Climate change interactions with agriculture, forestry sequestration, and food security

By

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Abstract

We evaluate the impacts of using carbon taxes and forest carbon sequestration to achieve 50% emission reductions. We consider four cases – carbon tax-only, combination of a carbon tax and equivalent sequestration subsidy, and the inclusion of crop yield shocks due to climate change in both policies (with 50% emissions reduction). We developed a new version of a computable general equilibrium model to do the analysis. We find that the tax/subsidy case causes substantial increases in food prices because of land competition between forest sequestration and crop production. When the climate induced yield shocks are added, the food price increases are huge – so large that it is clear this approach could not be adopted in the real world. We also compare a case with no mitigation and crop yield shocks appropriate for that case. The results suggest economic well-being falls more in that case than with 50% emission reductions.

Keywords: Forestry, carbon sequestration, food security, general equilibrium, climate change, crop yield, mitigation methods

JEL codes: Q15, R52, Q54.

There is a plethora of literature that describes the interaction among climate change, crop production and food security. These studies show that under adverse effects of climate change on agricultural yield, many regions could suffer from deficiencies in their food supply (Rippke et al. 2016, Burke and Lobell 2010, Lobell et al. 2008, Schmidhuber and Tubiello 2007, Gregory, Ingram, and Brklacich 2005, Stern 2007, Challinor et al. 2014). This situation is dramatic for poor families because agriculture is their main subsistence activity (GCEC 2014). As a consequence, living conditions for millions of people may be affected (Nagy et al. 2006).

Climate change can negatively affect crop productivity in many regions across the world (Ouraich et al. 2014, Nelson et al. 2010, Stern 2007, Qaderi and Reid 2009, IPCC 2007). Additionally, the demand for most agricultural products is often inelastic. Hence, a negative shock in food supply results in food price increases (Roberts and Schlenker 2010, Lobell, Schlenker, and Costa-Roberts 2011). This could leave many regions without the ability to produce and/or purchase enough food for their population (Stern 2007).

Agriculture was responsible for about 11% of greenhouse gases (GHGs) emissions in 2012 (Annex 1). Sources can be associated with intermediate input use (e.g. N_2O from fertilizers), primary factors (e.g. CH_4 from rice land) and sectoral outputs (e.g., CH_4 from livestock production) (US-EPA 2006, Golub et al. 2010, Herrero et al. 2016).

Forests help to reduce GHGs by sequestering CO_2 from the atmosphere as part of their photosynthesis process (US-DOE 2010, Daniels 2010). For this reason, reforestation and reduction of deforestation have been pointed out as a good alternative to mitigate climate change. A substantial body of evidence suggests that this method is relatively less expensive than other types of mitigation (Adams et al. 1999, Stavins 1999, Sohngen and Mendelsohn 2003, Richards and Stokes 2004, Golub et al. 2010, Sheeran 2006), bringing the attention of policy makers in the last quarter century (Goetz et al. 2013, US-DOE , Stern 2007, Golub et al. 2009).

Nevertheless, the existing literature has not (1) explicitly addressed the impacts of forest carbon sequestration (FCS) incentives on the global food supply and (2) taken into consideration the climate change effects on crop yields when evaluating FCS as a mitigation method.

Our study aims to improve our understanding of the interplay between climate change, mitigation policies, and their impacts on the global economy by addressing the following questions: what is the cost of emissions reduction with no FCS incentive? What is the mitigation cost incorporating FCS? What are the impacts of FCS on food security? What are the consequences for the global economy when crop productivity is affected by climate change? And, what is the economic value of reducing crop yield losses?

To fulfill our objectives, we defined two policies to reduce worldwide GHG emissions: (i) A global uniform tax on GHGs (in \$/tCO_2e) and (ii) the global uniform tax plus a FCS subsidy. Then using an extensively modified version of a well-known computable general equilibrium (CGE) model, we developed simulations to examine the extent to which these policies could affect the global economy under different future climate projections.

Our research contributes to the literature in several ways: (1) It develops a new CGE model entitled GTAP-BIO-FCS, which unlike its predecessors is suitable for the economic analysis of different mitigation practices including carbon tax, FCS, and biofuel production. (2) It provides evidence of the impact of FCS incentives on food security. (3) It highlights the economic and environmental consequences of including climate change crop yield impacts in the mitigation analysis.

Methodology

Many studies have explored climate change in different perspectives: projecting population, income, damages on infrastructure, health, among others. They have used a wide range of approaches such as integrated assessment models and dynamic modeling (van der Mensbrugghe 2013, Cai, Lenton, and Lontzek 2016). Instead, we followed a simpler comparative static approach to isolate the carbon taxes and FCS effects from the interaction with other exogenous variables (such as distributional income effects, demographic variation, and intertemporal discounting) (Weyant 2014) to understand their role in the global economy.

CGE modeling is recognized for being suitable for the evaluation of policy analysis including climate change mitigation (van der Mensbrugghe 2013, Golub et al. 2008). The standard GTAP model is a multi-sectorial CGE model which associates consumption, production, and trade in a multi-regional framework assuming perfect competition and constant returns to scale (Hertel 1999). In order to evaluate FCS and other mitigation alternatives, we develop a new comparative static version entitled GTAP-BIO-FCS which represents the global economy in 2004. This model is an adaptation of two well-known GTAP extensions: GTAP-AEZ-GHG and GTAP-BIO. The first model incorporates all GHG emissions (CO_2 and non-CO_2) and FCS (Golub et al. 2012). Nevertheless, this model suffered some technical deficiencies, does not calculate welfare and has no biofuels (Annex 2). The GTAP-BIO model has been extensively used to evaluate the economic and environmental consequences of energy and biofuel policies. This model has no technical issues and calculates welfare. Its land structure differentiates land conversion between forest and pasture to cropland, and its land transformation elasticities are tuned with historical observed land use patterns (Taheripour and Tyner 2013). Nevertheless, this model does not have non-CO_2 emissions and does not incorporate FCS.

We integrated the properties of both models and did the following modifications and improvements:

(1) We include CO_2 and non-CO_2 GHG emissions as well as forest carbon stocks. We also incorporate both biofuel and FCS in our modeling framework.

(2) We split forest carbon stock into stock associated with forest land and stock associated with managing biomass used by forest industry. Unlike the GTAP-AEZ-GHG model, this permits us to implement sequestration incentives on these inputs separately. It also ensures the correct capture of subsidies and balance of the regional I-O tables.

(3) The emissions on endowments (e.g., emissions from livestock production and land for paddy rice, among others) are evaluated and included in the I-O tables as primary factors. This allows the model to keep the accounting balances in order to obtain consistent equilibria in the capital account and welfare.

(4) We provide an "add-on" tool entitled GTAP-VIEW which provides checking of the equilibria and accounting balances in the model.

(5) We developed a welfare decomposition add-on which permits the evaluation of the contributions to the welfare variation (in $ of Equivalent Variation [EV]) such as allocation efficiency (changes due to reallocation of endowments), technical efficiency (due to improvements on productivity), and terms of trade, among others.

Thus, our GTAP-BIO-FCS model provides a more comprehensive basis for climate change mitigation including alternatives such as FCS and biofuels. We then use our new model to fulfill the objectives of our study implementing the following experiments:

1. Tax regime for GHG reduction (Tax-Only scenario***):*** This experiment implements a global uniform carbon tax to achieve a 50% reduction in net emissions from consumption, endowments, and production. This target of emission reduction follows the projections of the Representative Concentration Pathway 4.5 (RCP4.5) of the IPCC 5th Assessment Report (AR5) (IPCC-WGIII 2014) .

2. GHG tax-subsidy regime (Tax-Subsidy scenario***):*** This experiment uses a two-part instrument consists of a carbon tax and a subsidy on carbon sequestered in forestry to achieve the goal of 50% reduction in emissions.

3. Tax regime in the presence of crop yield shocks (Tax+CY): This experiment implements the tax region while it takes into account changes in crop yields due to climate change. This captures the costs emissions reduction when climate change affects crop yields.

4. GHG Tax-subsidy regime in the presence of crop yield shocks (TS+CY): We implemented a tax-subsidy policy together with the same climate change induced crop yield shocks used in the ***Tax+CY*** case. The ***TS+CY*** scenario was implemented to evaluate what is the extra cost for the society of implementing FCS in the presence of climate change on agricultural productivity.

Crop Yield Shocks. To evaluate the consequence of climate change for crop yields we rely on the existing research in this area. The crop productivity data (in metric ton/ha) are collected for the period 2000-2099 through the online package developed by Agricultural Model Comparison and Improvement Project (AgMIP) (Villoria et al. 2016) at grid cell level (i.e. 0.5° × 0.5° resolution) and then aggregated by AEZ and type of irrigation (Villoria et al. 2014) for each country at the global scale. Once we collected the data, we further aggregated them per GTAP region, AEZ, and crop sector. Finally, we used them to calculate our crop yield shocks. These values are then used in the third and fourth experiments as exogenous percentage changes in productivity of land. This procedure is described in more detail in Annex 3.

In addition, with the objective of quantifying the economic value of reducing the crop yield losses, we did another scenario called ***Crop Yield under Business As Usual (CYBAU)***. In this simulation we implement crop yield shocks in our model following the RCP 8.5 from the IPCC AR5 which assumes consumption and production behaves as usual (BAU) with no mitigation (Wayne 2013, Riahi et al. 2011). This case provides complementary insights of the costs for the global economy of the adverse effect of climate change under no mitigation efforts.

Results

Our simulations display a wide range of results in terms of economic and environmental variables at the sectorial and regional level. Here, we only present the key results to highlight the interactions among mitigation policies, FCS, and climate change induced crop yield shocks, and their implications for food security.

Tax requirement and GHG emission reduction

The ***Tax-Only*** scenario imposes a tax rate of \$150/tCO_2e to reduce emissions by approximately 13.5 GtCO_2e worldwide (50% global emissions reduction). This forces the electricity sector to fall by 53% of its actual production and accounts for 41% of the global reduction (-5.5 GtCO_2e). Similarly, the other industries decreased emissions 20-75% to achieve the target. With no subsidy, FCS contribution to emissions reduction is negligible (fig. 1).

When the subsidy on FCS is included, the tax-subsidy rate required to reduce the same quantity of GHG as our ***Tax-Only*** scenario is only 80\$/tCO_2e. The ***Tax-Subsidy*** scenario shows that FCS plays an important role in climate change mitigation. Approximately 3 GtCO_2e (i.e.

one-fifth of the GHGs reduction) is due to the capture of CO_2 by forest trees and land. This occurs mainly in regions with vast forest, such as South America (i.e. Amazon Region), Central America, Sub Saharan Africa, United States and India (fig. 2).

Including the presence of climate change impacts on agriculture produces an overall decline in crop productivity for most of the agricultural sectors and regions of the world (Annex 3). With the agricultural yield decreases, the FCS share of emissions reductions falls substantially (figs. 1) (from 21% to 14% share) and increases the carbon tax to \$100/tCO_2e (***TS+CY*** scenario). This result clearly demonstrates that FCS becomes somewhat less attractive once climate induced crop yield changes come into the picture.

