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REDD policy impacts on the agri-food sector and food security

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The REDD policy which preserves, enables substantial emission reductions. Since agricultural production and area expansion is a primary driver of tropical deforestation, REDD policies might limit the expansion possibilities of agricultural land use and therefore influence competitiveness, agricultural prices, trade, production and food security the world. This paper studies the impact of REDD policies on the agri-food sector and food security with a global CGE model called MAGNET. It focuses on the restrictions on agricultural land expansion within the REDD policy package. Simulation results show that REDD policies start to affect the agri-food sector in some lower developed countries if more than 15% of potentially available agricultural areas are protected from deforestation. A stringent REDD policy that protects 90% of land reserves that could potentially be used for agriculture production results in a global real agricultural price increase of almost 6%, and a worldwide agricultural production decrease of 1.5%.

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JEL codes: D58, O13, O50, Q11, Q18

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1. Introduction

Recent research shows that the combined contributions of deforestation, forest degradation and peat land emissions account for about 15% of greenhouse gas emissions (van der Werf et al., 2009). A large part of the emissions from deforestation and forest degradation has occurred in developing countries, where the share of deforestation-related greenhouse gas emissions has been estimated at around 25% (Houghton, 2005). Consistently, major forest losses (more than 0.5 percent annually) have occurred in the tropical forests of West and East Africa, South and Central America and, South East Asia (FAO, 2008). According to the FAO, the ten countries with the largest net forest loss per year between 2000 and 2005 (Brazil, Indonesia, Sudan, Myanmar, Zambia, United Republic of Tanzania, Nigeria, Democratic Republic of Congo, Zimbabwe and Venezuela) had a combined net forest loss of 8.2 million hectares per year compared with the worldwide net forest loss of 7.3 million hectares per year. At the same time, significant net forest gains were observed in East Asia (3.8 million hectares per year) and Europe (0.7 million hectares per year). Reducing Emissions from Deforestation and Forest Degradation (REDD) [1] policies were introduced to preserve forests and value standing forests, REDD proposes to compensate developing countries for avoided deforestation by means of contributions from industrialized countries.

Forest conversion to agricultural land is the predominant cause of deforestation as it accounts for 70 to 90 percent of global deforestation (FAO, 2000). Also, a recent study of Gibbs et al. (2010) concludes that “over 83% of new cropland areas in the tropical zone came at the expense of natural forests over the 1980-2000 period”. As agricultural production and area expansion are the primary drivers of tropical deforestation, REDD policies might limit the expansion possibilities of agricultural land use and therefore influence competitiveness, agricultural prices, trade, production and food security in the world. The Food and Agriculture Organization (FAO, 1996) defines food security as a condition that "exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". Dimensions of food security are: availability, access,

[1] REDD is collaborative initiative in developing countries. The REDD program was established under aegis of the United Nations Framework Convention on Climate Change (UNFCCC) in response to the UNFCCC decision on REDD at COP 13 and the Bali Action Plan (Dutschke M. and Wolf R., 2007)

utilization and stability. In this paper we focus on food availability and access. The pressure on the agricultural sector introduced by the implementation of REDD can be mitigated through displacement of agricultural production to such areas as savannas, wetlands and unprotected forest areas. The question arises as to whether trade-offs between REDD and agricultural production are unavoidable.

This paper analyses the economic and food security consequences and costs of REDD. The relationship between the degree of protection of carbon rich areas from deforestation and the impact on the agricultural sector is examined. We use various protection levels of carbon rich areas (and associated forest protection level) identified by Overmars et al. (2014) and perform scenario based analyses with a CGE model called MAGNET (Woltjer et al. 2014, Nowicki et al., 2009). Sensitivity analyses are performed with regards to key assumptions and parameters.

In modeling REDD measures, the actual implementation of REDD can take many forms and has implications for the results. This study assumes that non-Annex I[2] countries will protect carbon-rich areas against deforestation, and therefore will refrain from using these areas as agricultural land. When modeling REDD, we do not include compensatory payments of protecting forest for non-Annex I countries although that is part of the REDD policy of the United Nations. Our study identifies the impacts of REDD policies and therefore provides an indication of potential compensation payments from a food security perspective.

2. Methodology

Following Overmars, et al. 2014, it is assumed that non-Annex I countries protect carbon rich areas from deforestation, and therefore lose the opportunity to use that land for agricultural production. The impact of REDD on the agricultural sector is assessed with a global economic general equilibrium model (CGE) model, MAGNET, using a scenario approach. To represent the REDD, we endogenize the availability of agricultural land by using a flexible land supply function (Dixon at al., 2012) and proxy the implementation of the REDD policies as a decrease in potentially available agricultural land in various regions of the world in response to forest

[2] Annex I is an Annex in the United Nations Framework Convention on Climate Change listing those countries which are signatories to the Convention and committed to emission reductions. The Non-Annex I countries are developing countries, and they have no emission reduction targets (Kyoto Protocol Terms http://webarchive.nationalarchives.gov.uk/+/http://www.dti.gov.uk/sectors/ccpo/glossary/termsad/page20695.html

protection as assumed in REDD. In a series of simulation experiments, we protect increasingly more carbon rich areas from deforestation. The associated impact on agri-food sector in terms of price, production, land use and food security changes are calculated with using MAGNET. The stepwise exclusion of certain forest areas from agricultural expansion, ordered according to decreasing carbon content per unit of area, was based on a terrestrial carbon map available from the IMAGE model (Alcamo et al., 1998) database.

2.1. MAGNET model

The MAGNET model is a multi-regional, multi-sectoral, applied general equilibrium model based on neo-classical microeconomic theory (Nowicki at al., 2007, Nowicki at al., 2009 and van Meijl et al., 2006, Woltjer et al. 2014). It is an extended version of the standard GTAP model (Hertel, 1997). The core of MAGNET is an input–output model, which links industries in value added chains from primary goods, over continuously higher stages of intermediate processing, to the final assembly of goods and services for consumption. Primary production factors, namely, land, labor and capital, are employed within each economic region and returns to land and capital are endogenously determined at equilibrium, i.e. the aggregate supply of each factor equals its demand. On the consumption side, the regional household is assumed to distribute income across savings and (government and private) consumption expenditures according to fixed budget shares. Private consumption expenditures are allocated across commodities according to a non-homothetic CDE expenditure function and the government consumption according to Cobb-Douglas expenditure function.

The MAGNET model, in comparison to GTAP, uses a more general multilevel sector specific nested CES (constant elasticity of substitution) production function, allowing for substitution between primary production factors and (land, labor, capital and natural resources) and intermediate production factors and for substitution between different intermediate input components (e.g. energy sources, and animal feed components). MAGNET includes an improved treatment of agricultural sectors (like various imperfectly substitutable types of land, the land use allocation structure, a land supply function, substitution between various animal feed components, Meijl et al. 2006, Eickhout et al. 2009), agricultural policy (like production quotas and different land related payments, Nowicki et al. 2009) and biofuel policy (capital-energy substitution, fossil fuels-biofuels substitution, Banse et al. 2008). On the consumption side, a dynamic CDE expenditure function is implemented which allows for changes in income elasticities when purchasing power parity (PPP)-corrected real GDP per capita changes. Segmentation and imperfect mobility between agriculture and non-agriculture labor and capital are introduced in the modelling of factors markets,

2.2. Model aggregation and database

The analysis is based on version 6 of the GTAP database (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.

