RED Versus REDD:

The Battle Between Extending Agricultural Land Use and Protecting Forest

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Abstract:

This paper analyses the complex battle between RED and REDD policies and the resulting global consequences on land use, agricultural production, international trade flows and world food prices. A key methodological challenge is the representation of land use and the possibility to convert forestry land into agricultural land as REDD policies might prevent the use of forestry and wood lands for agriculture. The paper introduces a flexible land supply function allowing large changes in the total potential land availability for agriculture due to environmental considerations such as reducing emissions from deforestation. The parameters of the new land supply function are defined as variables of the model. In the paper, we simplify the implementation of the REDD policies as a shift in potential availability for agricultural land in various regions in the world.

Both analysed policies are designed to save emissions but their land use impacts are opposite. The paper shows that global RED policies expand global land use with 3% relative to the baseline. Land abundant countries such as Canada, USA and Indonesia extend their use of agricultural land and their agricultural production. Severe REDD policies that protect all forest and woodlands in especially tropical land abundant regions such as Central and South America, South Africa and Indonesia imply a global reduction of agricultural land by 5% and lead to higher food and land prices. REDD policies reverse production and trade patterns as previous land abundant countries become land scarce countries.

Keywords:
RED, REDD, flexible land supply function, land, land use changes

1. Introduction

Since 2001, a rapid grow of biofuel production has been observed driven by Renewable Energy Directives (RED) and high crude oil prices as well as by growing interest in reducing Greenhouse-Gas-Emissions (GHG). Biofuel policies increase demand for agricultural land use and might lead to deforestation (see, Banse et al. 2008, Banse et al. 2011, Hertel et al. (2010). In recent years, estimates for deforestation and forest degradation were shown to account for 20-25% of greenhouse gas emissions, higher than the transportation sector (Myers, 2007). Recent work shows that the combined contribution of deforestation, forest degradation and peatland emissions accounts for about 15% of greenhouse gas emissions, about the same as the transportation sector (Werf, et al. 2009). Reducing Emissions from Deforestation and Forest Degradation (REDD, Bali, 2007) is a set of steps designed to reduce the emissions of greenhouse gases from deforestation and forest degradation.

Agricultural production and area expansion is a primary driver for tropical deforestation. REDD policies are designed to reduce deforestation and might limit the expansion possibilities of agricultural land use due to RED policies. The restriction of land by REDD policies might change comparative advantage and will influence competitiveness, agricultural prices, trade, production and land use impacts of RED policies across the world. Agricultural implications of REDD are not well understood and next to no analyses there has been little discussion in the policy debate.

This paper assesses the complex interplay between global renewable energy directives (RED) and deforestation policies (REDD) and the resulting global consequences on land use, agricultural production, international trade flows and world food prices. The impact of global biofuel directive is studied with and without a severe global REDD policy.

Rajagopal and Zilberman (2007: 48) state that 'biofuels affect not only farmers, but also affect agro-industries, the well-being of consumers, balance of trade, and the government budget. Understanding the impacts of biofuels on the overall economy requires a modelling framework that accounts for the feedback mechanisms between biofuels and other markets. The technique that would allow for an assessment of such effects is a computable general equilibrium (CGE) analysis' (Sadoulet and de Janvry, 1995). We use a global, multi-region, multi-sector CGE model as RED and REDD policies may transmit to other areas of the world through endogenous impacts on agricultural prices and land returns.

A key methodological challenge is the representation of land use and the possibility to convert forestry land into agricultural land as REDD policies might prevent the use of forestry and wood lands for agriculture. We simplify the implementation of the REDD policies as a shift in the asymptote for agricultural land in various regions in the world. In most of CGE models, total land available for agriculture is an exogenous variable in the model. As the result, the total use is always equal to land availability and, consequently, no land can move outside of agricultural production supply. This paper extends the endogenous land supply curve developed by Meijl et al. (2006) and Eickhout et al. (2009). It introduces a more flexible land supply function allowing large changes in the total potential land availability for agriculture due to environmental considerations such as reducing emissions from deforestation. The parameters of the new land supply function are defined as variables of the model. They are automatically recalibrated to the initial equilibrium position when the asymptote is changed. In the paper, we show the main features and a way to calibrate this function. We simplify the implementation of the REDD policies as a shift in the asymptote for agricultural land in various regions in the world.

Section 2 of this article describes the methodological improvements and key features of the modelling tool applied. The scenario's analysed – "Global Biofuel Directives without REDD" and "Global biofuel directives with REDD" – are introduced in section 3.1. Section 3.2 presents the simulation results. The final section summarises and concludes.

2. Modelling of land use, RED and REDD

In this section we introduce the global CGE model and the methodological improvements. First, we introduce the standard general equilibrium model that is used as a starting point. The second section provides a description of the database and the adjustments to the model's data base to introduce biofuels. Third, improvements to the modelling of land markets are discussed with an emphasis on forestry protection. The fourth part describes the extensions of the energy markets necessary to model biofuel demand and the final section introduces the implementation of the RED and REDD policies.

2.1 Standard model features

Model simulations are conducted by using LEITAP, a multi-regional, static, applied general equilibrium model based on neo-classical microeconomic theory (Nowicki et al. 2007 and van Meijl et al., 2006). The LEITAP model is a multi-regional, multi-sectoral, static, applied general equilibrium model based on neo-classical microeconomic theory. It is an extended version of the standard GTAP model (Hertel, 1997). The core of GTAP and LEITAP models is an input–output model, which links industries in a value added chain from primary goods, over continuously higher stages of intermediate processing, to the final assembling of goods and services for consumption. Extensions incorporated in LEITAP model includes an improved treatment of agricultural sector (like various imperfectly substitutable types of land, the land use allocation structure, land supply function, substitution between various animal feed components), agricultural policy (like production quotas and different land related payments) and biofuel policy (capital-energy substitution, fossil fuels-biofuels substitution).

On the consumption side, dynamic CDE expenditure function was implemented which allows for changes in income elasticities when purchasing power parity (PPP)-corrected real GDP per capita changes. In the area of factors markets modeling, the segmentation and imperfect mobility between agriculture and non-agriculture labor and capital was introduced.