This happens because many regions (Europe, Japan, Canada and China) are discouraged to afforest due to decline in agricultural productivity, which leads them to use more land for crop production to satisfy their domestic consumption and exports of agricultural commodities. Thus, FCS is lower, forcing other industries (fig. 1) to have a bigger role. In contrast, for regions with vast forest (Brazil and Sub-Saharan Africa), the share of FCS is still one of the major contributions in GHG reduction due to the benefits of the sequestration subsidy.

The picture is different for the ***Tax+CY*** scenario. Due to the fact that there are no incentives for FCS: (i) The tax regime increases only \$5/tCO_2e (becoming \$155/tCO_2e) and (ii) all of the sectors declined production proportionally, which kept their shares in GHG reduction relatively constant.

Land use change

It is not surprising that imposing only a tax regime (***Tax-Only*** and ***Tax+CY*** scenarios) does not provoke land use change (Supp. Fig. 4) due to the absence of incentives to expand forest. Most regions remain with the same proportion of land except for Sub-Saharan Africa which has an increase of forest cover (+35 Mha) at expenses of pasture land.

The area variation across crop sectors in many regions is heterogeneous (Supp. Table 1). Paddy rice area declines, especially in Asia (i.e. China, India, and South East Asia). This is partially attributed to the fact that land growing rice emits methane to the atmosphere. In contrast, the area for the other crop sectors expands, especially for coarse grain and oilseeds as well as vegetables, fruits and other products (i.e. considered in the "other crops" category).

Figure 2 shows how the incentive in FCS attracts afforestation in most of the regions of the world. As expected, expansion of regional land cover occurs at the expense of cropland and pastureland in each scenario. This is mainly due to the high subsidy level which benefits places with vast forests depending on their carbon sequestration intensity. With the ***Tax-Subsidy*** scenario, about 700 Mha are reforested globally whereas cropland decreases by 378 Mha. The main increase in forest cover occurs in the tropical and temperate climates with long growth periods (e.g. AEZs 4-6, 10-12).

As expected, fig. 3 shows a global decline of 378 Mha in harvested area due to the extensification in forest land, especially in places that take advantage of the sequestration subsidy. This reduction is distributed to regions where crops are grown (Supp. Table 1). The main affected sectors are "other crops" globally (-112 Mha); coarse grains in Latin America (-15 Mha), US (-13 Mha) and Sub-Saharan Africa (-27Mha); oilseeds in US and South America, and paddy rice globally (-60 Mha).

The reduction of cropland in the ***Tax-Subsidy*** scenario drives up land rent (Supp. Table 2b) for almost all crop sectors, AEZs and regions of the world affecting especially economies that are more land intensive in production. As an indirect result, there is also substitution of land by labor (both skilled and unskilled) and capital (i.e. except for carbon-intensive industries such as dairy farms and ruminant sectors). If agricultural industries cannot substitute land with capital and labor, the negative impacts on crop production could significantly increase. Then higher tax-subsidy rates would be needed to reduce emissions by 50%. This means that with no substitution the FCS policy becomes more expensive.

On the other hand, despite the decreases in area, production of many crops increases. This is in part attributed to a boost in productivity to partially offset the land reduction (Annex 4). Thus, forest expansion due to FCS incentives has two effects on agriculture, according to our ***Tax-Subsidy*** experiment: (1) Forest expansion bids land away from agriculture. (2) It encourages improvements in land productivity to provide higher production in the remaining land (e.g., better management practices, fertilization) as well as substitution with other primary inputs (labor and capital).

In the ***TS+CY*** scenario, with decreased crop yields in many areas (Annex 3), the only possible responses to satisfy a given crop demand are either through extensification of agricultural land or importing products from other regions. Only a third as much cropland is converted compared to the ***Tax-Subsidy*** scenario and thus 20% less land is moved to forest (about 141Mha less). Thus, with the reduced crop yields, less land is available for FCS (fig. 2), so there is less total forest land added and more pasture land converted to avoid decreases in cropland. Hence, there is an expansion in global harvested area (fig. 3) for all the crop sectors compared to the ***Tax-Subsidy*** scenario including paddy rice. In addition, land becomes more valuable driving up its rent by 500% or higher in many places (Supp. table 2).

Changes in regional output

Here, we discuss both policies of tax and tax-subsidy under the effects of climate change on crop yield. We present the results for selected commodities including outputs and prices aggregated of aggregated three items (table 1): paddy rice, crops (all the other agricultural sectors), and livestock (ruminant, dairy farm cattle and non-ruminants). For further explanation on output and prices please refer to Annexes 5 and 6.

There is output redistribution for agriculture under the ***Tax+CY*** regime (Supp. table 3). Overall, the burden of the carbon tax on outputs (including goods and services) together with the adverse effects on yields drives down crop production for many regions. Paddy rice, ruminant and dairy farm outputs suffer the most due to their emissions (table 1).

The repercussion on agricultural output is worse when forest subsidy plays a role in the mitigation effort (***TS+CY*** scenario) (table 1, Supp. table 3). This is caused by the overall reduction in regional harvested areas due to the forest expansion together with losses in agricultural productivity. This drives down output for almost all the crops across the world, except for a few regions (Central European countries and Canada), which increase their output to satisfy their self-consumption and export food commodities.

Changes in regional domestic food price

Taking into account that the demand elasticities of food commodities are relatively inelastic for most of the regions, the changes in prices are higher than changes in output. Additionally, high losses in private consumption, decline in GDP and decrease in energy and livestock production drives heterogeneity in price increases in food commodities across regions, which cannot be alleviated by trade. This is particularly the case for India as well as other developing regions.

In the ***Tax+CY*** scenario, the price rise is much more pronounced in the agricultural sectors with GHG emissions due to the addition of the high carbon tax regime of \$155t/CO_2e. This is the case for paddy rice and the livestock sectors with price increases higher than 50% for almost all the regions (Table 1).

The implementation of the \$100/tCO_2e tax and subsidy changes the situation. Prices for (both non-carbon and carbon intensive emitter) agricultural commodities increase overall in the ***TS+CY*** compared to the ***Tax+CY*** scenario. This is a result of the land competition between forest and agriculture, low crop yields and abrupt rises in land rent. Thus, the prices for most agricultural products are often more than double (+200%) their original value. Hence, the loss in productivity reflects most of its response in prices. As a result, this further reduction in food supply and dramatic rise in food prices then acts as a major threat for food security. People, particularly low income groups, will have to spend a larger share of their income on food products, especially emerging economies where agriculture is an important subsistence activity (Sub-Saharan Africa, South East Asia, India, South and Central America).

Livestock prices also increase dramatically under both scenarios. Nevertheless, in some regions, the situation is worse under the ***Tax+CY*** regime (with a high tax of \$155/tCO_2e) because this sector is heavily penalized due to its emissions from land and capital (i.e. animal stock).

Changes in trade balance for food

Trade balance is the difference between regional exports and imports. Many places (India, Sub-Saharan Africa) opt to increase their trade deficit in agricultural commodities under the ***TS+CY*** scenario due to the adverse crop yield shocks. This drives up the import prices in these regions which motivates some regions (United States, Central Europe and Oceania) to increase their net food exports. The situation is overall similar under the other scenarios.

Macroeconomic variables

The incorporation of climate changes effects on agriculture into the picture shows that the overall consumer price index (CPI) increases mainly due to the high food prices (Annex 7, Supp. Table 5). Interestingly, in many (developed) regions the ***Tax+CY*** regime causes CPI to increase more substantially than imposing a ***TS+CY*** policy. This is the case, because these policies are implemented in the whole economy (i.e., manufacturing and services) and not only in agricultural products. Thus, the 155$/t$CO_2$e tax on emissions drives up the prices for sectors such as coal, oil, gas and energy intensive products higher than in the 100$/t$CO_2$e tax-subsidy case. In contrast, for several developing regions, especially the ones that were more affected by land use change and loss in productivity (e.g., among them, South Asia, India, China, South America, Sub-Saharan Africa), the overall prices are higher under the presence of the tax-subsidy regime (figure 4).

Both policies decrease real GDP (which is endogenous in our model) across the world (Supp. table 5). Nevertheless, given (i) the higher food prices (and CPI), (ii) land rent and (iii) land competition, the tax-subsidy rate (***TS+CY***) drives more abrupt declines in private consumption and energy production and increases in imports. These facts ultimately decrease real income by 0.1%-9.9% for most of the regions in the world. It is not surprising that the situation is more severe for developing economies (Sub-Saharan Africa, Central and Eastern Europe, Latin America, China, India) because of their income dependence into some extent on agriculture and decrease in net exports (which is a component of GDP) in order to satisfy domestic consumption (figure 4).

Welfare impacts

Table 2 shows an overall decline in the welfare (a measure of economic well-being in $ of equivalent variation [EV]) under the imposition of both policy regimes. We compare first the situation with no climate change effects, which has been the common practice in previous studies. Here, our results suggest that implementing the ***tax-subsidy*** regime drives a global welfare loss of about $457 billion, which is lower than the EV loss from applying the ***tax-only*** regime ($-760 billion). This result is consistent with the literature which considers FCS as a cost-effective method compared to other mitigation alternatives.

Climate change provokes adverse impacts mainly in (i) technical efficiency (i.e. effects of lower productivity) due to crop yield losses in all regions and (ii) allocation efficiency (i.e., changes in inputs and intermediate products from one sector to another), due to the reallocation of resources (e.g., more labor for agriculture, substitution of energy by capital, among others). As a consequence, the simulations suggest a significant underestimation of social welfare losses if the agricultural productivity variation is not included in the analysis of both policies. This is especially true for FCS modeling, in which these climate change impacts represented an additional $650 billion loss in welfare.

In addition, incorporating the overall adverse effects on agriculture provides an important insight: Under the presence of climate change, FCS becomes a less attractive alternative due to the land use competition, increase in land rent and food prices, larger reductions in private consumption and output production, and lower real income in many regions. Thus, the welfare losses are $200 larger when implementing FCS subsidies under this context compared to ***Tax+CY*** scenario. In other words, including crop yield shocks reverses the conventional wisdom and suggests that a carbon tax only is preferred to the tax combined with FCS.

In order to compare the welfare losses between RCP 4.5 and RCP 8.5, we first take the difference between the policy regime scenario and its respective policy including the climate change impacts on agricultural productivity. Specifically, we take the difference between ***Tax+CY*** and ***Tax-Only*** scenarios. We do this calculation in order to isolate the effects of the additional losses from the adverse crop yields under the RCP4.5 which permits to compare it with the consequences under the RCP 8.5. The procedure is similar for the tax-subsidy regime.

The global welfare loss due to the crop productivity under both mitigation methods (-$154 and -$650 billion, respectively) is lower than the total EV loss due to crop yield shocks under consumption and production as usual (***CYBAU*** scenario) which is $726 billion (table 2). This result suggests that there is an economic benefit of mitigating crop yield losses of about $76 billion under the tax-subsidy regime and approximately $570 billion gain worldwide under the tax-only policy. This benefit is before all the other benefits of mitigation in other sectors, so it is, even in isolation, a strong case for mitigation.

