0.02	0,	0,	0,	0.00	0,	1,	0,	0.06,	0.63,	0,	0;

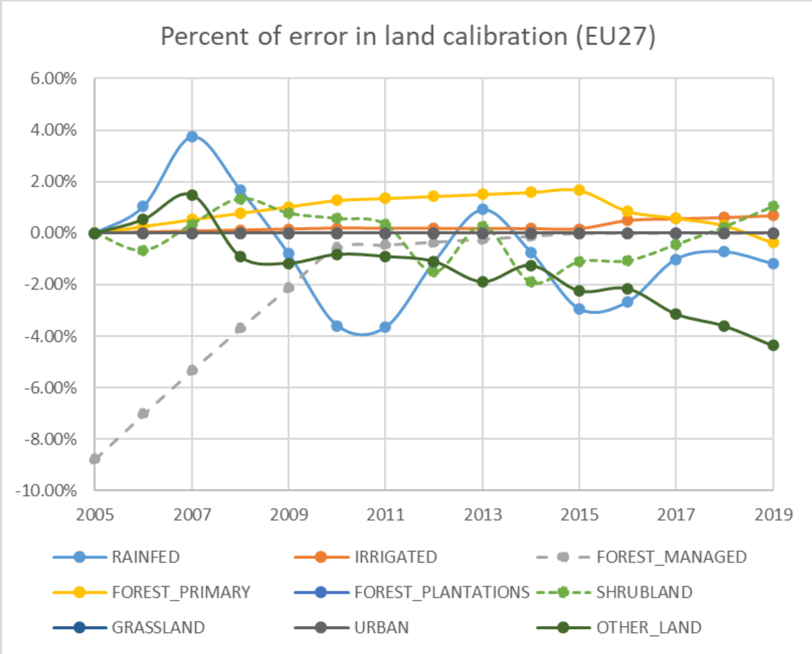

Figure 3. Percent of error between historical and simulated values of land uses in EU27 after the calibration.

UK

In Table 10 one can see the historical trends of land use change in UK. UK shows no significant change of forests and shrublands and loss of irrigated cropland (though the absolute value of irrigated cropland in UK is very small). Historical trends for cropland rainfed and plantations have been reduced a bit to adjust the loss of other land. Table 11 shows the calibrated shares. In general, land use changes are small in UK and the error between the historical and the simulated land use areas after the calibration are less than 6% for most land uses (Figure 4). The relative error of cropland irrigated is not considered important because the small area of this land use in UK makes it negligigle.

Table 10. UK initial and calibrated land use trend demands

	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
UK Initial trends of land demand (km2/Year)	352.0	-98.0	0.0	0.0	125.0	0.0	150.0	0.0	12.0	0.0	-1.0	-540.0
UK calibrated trends of land demand (km2/Year)	254.0	0.0	0.0	0.0	94.0	0.0	0.0	0.0	12.4	0.0	0.0	0.0

Table 11. UK calibrated matrices of shares of land use changes from others

Calibrated shares of land use changes from others (UK)												
share of --> that comes from:	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
RAINFED	0.00	1.00	0.30	0.00	0.30	0.00	0.00	0.00	0.75	0.45	0.00	0.00
IRRIGATED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FOREST_MANAGED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
FOREST_PRIMARY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FOREST_PLANTATIONS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
SHRUBLAND	0.92	0.00	0.30	0.00	0.30	0.00	0.00	0.00	0.13	0.12	0.00	0.00
GRASSLAND	0.06	0.00	0.40	0.00	0.40	0.00	0.00	0.00	0.06	0.40	0.00	0.00
WETLAND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
URBAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOLAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNOW_ICE_WATERBODIES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OTHER_LAND	0.02	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.06	0.00	0.00	0.00