2.2 GTAP data used

The analysis is based on version 6 of the GTAP data, Dimaranan (2006). The GTAP database contains detailed bilateral trade, transport and protection data characterizing economic linkages among regions, linked together with individual country input-output databases which account for intersectoral linkages. All monetary values of the data are in $US millions and the base year for version 6 is 2001. This version of the database divides the world into 88 regions. The database distinguishes 57 sectors in each of the regions. That is, for each of the 88 regions there are input-output tables with 57 sectors that depict the backward and forward linkages amongst activities.

The initial data base was aggregated and then adjusted to implement two new sectors – ethanol and biodiesel – to represent biofuel policy in the model. These new sectors produce two products each; the main product and byproduct. The ethanol byproduct is Dried Distillers Grains with Solubles (DDGS) and biodiesel byproduct - oilseed meals (BDBP).

Finally, we distinguish 45 regions, 26 sectors and 28 products. The sectoral aggregation includes, between others, agricultural sectors that use land (e.g. rice, grains, wheat, oilseed, sugar, horticulture, other crops, cattle, pork and poultry, and milk), the petrol sector that demands fossil (crude oil, gas and coal) and bioenergy inputs (ethanol and biodiesel) and biofuels production byproducts. The regional aggregation includes all EU-15 countries (with Belgium and Luxembourg as one region) and all EU-12 countries (with Baltic regions aggregated to one region, with Malta and Cyprus included in one region and Bulgaria and Romania aggregated to one region) and the most important countries and regions outside EU from an agricultural production and demand point of view.

2.3. The land supply curve

In most of CGE models, total land available for agriculture is an exogenous variable in the model. As the result, the total use is always equal to land availability and, consequently, no land can move outside of agricultural production supply. However, a land conversion from forestry use to agricultural use or the reverse occurs as a consequence of agricultural, trade and energy policy changes or demand shock for agri-food products. To model this possibility the land supply function was developed and implemented in LEITAP model (Meijl, et al. 2006, Eickhout et al. 2009, Nowicki at al., 2009). In LEITAP, land supply is an endogenous variable and dependent on the real land price. A higher real land price is pushing up land supply closer towards an asymptote. The asymptote can be interpreted as maximally available land suitable for agriculture.

The total land availability of agricultural land suitable for agriculture can change over time due to, e.g., increase of demand for land necessary for non-agricultural uses such as housing and infrastructure. Another cause could be land degradation, protection of natural areas or environmental protection of areas potentially suitable for agriculture. This process can be represented by an inward moving asymptote of the land supply function. Consequently, the asymptote of land supply function has to be treated not as the parameter of the model but as model variable which could be shocked. However, the current land supply function does not produce plausible results in a case of significant asymptote shocks. In this paper we develop a flexible land supply function producing sound results in such a case.

The agricultural land supply function in LEITAP model explains agricultural land supply by real land price and assumes limited availability of land suitable for agriculture. The applied function is specified as follows:

$$L = A - B/P^{C} \qquad (1)$$

where L is land supply, p is the real rental price of land, A is the land asymptote or maximal potentially available agricultural land and B and C are positive parameters. The land supply function (1) has the properties that

(a) The upper bound on land supply (equal to asymptote A), i.e. $L < A$.

(b) Falling price elasticity of land supply when lands use is increasing towards the asymptote.

The parameters of these function are calibrated using land supply elasticities in respect of real land price (Eickhout, et al., 2009) provided by Cixous, 2006 for EU countries or derived from biophysical data from the modelling framework IMAGE (Integrated Model to Assess the Global Environment; Alcamo et al., 1998). However, this functional form has proved to be unsatisfactory in simulations of the effects of large changes in the asymptote A. This is especially true when in the base situation only small percentage of available agricultural land is use.[1] Land use doesn't even become positive on the new supply function until the price reaches a high level.

We propose the new, flexible land supply function, which does not have the shortcomings of the current function. Therefore, the new function should have the following additional properties:

(c) For any positive land price (P) land supply (L) should be positive as well ($0 < L < A$).

(d) A given percentage reduction in agricultural land availability (A) should cause a sharper leftward shift in the supply function if high percentage of available agricultural land (L/A) is already used in the production process than if it is low. Thus an 80 per cent reduction in A when L/A is equal 10% should have has little effect on the relevant part of the supply curve whereas an 80 per cent reduction when L/A is 15% should have a more noticeable effect. At the same time, much smaller percentage reduction in A (e.g. 10%) should have a large effect on the relevant part of the supply curve if almost all suitable agricultural land (e.g. 80%) is already used in the production process.

(e) Reduction in the availability of agricultural land does not influence very much the shape of land supply function for L below the initialization point.

The condition (e) suggests that the land supply function should be anchored in two points: the initial equilibrium point and another point lieing on the land supply function on the right hand side of initial equilibrium point. Moreover, to fulfil the conditions (c) – (e), we assume that parameters of the land supply function are subject to change so that they are variables of the model.

To define the new land supply function, we set agricultural land area and real land price units in such a way that in the initial situation (benchmark equilibrium) agricultural land area (L_I) and real price (P_I) are one $L_I = P_I = 1$. The proposed land supply function is defined by the following formula:

$$P/P_I = \alpha / [\exp\{\beta \cdot (A/L_I - L/L_I)\} - 1] \tag{2}$$

were α and β are parameters of land supply function and (L_I) and (P_I) are agricultural land area and real land price in the initial situation (benchmark equilibrium) respectively, or

[1] This can be seen from linearized version of land supply function: dL/L = A/L dA/A + C (A-L)/L dP/P. For example, for Canada, which uses only 12.7% of land potentially available for agriculture in 2001, then this equation is: dL/L = 7.87 dA/A + 1.38 dP/P. For the initial situation in 2001 (L,P) = (0.525, 675040) and potential land availability 5312523 km2. Let's assume that we like to protect all forest and woody land in Canada. This leads to 81.5% reduction of available agricultural land for Canada to 979122 km2. This is, however, still 45% more than agricultural land used in 2001. When we implement this reduction in the simulation experiment, the agricultural land decreases 642% in the first step of the solution procedure according to equation (3). This results in increase land price in the following steps of the solution procedure and results in 99.5% reduction of land used by Canadian agriculture and real price of land increase by 159484% in the final solution. So, when the agricultural land availability is reduced by 81.5%, the supply function is shifted to the left and land use doesn't even become positive on the new supply function until the price reaches about 2000 (See, Figure 1).