Conclusions and final remarks

FCS has been acclaimed by the literature as a good alternative to mitigate climate change effects. In order to evaluate its effects on the global economy and food supply we developed a new computable general equilibrium entitled GTAP-BIO-FCS to isolate the effects of a carbon tax and sequestration subsidy to understand their role in the GHG emission reduction. We also include the effects of climate change on crop yields to analyze how the economic situation can be aggravated under these adverse impacts under both policy regimes.

Our estimates support previous findings in terms of the importance of FCS as a mitigation method for climate change: The cost of implementing FCS in terms of income and welfare (through sequestration subsidy) is lower than using only a carbon tax regime when the crop yield losses due to climate change are not considered. However, our findings add an important dimension: when we incorporate the overall adverse effects of climate change on agricultural productivity - the cost for society of providing FCS incentives can become a threat for food security because it increases the competition for land between forestry and agriculture and boosts abruptly cropland rent. An aggressive FCS policy drives a major decline in food and livestock production across the world leading to substantial increases in food prices, higher than 200% in many regions for most agricultural sectors, especially emerging economies. We observe this effect more clearly when we compare it to a tax-only regime to reduce emissions 50%. This shows the importance of including climate change crop yield impacts when evaluating the benefits of FCS as a mitigation method.

There are two important implications of this research. First, developing countries are affected much more severely than developed. Second, because of the adverse impacts, it may prove quite difficult to negotiate stringent emissions reductions policies, because it represents an important trade-off that especially developing economies have to make: implement mitigation measures to reduce GHG emissions and accept the losses in GDP and substantial food price increases – or not. Politically, it will be near impossible for developing countries to accept the food price increases and GDP losses.

Additionally, our results suggest that mitigating the adverse effects on climate change could result in an economic benefit in social welfare compared to a business as usual scenario.

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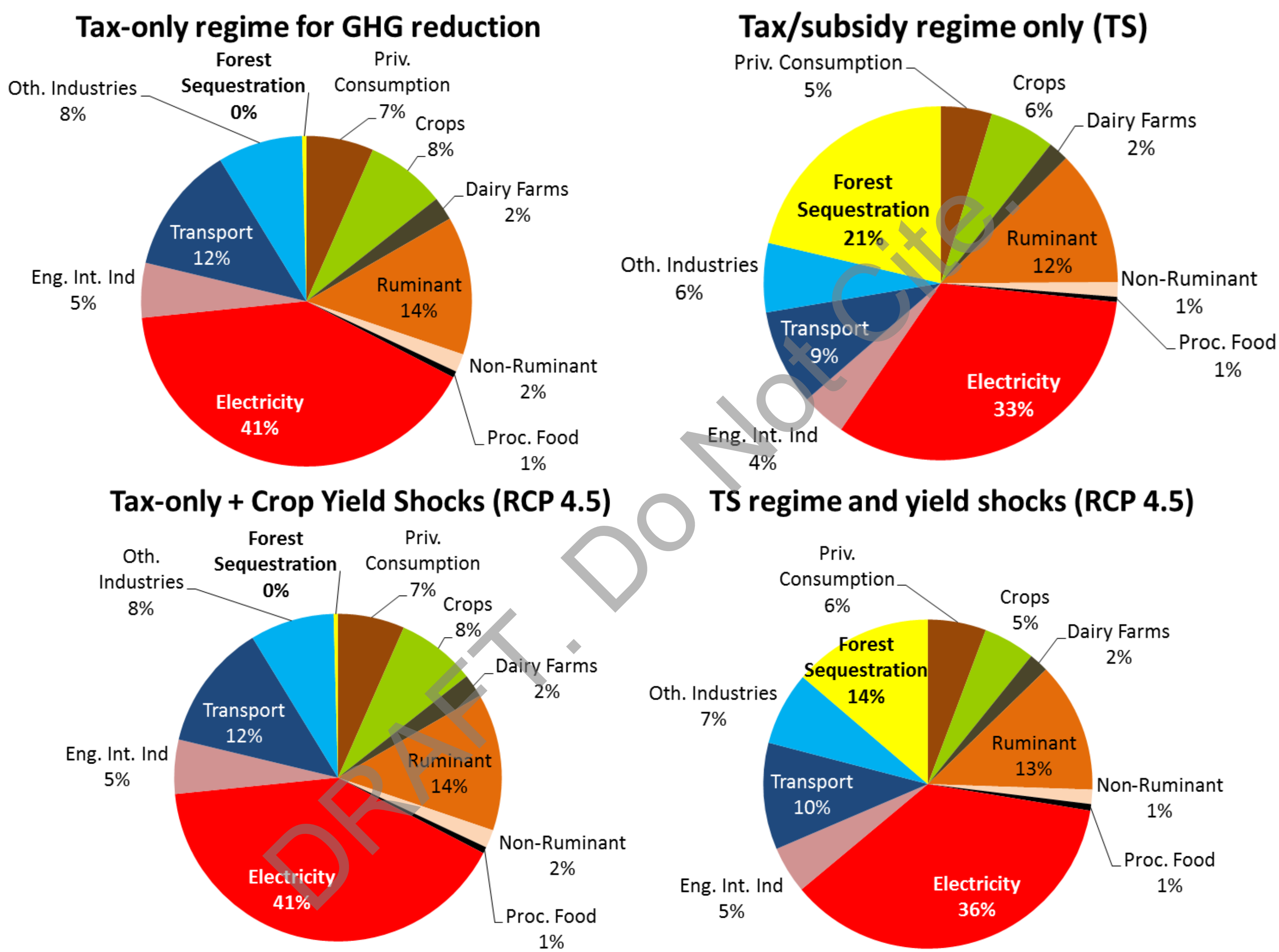


Figure 1: Sectoral shares (%) in global GHG emission reductions

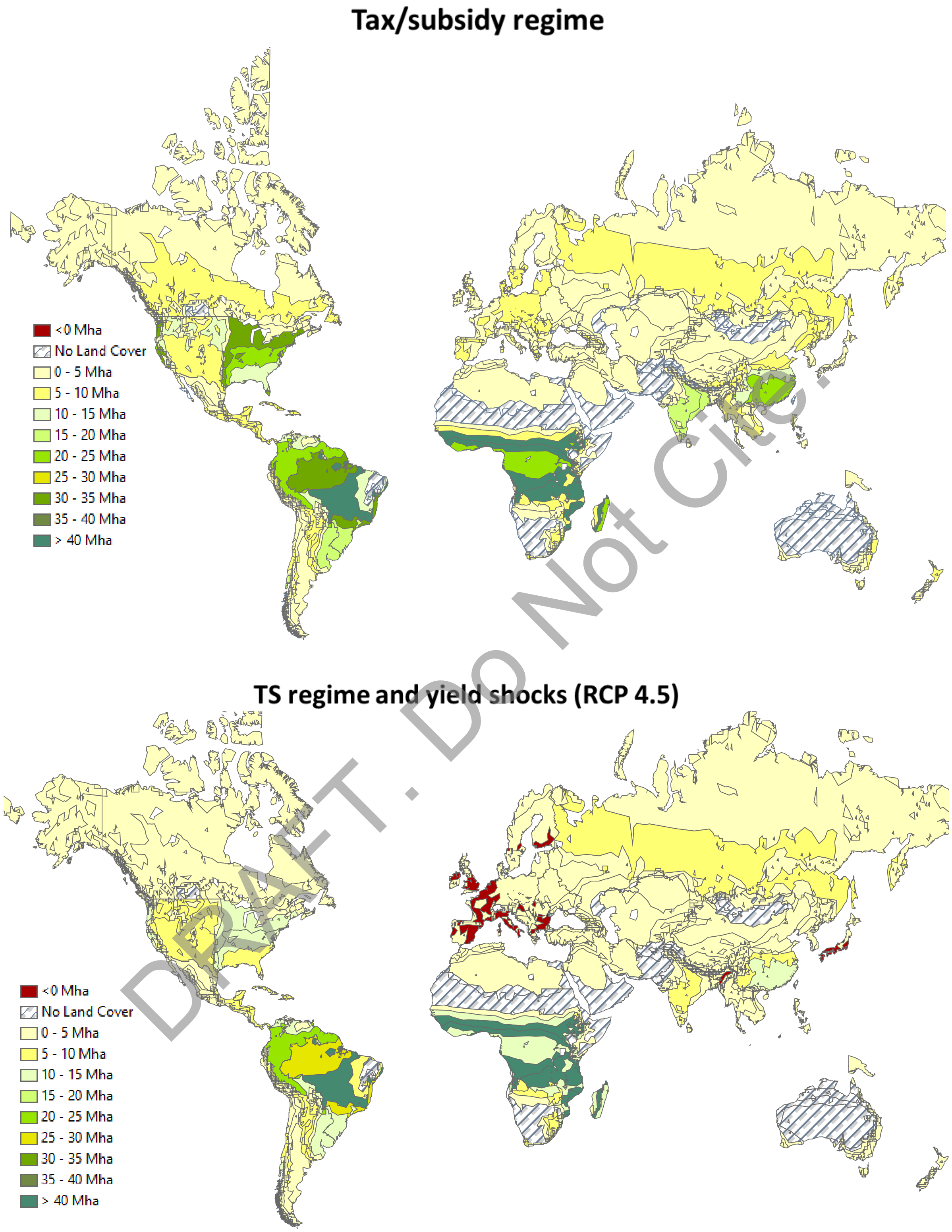


Figure 2. Changes in forest area for each region at the AEZ level (in Mha) for the *Tax-Subsidy* and *TS+CY* scenarios