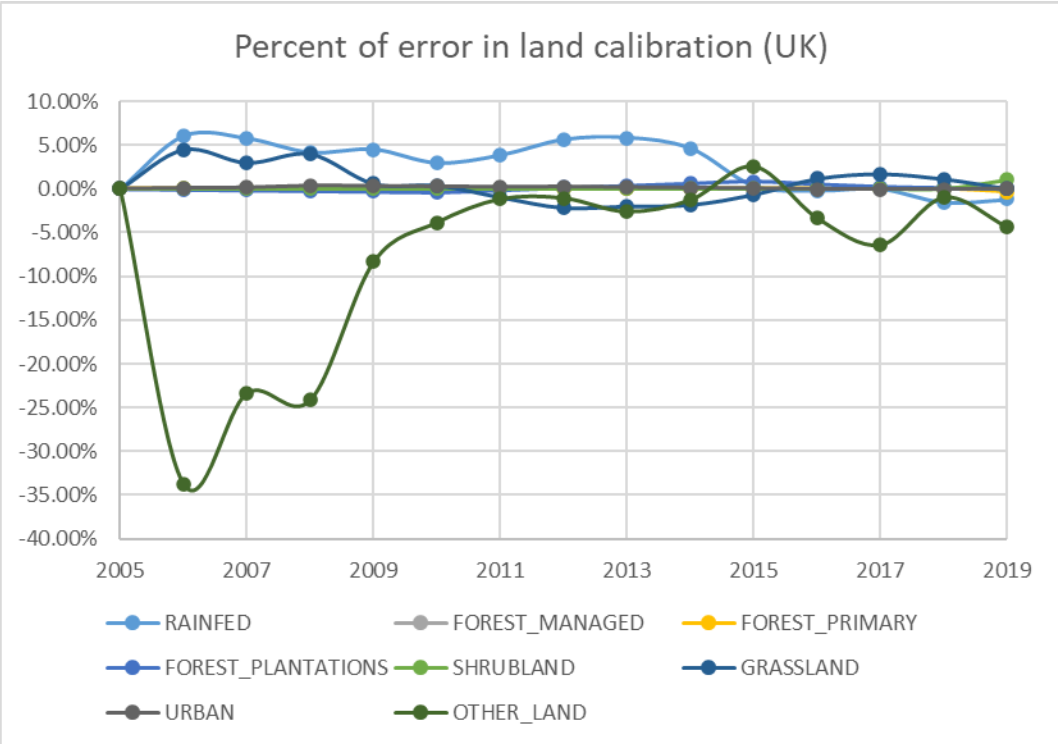

Figure 4. Percent of error between historical and simulated values of land uses in UK after the calibration.

CHINA

In Table 12 one can see the historical trends of land use change in China. China shows a large increase of forests, plantations and croplands that seems to come from other land. Irrigated land is much larger than in other regions. Urban expansion is large and irrigated land demand is increased to cope with the demands from urban. Table 13 shows the calibrated shares and the error between the historical and the simulated land use areas after the calibration are shown in Figure 5. The average error is less than 6% for all uses.

Table 12. China initial and calibrated land use trend demands

	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
China Initial trends of land demand (km2/Year)	1336.0	0.0	6991.0	0.0	13933.0	-29.0	0.0	0.0	3876.0	0.0	149.0	-26256.0
China calibrated trends of land demand (km2/Year)	4772.1	49056.1	6990.6	0.0	13933.1	0.0	0.0	0.0	3875.9	0.0	0.0	0.0

Table 13. China calibrated matrices of shares of land use changes from others

Calibrated shares of land use changes from others (China)												
share of --> that comes from:	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
RAINFED	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.15	0.00	0.00
IRRIGATED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
FOREST_MANAGED	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00
FOREST_PRIMARY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FOREST_PLANTATIONS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
SHRUBLAND	0.60	0.00	0.50	0.00	0.50	0.00	0.00	0.00	0.20	0.04	0.00	0.00
GRASSLAND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00
WETLAND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
URBAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOLAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNOW_ICE_WATERBODIES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
OTHER_LAND	0.00	0.00	0.50	0.00	0.50	0.00	1.00	0.00	0.01	0.65	0.00	0.00

