LAND DEGRADATION AND FOOD SECURITY: IMPACTS AND ADAPTATION OPTIONS

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Abstract

Land degradation is estimated to affect more than a quarter of the global land area. Together with climate change, land degradation is expected to increase the risk of food security in many regions of the world. Land degradation reduces the quality of the soil, which declines crop yields, production volumes and farming incomes. We use the global computable general equilibrium model ENGAGE to assess the potential economic impacts of land degradation across countries and across sectors. The ENGAGE model has been specially designed to assess agricultural and land use policies. It includes agro-ecological zones, first generation biofuels and irrigation. The relationship between soil nutrients losses and crop yields is modelled at the global scale by the biophysical crop model EPIC-IIASA. The results show that if the natural nutrients in the soil are not replaced with fertilisers or natural sources crop yields decline. This depletion of nutrients leads to nutrient mining compromising the long-term sustainability of agricultural systems and declining the economic benefits. Economic losses due to land degradation are considerable in developing countries, thus integrating to the policy mix adaptation strategies tackling land degradation is crucial for regional and global food security.

Keywords: Computable General Equilibrium, Irrigation, Water Policy

JEL classification: D58, Q17, Q25

1 Introduction

Land degradation is estimated to affect more than a quarter of the global land area. Together with climate change, land degradation is expected to increase the risk of food security in many regions of the world (IPCC 2019). Land degradation reduces the quality of the soil, which declines crop yields, production volumes and farming incomes. Land degradation and climate

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change are interlinked processes. Recent literature suggests that land degradation has the potential to influence the magnitude and direction of climate impacts and the effectiveness of adaptation options (Webb et al. 2017).

There are several causes for land degradation. In this study, we focus on land degradation through soil nutrient depletion by water erosion and nutrient uptake through crops. Water erosion degrades the soil structure and washes away the topsoil, which reduces the availability of nutrients to crops. In addition, soil nutrient depletion can be caused by a mismatch between an excessive uptake of soil nutrients through crops and insufficient replenishment of soil nutrients through natural and artificial fertilizer (Smaling et al. 1997). One of the most comprehensive assessments on global land degradation identifies water erosion as the main cause, which is responsible for more than half of global land degradation (Oldeman et al. 1991, Nkonya et al 2011).

While several studies estimate the magnitude of land degradation processes, such as the amount of global soil loss due to water erosion (Borrelli et al., 2017; Doetterl et al., 2012), not much attention has been given to the impact of land degradation processes on global crop yields. Recent studies use response functions to estimate the loss in crop yields as a function of the share of the total agricultural area with severe erosion (Sartori et al. 2019). However, response functions provide only an indication of the potential change using simplified, linear estimates of complex and non-linear erosion-crop productivity relationships.

In this study, we simulate water erosion, changes in soil nutrient stocks and the daily growth of maize using the IIASA global-gridded version of the Environmental Policy Integrated Climate (EPIC) crop model. This enables us to consider the impacts of crop management on water erosion and nutrient stocks, as well as to estimate the impact of nutrient depletion on maize yields based on daily changes in weather, soil properties and vegetation cover. Our methodology soft-links the global gridded EPIC-IIASA crop model with the global computable general equilibrium model ENGAGE-land to estimate the long-term economic impacts of land degradation and climate change under different managements scenarios. We use the Environmental Global Applied General Equilibrium (ENGAGE) model to assess the potential macro-economic impacts of maize yield losses due to land degradation and climate change across countries and across sectors. The ENGAGE-land model has been specially designed to assess agricultural and land use policies. It includes agro-ecological zones, first generation biofuels and irrigation.

2 Global water erosion, soil nutrient balance and agricultural productivity modelling

2.1. The EPIC-IIASA model

The Environmental Policy Integrated Climate (EPIC) crop model was developed in the early 1980s in the United States to assess the impact of erosion on soil productivity and later extended to a complex model of cropping systems (Williams, 1990). Today EPIC can simulate the daily growth and development of a wide range of crops responding to changes in climate, soil processes and field management. EPIC includes a detailed representation of water and nutrient cycling, soil processes including water erosion and the impacts of tillage on soil properties.

EPIC-IIASA is a modelling framework developed by the International Institute for Applied Systems Analysis (IIASA), which integrates EPIC in a global-gridded data infrastructure providing global data on soil, topography, daily weather and field management. The resolution of the 131,326 grids upon which the EPIC model is run is ranging between 5' x 5' and 30' x 30' (approximately 9 km to 56 km near the equator). Soil and topography data are provided at the basic resolution of 5' x 5', spatially aggregated based on similar topography and soil classes and intersected with country boarders. These are further intersected with a 30' x 30' climate grid, the resolution at which global gridded climate data are available. Each simulation unit is represented by one field combining the most common site characteristics of the respective grid. Slope length and field size of the representative field and the simulation of conservation practices such as terracing and contour ploughing are based on the most common slope per simulation unit derived from a global terrain slope database (IIASA/FAO, 2012). Bias-corrected weather parameters from representative concentration pathways (RCP) are taken from the HadGEM2 RCP 2.6 and 8.5 datasets covering the years 2005 – 2099 (Hempel et al. 2013). Both datasets represent two contrasting climate scenarios and are used to bracket predictions of weather parameters. Soil information is taken from the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012), and topography from USGS GTOPO30 (USGS, 1997).

Crop management in each simulation unit is based on reported growing seasons (Sacks et al., 2010) and spatially explicit nitrogen and phosphorus fertilizer application rates (Mueller et al., 2012). In between growing seasons, cover crops are simulated determined by the main Koeppen-Geiger regions (Kottek et al., 2006). In tropical regions, grass cover in between maize and wheat seasons represents soil cover from a year-round growing season. In arid regions, no grass cover is simulated in between growing seasons due to limited water supply. In temperate and snow regions, both soil cover throughout the year and bare soil in winter seasons is simulated. Maize and wheat are simulated under irrigated and rainfed conditions and three tillage scenarios representing conventional, reduced and no-tillage, which differ in their amount of cultivation operations, tillage depth, surface roughness and the amount of plant residues left after harvest. On slopes steeper than 5%, we considered only rainfed agriculture, as hilly cropland is irrigated predominantly on terraces that prevent water runoff.