The initial database was aggregated to 45 regions and 24 sectors and then adjusted in order to implement two new sectors – ethanol and biodiesel – to represent biofuel policy in the model. These new sectors produce two products each; a main product and a by-product. The ethanol by-product is Dried Distillers Grains with Solubles (DDGS) while the biodiesel by-product is oilseed meals (BDBP). Therefore, the final data base consists of 26 sectors and 28 commodities. These include, among others, agricultural sectors that use land (e.g. rice, grains, wheat, oilseed, sugar, horticulture, other crops, cattle, pork and poultry, and milk), a petrol sector that demands fossil fuels (crude oil, gas and coal) and bioenergy inputs (ethanol and biodiesel). The regional aggregation includes key regions from both an agricultural production and demand point of view.

2.3. Land supply modeling and REDD implementation

MAGNET includes a land supply function (Figure 1) which specifies the relation between total agricultural land supply and the real land price given constraints related to biophysical availability (potential area of suitable land) and institutional factors (agricultural and urban policy, preservation policies towards nature). These constraints are represented by an asymptote within the land supply function. The total land area suitable for agriculture production might change over time, for example, due to increasing demand for non-agricultural uses such as housing and infrastructure, land degradation, protection of forest or natural areas potentially suitable for agricultural production. Consequently, the asymptote of the land-supply function is not fixed, but treated as a model variable that can be modified.

In this paper, we implement the land supply function by an equation that determines the real land price as a function of land supply and an asymptote (i.e. by the inverse land supply function) proposed by Dixon at al. (2012):

$$P = \frac{A}{\exp\{B*(\Gamma - L)\} - 1} \tag{1}$$

where P is the real price of agricultural land, L is the supply of agricultural land, Γ is an upper bound on the supply of agricultural land (asymptote), that is the total potential land that could be available for agriculture, and where A and B are parameters with the same signs (either both positive or both negative).

The parameters A and B in this function are defined as variables in the model and are calibrated to the initial equilibrium situation that the initial value of the price elasticity of land supply is preserved. The initial land-supply elasticities for EU countries was estimated by Cixous (2006) and derived for other regions from biophysical data obtained from the IMAGE model (Eickhout et al., 2009).

Information used to determine the total potential land that could be available for agriculture (Γ) is taken from the IMAGE database (Eickhout et al. 2009). It is determined by the total available land excluding non-productive land (mainly ice and desert in regions like Canada and the Middle East), urban areas and protected reserves in order to take into account nature conservation.

REDD is implemented by assuming that some carbon-rich areas will be protected from deforestation, i.e., the conversion of these areas into agricultural land is not allowed. The protection of the land reserve (natural land that could be used for agriculture) limits the total potential land that could be available for agriculture. Therefore, we mimic the implementation of REDD by decreasing the asymptote in the land supply function. This is represented by moving the asymptote from position b (baseline) to x or y where x and y represent different levels of forest preservation. This reduces the area for agricultural land expansion and makes the land supply function steeper. Given a downward sloping demand curve, this leads to reduced land use and, consequently, higher land and agricultural prices. The latter results in lower demand for agricultural products and a higher degree of land use intensification. A change in the asymptote results to an endogenous recalibration of parameters A and B in such a way that the initial value of a price elasticity of land supply is preserved.

2.4. Scenario set-up

2.4.1. Baseline scenario

The baseline scenario represents business as usual developments in the world economy over the 2010 - 2030 period, based on conventional economic and demographic trends, and under an assumption of no new policy changes. The expected growth in GDP and associated technological progress together with population changes to a large extent determine the future demand for produced commodities and the supply of primary production factors. Labor and capital availability together with technological progress determine the production possibilities. The baseline scenario uses the macroeconomic projections data from the OECD Environmental Outlook to 2050 (OECD, 2012). The average annual growth rate is assumed to be 3.1% for world's GDP and a 0.9% increase in global population, during the 2005–2030 period (See, Figure 2). However, economic and population developments differ between countries and regions. Conforming to stylized facts of long-term economic growth, capital is assumed to grow at the same rate as GDP and long term employment growth is assumed equal to population growth. The baseline scenario assumes no policy changes and no new policies in the simulation period, and only applies existing policies and those agreed upon for the future, such as the milk quota abolition in the EU and the mandatory biofuel targets.

In the calibration stage, regional and sectoral specific technological change is calibrated by forcing the model to meet the exogenous GDP targets given the exogenous estimates of factor endowments - skilled labor, unskilled labor, capital and natural resources - and population. This level of technological change is translated to the sectoral level using a sector-specific growth ratio of total factor productivity based on CPB (2003) figures. We use additional information on crop yield improvements to mimic the land embodied technological progress. The technological change, in turn, is exogenous in the baseline scenario and simulation experiments, GDP becomes endogenous and calibrated values for technological changes are used.

The exogenous yield improvements are derived from the study by Bruinsma (2003) and land availability is based on IMAGE 2.4 data (Bouwman et al. 2006). Table 1 indicates that globally, agricultural yields will increase by about 1.7% annually. For Sub-Saharan Africa, North Africa, the Middle East and China yield increases are expected to increase faster than world averages, whereas for other regions, the annual growth rates are predicted to be lower than 1.5%.

Worldwide, only 58% of the area suitable for agricultural production (potential agricultural land) is used, according to biophysical data in IMAGE 2.4 (Table 1). North Africa, the Middle East, Europe, India and China use more than 80% of their potential agricultural land. In the remaining regions, agricultural land could still increase significantly into pristine natural lands, such as forests.

2.4.2. REDD scenarios

In order to study the agri-food and food security impacts of REDD measures, a series of scenarios have been developed, indicated accordingly as scenario: a, b, c, d, e, f, g, q and s. In these scenarios, all but one model input are the same as in the baseline scenario. In particular, we run each of the nine REDD scenarios with a different percentage of carbon rich area protected from deforestation. The scenarios differ by protection level of carbon rich areas from deforestation in Non-Annex I regions, which ranges from 10% of the terrestrial carbon protection in the least restrictive scenario to 83% of the terrestrial carbon protection in the most restrictive scenario in these regions. This is equivalent to the preservation of 2% to 91% of the land that is potential agricultural area under the baseline scenario and is now additionally protected under the REDD scenarios. These protected areas are assumed to be unavailable for agricultural expansion. The assumption is that national governments are able to control these areas and prevent them from being converted to agricultural land. The level of protection is translated into a reduction of the available agricultural land and implemented by a leftward shift in the asymptote Γ and, consequently, the agricultural land supply curve (1) moves to the left (Figure 1).

The stepwise exclusion of certain forest areas from agricultural expansion, ordered according to decreasing carbon content per unit of area, was based on a terrestrial carbon map available from the IMAGE 2.4 model database. One hundred percent of the above-ground carbon and 25% of soil carbon (Searchinger et al., 2008, Don, et al. 2011) was included in the terrestrial carbon stock calculation (Overmars et al. 2014). Based on IMAGE geographical and biophysical data, the regional distribution of protected areas was determined.