$$\Pi = \alpha / [\exp\{\beta \cdot(\Gamma - \Lambda)\} - 1] \qquad (3)$$

were Λ and Π are agricultural land area and real price measured in such units that they both are one in the initial situation: $\Lambda_I = \Pi_I = 1$. Function (3) implies that both were α and β must be of the same sign (either both positive or both negative) to get P (Π) positive for all Λ. Also for all P (Π) > 0 land agricultural land use cannot go below zero. For given values of the parameters α and β, Γ is the asymptote (upper bound) on land use. It can be easy seen when, we solved (3) for Λ:

$$\Lambda = \Gamma - 1/\beta \cdot \ln(\alpha/\Pi + 1) \qquad (4)$$[2]

To calibrate the parameters α and β for any $\Gamma > L_I$ we impose the following two constraints:

$$0.95 = \alpha / [\exp\{\beta \cdot(\Gamma - (1\text{-}E/20))\} - 1] \qquad (5)$$

$$1 = \alpha / [\exp\{\beta \cdot(\Gamma - (\Gamma/\Gamma_I)^{1/\Gamma I^{1.25}})\} - 1] \qquad (6)$$

where E is postulated (exogenously known) land supply elasticity in respect of real land price in the neighbourhood of initial equilibrium position $\Lambda_I = \Pi_I = 1$. With α, β and Γ satisfying (5), we are imposing the condition that P = 0.95 when land use is (1-E/20) per cent of its initial value. Hence, we are assuming that the elasticity of land supply in respect of real land price in the neighbourhood of initial equilibrium position is approximately equal E[3]. So, the elasticity E defines an "anchor" point (Λ,Π) = (0.95, 1-E/20) of the land supply function. With α, β and Γ satisfying (5) and (6), we are ensuring that our supply function is consistent with the initial situation ($\Lambda_I = \Pi_I = 1$). The exponent on the Γ/Γ_I term in equation (6) controls the extent of the fall in land use at the initial real land price. This exponent is set at $1/\Gamma_I^{1.25}$. For countries with less abundant land in comparison with their land use, the exponent $1/\Gamma_I^{1.25}$ is larger. This means that these countries experience a larger leftward shift in their land supply curve (percentage reduction in land used at the initial real land price) for any given percentage reduction in the asymptote. Solution of system of equations (5) and (6) will provide the initial values of the parameters α an β, in the initial equilibrium position $\Lambda I = \Pi I = 1$. They should be implement into the model together with new land supply function (4) since the asymptote change results in necessity of endogenous recalibration of α and β. This means that α, β, Λ, Π and Γ will be treated as variables in the model. However, in case of very low initial elasticities E are low the anchor point (Λ,Π) = (0.95, 1-E/20) could be too close to the initial equilibrium point which can cause numerical problems in solution procedure of the model. Therefore, we replace the equation (5) by:

$$P(0.5) = \alpha / [\exp\{\beta \cdot(\Gamma - 0.5)\} - 1] \qquad (7)$$

where P(0.5) is calculated using initial values of α_I and β_I the parameters α an β solving equations (5) and (6) in the initial equilibrium position.

$$P(0.5) = \alpha_I / [\exp\{\beta_I \cdot(\Gamma - 0.5\} - 1]. \qquad (8)$$

[2] This relation is valid only when $\alpha/\Pi + 1 > 0$.

[3] $(\delta\Lambda_I/\Lambda_I)/(\delta\Pi_I/\Pi_I) = 1\text{-}(1\text{-}E/20)/(1\text{-}0.95) = (E/20)/0.05 = E$.

The new land supply function provides plausible results in case when to protect all forest and woody land in Canada is protected. Figure 1 compares simulation results in such a case for old and new function.

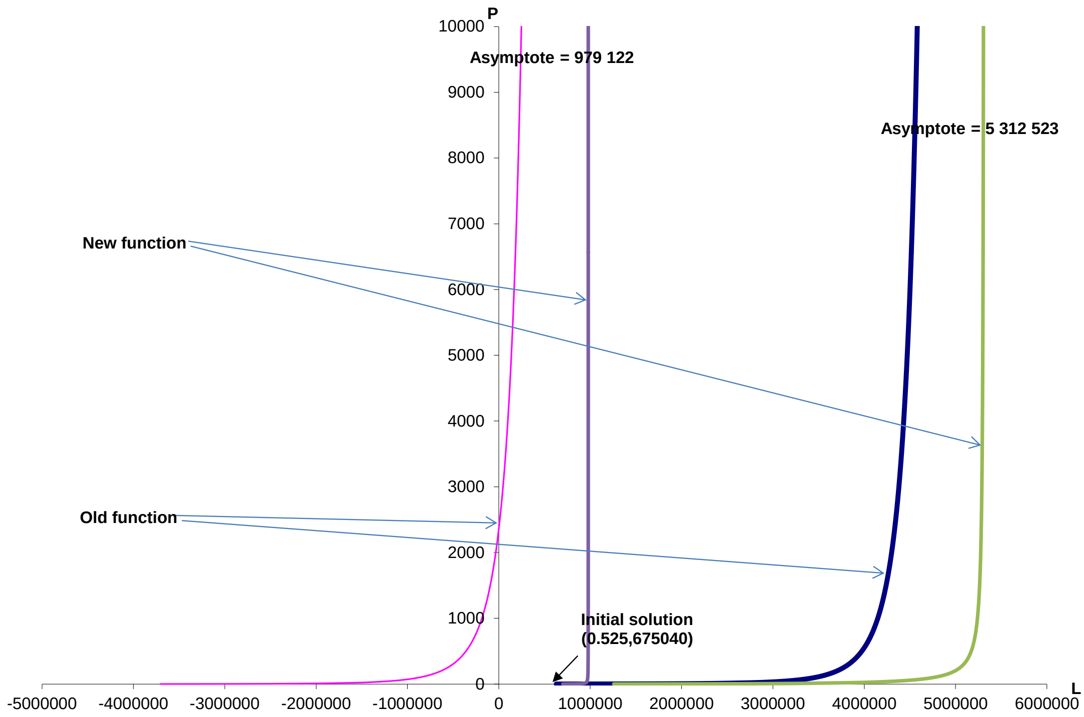

Figure 1: The application of new flexible land supply function shows that the protection all forest and woody land leads to decrease of land use in Canada by 0.15% and increase of land price by 0.11%.