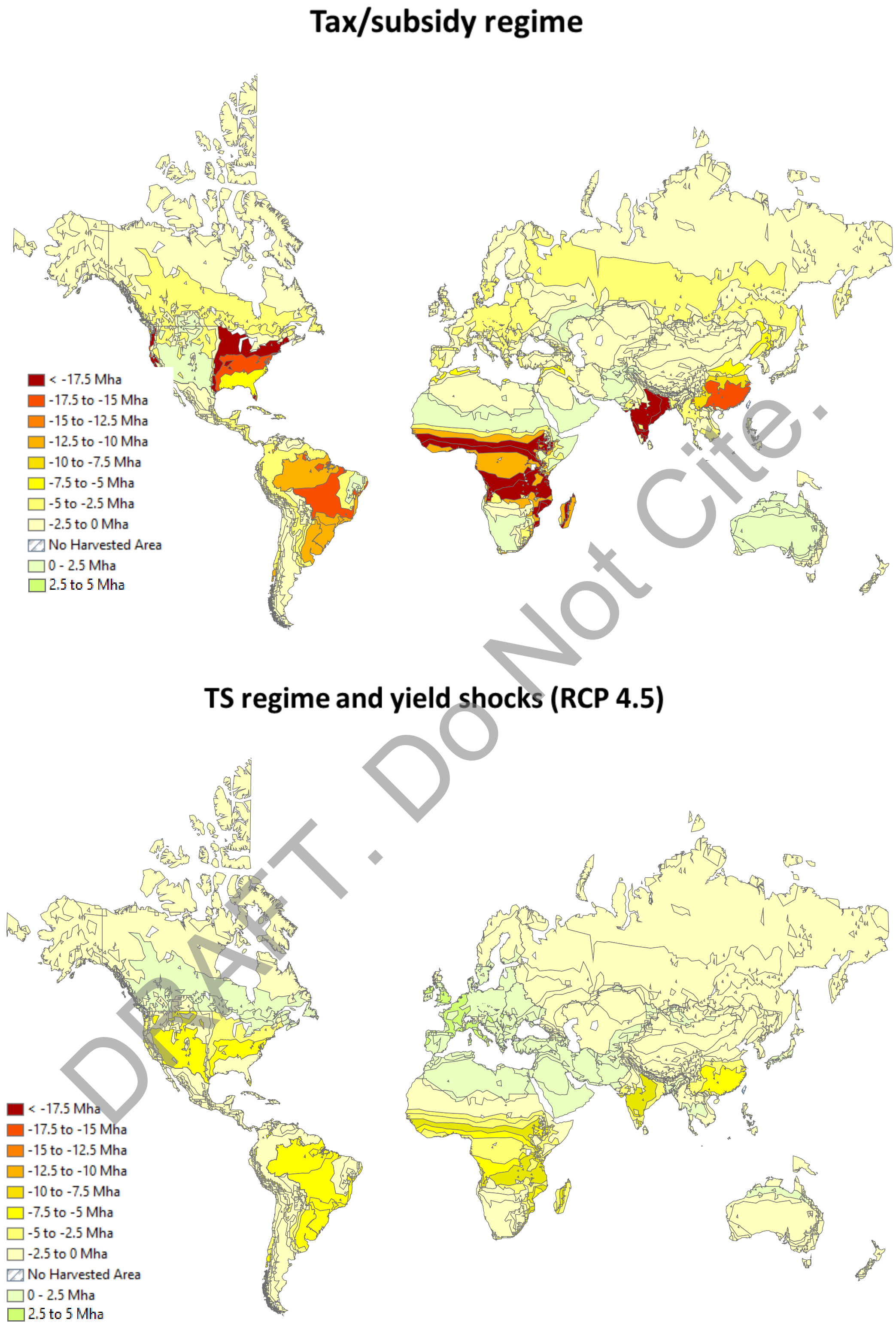


Figure 3. Changes in cropland area for each region at the AEZ level (in Mha) for the *Tax-Subsidy* and *TS+CY* scenarios

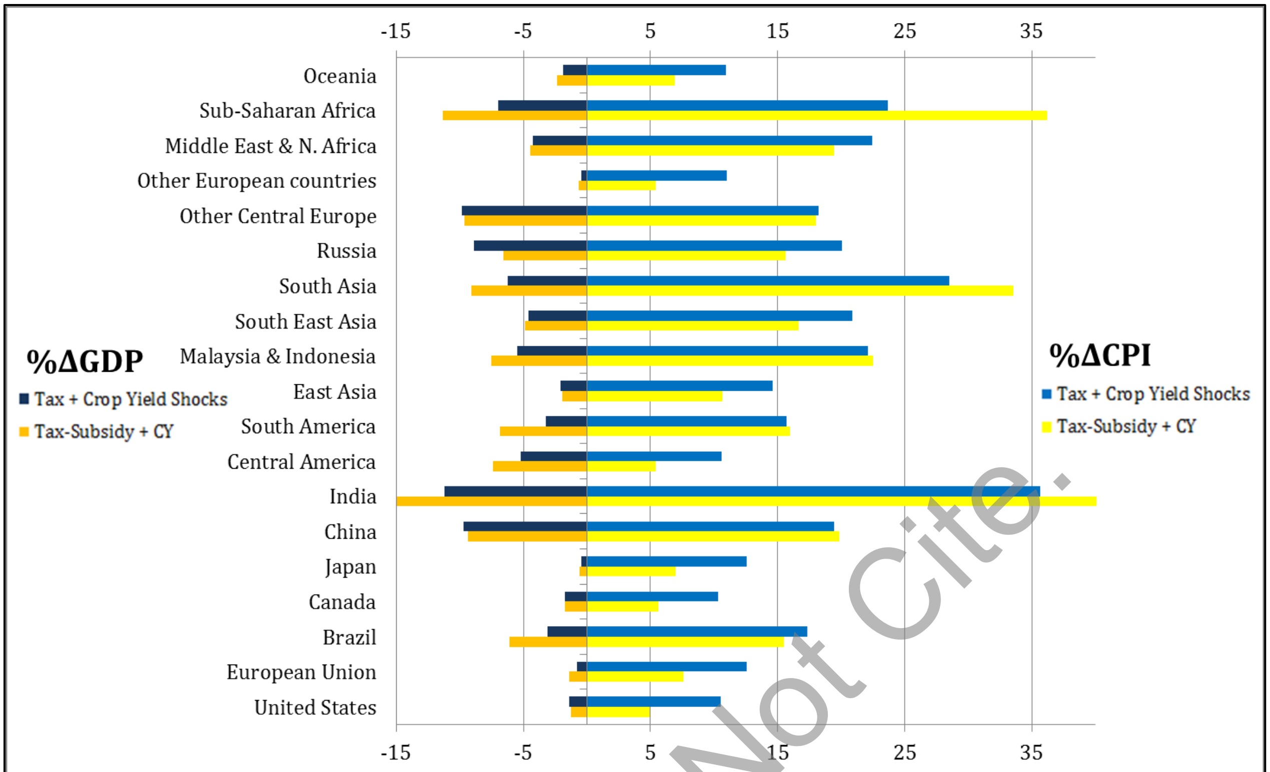


Figure 4. Percentage change in Consumer Price Index (right of diagrams) and regional GPD (left of diagrams) for each scenario

Table 1. Changes in food prices and output products (in %) for each scenario

Region	% Changes in Prices						% Changes in Output					
	Tax regime + CY			Tax-Subsidy + CY scenario			Tax regime + CY			Tax-Subsidy + CY scenario		
	Rice	Crops*	Livestock	Rice	Crops*	Livestock	Rice	Crops*	Livestock	Rice	Crops*	Livestock
United States	106	46	41	250	145	44	10	-7	-5	-9	-15	-7
European Union	87	47	40	147	105	37	21	-9	0	14	-1	-1
Brazil	79	36	278	213	166	224	-3	1	-40	-14	-26	-39
Canada	28	44	45	54	126	54	0	3	3	0	3	-5
Japan	36	25	31	98	83	40	1	0	1	-6	-1	-5
China	172	22	49	184	97	55	-29	-4	-16	-27	-11	-18
India	470	84	77	517	196	100	-21	-17	-16	-24	-24	-23
Central America	96	23	56	316	167	68	-6	0	-14	-50	-29	-23
South America	168	46	139	367	203	151	-18	-6	-22	-30	-40	-27
East Asia	134	57	51	216	132	64	-17	-15	-15	-24	-15	-23
Malaysia & Indonesia	164	49	57	211	142	56	-15	-9	-15	-20	-23	-18
South East Asia	194	28	87	222	107	75	-31	6	-21	-31	3	-21
South Asia	161	39	65	290	99	67	-16	-3	-10	-28	-5	-14
Russia	132	40	36	141	84	43	-21	-10	-13	-21	-12	-15
Other Central Europe	110	41	54	108	90	61	-24	-4	-10	5	2	-13
Other European countries	16	34	36	10	88	36	0	4	-2	0	12	-4
Middle East & N. Africa	57	32	54	95	93	55	43	-6	-17	61	-4	-19
Sub-Saharan Africa	171	35	272	299	164	200	-34	0	-37	-56	-29	-38
Oceania	141	37	73	160	159	61	21	-1	-13	71	-20	-3

Crops: This index is the weighted average of all crop sectors except paddy rice: wheat, sorghum and other coarse grains, palm, rapeseed, soybeans, sugar crops and “other crops”. Here we consider paddy rice independently because it is the only crop sector with land emissions (of methane).

Livestock considers three categories: dairy farms, ruminant and non-ruminant livestock.

Table 2. Changes in welfare (billions of USD) for the four scenarios

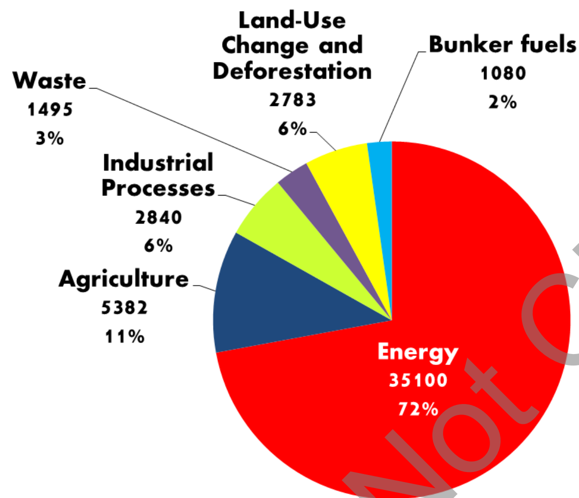
Region	Tax Only	Tax Subsidy	Tax + CY	TS + CY	ΔCY(4.5)*	CY(BAU)
United States	-116	-52	-125	-95	-10	-20
European Union	-1	11	-49	-162	-49	-234
Brazil	-15	-10	-13	-20	2	-3
Canada	-15	-8	-15	-11	0	1
Japan	8	4	3	-25	-5	-38
China	-194	-113	-195	-189	-1	-61
India	-32	-30	-69	-96	-37	-112
Central America	-53	-37	-58	-85	-5	-32
South America	-19	-18	-18	-31	1	-5
East Asia	-13	-7	-18	-25	-5	-19
Malaysia & Indonesia	-16	-12	-22	-29	-6	-28
South East Asia	-14	-7	-17	-14	-2	-12
South Asia	-8	-6	-13	-19	-4	-23
Russia	-61	-32	-67	-56	-7	-20
Other Central Europe	-47	-26	-54	-46	-8	-26
Other European countries	-9	-8	-11	-13	-1	-6
Middle East & N. Africa	-103	-71	-115	-115	-12	-53
Sub-Saharan Africa	-46	-33	-50	-70	-5	-35
Oceania	-6	-2	-5	-4	0	3
Global	**-760**	**-457**	**-913**	**-1,107**	**-154**	**-726**

*ΔCY (4.5) is calculated as the difference between the Tax and TAX+CY scenarios

The current table shows the welfare loss for the three main scenarios in $ of EV. Likewise, it shows the benefits and cost of mitigating crop yield losses comparing the additional impact of RCP 4.5 and the decrease in social welfare due to impacts under RCP 8.5

Annex 1 – Greenhouse emissions sources

Here we present that energy sector represented the largest contribution in the global greenhouse (GHG) emissions during the year 2012 (Supp. Fig. 1). Agriculture was the second emitter sector with 11% share in GHGs (CAIT 2015).