The percentage of potentially available agricultural land that is additionally protected as a consequence of REDD differs per Non-Annex I region and scenario (Figure 3). This is a result of the different carbon content of land areas and the scenario construction method which assumes that the forest areas with the highest carbon content are protected first. Scenario (a) starts with the least area protected, including the areas with the highest carbon content (exclusively forests). In subsequent scenarios, other biomass than forest area are also protected. This results in a high protection of forest land in Southeast Asia and Central and South America (areas with the highest carbon content) in all scenarios. In other Non-Annex I regions characterized by lower carbon content areas, the forest protection level is increasing significantly only if more than 64% of the terrestrial carbon is protected (scenarios q and s). This potentially prevents a significant expansion of agriculture in Sub-Saharan Africa where a lot of lower carbon content area potentially suitable for agriculture is available.

3. Results

3.1. Baseline scenario

Food consumption per capita increases in all regions in the baseline scenario (Figure 4). The increase is mainly caused by a significant increase in per capita income due to significant GDP growth. The pronounced increase of consumption is taking place in less developed but fast growing economies which have low initial consumption levels. The highest per capita food consumption increase is expected in Sub-Saharan Africa (75% compared with 2010 level) and in the India+ region (44%). In several other regions, such as North Africa, the Middle East, Former USSR and Southeast Asia region, the per capita consumption in 2030 exceeds the 2010 level by more than 20%. OECD countries and China expect consumption growth of less than 10%.

The baseline scenario shows a global increase in agricultural land of 11% in the 2010-2030 period (Figure 5). Agricultural land increases in response to a fast growing demand for food products, resulting from worldwide population and income growth, as well as from increasing biofuels production due to biofuel policy targets. Expected yields growth only partly mitigates this demand increase.

The most pronounced agricultural area increase is observed in the less developed countries of in Sub-Saharan Africa (SSA) - 42% - and Southeast Asia (SEA+) - 17% - where the highest population and income growth is expected and where, at the same time, the initial per capita food consumption is low. In addition, agricultural area is able to easily expand because there is a lot of potentially suitable agricultural land available in these regions. A significant increase of agricultural area is observed in North America driven by increased biofuel production (specially until 2020), but also as a result of increasing exports needed to fill a demand-supply gap for food products in regions facing land availability restrictions, e.g., India, North Africa and the Middle East. Agricultural area in the Chinese region decreases by almost 5% due to high yield growth in combination with low population growth. Also, low income elasticities of food demand do not drive food demand sufficiently to prevent a decline of agricultural area despite a high level of income growth in this region.

According to simulation results, about 123 million hectares of forest and woody land is converted to agricultural land in the simulation period. On average, 6.4 million hectares are converted per year which is a little bit less than the 7.3 million hectares per year calculated for historical period 2000 - 2005. This is, therefore, a continuation of trends observed in the past. Table 3 indicates that if, in a REDD scenario in which no forest and woody land would be allowed to be used for agricultural production, then the simulated baseline area expansion is simply not possible in the Central and South America (CSA), Sub-Saharan Africa (SSA), Former USSR (FUSSR) and especially Southeast Asia (SEA+) regions. This indicates that REDD policies will constrain agricultural land use expansion in these regions.

3.2. REDD scenarios

This section shows the consequences of the stepwise protection of increasingly larger forest areas in Non-Annex I regions as a result of increasingly larger terrestrial carbon protection (see, Figure 3) on agricultural sector.

Figure 6 shows that the forest protection introduced by REDD in non-Annex I countries leads to a decrease of agricultural area in the non-Annex I regions relative to the baseline scenario. Global agricultural land use decreases in 2030 when compared with the baseline scenario implying that the decrease of agricultural area in non-Annex I countries is only partly compensated by an increase of agricultural land in Annex-I countries. The decline in world agricultural area becomes significant (higher than 1%) if 40% of global terrestrial carbon is protected (scenario D) and reaches a decline of almost 10% if 91% of global terrestrial carbon is protected (scenario S). A substantial share of the agricultural land reduction in this scenario is within Sub-Saharan Africa (SSA). SSA agricultural land decreases by 445 million hectares in the REDD scenario S compared with the baseline and is 83% of global decrease amounting to 536 million hectares. A substantial decrease in hectares is also observed in Central and South America (CSA), the China+ region and the Southeast Asia (SEA+) region. SEA+ is losing 7% of agricultural land when compared to the baseline scenario, in REDD scenario D (40% of global terrestrial carbon protected) as carbon rich forest areas of Southeast Asia region (SEA+) will be protected first. SSA observes a decline in agricultural land only in scenario G in which less carbon rich areas are also protected. The SEA+ agricultural sector is, therefore, more exposed to the consequences of REDD than other regions as low levels of forestry protection are more restrictive.

A decrease of agricultural area does not necessary lead to a comparable decrease of agricultural production due to endogenous yield increases. Global agricultural production is an indicator of food availability at the global level. In the most restrictive scenario S, the world's agricultural output decreases by only 2.5%, while at the same time the global agricultural area decreases by almost 10%. Production intensification (yield increase) of 7.5% is implied. Yields increase in the MAGNET model due to increased scarcity of land and induced higher land prices or land rental rates. Higher land prices provide an incentive to farmers to substitute away from land to relatively cheaper production factors and inputs which induce higher yields. For example, yields increase as per hectare more labor and capital are used.

Table 4 shows the production, land use and yield developments in the non-Annex 1 countries that face additional land use restrictions under REDD. Again, similarly to land use changes, the less developed regions - Central and South America (CSA), Southeast Asia (SEA+) and Sub-Saharan Africa (SSA), suffer the most. Southeast Asia and Sub-Saharan Africa lose about 20% of their agricultural output, while Central and South America lose 8% in the most restrictive scenario S relative to the baseline scenario. Southeast Asia observes a decrease of 4% of agricultural output in the D scenario (when “only” 40% of global terrestrial carbon is protected). In this case, land use reduces by 7% and yields increase by 3% and therefore production decreases by “only” 4%. Central and South America is only affected in the Q scenario in which land use decreases by 11%, yields increase by 4% and production declines by 7%. In India, land effects are zero as there is no idle land. In China, production effects are limited because the decrease in land area is compensated for with higher yields. In Sub-Saharan Africa, the impact on production is rather limited, except for the most severe REDD scenario S in which land use decreases by 28%, yields compensate for about 9%, but on the whole, production decreases with by than 20%.

The agricultural production reduction in less developed countries is partly compensated for with an increase in agricultural output in developed regions. The question is whether this enables developing countries to be as food secure as in the baseline scenario.

Figure 7 shows that agri-food consumption per capita decreases relative to the baseline scenario. This is especially apparent in the restrictive Q and S REDD policy scenarios in which global agri-food consumption per capita is reduced by 0.7% and 1.2% respectively. The most vulnerable less developed regions face a much higher decrease. For example, Sub-Saharan Africa faces a decrease of 4% in the most restrictive S scenario compared to the baseline scenario. Sub-Saharan Africa suffers only in the restrictive S scenario because in the other scenarios the reduction in consumption is less pronounced because of limited reduction of available area for agricultural expansion (see Figure 3) and a relatively high intensification of agricultural production (Table 4). Southeast Asia faces substantial per capita agri-food consumption loses of almost 1.5% in the D scenario, a figure which increases to almost 2.5% in the S scenario. Similarly, a decline in per capita agri-food consumption is observed in INDIA+ and CSA regions. These changes can be harmful despite higher consumption growth in the baseline (See, Figure 4) because initial agri-food consumption levels are lower in these regions.