3 Global economic modelling

3.1. The ENGAGE-land model

The Environmental Global Applied General Equilibrium (ENGAGE) model is a standard multi-sectoral, multi-region, dynamic computable general equilibrium model. The ENGAGE model was developed at UCL for the analysis of energy, environmental, resource and economic policies (Winning et al. 2017; Nechifor et al. 2019). ENGAGE is based upon standard Walrasian general equilibrium assumptions such a market clearance, zero profits, and utility maximisation/cost minimisation of representative agents. All industries are modelled through a representative firm, which maximizes its profits in perfectly competitive markets. The production functions of each economic sector to create a level of sectoral output are specified using a series of nested constant elasticity of substitution (CES) functions. Domestic and foreign inputs are not perfect substitutes and therefore are modelled using the "Armington assumption", which accounts for product heterogeneity between different world regions. A representative consumer in each region receives household income, defined as the service value of national primary factors. The national income is allocated between aggregate household consumption, public consumption and savings. A money metric measure of economic welfare, the equivalent variation, can be computed from the model output.

ENGAGE uses national accounts data and a system of non-linear equations to solve for a baseline equilibrium against which policy shocks can be implemented. ENGAGE uses the latest GTAP database as a main data source, which is combined and enhanced with other databases (e.g. EXIOBASE, FAO). The ENGAGE model is written in GAMS and based upon the GTAP9inGAMS model in MPSGE developed by Lanz and Rutherford (2016).

A detailed land use version of ENGAGE is used here to assess the impact of climate change and land degradation on global agriculture. The ENGAGE-land model includes agro-ecological zones (AEZ) to represent land heterogeneity, as each AEZ is characterised by its particular climate, soil and landform conditions, which are basic for the supply of water, energy, nutrients and physical support to plants. We use GTAP LULC v9 data (Lantz 2017) where AEZ are created combining information on length of growing period and thermal climate from FAO/IIASA GAEZ v.3 (2012). Thus, within each region and AEZ, land is allocated to different uses according to a series of nested constant elasticity of transformation (CET) functions, where the easy of the transformation between different land uses depends on the elasticity of transformation. We adopted a similar approach as Calzadilla et al. (2016) with a three-level nesting structure. In the first level, land is allocated between land for agriculture and managed forest. In the next level, agricultural land is allocated between pasture and crops. At the top level, crop land is allocated between rice, sugar cane/beet and annual crops (wheat, cereal grains and other crops). At each level, the elasticity of transformation increases, recognising that land is more likely to be mobile between crops than between forestry and agriculture. Figure A1 in the Annex represent graphically the land transformation function in ENGAGE-land.

First generation biofuels are included in ENGAGE-land, as their production based on traditional food and feed crops has direct relevance for food security (Ewing and Msangi 2009; Al-Riffai et al. 2010; Zhang et al. 2013). Food security policies and biofuel policies are interlinked and their effects need to be studied in a holistic approach, prioritising food security and the right to food when designing biofuel policies (HLPE 2013). We use the DART-BIO database (Calzadilla et al. 2016) which includes: a) ethanol production from sugar cane/beet, wheat, maize and other grains, b) biodiesel production from palm oil, soybean oil, rapeseed oil and other oilseed oils, and c) dried distillers grains with solubles (DDGS) and oilseed meals and cakes, by-products generated during the production process of ethanol and the vegetable oil industry, respectively. ENGAGE-land use this detailed database to represent in a simple but meaningful manner biofuel production and policies.

ENGAGE-land is calibrated to the GTAP9a database (Aguiar et al. 2016), which represent the global economy in 2011. The current version of ENGAGE-land has 23 regions, 25 sectors and 21 factors of production (see Table A1 and A2 in the Annex). The model solves recursively for the period 2011 to 2050.

3.2. Baseline simulation

Our analysis combines crop and economic modelling to project the long-term impacts of climate change and land degradation on global food production. These impacts are based on future scenarios regarding crop management practices and different climate, economic, and policies pathways. Section 2 describes in detailed the scenarios used in the EPIC-IIASA crop model, this section focuses on the assumptions behind the *baseline simulation* in the economic model. Baseline or business as usual simulations are used in economic models as a reference against which alternative scenarios are compared.

As most of the global macro-economic models, ENGAGE-Land is calibrated to represent the regional GDP and population growth behind the SSP2 “middle of the road” scenario (van Vuuren et al., 2014). This is achieved by changing exogenously total factor productivity, labour supply and population in each region. The sector-specific changes in total factor productivity account for structural changes in the regional economies and are based on the OECD ENV-growth model (Dellink et al. 2017).

In addition, the *baseline simulation* in ENGAGE-land includes changes in agricultural area according to the Food and Agriculture Organization’s long term baseline outlook (Alexandratos and Bruinsma 2012). The data shows that global crop area is expected to increase by around 7%. Expansion of arable land will continue to be an important source of agricultural growth in sub-Saharan Africa, Latin America and East Asia.

Besides the above assumptions, the *baseline simulation* assumes that all other macro-economic and agricultural policies currently in place would not change in the future. In addition, the SSPs scenarios do not account for explicit climate change adaptation or mitigation polices. In fact, the SSPs, by design, do not include the effects of climate change on socio-economic and bio-physical systems (O’Neill et al., 2014).

3.3. Results

Global agricultural production more than doubles between 2011 and 2050 in response to expansion of agricultural area, crop productivity assumptions, and population and income growth. Global agricultural commodities prices increases by around 27% reflecting an increase in production costs which includes intermediate inputs and factor inputs. Compared with current literature, these *baseline simulation* results fall in the upper bound of the reference scenario in the AgMIP model comparison study (von Lampe et al. 2014), where global agricultural production increases between 60% and 111% for the period 2005-2050, and global agricultural price ranges from a decline of 15% to an increase of 39% (von Lampe et al. 2014).

At the regional level, sub-Saharan Africa, the Middle East & North Africa, and Latin America have the largest increase in agricultural production (Figure 1). This is mainly driven by the growth in their domestic demand and the fast growth in agricultural productivity to close the yield gap. Agricultural prices in sub-Saharan Africa and the Middle East & North Africa decline slightly compared to the 2011 level. In Europe and Japan the increase in agricultural production and prices is modest, as the internal demand for food declines with population. The effect of reduced demand is expected to be stronger in Russia—the only country with a decline in agricultural production.