Supp. Figure 1. GHG emissions (in $MtCO_2e$) by energy sector in 2012

Source: CIAT, World Research Institute (2016), adapted by the authors

In terms of non-CO_2 gases (CH_4 and NH_3), agriculture was the largest emitter in the previous decade, being responsible for about 59% of non-CO_2 emissions in 2001. The most important sources were paddy rice (e.g. its land releases methane), ruminant sector and dairy farm (e.g. animals releases non-CO2 GHG emissions through livestock enteric fermentation) (US-EPA 2006, Golub et al. 2010). In particular, livestock represents 50% of the global agricultural GDP. Because of this reason, 30% of the land area for grazing and one-third of harvested area is devoted to feed around 20 billion animals making this sector an important source of GHGs. In the period of 1995-2005, livestock total emissions were 2.0-3.6 $GtCO_2e$ (Herrero et al. 2016).

Annex 2 – The GTAP-BIO-FCS model

Background of the model framework

Computable General Equilibrium (CGE) models are recognized to assess economic impacts of changes in the global production, trading systems, migrant movements, among others. Recent studies have also modeled impacts on natural resources and commodities. For these reasons CGE models have become popular for policy analysis debates, starting since the evaluation of the impacts of the Uruguay Round in the late 1980s (van der Mensbrugghe 2013).

The Global Trade Analysis Project (GTAP) is one of the pioneer models in this area. Its database its recognized to be a very important source of information for many CGE models, including the well-known GTAP model (from the same organization) and ENVISAGE model (from the World Bank) (van der Mensbrugghe 2013). The GTAP model is a multi-sectorial CGE model which associates consumption, production and trade in a multi-regional framework. It assumes perfect competition and constant returns to scale (Hertel and Tsigas 1997).

The GTAP model and database have several extensions, among them: GTAP-E, which incorporates carbon emissions from fossil fuels, capital-energy substitution and emission trading (Burniaux and Truong 2002, Truong, Kemfert, and Burniaux 2007). GTAP-AEZ divides land use into agro-ecological zones (Saez) and land-based GHG emissions (Lee 2004). Posteriorly, two well-known models were elaborated from this extension:

(i) GTAP-AEZ-GHG, which incorporates non-CO_2 emissions and link them to their sources (i.e. consumption of fossil fuels, land emissions from paddy rice, capital emissions [emissions from animals] from livestock, among others). It also includes forest carbon stocks per region and is able to model climate change mitigation methods such as forest carbon sequestration (FCS). Nevertheless, this model presents some technical issues (imbalances in the capital account when carbon taxes rise, not proper allocation of subsidies on outputs outside the I-O tables, among others); it does not provide welfare decomposition and does not include mitigation alternatives such as biofuels(Golub et al. 2009).

(ii) GTAP-BIO, which is used for the economic and environmental evaluation of energy and biofuel policies(Taheripour et al. 2007, Birur, Hertel, and Tyner 2008). The extended version by Taheripour and Tyner (2013) have important updates with respect to the land structure: It differentiates land conversion from pasture and forest to cropland, recognizing that the opportunity cost are different depending on each land type. The land transformation elasticities are tuned with historical land use change observations from the last decades. This model also has not technical issues and calculates welfare. However, it only has carbon emissions and does not incorporate FCS.

Thus, GTAP-BIO-FCS is a multi-regional multi-sectorial static CGE model which associates the economic behavior to their environmental consequences (i.e. land use change, GHG emissions). This model represents the economy in 2004 integrating both extensions (GTAP-AEZ-GHG and GTAP-BIO) and unlike its parents is suitable for the economic analysis of different mitigation practices including carbon tax, FCS, and biofuel production. The modifications and improvements of this model are described in the following sub-sections and full detail in Pena-Levano, Taheripour, and Tyner (2016).

The modifications in the database

The model uses the 19 GTAP regional aggregation and it utilizes the GTAP-BIO and GTAP Land Use Database version 7. It is divided in 43 industries (agricultural, manufacture and service sectors), 48 tradable commodities (including biofuel byproducts) and it has 25 endowments (18 AEZs, capital, skilled and unskilled labor, natural resources and 3 sources of emissions). We included the following information in the database:

(1) The non-CO_2 emissions by commodity, sector and region. Thus, GHGs are emitted from: (i) Private and government consumption of fossil fuels, (ii) Intermediate use of fuels and energy intensive products of each sector and (iii) Emissions from primary inputs.

(2) GHG emissions from land, capital and output are included; nevertheless, we incorporate them as primary input factors inside the production rather than independent sources. Thus, the GHGs are now included in the I-O tables as endowments. For this reason there is no need to create new nests in the model to make substitution between emissions and inputs/outputs. This is an advantage over the GTAP-AEZ-GHG model because it allows keeping the accounting balances in order to obtain consistent equilibria in the capital account and welfare.

(3) We also include forest carbon stocks. However, we distinguish between from carbon stocks from forest land and stock from managing biomass used by forest industry. Unlike the GTAP-AEZ-GHG model, this permits us to implement sequestration incentives on these inputs separately. It also ensures the correct capture of subsidies and balance of the regional I-O tables.

The consumption structure

The government demand structure is similar to the standard GTAP, in which all the tradable commodities compose the aggregated consumption trough a CES function. The private household follows a similar structure as the modified GTAP-BIO version by Taheripour and Tyner (2013). In particular, the energy nest of the model is specified to have a CES sub-structure that allows for substitution between petroleum and biofuels commodities (For a detailed explanation please refer to Pena-Levano, Taheripour, and Tyner (2016)).

The production structure

The production structure for a commodity has also a similar nest feature as the modified GTAP-BIO version by Taheripour and Tyner (2013). The organization structure includes biofuels products (i.e. ethanol and biodiesels) to be substitutes of petrol products; DDGS (Distiller's dried grains with soluble) from coarse grains to be used as livestock feedstock; and also oilseed byproducts (vegetable oils) to be used as intermediate goods in the production tree (Pena-Levano, Taheripour, and Tyner 2016).

Emissions on land, capital and output are declared as sluggish endowments and are tied proportionally to their respective inputs/outputs. These emissions are assigned ad-hoc values following Golub et al. (2010) study. All of the primary factors are then incorporated in the value-added energy nest. Furthermore, this formation allows and permits substitution between capital and energy in the presence of external disturbances such carbon taxes.

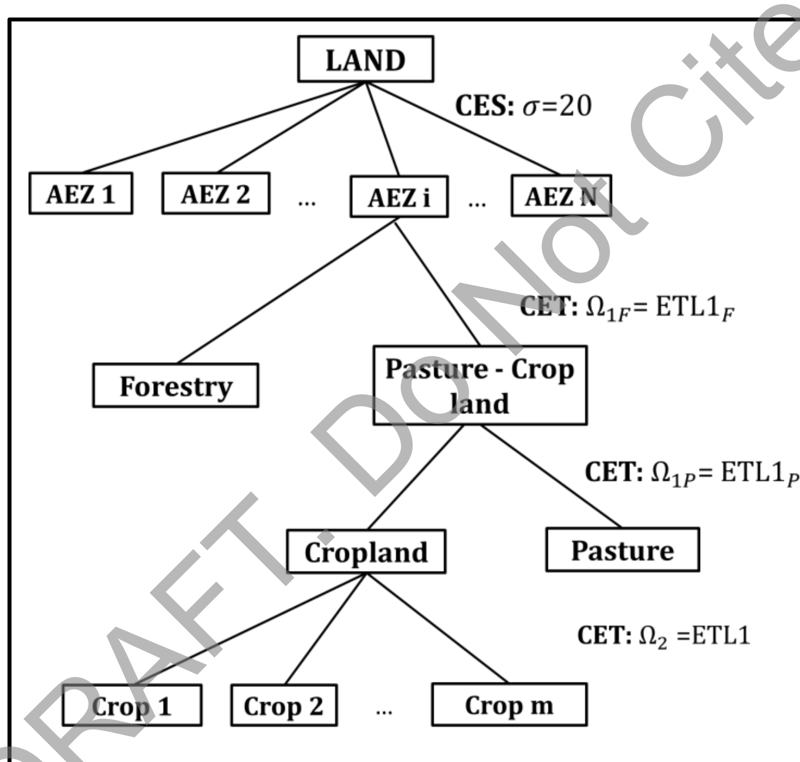
We modify the endowment structure to separate the effects of carbon taxes with other taxes, thus we have ***VFM*** which is the market value of primary products, ***EVFANC*** which represents carbon tax-exclusive endowment values and ***EVFA*** which is the carbon tax-inclusive value of factor endowments, similar to the GTAP-AEZ-GHG structure.

Carbon tax-inclusive prices $pfe_{(i,j,r)}$ for the endowment emission i (land, capital or output) produced by sector *j* is defined as follows:

$$pfe_{(i,j,r)} = \theta_{EVFANC_{(i,j,r)}}\left[pm_{(i,j,r)} + tf_{(i,j,r)}\right] + 100\theta_{FFEVFA_{(i,j,r)}}NCTAXB_{(r\in b)}$$

where the price is a composite of the (i) ad-hoc endowment price $pmes_{(i,j,r)}$ and carbon tax-exclusive of endowments $tf_{(i,j,r)}$ and (ii) carbon tax on emissions $NCTAXB_{(r\in b)}$; each of them with their respective shares. For the other endowments and non-forest commodities, the price formulation is similar as the GTAP-BIO version by Taheripour and Tyner (2013).

All the sub-nests in the value-added energy consider a constant elasticity of substitution (CES) structure, except the land at the AEZ level (Supp. Fig. 2). Land owners are assumed to be rent maximizers and therefore the land nest follows a constant elasticity of transformation (Fawcett, Clarke, and Weyant) (Fawcett, Clarke, and Weyant) at the AEZ level.

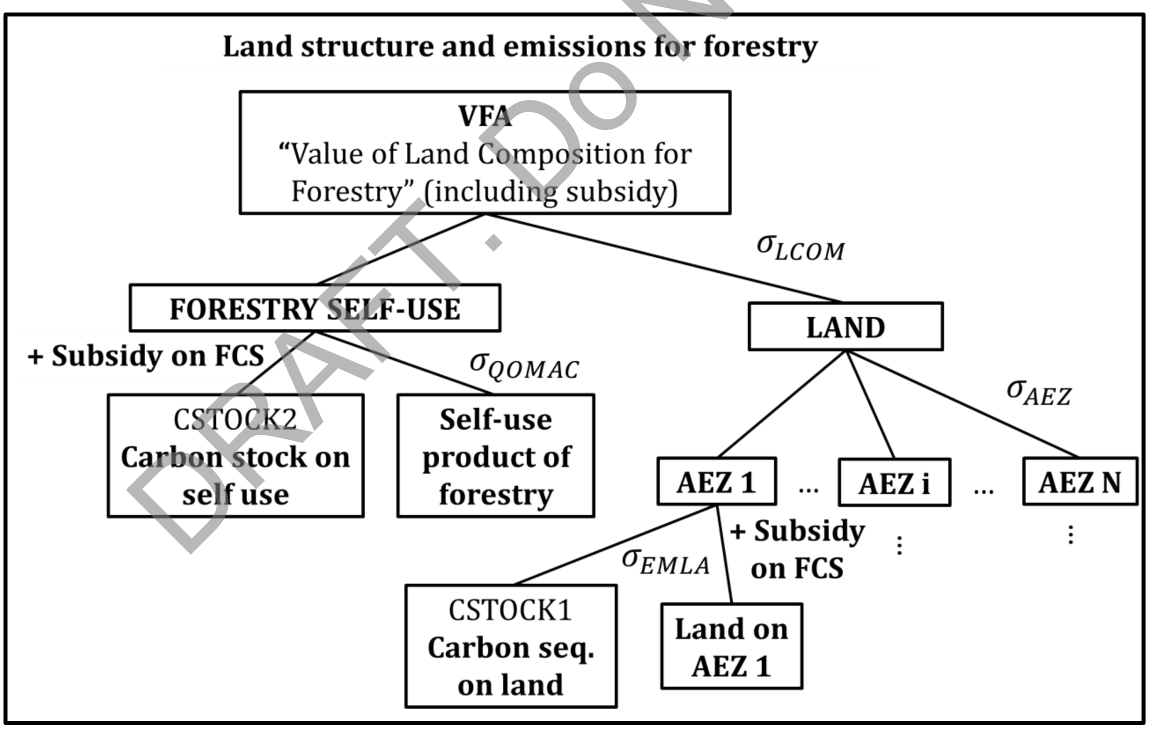


Supp. Fig. 2 Land structure for all the land types

For each AEZ, there is distribution of land for each cover type (i.e. pasture, forest and cropland). The organization in this model takes into consideration that overall pasture land rent per hectare is higher than forest cover rent; and both rents are smaller than cropland rent returns (Gurgel, Reilly, and Paltsev 2007). For this reason, cropland and pasture are aggregated in one bottom level nest called "*pasture-crop*" composite, whereas there is a top level that represents the substitution between forest and "*pasture-cropland*" composite. At the bottom level, cropland is distributed to all the agricultural crop sectors. The original CET elasticities were tuned with historical land pattern observations from the previous decade.