The increase of agri-food production in developed countries is not significant enough to feed less developed countries. There are various interrelated reasons for this. First, domestic demand for domestic production increases as imports from less developed regions decrease in developed countries. Second, export demand is not flexible enough as existing trade channels between less and developed regions are minimal. To fill the 2.5% output gap created by REDD in the S scenario, it would be necessary to increase developed countries agri-food exports by 50% and domestic output by 6.5% when compared with the baseline, while simulation results predict increases of only 14.5% and 2.5% for exports and output respectively. Third, land expansion possibilities in many developed countries are limited as they have already exploited these opportunities. This implies that production can only be expanded through an increase in production costs. Land and, subsequently, food prices will increase in developed countries and consumption will fall. This argument is not only related to land but also to all other production factors and inputs used in agriculture and, especially, those specifically oriented to agriculture.

Figure 8 shows that REDD leads to noticeable increases of agri-food exports by countries not directly affected by REDD policies such as North America (NAM), Europe and Turkey (EURTUR). Three important net-exporters of agri-food products in the baseline scenario - Central and South America (CSA), Southeast Asia (SEA+) and Sub-Saharan Africa (SSA) – gradually decrease their net exports as REDD implementation protects more areas potentially useful for agriculture. SSA even becomes a net-importer in the S scenario. Surprisingly, the INDIA+ region although experiencing a reduction in food consumption, decreases its net–imports. The INDIA+ case is an example of a non-Annex I region which faces relatively low restrictions from REDD and inertia in the regional trade patterns. The three most important trade partners of INDIA+ are CSA, SEA+ and SSA, which are together responsible for 64% of Indian imports. Food production in these regions decreases due to REDD policies and therefore exports to INDIA+ also decrease and become more expensive. Remaining regions are not able to increase their low import shares sufficiently to replace this reduction ofimports from these regions.

While the previous section analysed food availability under REDD scenarios, this section evaluates the consequences of REDD policies for two food access indicators within the food security concept. Food access is related to the food purchasing power of (poor) people and therefore food prices, dietary patterns, and income developments.. We select changes in agri-food prices as a proxy of the first food access indicator. A second constructed indicator is a proxy for the food purchasing power, i.e., it measures the price development of a food consumption basket in relation to income developments of a particular income group. We use consumption of cereals as a proxy for the diet of people potentially in poverty as rice is an important food component of poor people in Asia, while grains are important in Africa. We use changes in the wages of unskilled workers as a proxy for the income component of poor people. .

Figure 9 shows the development of the first indicator of food access - real agri-food prices - resulting from REDD policies. REDD does not lead to a very large increase in global real agri-food prices because world price increases are about 5.5% higher when compared to the baseline in the most restrictive scenario. However, food access is an issue in Southeast Asia (SEA+) and Sub-Saharan Africa (SSA) as real agri-food prices increase around 23% in these regions. Very high levels of forest area protection and an insufficient increase in imports of agri-food products are responsible for this increase. Real agri-food price increases in less restricted REDD scenarios A - D is limited to about 1 percent or even less in all regions except SEA+.

The food access indicator measured by the cereals purchasing power of unskilled workers gives rise to a similar pattern (see, Table 5). If 40% of global terrestrial carbon (scenario D) is protected, then only in SEA+ do we see a significant decline in this indicator (20%). For all other regions, the food purchasing power indicator decreases by only a few percentage points. Protection of 75% of global terrestrial carbon (scenario Q) leads to moderate reductions in food purchasing power for unskilled workers in Central and South America (CSA),15% and 12% respectively, and a severe reduction in South East Asia (SEA+) of 39%. If protection rises to the most protective S scenario, then there is a sharp decrease in the food purchasing power of unskilled workers in Sub-Saharan Africa (SSA) as this index drops by53%.

This section focused on the impact of restricting land available for agriculture within the REDD policy package on food prices, production and food security indicators. Our analyses indicate that for higher levels of forest protection, the impacts are negative for some developing countries and there is indeed a clear need for compensation payments to complement the forest protection measures within REDD. GDP losses due to REDD policy implementation can give an indication of the amount needed to compensate developing countries.

Global GDP in the REDD scenarios compared with the baseline scenario decrease slowly as more carbon-rich areas are protected. Worldwide GDP decreases in the most restricted scenario by about 0.24% (or by 177 billion USD) by 2030 compared with the baseline scenario. Sub-Saharan Africa (SSA) and Central and South America (SEA) face a GDP loss of 27 billion (2%) while GDP losses for Central and South America (CSA) will be 28 billion (0.5%). Southeast Asia (SEA+) experiences the highest absolute GDP loss (54 billion, USD in scenario S with 2.2%). Avoiding food security impacts requires that part of this money be spent on price or income support for poor people or on productivity investments within agricultural sectors.

3.3. Sensitivity analyses

Both the parameters within the land supply function and the yield assumptions made are key for assessing the effects of the REDD policies as reported above. These assumptions and parameters are characterized by a degree of uncertainty in regards to the ease with which additional land can be brought into agricultural production. We therefore conducted sensitivity analyses with regards to the land supply function parameters and yield assumptions. We perform the sensitivity analyses around an "average" policy scenario (G scenario) as it has a significant amount of global terrestrial carbon protection, but it is not the most extreme scenario in our study. The impacts of the sensitivity analyzes are reported for the agri-food prices and the agri-food consumption per capita outcomes as these are important indicators in the field of food security. The three sensitivity scenarios are run for the baseline and G scenarios:

- The LEL scenario reduces the ease with which land can be brought into: land supply elasticity 50% lower in each region.
- The SU scenario increases the substitution elasticity between the land and non-land endowments bundle (labour, and capital) by a factor 2.
- The Y scenario reduces yield increases by25% in each region for each crop over the 2005–2030 period.

Table 6 shows that a reduction in the ease with which land can expanded (LEL) and the lower yields (Y) scenario raises, as expected, the price level of agri-food products in comparison to the original scenario.. Land becomes a tighter constraint in these scenarios and therefore land and food prices increase accordingly. Scenario SU, in which land can be more easily substituted with other inputs such as labor and capital, leads, as expected, to lower price increases. The land constraint can be reduced through intensification which leads to smaller increases in land and food prices. However, the deviations are rather limited form the original results and we can conclude that the calculated results with regard to agri-food prices are robust in the originally calculated scenarios. Table 7 shows the results of the sensitivity analyses for agri-food consumption per capita. The results are consistent with the agri-food price results in that the LEL and Y scenarios reduce agri-food consumption per capita, while the SU scenario increases this indicator. Again, the originally calculated results on agrifood consumption are robust.