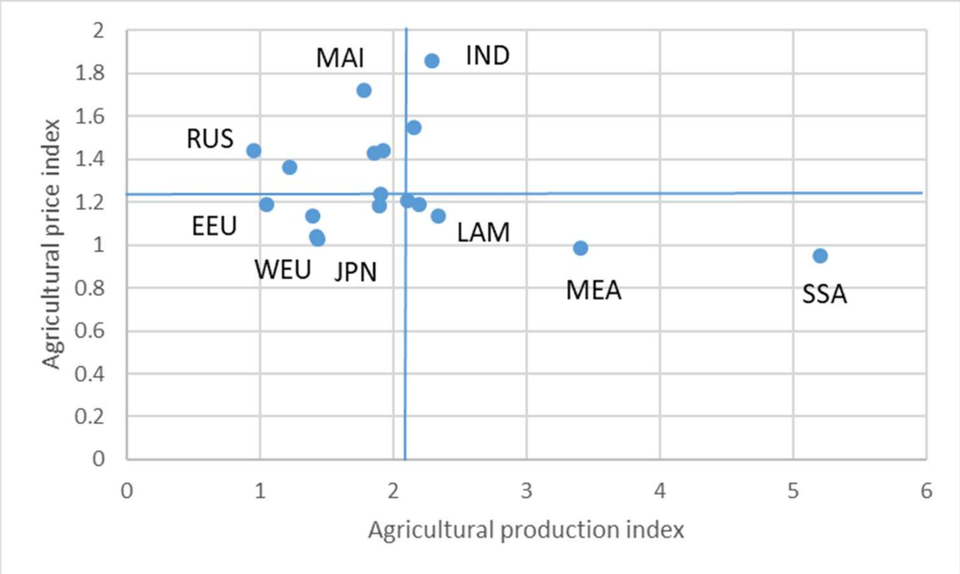

Figure 1. Regional producer price and production indexes for 2050 (2011=1) (*Baseline simulation*)

Source: ENGAGE-land, model results.
Note: Western Europe (WEU); Eastern Europe (EEU); USA (USA); Canada (CAN); Australia, New Zealand (ANZ); Japan (JPN); Russia (RUS); Rest of Former Soviet Union and Europe (FSU); Brazil (BRA); Paraguay, Argentina, Uruguay, Chile (PAC); Rest of Latin America (LAM); China (CHN); India (IND); Malaysia, Indonesia (MAI); South East Asia (SEA); Middle East, North Africa (MEA); Sub-Saharan Africa (AFR); Rest of the World (ROW).

4 Economic impacts of climate change and land degradation

4.1. Scenarios

Two alternative climate change scenarios are used to reflect different challenges to agricultural systems. The global EPIC-IIASA crop model uses climate model data produced according to the Representative Concentration Pathways (RCPs) 2.6 and 8.5. The RCPs outline alternative scenarios for the concentration of CO_2, other GHGs and pollutants in the atmosphere by the year 2100 (van Vuuren et al., 2011). RCP 2.6 is the lowest concentration pathway, which assumes that emissions peak between 2010 and 2020 and decline substantially thereafter. The highest concentration pathway is represented by the RCP 8.5, which is characterised by significantly increasing CO_2 and GHG emissions. For both climate scenarios, crop yields are estimated with and without the CO_2 fertilization effect, which can counteract some of the negative impacts of climate change.

Soil management practices play a key role determining soil conservation and have a significant impact on land degradation. Three tillage management scenarios directly connected to land degradation are assessed in EPIC-IIASA. The *conventional tillage scenario* represents a business as usual situation where farmer's practices may have an adverse effect on long-term soil productivity due to erosion and loss of organic matter. The *reduced tillage scenario* diminish the soil disturbance by decreasing cultivation operations, tillage depth and surface roughness. The *no-tillage scenario* is a minimum tillage practice in which the crop is sown directly into soil not tilled since the harvest of the previous crop. Based on these three tillage management scenarios, maize yield declines due to the resulting land degradation are calculated in EPIC-IIASA. As opposed to climate change impacts that affects all agricultural crops, land degradation impacts are only assessed for maize.

The global gridded data has been aggregated to the ENGAGE-land regions and AEZs to carry out an economy-wide assessment of the impacts on climate change and Land degradation. Yields were aggregated using the MIRCA2000 growing areas as a weighting factor (Portmann et al. 2010). Figure 2 shows random examples of the input data used in ENGAGE-land. Yield changes were calculated as the average for the 31-year period centred on the given year (i.e. yields in 2050 represent the average for the 2035-2065 period). The Figure shows that climate change impacts are unevenly distributed. While some areas have mild changes in maize yields (Mexico and India) and even positive impacts in the short-term (USA, Ethiopia), others are badly affected (Brazil, Ukraine) under the RCP 2.6 scenario with CO_2 fertilization effect. In both climate change scenarios, CO_2 fertilization improves maize yields, and it does more in the long-term and *RCP 8.5* CO_2 *scenario*. With a stronger climate change scenario (RCP 8.5), maize yields declines in all selected areas, except in some AEZs in Brazil and Australia.

The decline in yields driven by land degradation, through water erosion and nutrient uptake by crops, are more evident in developing countries, as these countries cannot compensate for nutrient loss through fertilizer application. Maize yields in the US are more stable, as result of fertilizer management practices. Sustainable soil management practices, assessed under the *no-tillage scenario*, help to reduce the negative impact on yields caused by land degradation, as soil nutrient stocks are replenished through crop residues and less nutrients are lost due to reduced soil disturbance.