2.4. Energy markets

To model biofuels use in the fuel production, we adapt the nested CES function of the GTAP-E model, Burniaux and Truong (2002) and applied it for petrol sector (2). To introduce the substitution possibility between crude oil, ethanol and biodiesel, we create the intermediate input commodity in petrol sector called fuel being CES aggregate of these fluid fuels. The nested CES structure implies that biofuel demand is determined by the relative prices of crude oil versus ethanol and biodiesel including taxes and subsidies.

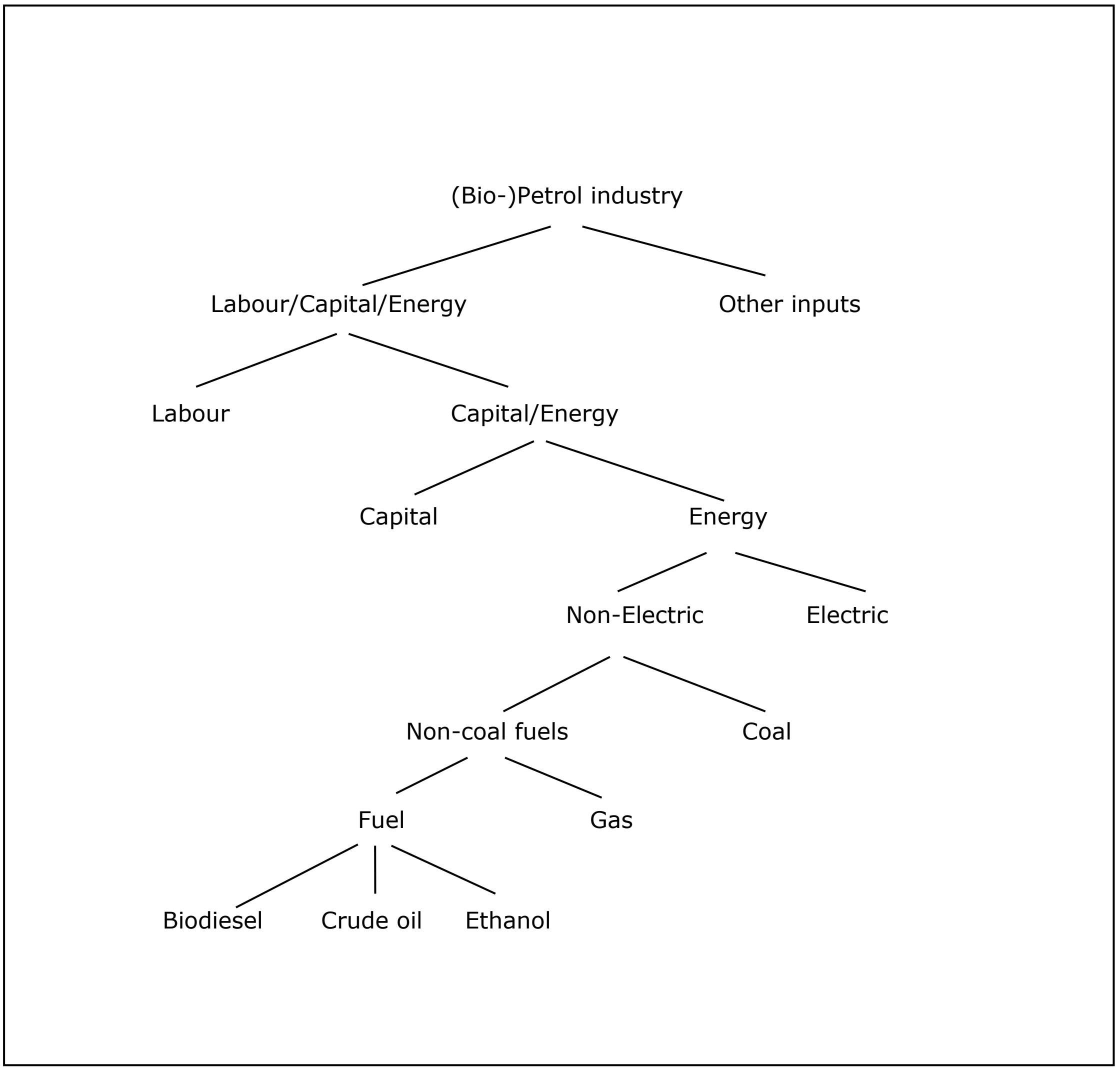

Figure 2: The (bio-) petrol industry nested production structure

The feed byproducts of biofuel production (DDGS and BDBP) are demanded only by livestock sectors in LEITAP. This demand is generated through the substitution process in the feed nest in the livestock sector. The market price for the feed byproducts serves as the variable equilibrating demand for byproducts with its supply.

In order to model substitution between different feed components and feed byproducts of biofuel production, we use two-level CES nest describing the substitution between different inputs in the animal feed mixture production (**Error! Reference source not found.**). The top level describes the substitution possibility between concentrated feed and its components and grassland (i.e., roughage). The lower level intermediate describes the composition of different types of feed commodities (cereal, oilseeds, byproducts and other compound feed).

The crude oil price development, which crucial for biofuels growth, is endogenous in the model. However, it is significantly driven by assumed future crude oil production derived from IEA (2008) and EIA (2009). In the simulation experiment, we translate the crude oil production figures to the country specific efficiency of natural resources utilization in crude oil sectors. They show decreasing productivity of natural resources in crude oil sector for almost all regions, which is generally consistent with observed and expected decline of output from oilfields (IEA, 2008).