3.3. Conclusions

On first sight, the implementation of REDD does not have a pronounced impact on worldwide agricultural production. Even in the most restrictive REDD scenario, which implies a global terrestrial carbon protection level of 83% (or 90% of potential agricultural area protection), results in only a 1.5% reduction in agricultural production and 1.2% reduction in per capita food consumption. The global agricultural area decreases by almost 10%, however the negative impact of this fall in production is mitigated by yield increases.

The regional impact of REDD is diverse across regions. While highly developed regions are largely unaffected by REDD, less developed countries suffer substantially. Three less developed regions, Central and South America (CSA), Southeast Asia (SEA+) and Sub-Saharan Africa

(SSA), decrease their agricultural production by between 8% to 20%, and per capita agri-food consumption by between 1.5% to 4% in the most restrictive REDD scenario S as compared to the baseline scenario. The significant increase of agri-food prices in these regions can also cause large food security differences between rich and poor households. If less restrictive REDD policies are implemented, the impact of REDD is rather modest.

However, the impact of REDD on less developed countries depends significantly on the terrestrial carbon protection level. When 64% of global terrestrial carbon is protected (i.e., 28% of the potential agricultural area) in the REDD scenario G, per capita agri-food consumption decreases by 1% or less in the most affected regions. Food access for poor people measured by real agri-food prices and the food purchasing power of unskilled workers is an issue for Southeast Asia (SEA+) beginning in the C scenario (i.e. when 32% of global terrestrial carbon or, equivalently, 10% of the potential agricultural area in protected) as agri-food prices increase by5%. A stringent REDD policy that protects 83% of global terrestrial carbon (i.e. 90% of the land reserve that could potentially be used for agriculture), as modelled in scenario S, results in a global real agricultural price increase of almost 6%. Regional differences are again large. For example, in the case or real agricultural prices, price changes ranging from 1.1% in North America to about 22% in Sub-Saharan Africa and South-East Asia were observed. The Q scenario (which protects 75% of global terrestrial carbon i.e. 69% of the available land) ,has severe food access effects in South East Asia (SEA+) as the food purchasing power of unskilled workers decreases by39%, and are significant in Central and South America (CSA) and Sub-Saharan Africa,15% and 12% respectively. The most protective S scenario has severe consequences, for instance, food purchasing power of unskilled workers in Sub-Saharan Africa (SSA) drops by53%.

Global GDP in REDD scenarios as compared with the baseline scenario decreases slowly as more carbon-rich areas are protected. In the most protective scenario, global GDP decreases by0.24% by 2030 as compared tothe baseline scenario. For Sub-Saharan Africa (SSA) and Southeast Asia (SEA+), the reduction in GDP is about 2%, while for South America the reduction is about 0.5%. The reduction in GDP provides an indication of the required compensation payments needed by developing countries.

Sensitivity analyses with regards to the assumptions regarding the ease with which land can be expanded, , the substitution possibilities of land with other production factors like labor and capital, and yields, showed that deviations from the original results were limited. Therefore, we can conclude that the calculated results with regard to agri-food prices and consumption per capita are robust in the originally calculated scenarios.

The impact of REDD on agricultural sectors and food security in developing regions can be significantly mitigated, as proposed by REDD, through compensatory payments to developing countries for avoided deforestation by payments from highly developed regions. These payments can be used to directly compensate for higher food prices and lost incomes or to stimulate good agricultural practices and technical progress to increase agricultural productivity. The simulation results point to the importance of these payments if the level of forestry protection becomes higher from a food security perspective. As we did not include compensatory payments in our analyzes, they will be the subject of future research.

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Appendix A. Regional aggregation

Name	Regions/countries included
NAM	North America (USA and Canada)
CSA	Central and South America
SSA	Sub-Saharan Africa
NAFME	North Africa and the Middle East
EURTUR	Europe and Turkey
FUSSR	Former USSR
INDIA+	India (+ Pakistan Afghanistan, Bangladesh)
CHINA+	China (+ North Korea, South Korea, Japan, Taiwan)
SEA+	Southeast Asia (Indonesia, rest of Southeast Asia)
OCEA	Oceania (Australia, New Zealand)

Figures and tables

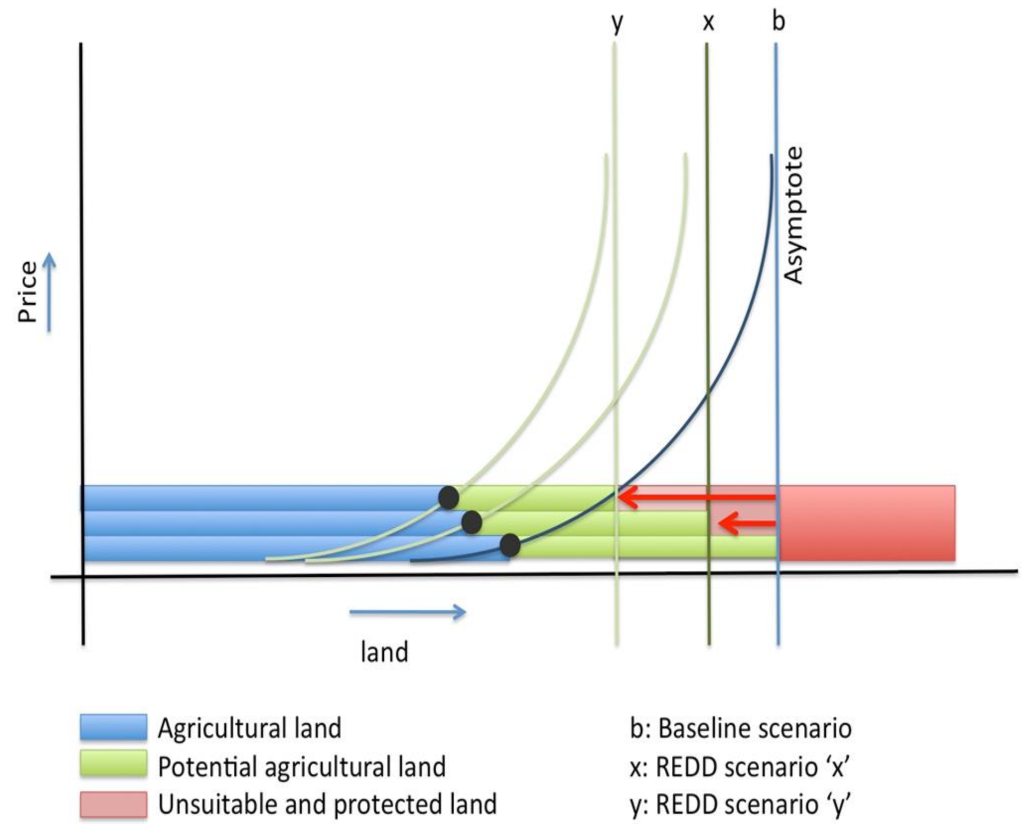

Figure 1. Land supply curve (Meijl, et al. 2006, Eickhout et al. 2009, Overmars, et al. 2014) and schematic land supply curve adjustments.