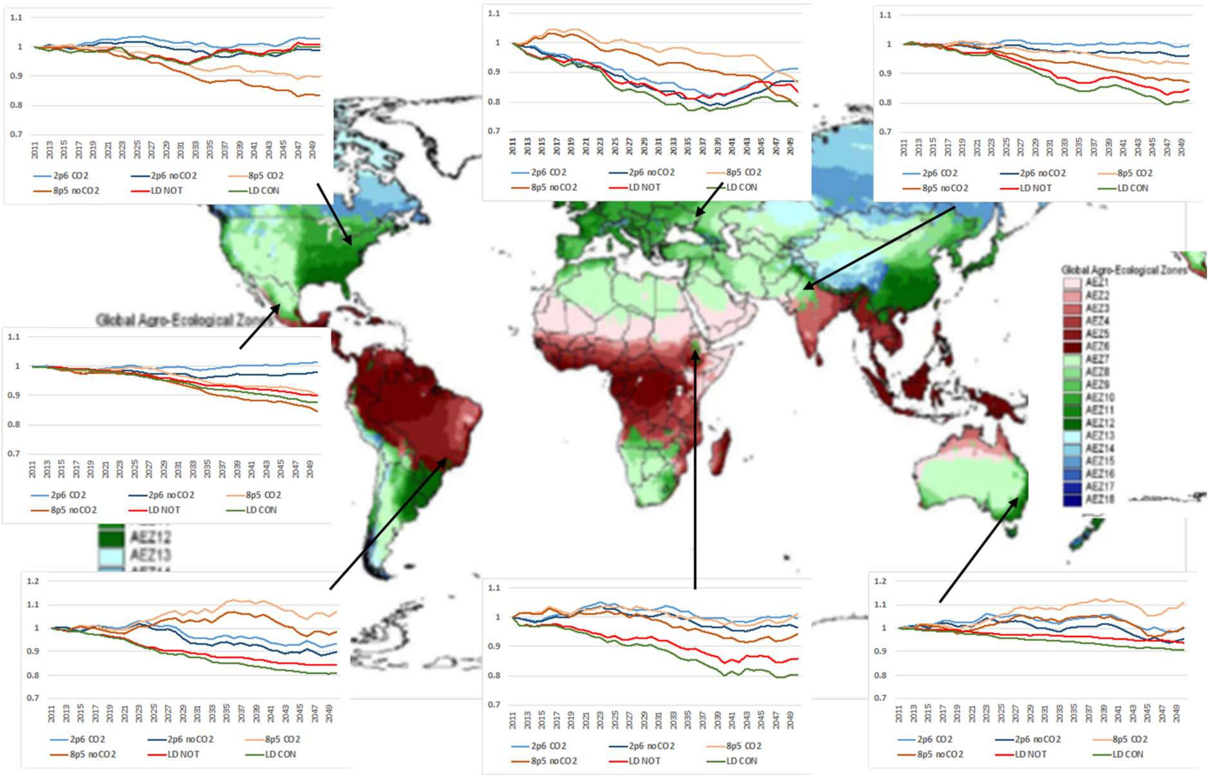

Figure 2. Maize yield changes due to climate change and land degradation for selected AEZs (ENGAGE-land inputs)

Source: Based on EPIC-IIASA model results.

4.2. Results

As most Integrated Assessment Models, ENGAGE-land results show a decline in agricultural production and increase in food prices under both climate change scenarios. Figure 3 shows for the main 5 crops (maize, rice, wheat, oil seeds and sugar cane/beet) that global production declines and food price increases in all climate change scenarios with the exception of the RCP 2.6 with CO_2 fertilization—as the CO_2 fertilization effect on plant growth more than compensate the adverse impacts of a moderate climate change scenario. Under the *RCP 8.5 no CO_2 scenario*, global production declines by 5.6% and the average food price increases by 17.5%. These impacts are in line with the AgMIP model comparison that reports an average increase in international producer prices by around 20% (von Lampe et al. 2014).

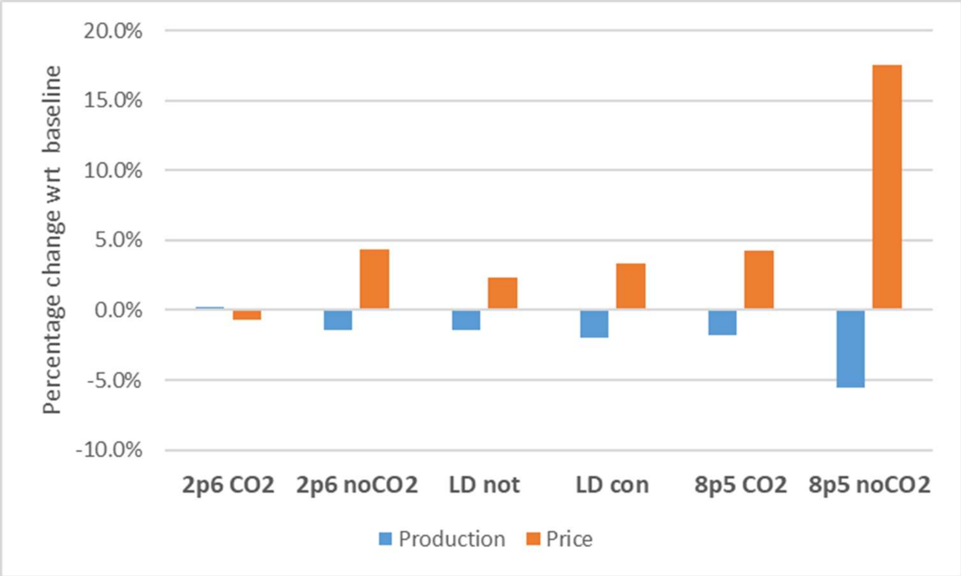

Figure 3. Changes in global average price and production for five main crops in 2050 due to climate change and land degradation

Source: ENGAGE-land.

At the crop level, production, under the *RCP 2.6 no* CO_2 *scenario*, decreases between 0.6% (plant-based fibres) and 2.4 % (rice), and price increases between 0.8% (plant-based fibres) and 9.3% (rice) (Figure 4). The impact on production and prices is amplified under the *RCP 8.5 no* CO_2 *scenario*. Production declines between 0.5% (plant-based fibres) and 7.6% (rice), and prices increases between 8.5% (wheat) and 30.7% (rice). As annual crops (wheat, cereal grains and other crops) can be easily switch in a parcel of land, its production and price changes are smaller compared to more immobile crops such as rice or sugar cane/beet.

Figure 4 also shows production and price changes for downstream sectors. It gives an economy-wide perspective of the impacts of climate change on crop production. Outdoor and indoor livestock are the sectors less affected by crop yield declines (production is expected to decrease by 2% and prices increase by more than 3%, under the *RCP 8.5 no* CO_2 *scenario*). The food industry and vegetable oils show moderate impacts (production declines by around 3% and prices increases by more than 5%). The sugar industry is the food-related sector with the largest decline in production and increase in prices (around 5% and 9%, respectively), as the sugar cane/beet sector is one of the most affected crops after rice.

Figure 4. Changes in global average price and production in 2050 due to climate change

Note: Paddy rice (pdr); wheat (wht); cereal grains (gro); vegetable & fruits (v_f); oil seeds (osd); sugar cane/beet (c_b); plant-based fibres (pbf); other crops (ocr); outdoor livestock (oilvs); indoor livestock (ilvs); food industry (fod); vegetable oils (vol); sugar (sgr).
Source: ENGAGE-land.

The impact of land degradation on maize yields is expected to decrease global maize production by 5.6% and increase global maize prices by 11% under the *conventional tillage scenario* (Figure 5). Under the *no-tillage scenario* impacts are smaller, 4.2% and 7.7% respectively, as soil conservation improves. Both land degradation scenarios are directly comparable to the *RCP 2.6 no* CO_2 *scenario*, as the land degradation scenarios do not consider dynamic CO_2 fertilization through an increase in atmospheric CO_2 and are based on the RCP 2.6 climate forcing. In terms of production and price changes, the *conventional tillage scenario* produce similar impacts as the *RCP 8.5 no* CO_2 *scenario*. This highlights the importance of including nutrient depletion through water erosion and nutrient uptake by crops, and other forms of land degradation to the analysis of global food security. As the impacts of land degradation considered in this paper are only assessed for maize, we could expect a multiplicative effect when including other crops to the analysis.