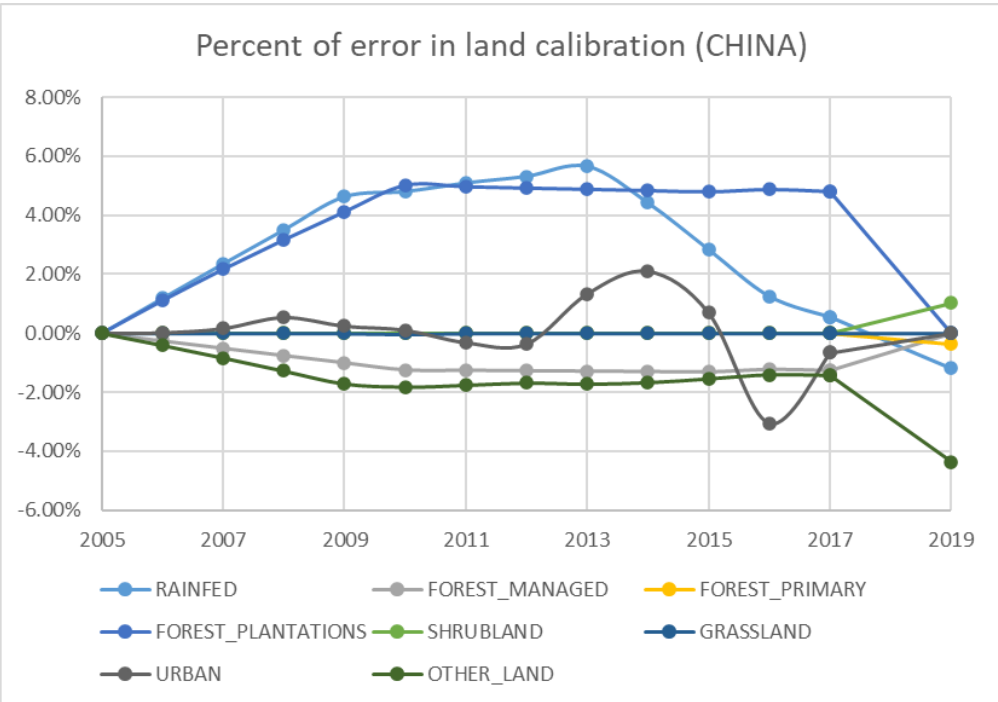

Figure 5. Percent of error between historical and simulated values of land uses in China after the calibration.

In Table 14 one can see the historical trends of land use change in EASOC. Both croplands experiment important increases that seem to be compensated with the decrease of forest managed and primary. Table 15 shows the calibrated shares.

The error between the historical and the simulated land use areas after the calibration are shown in Figure 6. There is a relevant error for shrubland and other land that we cannot compensate with the calibration. It seems to come from the fact that shrubland and other land areas have not been obtained from real historical data but from and approximation (assuming constant proportions between them) and this assumption might not hold. In any case, these uses are of very little importance for out model.

Table 14. EASOC initial and calibrated land use trend demands

	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
EASOC Initial trends of land demand (km2/Year)	15692.0	-155.0	-6669.0	-1477.0	3309.0	466.0	######	0.0	1341.0	0.0	-53.0	25710.0
EASOC calibrated trends of land demand (km2/Year)	15691.9	-155.0	0.0	0.0	3640.3	0.0	######	0.0	1341.3	0.0	0.0	0.0

Table 15. EASOC calibrated matrices of shares of land use changes from others

Calibrated shares of land use changes from others (EASOC)												
share of --> that comes from:	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
RAINFED	0.00	1.00	0.30	0.00	0.30	0.00	0.00	0.00	0.75	0.63	0.00	0.00
IRRIGATED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00
FOREST_MANAGED	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.06	0.00	0.00
FOREST_PRIMARY	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FOREST_PLANTATIONS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
SHRUBLAND	0.46	0.00	0.30	0.00	0.30	0.00	0.00	0.00	0.04	0.06	0.00	0.00
GRASSLAND	0.00	0.00	0.40	0.00	0.40	0.00	0.00	0.00	0.06	0.08	0.00	0.00
WETLAND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
URBAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOLAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNOW_ICE_WATERBODIES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
OTHER_LAND	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.07	0.02	0.00	0.00