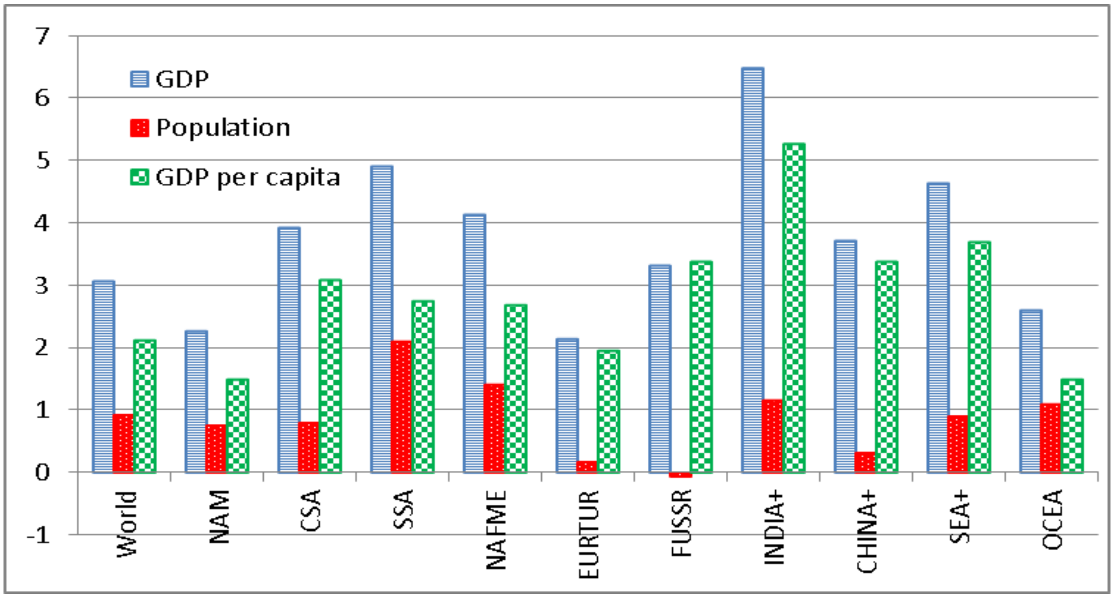

Figure 2. Macro-economic assumptions – average yearly growth rates of GDP, population and GDP per capita in 2010 - 2030. The regional aggregation and their abbreviations are presented in Appendix A. NAM = Northern America, CSA = Central and South America, SSA = Sub-Saharan Africa, NAF = North Africa and Middle East, SEA = South East Asia, OCEA = Oceania.

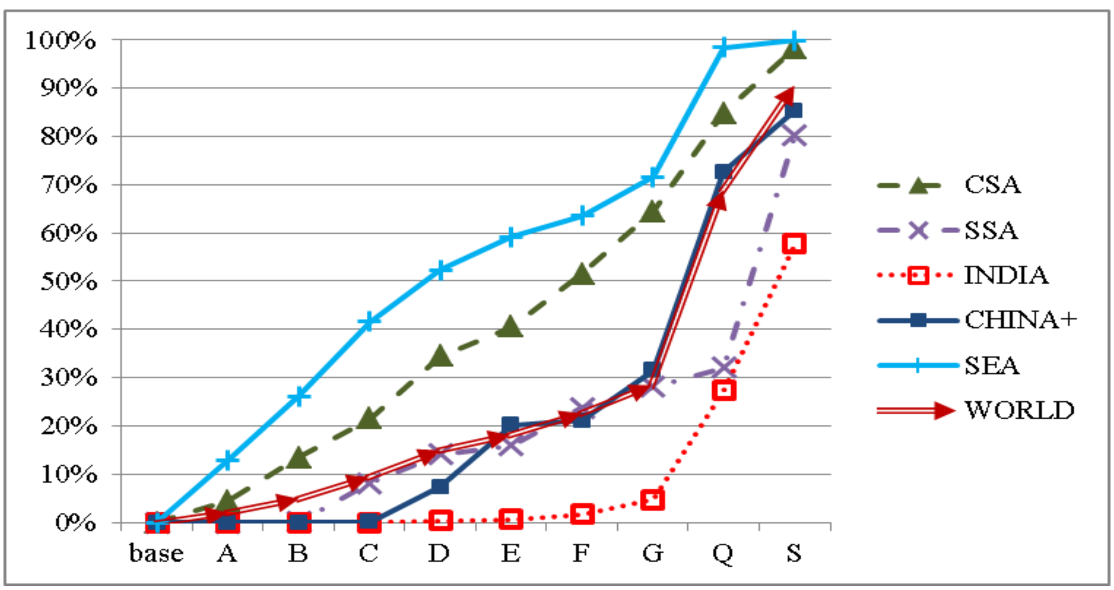

Figure 3. Percentage of the agricultural land preserved (land that could be potentially used as agricultural land) that is protected in the REDD scenarios (Overmars, et al. 2014).

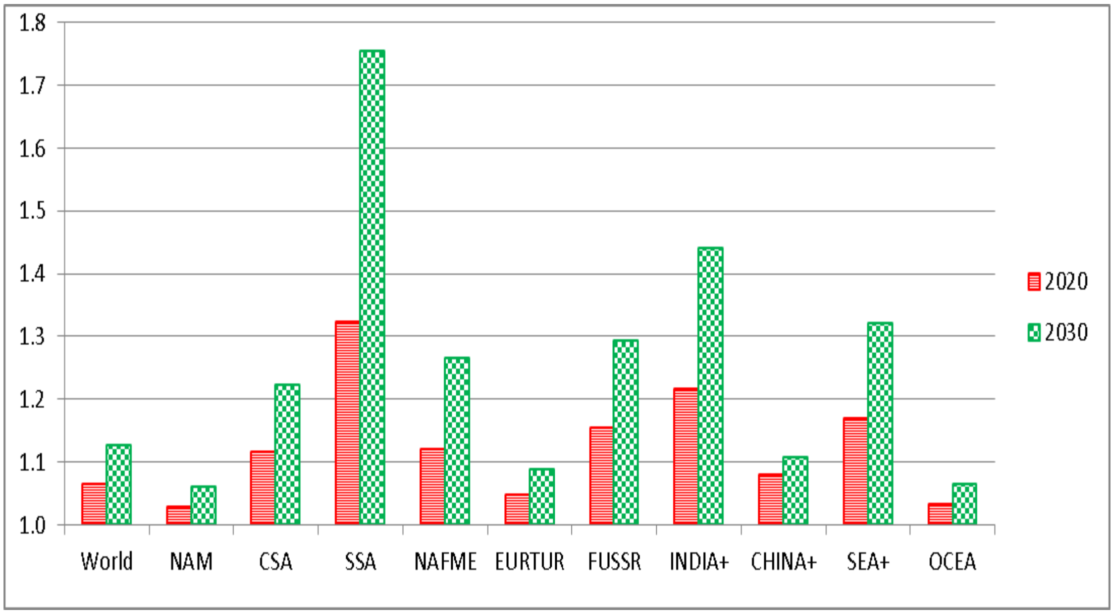

Figure 4. Per capita food consumption baseline in 2020 and 2030 (2010 = 1).