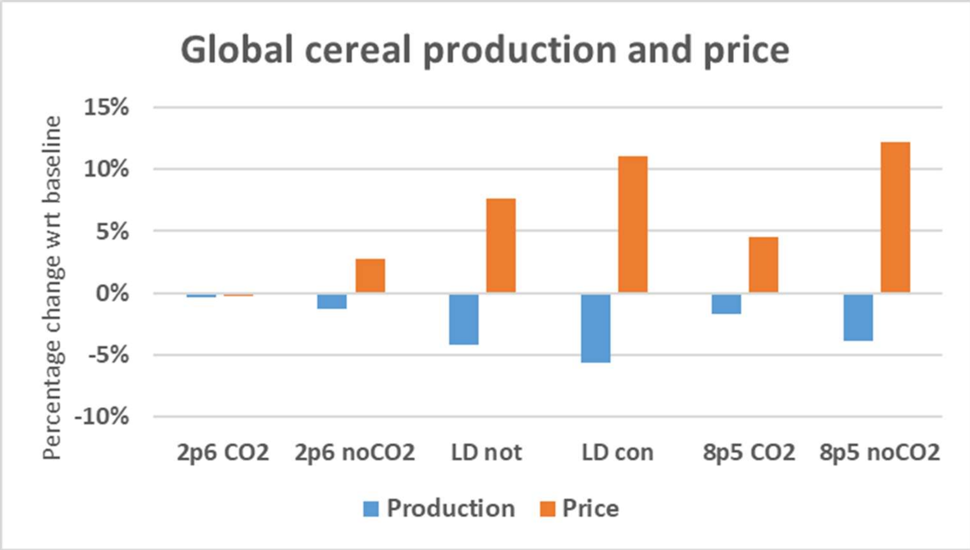

Figure 5. Changes in global average maize price and production in 2050 due to climate change and land degradation

Source: ENGAGE-land.

At the regional level, climate change impacts on crop production are unevenly distributed. South East Asia, sub-Saharan Africa, the Middle East & North Africa, and Latin America are adversely affected under the *RCP 2.6 no* CO_2 *scenario*, whereas regions with temperate climates and in the boreal north see positive impacts (Figure 6, upper graph). Temperate regions where production is expected to increase will export more (Figure 6, lower graph). In fact, the relative increase in exports in these regions (with respect to the baseline) is larger than the relative increase in production (darker green areas in exports, Figure 6). The opposite occurs in regions where production is expected to decrease—exports decrease more than proportionally. Climate change, through its impacts on crop yields, generates new opportunity costs and modifies comparative advantages in food production. Trade patters will change across regions and countries responding to this new situation. Farmers in regions where production increases by climate change may experience a greater access to markets, while farmers in regions adversely affected by climate change may lose their market share, as they face lower yields and greater competition from elsewhere.

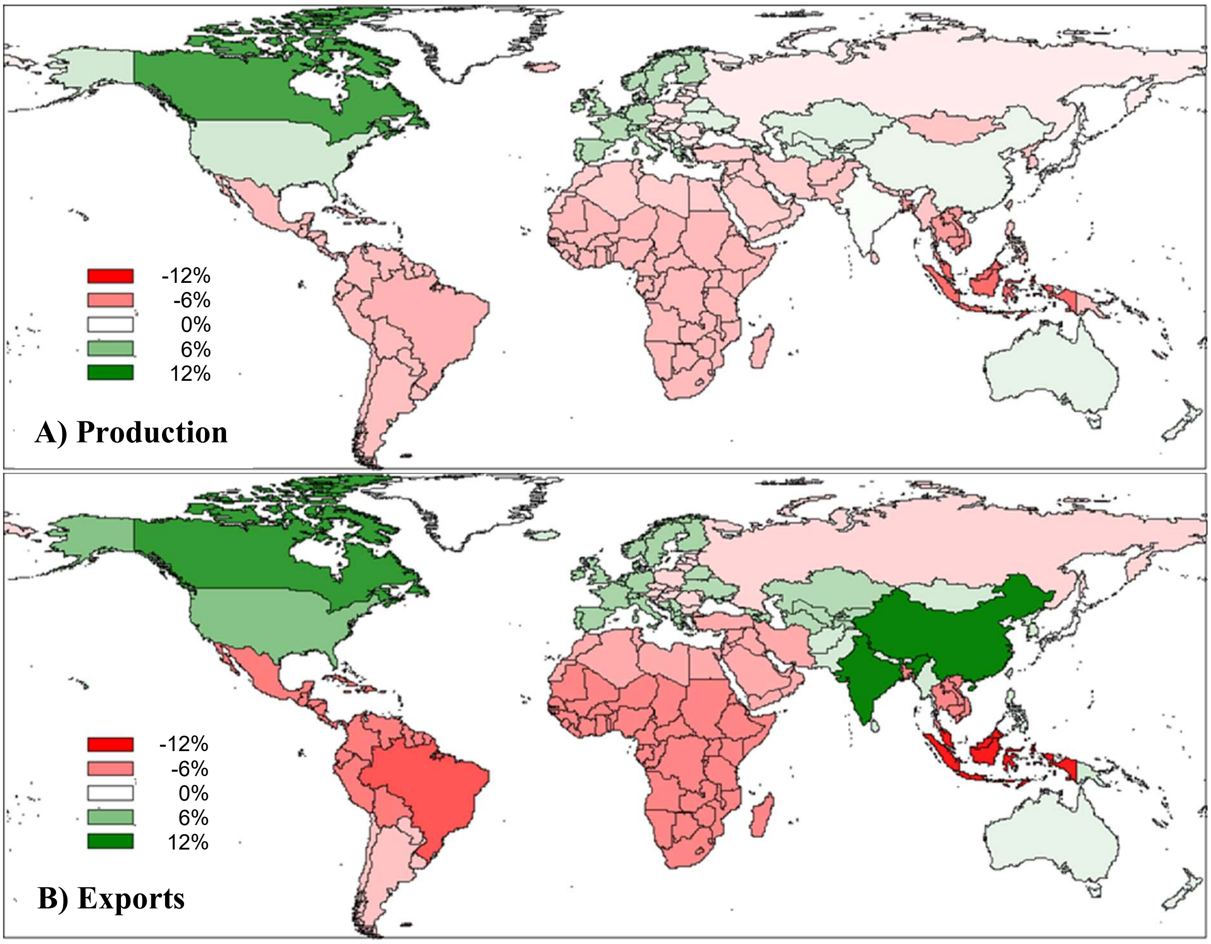

Figure 6. Changes in average production (A) and exports (B) for five main crops in 2050, *RCP 2.6 no CO_2 scenario* (percentage change with respect to baseline)

Source: ENGAGE-land.