Forest carbon sequestration (FCS)

FCS is obtained based on the global timber model used by Golub et al. (2012) in the GTAP-AEZ-GHG model. Nevertheless, we split the forest carbon stock in the components of the value forestry self-use on forestry industry, thus FCS occurs by increasing (i) forest land and (ii) forest biomass (Supp. fig. 3). This permits the implementation of the subsidy on inputs rather than outputs to preserve the correct capture of subsidies and keep the balance of the regional I-O tables.



Supp. Fig. 3 Land structure and sequestration for forestry

Two important variables in the production structure are ***qf(i,j,r)*** and ***pf(i,j,r)*** which represent demand and firm's price of commodity ***i*** for use by sector ***j*** in ***r***. For the value of forestry (***landcomp***), we incorporate substitution ($\boldsymbol{\sigma_{LCOM}}$) between land (***emland***) and own use in forestry (***forestry***) into a CES structure. This permits us to separate the forest carbon stocks of self-use (***CSTOCK1***) and land (***CSTOCK2***). The price and demand for inputs in the land-own use forest sub-production are given by the following equations:

$$pf_{("landcomp",j,r)} = \sum_{k\in LCOMP\_COMM} \{\theta_{SHLCOMP}(k,j,r)[pf_{(k,j,r)} - af_{(k,j,r)}]\}$$

$$qf_{(i,j,r)} = -af_{(i,j,r)} + qf_{("landcomp",j,r)} - \boldsymbol{\sigma_{LCOM}}(r)[pf_{(i,j,r)} - pf_{("landcomp",j,r)} - af_{(i,j,r)}]$$

where $i,k \in LCOMP\_COMM = \{emland, forestry\}$, $j \in FOREST$, $\theta_{SHLCOMP}(k,j,r)$ is the share of *k* in the value of *landcomp*.

We now define the forest land structure, here the percentage change in demand price for forest land *j* at the AEZ level *i* [$\boldsymbol{pfe_{(i,j,r)}}$] including the sequestration subsidy is:

$$pfe_{(i,j,r)} = \theta_{EVFANC}(i,j,r)[pmes_{(i,j,r)} + tf_{(i,j,r)}] - 100\theta_{SEQEVFA}(i,j,r)NCTAXS_{(r\in b)}$$

where $\boldsymbol{pmes_{(i,j,r)}}$ is the carbon tax-exclusive land rent in forestry, $\boldsymbol{tf_{(i,j,r)}}$ is the tax on primary inputs, $\boldsymbol{\theta_{EVFANC}}(i,j,r) = \frac{EVFANC(i,j,r)}{EVFA(i,j,r)}$ is the share of carbon tax-exclusive domestic value of primary products, $\boldsymbol{\theta_{SEQEVFA}}(i,j,r) = \frac{CSTOCK1(i,j,r)}{EVFA(i,j,r)}$ is the sequestration intensity (share of carbon stock from forest land), and $\boldsymbol{NCTAXS_{(r\in b)}}$ is the sequestration subsidy applied to region *r* which belongs to the bloc *b*.

The other two important components in the production tree are ***qfd(i,j,r)*** and ***pfd(i,j,r)*** which represents domestic demand and firm's price of tradable commodity ***i*** for use by sector ***j*** in region ***r***. Thus, moving downward in the production structure of forest, the demand of self-use of forestry is determined as in the standard GTAP-E model, whereas the domestic price of the forestry self-use nest [$\boldsymbol{pfd}_{(\boldsymbol{forest},\boldsymbol{forest},\boldsymbol{r})}$] is determined similarly as the forest land rent:

$$pfd_{(i,j,r)} = \theta_{VDFANC}(i,j,r)[pm_{(i,r)} + tfd_{(i,j,r)}] - 100\theta_{SEQVDFA}(i,j,r)NCTAXS_{(r\in b)}$$

where $i,j \in Forest$, $\boldsymbol{pm}_{(\boldsymbol{i},\boldsymbol{r})}$ is the market price, $\boldsymbol{tfd}_{(\boldsymbol{i},\boldsymbol{j},\boldsymbol{r})}$ is the tax on domestic intermediate purchase, $\boldsymbol{\theta}_{\boldsymbol{VDFANC}}(i,j,r) = \frac{VDFANC(i,j,r)}{VDFA(i,j,r)}$ is the share of carbon tax-exclusive domestic value of intermediate products, and $\boldsymbol{\theta}_{\boldsymbol{SEQVDFA}}(i,j,r) = \frac{CSTOCK2(i,j,r)}{VDFA(i,j,r)}$ is the forest biomass sequestration intensity.

Net emissions

The gross GHGs emission [$\boldsymbol{GHSR}_{(\boldsymbol{i},\boldsymbol{r})}$] of tradable good *i* at region *r* is the sum of the emissions from consumption and production following the principle of the GTAP-E model:

$$GHSR_{(i,r)} = GHTDP_{(i,r)} + GHTIP_{(i,r)} + \sum_{j\in ALL\_INDS}\left[GHTDF_{(i,j,r)} + GHTIF_{(i,j,r)}\right] +$$
$$GHTDG_{(i,r)} + GHTIG_{(i,r)} + GHTFFTCOMM_{(i,r)}$$

Gross emissions of tradable good *i* is the sum of fossil fuel consumption by private households [domestic $GHTDP_{(i,r)}$ and imported $GHTIP_{(i,r)}$] and government [$GHTDG_{(i,r)}$) and $GHTIG_{(i,r)}$], intermediate use from all industries [$GHTDF_{(i,j,r)}, GHTIF_{(i,j,r)}$], and from factor endowments emissions [$GHTFFTCOMM_{(i,r)}$]. Likewise, forest captures carbon reduces GHG emissions [here total forest carbon stock $CSTOCKFOR_{(r)} = CSTOCK1_{(r)} + \sum_{z\in AEZ\_COMM}\left[CSTOCK2_{(z,r)}\right]$], hence the regional net emissions ($EMITR$) is defined as:

$$EMITR_{(r)} = \sum_{i \in TRAD\_COMM} [GHSR_{(i,r)}] - CSTOCKFOR_{(r)}$$

Thus, regional net emissions are the difference of the gross emissions and total carbon sequestration .

Net revenue from emission trading

Net revenue from emission trading was adjusted to account for the total GHG emissions. The variables ***EMITQ*** and ***emq*** represent the level and percentage change of GHG emissions quota, respectively, following McDougall and Golub (2008) notations. The variable ***DVCO2TRA*** now represents the change in net GHG emissions trading revenue:

$$\begin{aligned} DVCO2TRA_{(r)} = {} & 0.01 \times EMITQ_{(r)} \times emq_{(r)} \times NCTAXLEV_{(r)} \\ & - 0.01 \times EMITR_{(r)} \times emt_{(r)} \times NCTAXLEV_{(r)} \\ & + [EMITQ_{(r)} - EMITR_{(r)}] \times NCTAXB_{(r \in b)} \end{aligned}$$

Welfare decomposition

One of the major improvements done in the model is the implementation of the “add-on” module for “welfare decomposition” which facilitates the analysis of welfare variation [expressed in $ of equivalent variation (EV)]. We built up from the revised McDougall and Golub (2008) version. Thus, we account for the addition of new GHG emissions, new sub-nesting commodities and FCS formulations. Arising from the previous versions, there are three major changes in the welfare decomposition:

(1) We adjust the revenues from reducing emission

(2) The carbon tax and other taxes on endowments are included in the variable ***CNTqfer***, which is the contribution to EV of changes in all endowments:

$$CNTqfer_{(r)} = 0.01\, \varphi_r \sum_{i \in ENDWCOMM} \sum_{j \in ALLINDS} \left[ETAX_{ijr} + ECTAX_{ijr}\right]\left[qfe_{ijr} - pop_r\right]$$

where $ETAX_{ijr}$ and $ECTAX_{ijr}$ are the value of endowment carbon tax-inclusive and exclusive, respectively.

(3) It accounts for all the changes output augmenting technical changes for all industries; this modification is added to the variable ***CNTtech_aor***.

For further details and explanation please refer to Pena-Levano, Taheripour, and Tyner (2016).

Annex 3 – The crop productivity yields

The original productivity values (in metric ton/ha) are collected for the period 2000-2099 through the online package developed by Agricultural Model Comparison and Improvement Project (AgMIP)(Villoria et al. 2016) at grid cell level (i.e. 0.5° × 0.5° resolution). We collect information for eight different crops: maize, soybeans, millet, rice, rapeseed, sugarcane, sugar beets, and wheat. The data is then grouped by the AGMIP aggregation tool by country, crop and AEZ for each irrigation type (i.e. irrigated and rainfed).

Aggregation of crop productivity shocks

1) Initial and final productivities: From the database, we first obtain the initial and the final productivity (in tons/ha). Nevertheless, the data present high variability in yields from one year to the next. To avoid this issue we define our initial productivity as the average of the productivities of 2000-2009. In the same way, the final productivity is the average of the yields from 2091-2099. These yields are defined by region, AEZ, irrigation method and crop.

2) Aggregation weights: In order to aggregate our productivities from 161 countries to the 19 GTAP regions, we use as weights the production of each grid cell which is obtained from Nelson Villoria, a main contributor of the AGMIP project. These values were aggregated to the country level by AEZ and crop. Then, the weight per crop was calculated as the production in that country divided by the total production of the region at the AEZ level.

3) Regional crop productivity shocks: The aggregated initial (final) productivities (per region, AEZ, irrigation method and crop) were calculated as the weighted average of the initial (final) productivities depending of the region located. We used the weights calculated in the previous step. We took the percentage difference between the final and initial productivities to obtain the agricultural productivity shocks per crop, region, AEZ, and irrigation method.