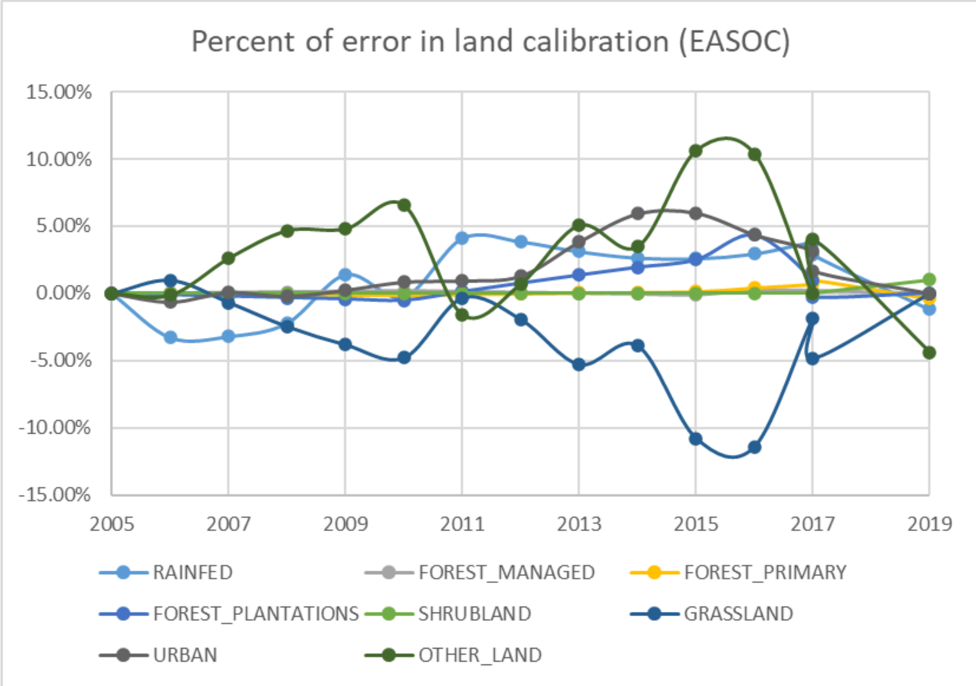

Figure 6. Percent of error between historical and simulated values of land uses in EASOC after the calibration.

INDIA

In Table 16 one can see the historical trends of land use change in India. Table 17 shows the calibrated shares. India shows an important growth of irrigated cropland and plantations that seems to come from rainfed cropland. The error between the historical and the simulated land use areas after the calibration are shown in Figure 7. The error found in forest plantations is due to the fact that we are assuming linear

Table 16. India initial and calibrated land use trend demands

	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
INDIA Initial trends of land demand (km2/Year)	-6036.0	5781.0	860.0	0.0	1533.0	-71.0	-136.0	0.0	708.0	0.0	169.0	-2808.0
INDIA calibrated trends of land demand (km2/Year)	-3500.4	5781.4	484.0	0.0	1533.1	0.0	-136.4	0.0	708.1	0.0	0.0	0.0

Table 17. India calibrated matrices of shares of land use changes from others

Calibrated shares of land use changes from others (INDIA)												
share of --> that comes from:	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
RAINFED	0.00	1.00	0.30	0.00	0.30	0.00	0.00	0.00	0.84	0.13	0.00	0.00
IRRIGATED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.00	0.00
FOREST_MANAGED	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00
FOREST_PRIMARY	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FOREST_PLANTATIONS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
SHRUBLAND	0.24	0.00	0.30	0.00	0.30	0.00	0.00	0.00	0.07	0.08	0.00	0.00
GRASSLAND	0.18	0.00	0.40	0.00	0.40	0.00	0.00	0.00	0.05	0.23	0.00	0.00
WETLAND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
URBAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOLAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNOW_ICE_WATERBODIES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
OTHER_LAND	0.10	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.01	0.14	0.00	0.00

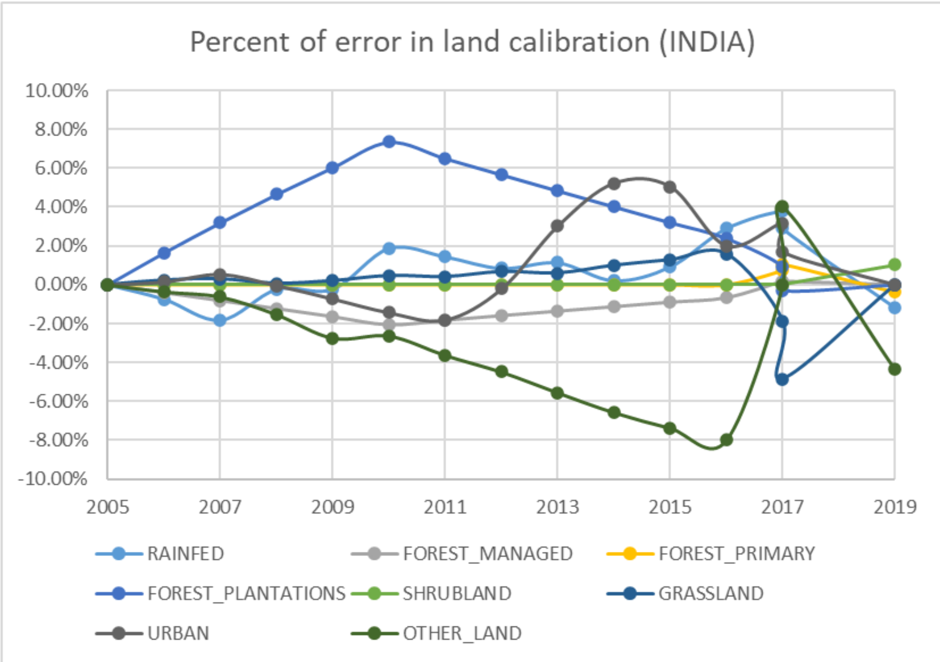

Figure 7. Percent of error between historical and simulated values of land uses in India after the calibration.