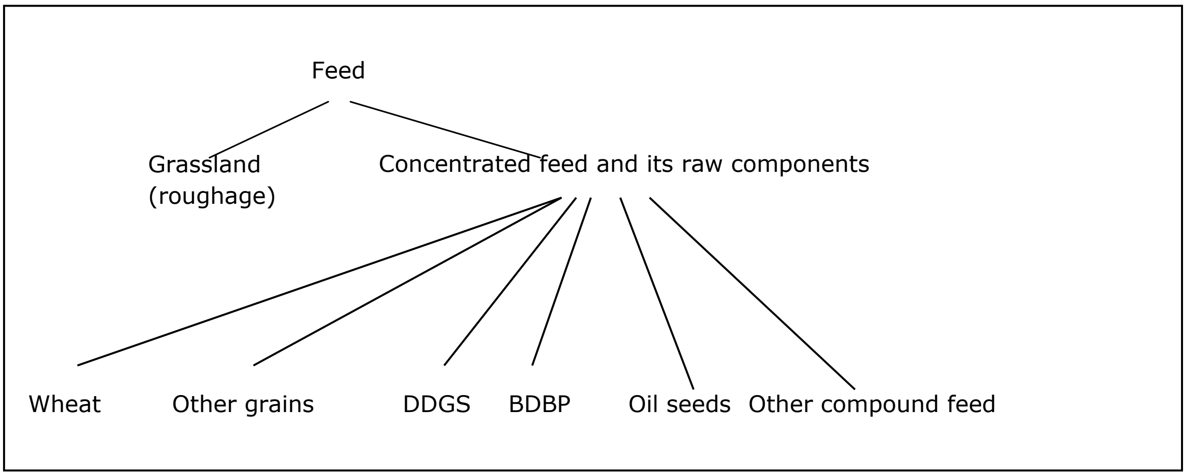

Figure 3: The animal feed nested structure

2.5. Implementation of RED and REDD

In this section we describe the implementation of the Renewable Energy Directives (RED) and Reducing emissions from deforestation and forest degradation (REDD). First we focus on the global mandatory blending requirement for biofuels (RED). This directive fixes the share of biofuels in transport fuel. It should be mentioned that this mandatory blending is budget-neutral from a government point of view. To achieve this in a CGE model involves implementing two policies. First, the biofuel share of transport fuel is specified and made exogenous such that it can be set at a certain target. An endogenous subsidy is modelled to achieve the required biofuel share. Second, to ensure that this incentive instrument is budget-neutral, the biofuels subsidy is counter financed by an end-user tax on petrol consumption, implying that the petrol user pays for the extra cost involved for using fuel with higher biofuel blending rates. Secondly, the REDD policies limit the conversion possibilities from forestry to agricultural land. In this paper, we simplify the implementation of the REDD policies by implementing restriction on land conversion by not allowing forestry and woody land to be converted to agricultural land. This implies a shift from the asymptote or total available land for agriculture to the left (variable A in equation 2).

3. Consequences of RED and REDD policies for land use and the agri-food sector

The macroeconomic, population growth and the RED policies increase the demand for food and consequently imply an agricultural land use expansion (mitigated by yields growth and conversion of managed forests, or other natural, non-agricultural ecosystems into agriculture. The REDD policy leads to forest protection which in consequence limits the supply of land suitable for agricultural production. In this section we we investigate the complex interplay between macro factors, RED and REDD policies.

3.1. Scenario experiments

To quantify the effect of RED and REDD on land use and the agricultural sector we introduce three consecutive scenarios that build upon each other :

- Base scenario: business as usual baseline scenario
- RED scenario: global RED or biofuel mandate scenario implemented for all countries on top of the Base scenario;
- REDD scenario: severe REDD policy scenario to protect both forest and woodland on top of the RED scenario;

The scenarios have been built as a recursive updating of the database in three consecutive time steps: 2010-2013, 2013–2020 and 2020–2030. By comparing results of first two scenarios we study the RED effect and by comparing the results of the two last scenarios, we investigate effect of REDD.

In all scenarios we assume the macroeconomic development projected by USDA (2010). A pre-simulation scenario is run (for a period of 10 years) to translate the exogenous GDP targets to the overall country level technological change which is endogenously determined within the model (Hertel et al., 2004). This technological change is in turn exogenous in the remaining simulation experiments. The sectoral total factor productivities (TFP) are a linear function of country level technological change. Following Central Planning Bureau (CPB, 2003), we assumed different technological development by sector and common trends for relative sectoral TFP growth. CPB assumed that all inputs achieve the same level of technical progress within a sector (i.e., Hicks neutral technical change). We deviate from this approach by using additional information on yields from FAO (Bruinsma, 2003) for land using sectors. For the non-land using sectors we assume Hicks neutral technical change.

Table 1. Macroeconomic scenario assumptions: growth rates over period 2010 – 2030.

	World	Europe	C&S America	USA	Canada	South Africa	Rest Africa	RusPlus	China	Southeast Asia	Indonesia	Oceania	Rest Asia
GDP	100	50	118	76	72	169	143	138	305	150	154	83	90
Population	21	-1	22	18	14	28	50	-4	8	24	19	24	28
Yields (average)	39	20	32	19	21	44	64	17	55	30	31	28	44

In the RED and REDD scenarios, targets for using biofuels in the transportation sector (biofuel mandates) should be achieved in 2020. The mandatory but also voluntary requirements are currently imposed for liquid biofuels in all major world economies except of

Russia. In EU, US, Canada, Brazil, Argentina, Colombia, India, Thailand, Indonesia and Philippines the mandatory requirements for both ethanol and biodiesel are introduced. Paraguay and Ecuador employ ethanol mandate and Uruguay and Thailand biodiesel mandate. The targets are differently formulated in different countries. In the EU, the US, Canada, Brazil, Argentina, Colombia, India, Thailand, Indonesia and Philippines mandatory requirements for both ethanol and biodiesel have been introduced. Paraguay and Ecuador employ ethanol mandates and Uruguay and Thailand apply biodiesel mandates. In these countries the targets are set at different levels. In the EU, 10% biofuels in transport in 2020 are obligatory; by 2022 36 billion gallons of fuels from renewable energy must be used in US transportation, while Canadian mandates apply for 5% renewable content in gasoline by 2010 and 2% renewable content in diesel fuel and heating oil by 2012. In the remaining countries targets are mainly set for E10 and B5[4] in 2010 which are supposed to increase over time to E10+ and B20+, respectively. For instance, the Brazilian target for 2013 is E25 and in Indonesia the mandatory level of biofuels consumption is supposed to increase to E15 and B20 by 2025. Also China, Japan and Australia set non-binding targets for biofuel production. The biofuel shares implied by these targets for EU, US, Canada, Brazil, Rest of South America, India, and South-East Asia are presented in table 2. In the RED and REDD scenarios, these targets should be achieved in 2020.