4) Aggregation of the types of irrigation: We proceed to combine the types of irrigation (i.e. fully irrigated and rainfed) into one productivity shock. In order to do that, we use the production of each irrigation method of the corresponding GTAP sector as weights. These values (by irrigation type, GTAP region, AEZ, and GTAP sector) were provided by Taheripour (2015) for the 2001 production. Thus, we obtain crop productivity shock by GTAP region, AEZ and crop sector.

5) Getting the final aggregated crop yield shocks: We finally aggregate the productivities from step 4 into crop yield shocks per GTAP sector, region and AEZ. These are considered as the climate change induced agricultural productivity shocks that we will implement in the GTAP-BIO-FCS model.

This procedure is followed for the crop yield shocks for both RCPs (i.e. RCP 4.5 and RCP 8.5). Their values are overall negative for each of the crop sectors, by AEZ and region. In general the adverse effects are higher in the RCP 8.5.

For the sugar sector, the changes are mixed, because this sector combines sugar cane (cultivated mainly in tropical regions) and sugar beet (cultivated in colder regions). The “other crops” category is the only sector which is not shocked.

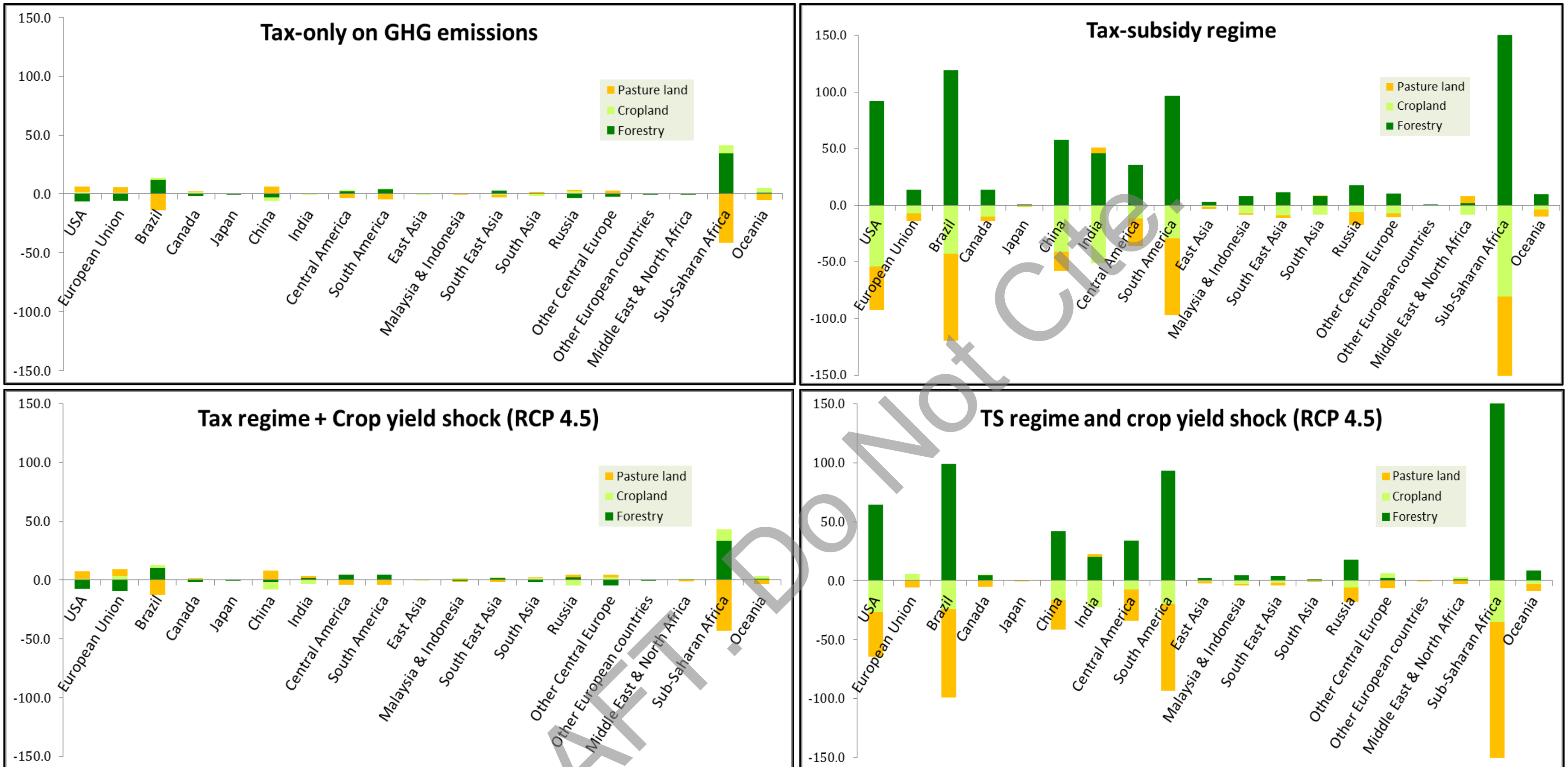
Annex 4 – Additional discussion yields and changes in land use

In our initial set up for the ***Tax-Only*** and ***Tax-Subsidy*** scenarios, we allow adjustments in the productivity of land. This can be achieved by better management practices, improvements in technology, and decreases in productivity gaps, among others. For the ***Tax-Only*** scenario, the proportion of land cover remains constant (Supp. fig. 4) because there are no incentives in moving land to forest. Therefore, area available for agriculture is relatively constant. Likewise, paddy rice land emits methane which leads to a general decrease in area for many regions (Supp. Table 2). As a consequence, there is more land available for the other crops, and therefore these crops do not need to improve productivity of land.

In contrast, for the ***Tax-Subsidy*** scenario, there is land competition between forest and agriculture, driving land rent up, especially for developing countries where the production is more land intensive. There is also internal competition between crop sectors for this input. This results in the necessity of improving land productivity to satisfy a given demand considering that land for agriculture is scarcer and more valuable. Thus, many regions need to improve yields by 25% their original value. For the case of Sub-Saharan Africa and Latin America, which are places with vast forest and can take advantage of the sequestration subsidy, the increase have to be superior to 150% for many AEZs, and yields have to be higher than 100% for many crops.

Under the presence of climate change on agriculture, we implement the impacts on crop productivity which permits to provide a more realistic scenario and helps to isolate the effect of the tax regimes under the climatic variations. The impact is worse for the ***TS+CY*** scenario due to two effects: (i) the competition for land with forestry driven by the sequestration subsidy (i.e., land use change) and (ii) the overall negative effects on crop yields. For these reasons, land rents are driven up more drastically by even higher than 300% for most regions.

In the ***Tax+CY*** scenario, the impacts are reflected on noticeable increases in crop land rent as well as substantial substitution with unskilled and skilled labor. With respect to the internal variation of harvested area, there is a global decrease in rice land (due to its methane emissions) as well as area for "other agricultural products" in order to compensate the necessary increase of harvested area for the other crops (table 1.c). It is important to note that the "other crops" sector was not shocked; hence it can give up more land than the other crop categories with adverse yields.



Supp. Fig. 4 Changes in land cover by type (in Mha)

Table 1.a Changes in area (Mha) per region and crop in the *Tax-Only* scenario

Region	Rice	Wheat	Coarse Grains	Soybeans	Rapeseed	Other Oilseeds	Sugar crops	Oth. Agri. Products
USA	-0.6	-1.3	1.7	2.0	0.0	0.1	0.0	-0.9
European Union	-0.2	0.2	1.1	0.0	0.2	0.4	0.0	-0.6
Brazil	-1.0	-0.7	2.6	1.3	0.0	0.0	2.2	2.2
Canada	0.0	0.3	0.9	0.0	0.1	-0.1	0.0	0.5
Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
China	-14.8	0.0	3.2	0.7	1.1	0.7	0.4	5.5
India	-9.2	1.8	1.4	0.5	0.4	1.2	0.1	3.3
Central America	-0.1	0.2	-0.1	0.0	0.0	0.0	0.0	0.7
South America	-0.9	0.3	0.7	-0.3	0.0	-0.3	0.2	1.1
East Asia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malaysia & Indonesia	-2.4	0.0	0.4	0.1	0.0	1.6	0.0	1.0
South East Asia	-10.6	0.1	1.2	0.3	0.0	3.3	0.6	4.7
South Asia	-2.7	0.0	0.3	0.0	0.0	0.0	0.1	0.7
Russia	-0.1	2.6	0.1	0.0	0.0	0.4	0.0	-1.0
Other Central Europe	-0.3	0.1	0.3	0.0	0.0	0.3	0.0	-0.5
Other European countries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Middle East & North Africa	-0.5	0.4	-0.1	0.0	0.0	0.3	0.0	0.1
Sub-Saharan Africa	-6.0	0.3	4.4	0.2	0.0	3.1	0.1	4.6
Oceania	0.0	3.6	0.8	0.0	0.2	0.1	0.0	-0.2
GLOBAL	**-49.5**	**7.7**	**18.9**	**4.9**	**2.1**	**11.1**	**3.7**	**21.2**

Table 1.b Changes in harvested area per region and crop in the *Tax-Subsidy* scenario

Region	Rice	Wheat	Coarse Grains	Soybeans	Rapeseed	Other Oilseeds	Sugar crops	Oth. Agri. Products
USA	-0.8	-6.1	-13.1	-12.2	-0.1	-0.4	-0.3	-13.0
European Union	-0.1	-1.7	-2.6	0.0	-0.1	0.0	-0.2	-2.6
Brazil	-2.0	-1.8	-6.4	-11.1	0.0	-0.3	-2.8	-6.3
Canada	0.0	-2.5	-1.9	-0.4	-1.7	-0.2	0.0	-3.0
Japan	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	-0.4
China	-14.5	-5.3	-4.9	-1.9	-1.6	-1.5	-0.2	-10.9
India	-15.6	-6.4	-6.6	-1.7	-0.9	-3.9	-1.0	-14.7
Central America	-0.4	-0.1	-5.3	0.0	0.0	-0.5	-0.9	-4.6
South America	-1.2	-3.9	-3.6	-9.0	0.0	-1.6	-0.5	-9.2
East Asia	-0.3	-0.1	-0.2	-0.1	0.0	0.0	0.0	-0.5
Malaysia & Indonesia	-3.4	0.0	-0.4	-0.1	0.0	-1.9	-0.1	-1.4
South East Asia	-9.8	0.0	-0.1	0.1	0.0	0.6	0.0	0.5
South Asia	-5.2	-1.2	-0.3	0.0	-0.1	-0.3	-0.1	-1.3
Russia	-0.1	-0.9	-1.2	0.0	0.0	0.2	-0.1	-3.7
Other Central Europe	-0.3	-2.0	-2.0	0.0	0.0	-0.2	-0.2	-2.7
Other European countries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Middle East & North Africa	-0.5	-2.8	-2.2	0.0	0.0	-0.6	-0.1	-1.9
Sub-Saharan Africa	-6.0	-1.2	-27.6	-0.5	0.0	-8.9	-0.6	-35.4
Oceania	0.0	-0.8	-0.7	0.0	-0.2	-0.1	-0.1	-1.7
GLOBAL	**-60.4**	**-36.6**	**-79.3**	**-37.2**	**-4.8**	**-19.6**	**-7.1**	**-112.9**