This result highlights the role of international trade as an important mechanism of adaptation. In fact, global trade is expected to increase in both climate change scenarios, by 0.1% in the *RCP 2.6 no CO_2 scenario* and by 1% in the *RCP 8.5 no CO_2 scenario*. Although these effects are limited at the global, at the regional level both climate impacts on crop production and climate-induced changes in competitiveness are crucial factors to determine the overall economic gains and losses. Figure 7 shows that welfare gains are observed in regions with higher maize production and exports. Welfare gains are the largest in India (1.6% larger than in the *baseline simulation*) where producer gains driven by larger exports more than compensate consumer losses caused by a lower availability of food. In fact, Figure 6 shows a huge increase in exports in India of all five main crops. Welfare losses occur in regions where maize production and exports decline, an exception is the region "Rest of the World" where welfare gains are associated to higher exports of other crops.

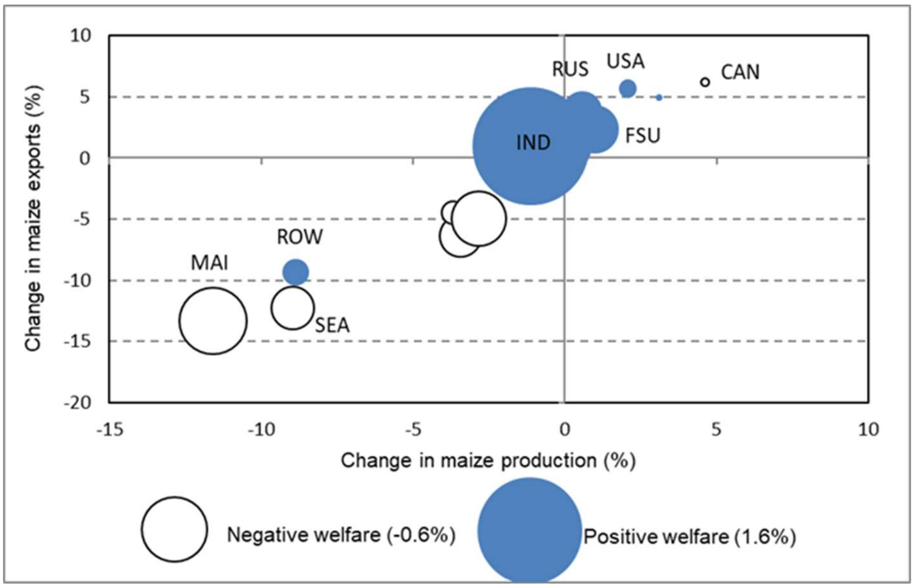

Figure 7. Changes in regional maize production and exports in 2050, *RCP 2.6 no CO_2 scenario* (percentage change with respect to baseline)

Note: Western Europe (WEU); Eastern Europe (EEU); USA (USA); Canada (CAN); Australia, New Zealand (ANZ); Japan (JPN); Russia (RUS); Rest of Former Soviet Union and Europe (FSU); Brazil (BRA); Paraguay, Argentina, Uruguay, Chile (PAC); Rest of Latin America (LAM); China (CHN); India (IND); Malaysia, Indonesia (MAI); South East Asia (SEA); Middle East, North Africa (MEA); Sub-Saharan Africa (AFR); Rest of the World (ROW).
Source: ENGAGE-land.

Land degradation impacts are considerable in developing countries, where the decline in soil nutrients are not compensated with fertilizers. Maize production is expected to decline mainly in Latin America, India and sub-Saharan Africa, while maize prices are expected to increase up to 30% under the *conventional tillage scenario* (Figure 8). With sustainable soil conservation practices, *no-tillage scenario*, the production losses and price increases are smaller in all regions. In the US, maize yields are almost unaffected by land degradation, as fertilizers compensate for soil nutrient loss. However, maize production in the US increases in both land degradation scenarios as a result of a greater access to international markets. With better soil management practices yield losses in developing countries are smaller and maize production in the US increases to a lower extent.

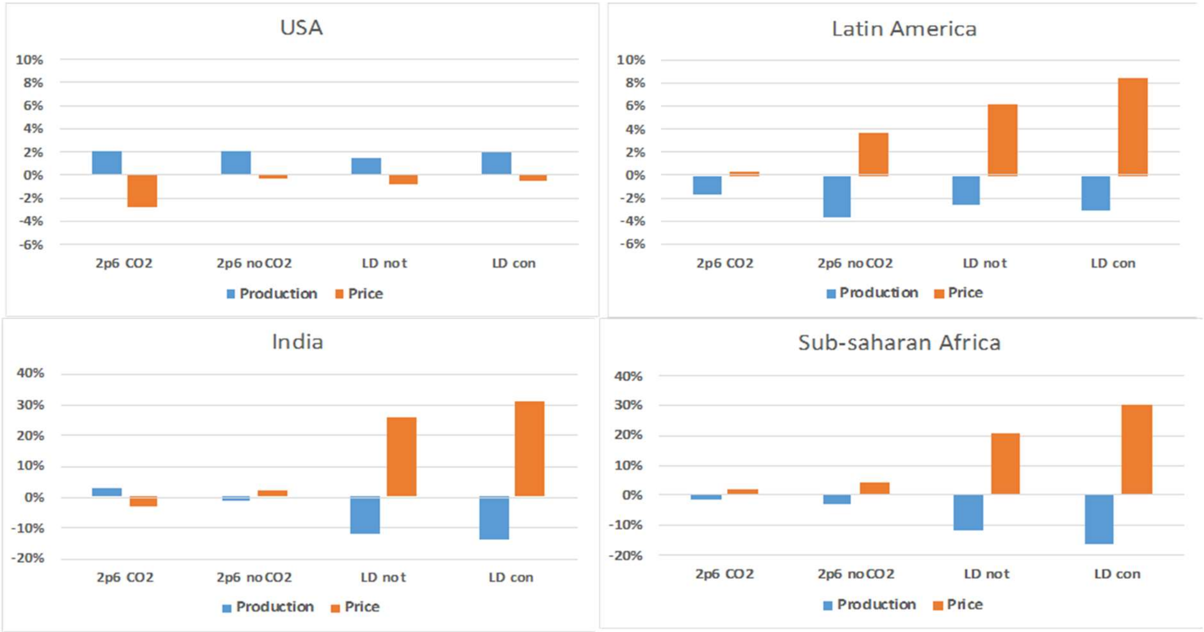

Figure 8. Changes in maize production and price in 2050 for selected regions (percentage change with respect to baseline)

Source: ENGAGE-land.