LATAM

In Table 18 one can see the historical trends of land use change in LATAM. LATAM shows a destruction of forest and grasslands that is only partially compensated by the expansion of cropland. The rest of the loss of grassland and forest has to be compensated with negative demand of these land uses. This would correspond to deforestation or desertification due to causes not related to cropland expansion (probably mining, logging, desertification and other factors).

Table 19 shows the calibrated shares. The error between the historical and the simulated land use areas after the calibration are shown in Figure 8. The large error in other land cannot be compensated, it is probably due to the fact that shrubland and other land areas have not been obtained from real historical data but from and approximation (assuming constant proportions between them) and this assumption might not hold. In any case, these uses are of very little importance for out model.

Table 18. LATAM initial and calibrated land use trend demands

	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
LATAM Initial trends of land demand (km2/Year)	4795.0	1933.0	-32820.0	0.0	4762.0	401.0	######	0.0	631.0	0.0	-114.0	33804.0
LATAM calibrated trends of land demand (km2/Year)	8000.3	1932.5	-30000.0	0.0	4761.9	0.0	######	0.0	631.3	0.0	0.0	0.0

Table 19. LATAM calibrated matrices of shares of land use changes from others

Calibrated shares of land use changes from others (LATAM)												
share of --> that comes from:	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
RAINFED	0.00	1.00	0.00	0.00	0.00	0.00	0.34	0.00	0.45	0.11	0.00	0.00
IRRIGATED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FOREST_MANAGED	0.18	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.11	0.00	0.00	0.00
FOREST_PRIMARY	0.63	0.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.00	0.00
FOREST_PLANTATIONS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SHRUBLAND	0.18	0.00	0.90	0.00	0.90	0.00	0.04	0.00	0.35	0.01	0.00	0.00
GRASSLAND	0.01	0.00	0.10	0.00	0.10	0.00	0.00	0.00	0.08	0.01	0.00	0.00
WETLAND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
URBAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOLAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNOW_ICE_WATERBODIES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OTHER_LAND	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.01	0.87	0.00	0.00

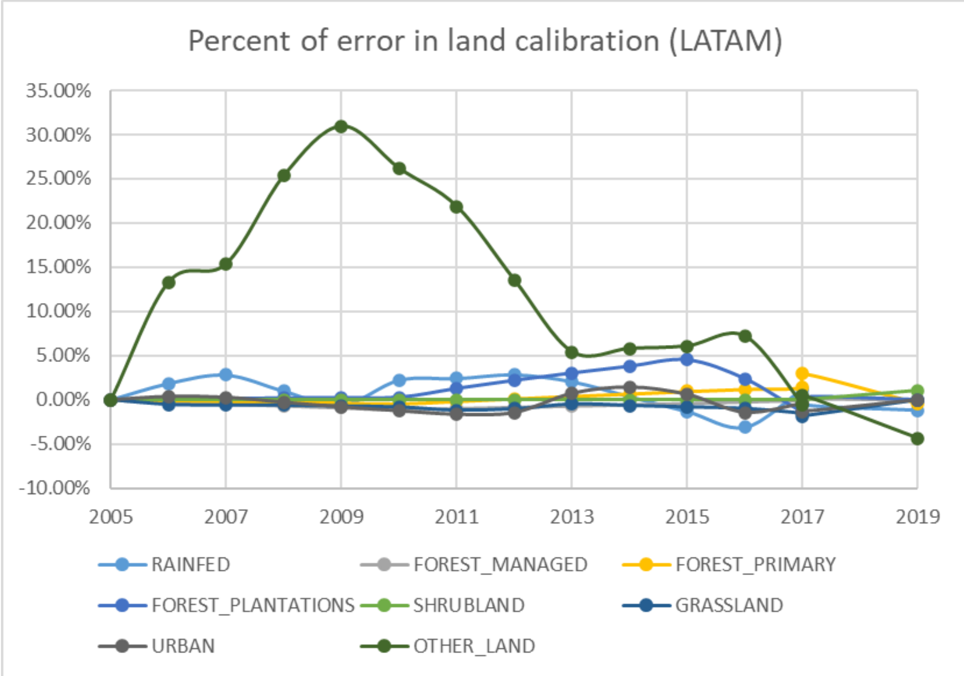

Figure 8. Percent of error between historical and simulated values of land uses in LATAM after the calibration.