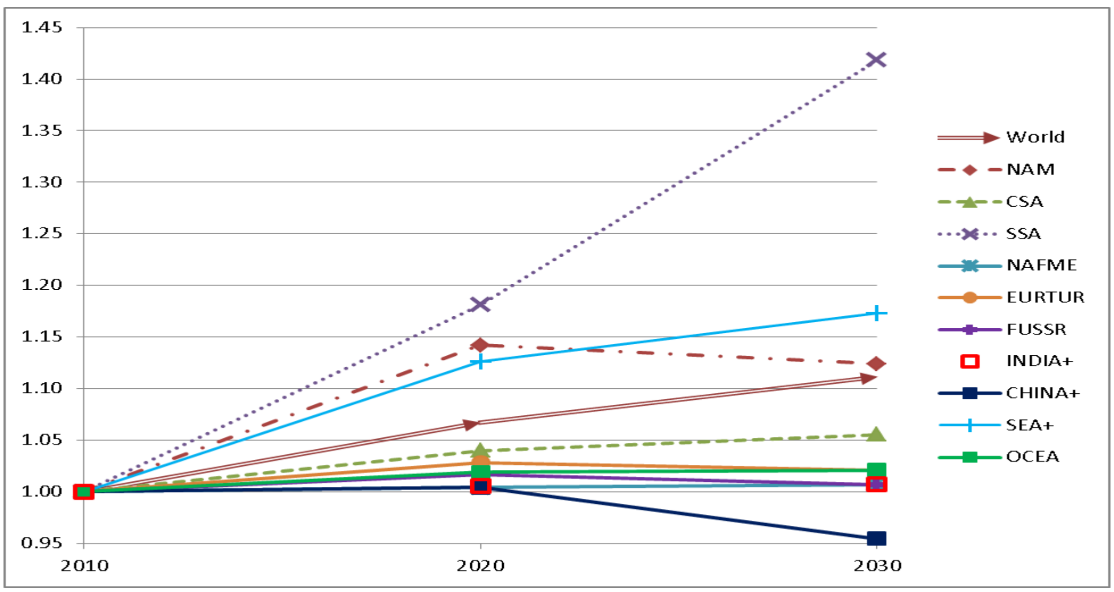

Figure 5. Agricultural land development in baseline scenario in 2010-2030 scenario (2010 = 1).

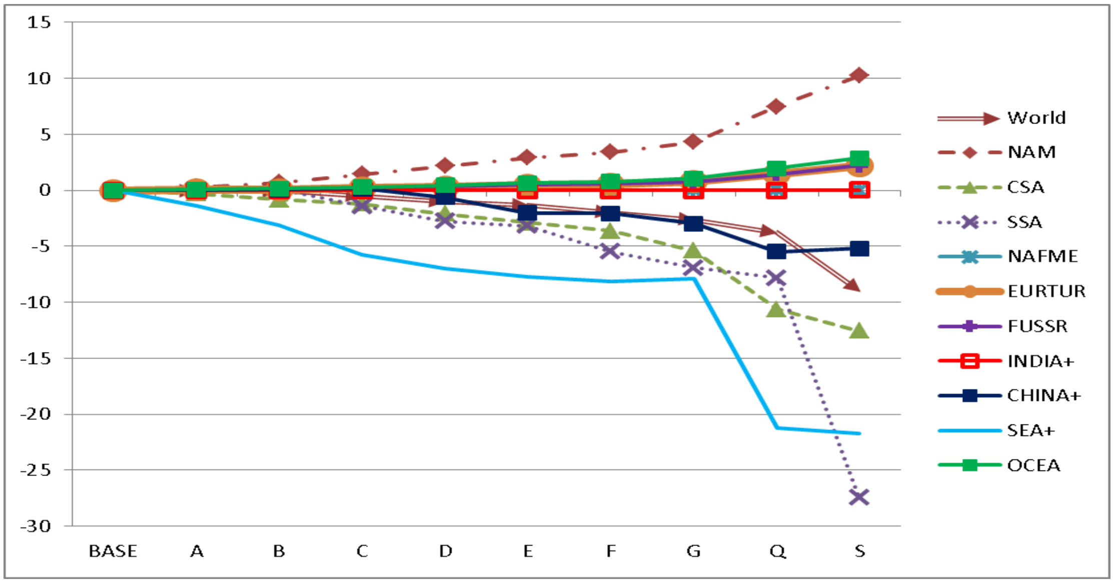

Figure 6. Agricultural land in 2030 in different REDD scenarios in % relative to the baseline scenario.

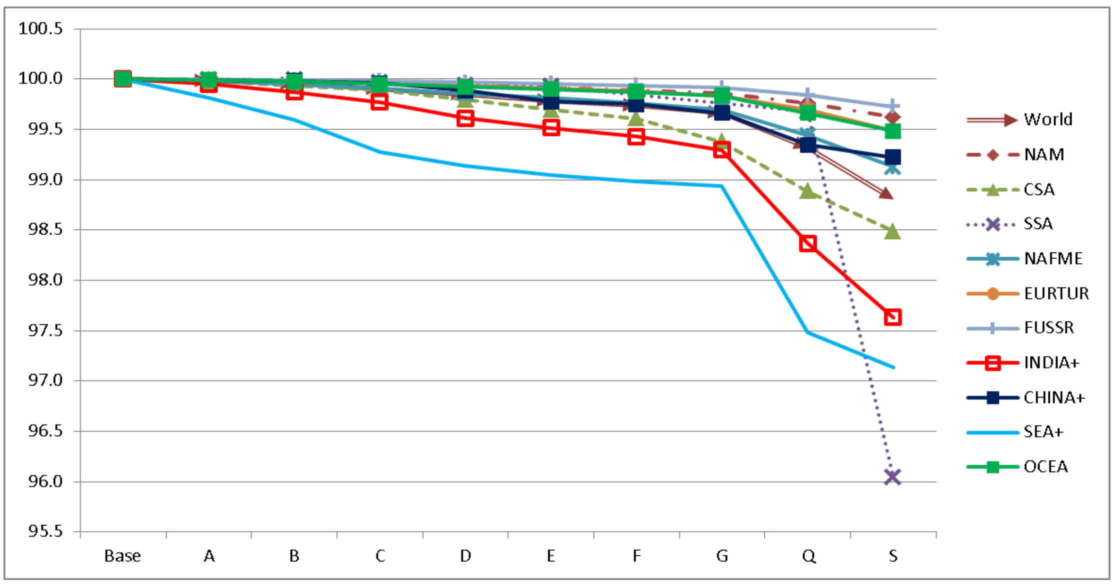

Figure 7. Agri-food consumption per capita in 2030 in different REDD scenarios in % relative to the baseline scenario.