The impacts of land degradation on maize yields change food production and exports of the five main crops (Figure 9). Production in developing countries declines, especially in India, sub-Saharan Africa and Paraguay-Argentina-Chile-Uruguay (1.6%, 9% and 9.6%, respectively), while production in developed countries increases (up to 7.9% in the US) in the *conventional tillage scenario*. As mentioned above, food exports react more than proportionally, it declines more in India, Paraguay-Argentina-Chile-Uruguay and sub-Saharan Africa (12.3%, 13.3% and 18.1%, respectively) and increases mainly in Western Europe, Scandinavia and the US (8.9%, 9% and 22.5%, respectively).

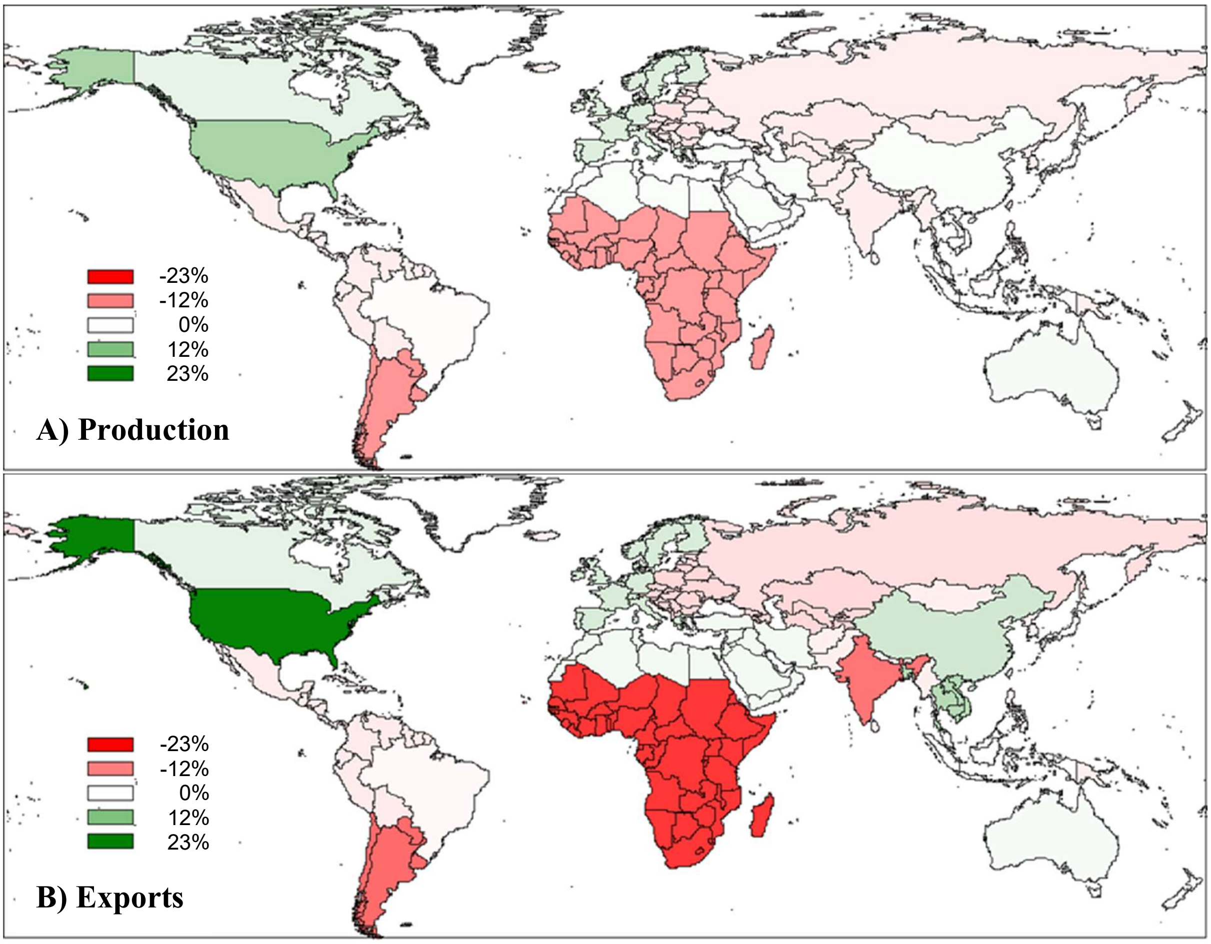

Figure 9. Changes in average production (A) and exports (B) for five main crops in 2050, *conventional tillage scenario*

Source: ENGAGE-land.

The combined impact of land degradation and climate change on global GDP losses are small, around 0.1% in the *conventional tillage scenario*. However, at regional level there are winners and losers, although the impacts are also modest. Most of the regional welfare gains observed in the climate change scenario (Figure 7) disappear when the impacts of land degradation are included (Figure 10). In fact, only the US and China have small positive welfare impacts in the *conventional tillage scenario*. Therefore, land degradation could significantly amplify the negative impacts of climate change.

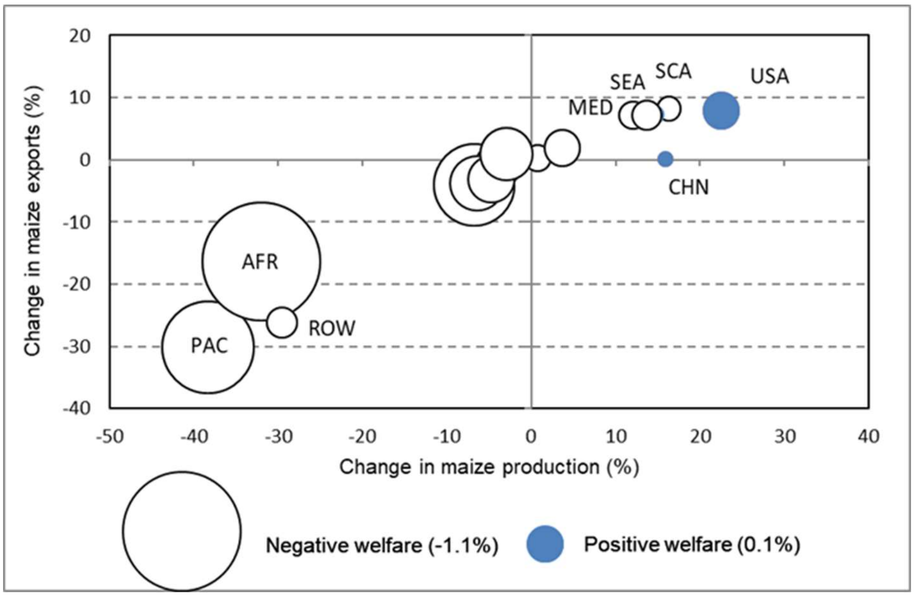

Figure 10. Changes in regional maize production and exports in 2050, *conventional tillage scenario* (percentage change with respect to baseline)