RUSSIA

In Table 20 one can see the historical trends of land use change in Russia. Land areas vary very little in Russia. Table 21 shows the calibrated shares. The error between the historical and the simulated land use areas after the calibration are shown in Figure 9. Although the relative error forest plantations reaches 8%, its absolute value is very small and reaches no significance.

Table 20. Russia initial and calibrated land use trend demands

	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
RUSSIA Initial trends of land demand (km2/Year)	63.0	-162.0	1226.0	0.0	995.0	7507.0	-34.0	0.0	341.0	0.0	-509.0	-9427.0
RUSSIA calibrated trends of land demand (km2/Year)	62.9	-162.1	1225.8	1404.0	1100.0	0.0	0.0	0.0	341.1	0.0	0 0	0.0

Table 21. Russia calibrated matrices of shares of land use changes from others

Calibrated shares of land use changes from others (RUSSIA)												
share of --> that comes from:	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
RAINFED	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.64	0.00	0.00
IRRIGATED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FOREST_MANAGED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.03	0.00	0.00
FOREST_PRIMARY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FOREST_PLANTATIONS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
SHRUBLAND	0.50	0.00	0.50	0.00	0.50	0.00	0.00	0.00	0.12	0.02	0.00	0.00
GRASSLAND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.02	0.00	0.00
WETLAND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
URBAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOLAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNOW_ICE_WATERBODIES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OTHER_LAND	0.50	0.00	0.50	0.00	0.50	0.00	1.00	0.00	0.04	0.26	0.00	0.00

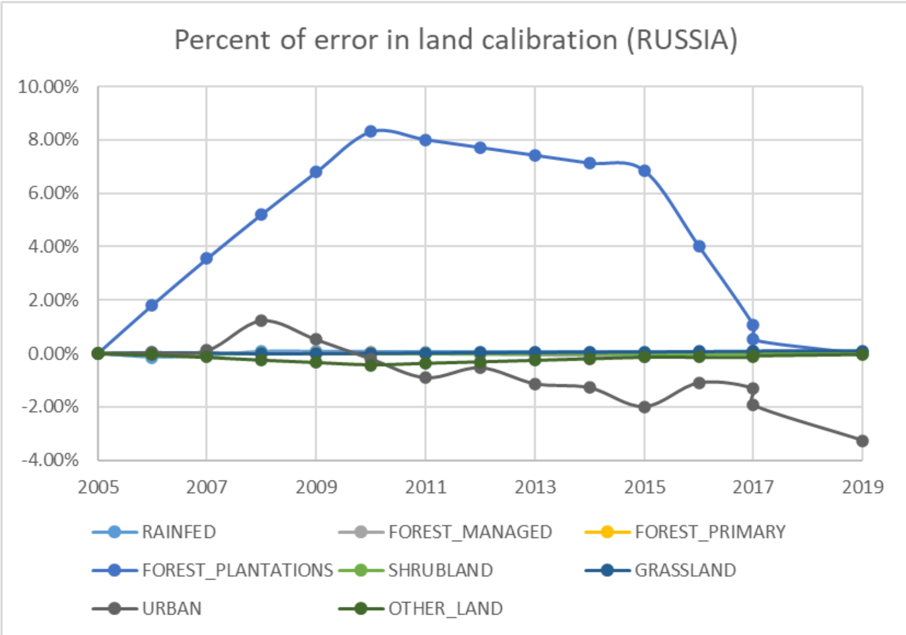

Figure 9. Percent of error between historical and simulated values of land uses in Russia after the calibration.

USMCA

In Table 22 one can see the historical trends of land use change in USMCA. Table 23 shows the calibrated shares. USMCA shows a loss of rainfed cropland that seems to go to the uses that showed increases (forest, shrubland). Making this assumption the error between the historical and the simulated land use areas after the calibration are shown in Figure 10 and reaches a small value.