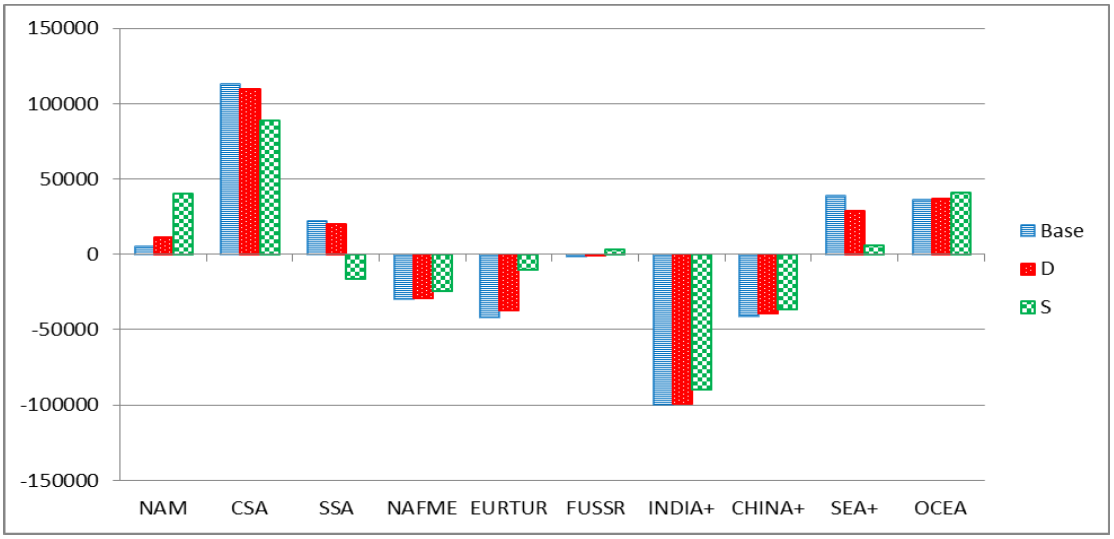

Figure 8. Net exports in base and D and S REDD scenarios in millions USD in 2001 prices.

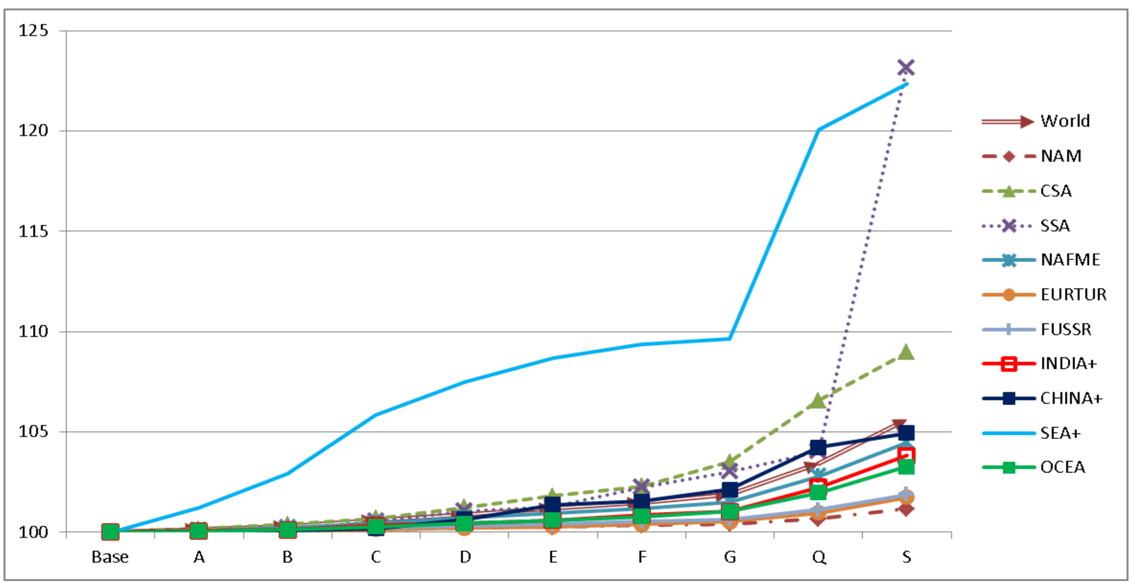

Figure 9. Real agri-food prices in 2030 in different REDD scenarios in % relative to the baseline scenario.

Table1. Exogenous growth yields and land availability in baseline scenario.

World regions	Average yearly yields growth rates in 2005 – 2030	Share of current agricultural land in total available land (%) in 2005	non-Annex I regions
World	1.7	58	
NAM	0.9	37	No
CSA	1.4	47	Yes
SSA	2.3	61	Yes
NAFME	2.3	99	No
EURTUR	0.9	81	No
FUSSR	0.8	44	No
INDIA+	1.0	99	Yes
CHINA+	2.2	90	Yes
SEA+	1.3	34	Yes
OCEA	1.3	72	No

Table 2.The REDD scenarios.

Scenario	A	b	C	d	e	F	g	q	s
% of global terrestrial carbon protected	10	21	32	40	49	58	64	75	83
% of the potential agricultural area protected	2	5	10	15	18	23	28	69	91

Table 3. Agricultural area in 2030 as a percentage of total available agricultural land excluding forests and woody lands.

World	NAM	CSA	SSA	NAFME	EURTUR	FUSSR	INDIA+	CHINA+	SEA+	OCEA
101	87	107	106	100	89	103	100	99	117	95

Note. Figures larger than 100 indicate deforestation in the baseline.

Table 4: REDD scenarios: Changes of agricultural production, land use and yields in Non-Annex I regions in 2030 compared with Base scenario

Non-Annex I regions	Scenarios	Output	Land use	Yields
CSA	D	-1.2	-2.1	1.0
	Q	-6.7	-10.6	4.4
	S	-8.2	-12.6	5.0
SSA	D	-0.9	-2.8	1.9
	Q	-2.7	-7.8	5.6
	S	-20.7	-27.5	9.4
INDIA+	D	0.1	0.0	0.1
	Q	0.2	0.0	0.2
	S	0.3	0.0	0.3
CHINA+	D	0.1	-0.6	0.7
	Q	-1.2	-5.5	4.5
	S	-0.7	-5.2	4.8
SEA+	D	-4.4	-7.0	2.8
	Q	-18.6	-21.2	3.3
	S	-19.0	-21.7	3.5

Table 5: Food purchasing power indicator[1] of unskilled labor in selected Non-Annex I regions relative to the baseline scenario.

Scenarios	Non-Annex I regions		
	CSA	SA	SEA+
D	0.97	0.97	0.80
Q	0.85	0.88	0.61
S	0.81	0.47	0.59

[1] % change in consumption expenditures on cereals (wheat, other grains, rice) minus % change in unskilled wage rate (constant 2007 prices)

Table 6: Real agri-food prices in 2030 in different G-REDD scenarios in % relative to the baseline scenario for the original, LEL, S and Y scenario

	Original	LEL	SU	Y	Average	St. dev.
CSA	103.5	104.2	102.9	104.7	103.8	0.8
SSA	103.0	103.5	102.2	106.1	103.7	1.7
INDIA+	101.0	101.2	100.9	101.4	101.1	0.2
CHINA+	102.1	102.5	101.9	103.1	102.4	0.5
SEA+	109.6	110.1	110.0	110.3	110.0	0.3

Table 7: Agri-food consumption per capita in 2030 in different G-REDD scenarios in % relative to the baseline scenario for the original LEL, SU and Y scenario

Scenarios	Original	LEL	SU	Y	Average	St. dev.
CSA	99.4	99.3	99.5	99.2	99.3	0.1
SSA	99.8	99.7	99.8	99.2	99.6	0.3
INDIA+	99.3	99.2	99.4	98.9	99.2	0.2
CHINA+	99.7	99.6	99.7	99.5	99.6	0.1
SEA+	98.9	99.1	98.9	98.8	98.9	0.1