Note: Western Europe (WEU); Eastern Europe (EEU); USA (USA); Canada (CAN); Australia, New Zealand (ANZ); Japan (JPN); Russia (RUS); Rest of Former Soviet Union and Europe (FSU); Brazil (BRA); Paraguay, Argentina, Uruguay, Chile (PAC); Rest of Latin America (LAM); China (CHN); India (IND); Malaysia, Indonesia (MAI); South East Asia (SEA); Middle East, North Africa (MEA); Sub-Saharan Africa (AFR); Rest of the World (ROW).
Source: ENGAGE-land.

5 Discussions and conclusions

The simulated impact of water erosion on maize yields per country is strongly influenced by both environmental conditions such as precipitation intensity and slope steepness, and the intensity of fertilizer use. Our results show that the most vulnerable countries to land degradation are mostly located in the tropics, have a low fertilizer input and large area of hilly cropland facilitating water erosion. Maize yields in these countries are expected to decline by more than 10% due to land degradation at the end of the simulation period. The decline of maize yields in five of the most important maize producer countries is lower than 3 %, but due to their large market share they contribute a significant share of the total decline in global maize production. This low impact of nutrient depletion on crop yields in the most important maize producer countries is mainly the result of their large use of fertilizers.

Land degradation impacts are considerable in developing countries, where the decline in soil nutrients are not compensated through fertilizers. Maize production is expected to decline mainly in Latin America, India and Sub-Saharan Africa, while prices are expected to increase up to 30%. The decline in global cereal production and the increase in price in some land degradation scenarios are comparable to the worst-case climate change scenario analysed

(RCP 8p5, no CO_2 fertilization). Therefore, nutrient depletion could significantly amplify the impacts of climate change. As fertilizers, we observe that soil management practices play a key role on reducing the impacts of land degradation and lowering nutrient depletion. The combined impact of land degradation and climate change on global GDP losses are small, however at regional level there are winners and losers, with land degradation having a negative impact in most of the regions.

The results show that if the natural nutrients in the soil are not replaced with fertilisers or natural nutrient sources maize yields decline. This depletion of nutrients leads to nutrient mining, compromising the long-term sustainability of agricultural systems and declining the economic benefits. Economic losses due to land degradation are considerable in developing countries, thus integrating to the policy mix adaptation strategies tackling land degradation is crucial for regional and global food security.

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Annex

Table A1. List of regions and sectors in ENGAGE-land

18 Regions		24 Sectors	
WEU	Western Europe	pdr	Paddy rice
EEU	Eastern Europe	wht	Wheat
USA	USA	gro	Cereal grains
CAN	Canada	v_f	Vegetables fruit
ANZ	Australia New Zealand	osd	Oil seeds
JPN	Japan	c_b	Sugar cane/beet
RUS	Russia	pfb	Plant-based fibers
FSU	Rest of Former Soviet Union and rest of Europe	ocr	Other crops
BRA	Brazil	olvs	Outdoor livestock
PAC	Paraguay Argentina Uruguay	ilvs	Indoor livestock
LAM	Rest of Latin America	frs	Forestry
CHN	China	fod	Rest of food
IND	India	vol	Vegetable oils
MAI	Indonesia Malaysia	sgr	Sugar
SEA	South East Asia	fri	Forest related industry
MEA	Middle East North Africa	pcm	Processed animal products
AFR	Sub Saharan Africa	coa	Coal
ROW	Rest of the World	oil	Oil
		gas	Gas
		p_c	Petroleum coal products
		ely	Electricity
		crp	Chemical rubber plastic prods
		ets	Paper, minerals and metals
		oth	Other goods and services

Table A2. List of factors of production in ENGAGE-land

Agro-ecological zones (18)	
AEZ1	
AEZ2	
AEZ3	
AEZ4	
AEZ5	
AEZ6	
AEZ7	
AEZ8	
AEZ9	
AEZ10	
AEZ11	
AEZ12	
AEZ13	
AEZ14	
AEZ15	
AEZ16	
AEZ17	
AEZ18	
Other factors (3)	
LAB	Labor
CAP	Capital
RES	Natural resources

GTAP class	Moisture regime	Climate zone
AEZ1	Arid	Tropical
AEZ7	(LGP 0-59 days)	Temperate
AEZ13		Boreal
AEZ2	Dry semi-arid	Tropical
AEZ8	(LGP 60-119 days)	Temperate
AEZ14		Boreal
AEZ3	Moist semi-arid	Tropical
AEZ9	(LGP 120-179 days)	Temperate
AEZ15		Boreal
AEZ4	Sub-humid	Tropical
AEZ10	(LGP 180-239 days)	Temperate
AEZ16		Boreal
AEZ5	Humid	Tropical
AEZ11	(LGP 240-299 days)	Temperate
AEZ17		Boreal
AEZ6	Humid; year-round growing season	Tropical
AEZ12	(LGP >300 days)	Temperate
AEZ18		Boreal

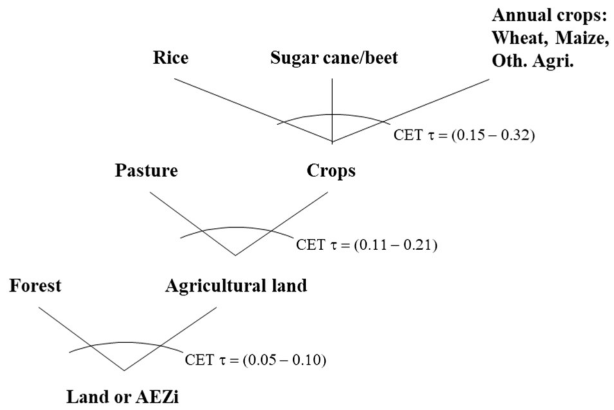

Figure 9. Land transformation function in ENGAGE-land