Table 22. USMCA initial and calibrated land use trend demands

	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
USMCA Initial trends of land demand (km2/Year)	-10225.0	744.0	-5936.0	-1057.0	6813.0	4214.0	-5585.0	0.0	2131.0	0.0	595.0	8306.0
USMCA calibrated trends of land demand (km2/Year)	-12000.0	744.1	0.0	0.0	6813.0	0.0	-5584.6	0.0	2130.9	0.0	0.0	0.0

Table 23. USMCA calibrated matrices of shares of land use changes from others

Calibrated shares of land use changes from others (USMCA)												
share of --> that comes from:	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
RAINFED	0.00	1.00	0.30	0.00	0.30	0.00	0.00	0.00	0.40	0.22	0.00	0.00
IRRIGATED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FOREST_MANAGED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.13	0.00	0.00
FOREST_PRIMARY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FOREST_PLANTATIONS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00
SHRUBLAND	0.25	0.00	0.30	0.00	0.30	0.00	0.00	0.00	0.24	0.34	0.00	0.00
GRASSLAND	0.00	0.00	0.40	0.00	0.40	0.00	0.00	0.00	0.16	0.17	0.00	0.00
WETLAND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
URBAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOLAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNOW_ICE_WATERBODIES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OTHER_LAND	0.75	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.03	0.00	0.00	0.00

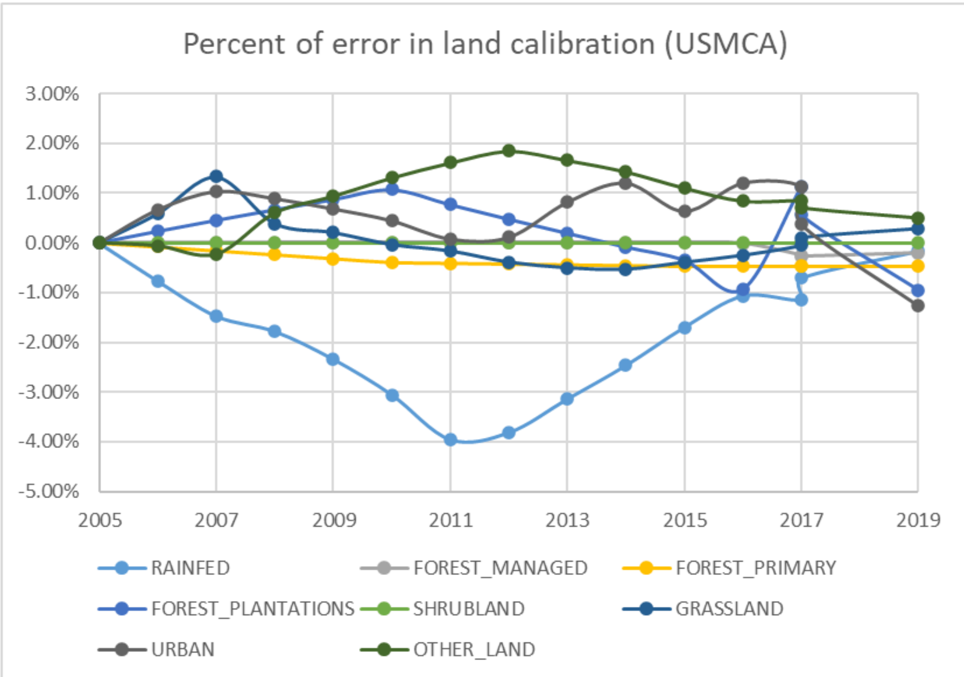

Figure 10. Percent of error between historical and simulated values of land uses in USMCA after the calibration.

LROW

In Table 24 one can see the historical trends of land use change in LROW, that shows a large cropland expansion that can explain the losses of managed and primary forests. Table 25 shows the calibrated shares. The errors are below 6% and can be assumed.

Table 24. LROW initial and calibrated land use trend demands

	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
LROW Initial trends of land demand (km2/Year)	28841.0	-7048.0	-50912.0	-12302.0	3430.0	-4258.0	######	0.0	2872.0	0.0	-2231.0	66945.0
LROW calibrated trends of land demand (km2/Year)	14000.0	-7048.2	-37000.0	-7000.0	3429.7	0.0	######	0.0	2872.4	0.0	0.0	0.0

Table 25. LROW calibrated matrices of shares of land use changes from others

Calibrated shares of land use changes from others (LROW)												
share of --> that comes from:	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
RAINFED	0.00	1.00	1.00	1.00	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00
IRRIGATED	1.00	0.00	0.00	0.00	0.54	0.54	0.08	0.08	0.00	0.00	0.00	0.00
FOREST_MANAGED	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FOREST_PRIMARY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FOREST_PLANTATIONS	0.70	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SHRUBLAND	0.00	0.00	0.00	0.00	0.09	0.09	0.02	0.02	0.00	0.00	0.00	0.00
GRASSLAND	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WETLAND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
URBAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SOLAR	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00
SNOW_ICE_WATERBODIES	0.00	0.00	0.00	0.00	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00
OTHER_LAND	0.00	0.00	0.00	0.00	0.20	0.20	0.08	0.08	0.00	0.00	0.00	0.00