Table 2. Share of biofuels in transport fuel (%).

EU27	Canada	USA	Brazil	Rest of South America	India	China	South-east Asia	Indonesia	Japan	Oceania
10	3	15.4	25	10	20	15	5	12	5	3

In REDD scenario, full restrictions on forest and woody land conversion to agricultural land are implemented in 2010 - 2013 simulation period. The relevant data are constructed in the EURURALIS project framework (Stehfest at al. 2010) and are presented in table 3.

[4] E# describes the percentage of ethanol in the ethanol-gasoline mixture by volume, e.g. E10 stands for fuels with 90% gasoline and 10% ethanol. B# describes the percentage of biodiesel in the biodiesel-diesel mixture by volume; for example, B5 stands for diesel fuel with 95% ('fossil'-)diesel and 5% biodiesel.

Table 3. Decrease of land availability for agriculture due to forest and woody land conversion restrictions (%); see figure also Figure 4.

World	Europe	Central and South America	USA	Canada	South Africa	Rest Africa	RusPlus	China	Southeast Asia	Indonesia	Oceania	Rest Asia
-34.8	-3.7	-52.8	-32.4	-81.6	-30.1	-8.8	-55.5	-9.6	-71.0	-54.8	-22.2	-2.1

3.2. Scenario results

The RED scenario shows an expansion of agricultural land driven by strong increase of demand for agricultural products caused by the biofuel directive implemented in many world countries. Worldwide, the agricultural area increases by 2.9% compared with baseline scenario (Table 4). The highest expansion is observed in regions where land availability is high, i.e. in USA, Canada, Southeast Asia and Indonesia.

Table 4. Agricultural land increase in RED and REDD scenario in 2030 compared with Base scenario (%)

	World	Europe	C&SAmer	USA	Canada	SAfrica	RestAfrica	RusPlus	China	SouthEastAsia	Indonesia	Oceanie	RestAsia
RED	2.9	1.1	3.3	17.2	23.8	0.3	1.1	1.8	0.6	6.7	12.6	1.4	0.3
REDD	-5.3	3.3	-11.0	13.9	24.4	-27.5	1.1	-6.7	-6.4	-8.5	-13.9	-8.4	-0.2

In many regions, the agricultural land expansion is achieved at the cost of deforestation. This happens in great extent in South Africa, Southeast Asia and Indonesia and in the smaller scale in Central and South America, Russia and former Soviet Union countries (Figure 4). This is a continuation of currently observed trends which shows major losses (more than 0.5 percent annually) in the tropical forests of West and East Africa, South and Central America and, South East Asia. Implementation of REDD policy leads to significant decrease of agricultural land availability (by 35%) and, consequently, agricultural land use in these regions compared with reference RED scenario. Globally, in the REDD scenario, the agricultural area is decreasing by 5.3% to compared with the Base scenario and 8% compared with RED scenario. The agricultural area is decreasing in all world regions except of Europe and Canada.

Restrictions on agricultural land availability imposed by REDD shift asymptote and a whole land supply functions to the left which results in increase of land prices and, in turn, agricultural prices (and production costs) and food prices. Impact of the REDD policy on agricultural prices is very pronounced. The average price increase is equal to 34% but the regional differences are very significant and depends on a scale of forest and woody land protection compared with the current size of land use. They vary from about 8% in Rest of Asia and 15% in Europe to about 160% in South Africa (Figure 5). In Canada, Indonesia and Oceania, land prices more than doubled.

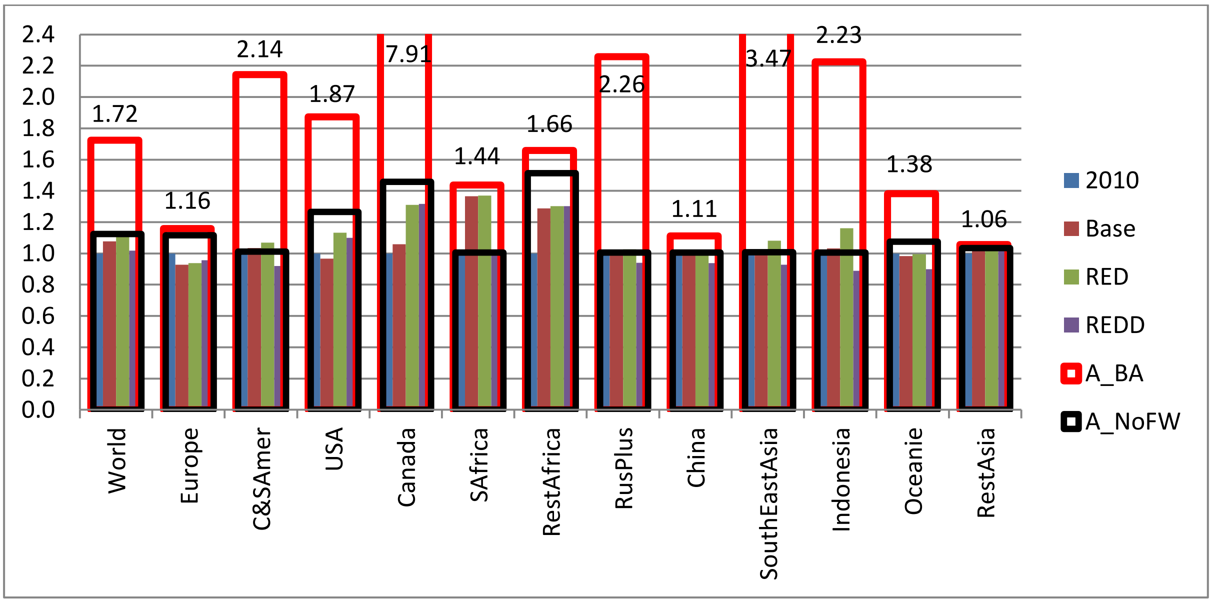

Figure 4. Agricultural land use development from 2010 to 2030, maximal area that is suitable for agriculture (A_BA) the and the non-forest and woody land area (A_NoFW) suitable for agriculture: agricultural land use in 2010=1.

Note: The A_BA area cap reflects the maximal area that is defined as area suitable for agricultural. The associated numbers shows how many times maximally the agricultural land use can increase from the 2010 level equal 1.

The A_NoFW area cap reflects the area that is defined as area suitable for agricultural production that does not include forest and woody land. If the column is higher than the capped area (horizontal) line, the expansion of agriculture is only possible with pulling forest or wood land into agricultural land.

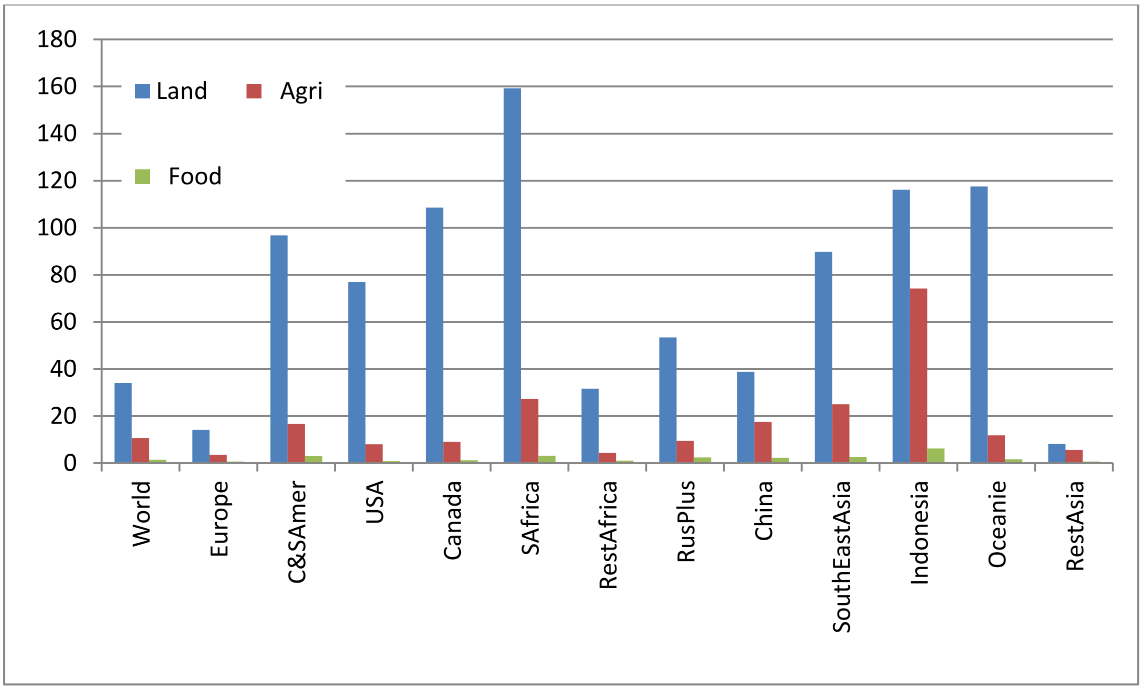

Figure 5. Land, agricultural and food real prices difference in REDD to compare with RED scenario in 2030 in %.

The impact of land prices on agricultural and food prices is less pronounced due to increase of agricultural yields (Figure 7) and low share of land cost in total agricultural production cost in some countries. The overall increase of agricultural and food rises due to REDD polices is 10.6% and 1.5% respectively. The most significant increase of these prices is observed in South Africa, China, South East Asia and Indonesia where land cost in total agricultural production cost exceeds 20% and where agricultural land use decreases as result of REDD policy implementation. Indonesia suffers the most from implementation of REDD policy. The agricultural and food real prices decrease is 75% and 6% respectively which leads to significant worsening of food security in this region (Figure 6).

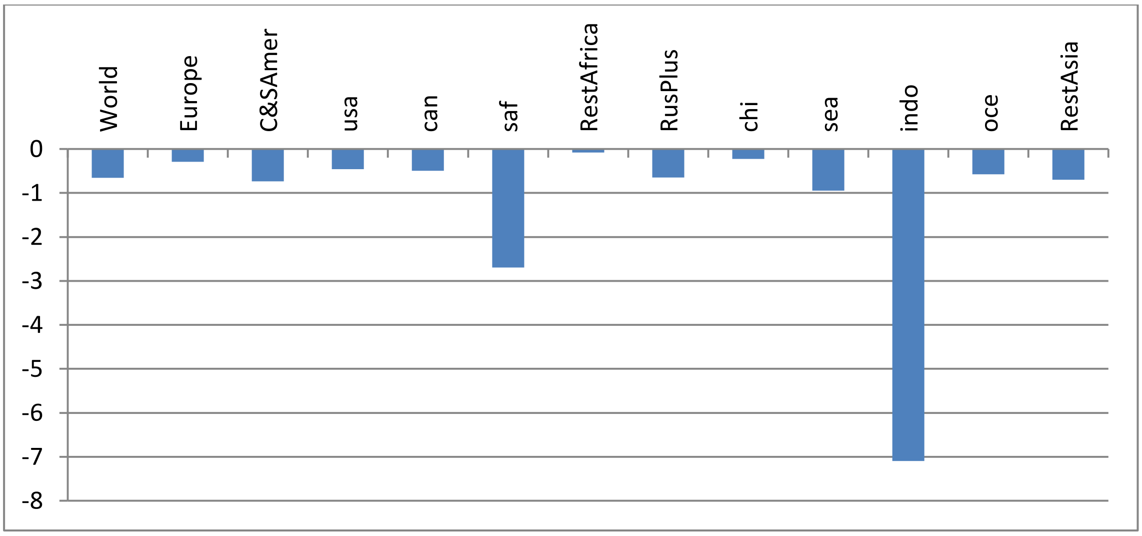

Figure 6. Agri-food consumption difference in REDD to compare with RED scenario in 2030 in %.

On average, the worldwide food consumption slightly decreases as result of REDD policy (Figure 6). However, this cost of REDD policy is not uniformly distributed among countries and regions. Consistently with agri-food price movements, the agri-food consumption in South Africa and Indonesia drops the most - by 2.7% and 7.1% respectively. This indicates that countries directly affected by forest and woody land protection would be the most economically vulnerable when REDD policy will be implemented. However, the full REDD policy setting foresees compensation for these countries to cover their economic losses. The regional pattern of production development is similar to a pattern of land use developments (Figure 7). However, production decrease is mitigated by yields increase caused by intensification of a production process. Worldwide, agricultural production decreases 1.5% while yields increase by 7% in REDD scenario compared with RED scenario. In most regions, the high decrease of agricultural land use is compensated by high increase in yields and therefore the production effect of REDD scenario is relatively low. The most pronounced exception of this pattern is Indonesia where the RED policy moves land from much more productive animal sectors to arable land which leads to yield decrease.