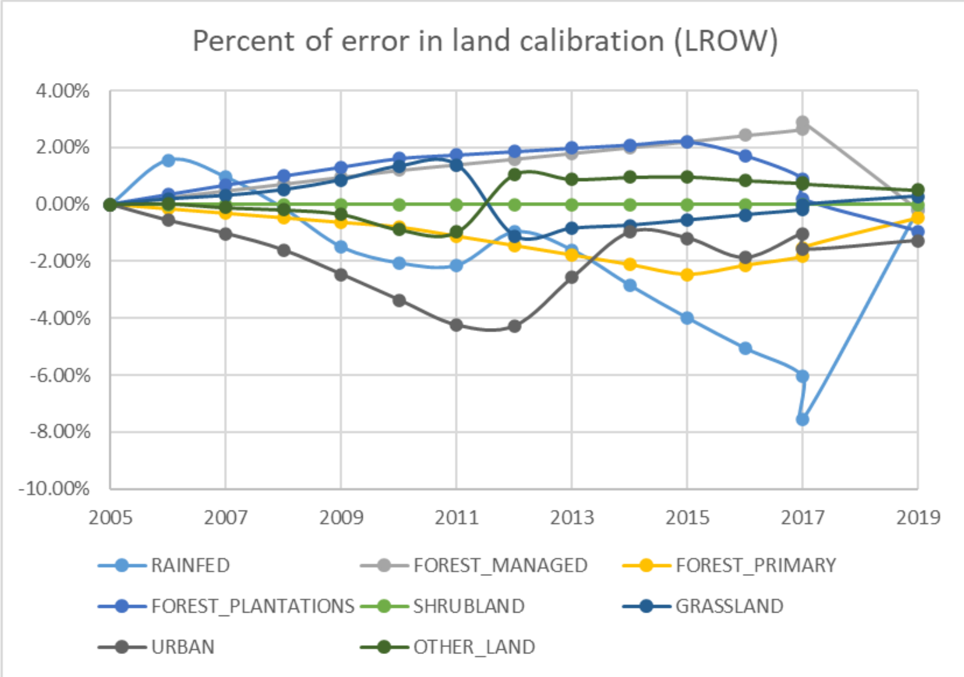

Figure 11. Percent of error between historical and simulated values of land uses in LROW after the calibration.

The future trends of land expansion used in the model when the historical period ends are not necessarily the same as the historical ones, since some uses show clear rupture of the past trends. The trends used after the historical data are shown in table 26.

Table 26. Trends of land expansion used in the simulation of the model after the historical period

TRENDS OF FUTURE LAND DEMAND BY REGION	RAINFED	IRRIGATED	FOREST_MANAGED	FOREST_PRIMARY	FOREST_PLANTATIONS	SHRUBLAND	GRASSLAND	WETLAND	URBAN	SOLAR	SNOW_ICE_WATERBODIES	OTHER_LAND
REGIONS_I|LANDS_I	[Mm2/Year	[Mm2/Year]	[Mm2/Year]	[Mm2/Year]	[Mm2/Year	[Mm2/Y€	[Mm2/Y€	[Mm2/Y	[Mm2/Y€	[Mm2/Y€	[Mm2/Year]	[Mm2/Yea
EU27	0	0	0.00112702	0	0.003515	0	0	0	0.0007	0	0	0
UK	0	0	0	0	0.000125	0	0	0	1E-05	0	0	0
CHINA	0.004	0.00342736	0.01	0	0.013933	0	0	0	0.0039	0	0	0
EASOC	0.015551	9.0001E-05	0	0	0.00364	0	0	0	0.0013	0	0	0
INDIA	0	0	0.000484	0	0.001533	0	0	0	0.0007	0	0	0
LATAM	0.008	0.00193252	-0.03	0	0.004762	0	0	0	0.0006	0	0	0.04
RUSSIA	6.29E-05	-0.0001621	0.00122584	0.001404	0.0011	0	0	0	0.0003	0	0	0
USMCA	0	0.00074409	0	-0.001057	0.006813	0	0	0	0.0021	0	0	0
LROW	0.028841	0	-0.0509123	-0.012302	0.001715	0	0	0	0.0029	0	0	0.044

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