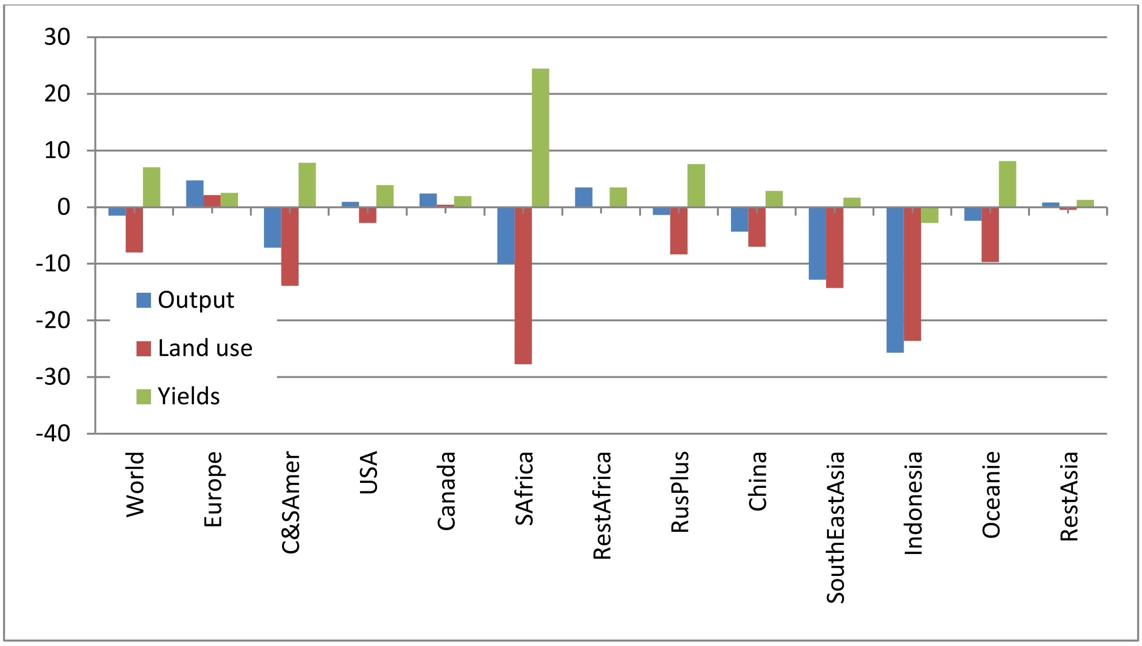

Figure 7. Agricultural output, land use and yields difference in REDD to compare with RED scenario in 2030 in %.

Implementation of REDD policy leads also to a slowdown of agricultural trade. Under the REDD scenario, the agricultural trade volume decreases by 3% compared with RED scenario in a period 2010 - 2030. Also, two important net exporters of agricultural products Central and South America and Southeast Asia become importers and Indonesia which has neutral trade balance in agricultural products under RED scenario become net importer under REDD scenario. Comparative advantage is reversed as land abundant countries become land scarce countries.

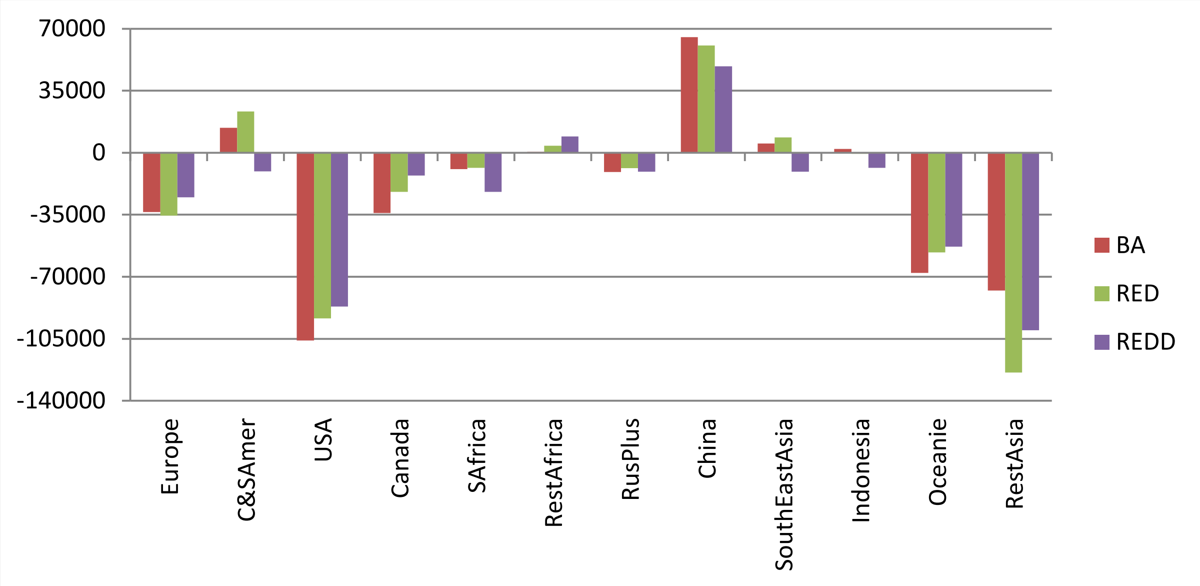

Figure 8. Net-exports value of agricultural commodities (excluding transport costs) in Base, RED and REDD scenarios in million 2001 dollars.

4. Summary and conclusions

This paper shows the complex battle between RED and REDD policies. Both policies are designed to save emissions but their land use impacts are opposite. Global RED policies expand global land use with 3% relative to the baseline. Land abundant countries such as Canada, USA and Indonesia extend their use of agricultural land and their agricultural production. Severe REDD policies that protect all forest and woodlands in especially tropical land abundant regions such as Central and South America, South Africa and Indonesia imply a global reduction of agricultural land by 5% and lead to higher food and land prices. REDD policies reverse production and trade patterns as previous land abundant countries become land scarce countries.

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