Table 1.c Changes in harvested area per region and crop in the *Tax+CY* scenario

Region	Rice	Wheat	Coarse Grains	Soybeans	Rapeseed	Other Oilseeds	Sugar crops	Oth. Agri. Products
USA	0.4	1.7	1.4	1.3	-0.1	0.5	0.1	-2.1
European Union	0.2	0.9	4.1	-0.1	0.8	0.1	0.5	-3.0
Brazil	0.6	0.3	1.6	4.5	0.0	0.4	0.2	0.9
Canada	0.0	0.7	0.3	0.3	0.0	-0.2	0.0	0.1
Japan	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
China	-6.7	-2.3	1.4	0.7	2.3	1.1	-0.4	-2.7
India	0.5	2.0	0.9	3.3	-0.3	1.9	0.2	-12.1
Central America	0.2	0.0	-0.2	0.0	0.0	0.0	-0.3	0.2
South America	-0.2	1.1	0.4	-0.2	0.0	-0.1	-0.2	-0.8
East Asia	0.1	0.0	0.0	0.0	0.0	0.0	0.0	-0.3
Malaysia & Indonesia	0.3	0.0	0.1	-0.1	0.0	1.4	0.0	-0.2
South East Asia	-3.1	0.2	0.4	0.2	0.0	1.6	0.0	1.1
South Asia	1.3	-0.1	0.1	0.0	0.1	0.1	0.1	-0.1
Russia	0.0	-1.2	1.2	0.2	0.2	-0.1	0.1	-4.9
Other Central Europe	0.0	0.5	0.6	0.1	0.0	1.4	0.3	-0.7
Other European countries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Middle East & North Africa	0.8	0.8	0.0	0.0	0.0	0.3	0.0	-0.7
Sub-Saharan Africa	-0.4	0.3	3.2	0.5	0.0	4.0	-0.3	2.6
Oceania	0.0	1.3	0.6	0.0	0.0	0.1	-0.1	0.3
GLOBAL	**-5.9**	**6.4**	**16.1**	**10.7**	**3.2**	**12.2**	**0.2**	**-22.4**

Table 1.d Changes in harvested area (Mha) per region and crop in the *TS+CY* scenario

Region	Rice	Wheat	Coarse Grains	Soybeans	Rapeseed	Other Oilseeds	Sugar crops	Oth. Agri. Products
USA	0.1	0.5	-5.9	-4.7	0.1	0.6	0.0	-3.7
European Union	0.1	-1.2	2.2	-0.1	2.1	0.4	0.5	1.1
Brazil	0.2	-0.7	-2.7	-2.0	0.0	0.0	-1.2	-3.3
Canada	0.0	0.5	0.1	-0.1	0.1	0.0	0.0	0.2
Japan	-0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
China	-6.1	-2.9	-0.2	-0.4	0.2	0.0	-0.4	-6.4
India	-1.0	-1.9	-3.3	-0.4	1.5	-2.7	-0.4	-14.1
Central America	-0.2	0.1	-3.4	0.0	0.0	-0.4	-0.5	-3.2
South America	-0.5	-3.2	-2.2	-4.9	0.0	-1.1	-0.3	-7.4
East Asia	-0.1	0.0	-0.1	-0.1	0.0	0.0	0.0	-0.3
Malaysia & Indonesia	-0.5	0.0	-0.1	0.0	0.0	-1.4	0.0	-1.1
South East Asia	-3.2	0.2	-0.1	0.0	0.0	0.5	0.0	0.8
South Asia	-1.0	0.5	0.0	0.0	0.3	-0.1	0.1	-0.4
Russia	0.0	-1.5	0.0	0.4	0.3	0.5	0.0	-5.3
Other Central Europe	0.1	0.7	-1.3	0.2	0.0	2.2	0.2	2.5
Other European countries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Middle East & North Africa	1.1	0.7	0.2	0.1	0.1	0.0	-0.1	-0.4
Sub-Saharan Africa	-2.8	-0.5	-6.8	-0.3	0.0	-3.0	-0.4	-21.5
Oceania	0.1	1.0	0.8	0.0	-0.1	0.0	-0.1	-4.8
GLOBAL	**-13.8**	**-7.6**	**-22.7**	**-12.4**	**4.6**	**-4.4**	**-2.7**	**-67.2**

Note: Coarse grains is composed by the sectors: sorghum and other coarse grains. Other Oilseeds is the summation of palm and "other oilseeds". Here we simply summed them up to illustrate the major changes.

Table 2.a Changes in average crop land rent (%) at the AEZ level in the *Tax-Only* Scenario

Region	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16	AEZ17	AEZ18
USA	0	0	0	0	0	0	19	19	20	22	20	17	15	14	12	12	0	0
European Union	0	0	0	20	0	0	0	18	17	17	17	17	20	13	14	16	0	0
Brazil	-20	-10	-9	-7	-7	-3	0	0	0	-4	-3	-9	0	0	0	0	0	0
Canada	0	0	0	0	0	0	13	13	11	13	11	0	13	10	11	11	0	0
Japan	0	0	0	0	0	0	0	0	13	11	10	10	0	0	13	0	0	0
China	0	0	0	-8	-8	-9	-4	-5	-6	-6	-11	-13	-2	-2	-6	-6	-5	0
India	4	3	1	-2	1	-2	3	2	3	3	2	0	5	4	5	5	0	0
Central America	13	13	10	8	9	9	9	8	7	8	8	9	0	0	0	0	0	0
South America	-2	-3	-2	-3	-2	-2	-2	-2	-2	-1	-2	-3	-4	-3	-2	-1	0	-3
East Asia	0	0	0	0	0	0	3	3	9	8	8	0	20	5	10	0	0	0
Malaysia & Indonesia	0	0	0	1	-2	5	0	0	0	0	0	0	0	0	0	0	0	0
South East Asia	0	0	0	-27	-24	-19	0	0	0	-25	-23	-19	0	0	-41	-11	0	0
South Asia	3	0	-6	-9	-10	3	5	3	6	3	-1	1	-5	1	-15	-2	0	0
Russia	0	0	0	0	0	0	17	21	19	17	18	0	20	17	15	17	0	0
Other Central Europe	0	0	0	0	0	0	19	20	19	19	19	19	21	20	19	19	0	0
Other Europe	0	0	0	0	0	0	0	0	0	20	0	0	0	16	19	21	0	0
Middle East & N. Africa	0	1	4	5	0	0	3	3	4	5	0	0	0	0	0	0	0	0
Sub-Saharan Africa	-4	2	2	1	2	2	-2	1	2	2	3	3	0	0	0	0	0	0
Oceania	-2	4	6	13	15	18	10	25	26	21	12	12	0	0	1	-3	11	0

Table 2.b Changes in average crop land rent (%) at the AEZ level in the *Tax-Subsidy* Scenario

Region	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16	AEZ17	AEZ18
USA	0	0	0	0	0	0	94	110	111	154	160	167	174	221	233	240	0	0
European Union	0	0	0	33	0	0	0	31	33	34	32	32	30	46	43	39	0	0
Brazil	152	170	172	274	264	339	0	0	0	180	179	245	0	0	0	0	0	0
Canada	0	0	0	0	0	0	103	106	161	151	163	0	122	170	164	157	0	0
Japan	0	0	0	0	0	0	0	0	101	106	105	105	0	0	102	0	0	0
China	0	0	0	45	70	57	47	53	58	61	64	58	49	57	84	76	44	0
India	73	88	96	123	99	103	69	73	78	82	89	126	73	70	71	70	0	0
Central America	120	155	190	187	202	210	131	174	156	186	204	185	0	0	0	0	0	0
South America	183	300	199	171	197	278	224	287	229	196	211	226	185	313	318	345	396	156
East Asia	0	0	0	0	0	0	54	55	130	83	69	0	35	91	104	0	0	0
Malaysia & Indonesia	0	0	0	43	39	60	0	0	0	0	0	0	0	0	0	0	0	0
South East Asia	0	0	0	5	13	16	0	0	0	14	23	28	0	0	-10	44	0	0
South Asia	38	0	66	71	68	46	37	37	37	56	72	38	36	36	38	38	0	0
Russia	0	0	0	0	0	0	24	27	25	24	25	0	30	49	42	24	0	0
Other Central Europe	0	0	0	0	0	0	29	32	36	36	35	35	31	36	39	36	0	0
Other Europe	0	0	0	0	0	0	0	0	0	28	0	0	0	38	32	28	0	0
Middle East & N. Africa	33	35	40	41	0	0	40	43	76	49	0	0	0	0	0	0	0	0
Sub-Saharan Africa	139	171	212	261	263	305	146	185	192	275	296	302	0	0	0	0	0	0
Oceania	79	83	90	155	284	126	90	100	102	162	262	276	0	0	81	124	305	0

Table 2.c Changes in average crop land rent (%) at the AEZ level in the *Tax+CY* Scenario

Region	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16	AEZ17	AEZ18
USA	0	0	0	0	0	0	25	49	369	107	-21	-18	5	-3	-5	-4	0	0
European Union	0	0	0	27	0	0	0	3103	181	22	138	143	40	-6	-16	-3	0	0
Brazil	-97	-81	-41	295	-2	-24	0	0	0	-93	-6	75	0	0	0	0	0	0
Canada	0	0	0	0	0	0	17	1082	3	43	3	0	-8	-5	1	4	0	0
Japan	0	0	0	0	0	0	0	0	63	-6	73	238	0	0	88	0	0	0
China	0	0	0	-72	-20	-39	18	17	-8	-20	-22	-25	8	10	-1	-4	-3	0
India	-85	-63	-6	-10	-1	10311	426	-43	-18	-18	-1	-36	-11	-14	-14	-14	0	0
Central America	-22	1057	58	71	16	36	-56	-42	-64	-57	-48	-48	0	0	0	0	0	0
South America	37	-8	2267	10	0	-15	-25	-30	276	42	1	-25	-26	-22	-21	-17	-15	-20
East Asia	0	0	0	0	0	0	25	36	-33	-42	159	0	616	64	-12	0	0	0
Malaysia & Indonesia	0	0	0	-19	142	37	0	0	0	0	0	0	0	0	0	0	0	0
South East Asia	0	0	0	58	-25	19	0	0	0	4	-14	5	0	0	-66	3	0	0
South Asia	35	0	13	72	168	12	26	26	17	6	17	32	1	11	-64	-50	0	0
Russia	0	0	0	0	0	0	-11	1	-26	-30	15495	0	-7	-14	-19	-1	0	0
Other Central Europe	0	0	0	0	0	0	24	88	45	41	195	91	15	19	10	12	0	0
Other Europe	0	0	0	0	0	0	0	0	0	65	0	0	0	20	27	44	0	0
Middle East & N. Africa	45	-53	-58	893	0	0	43	51	7	523	0	0	0	0	0	0	0	0
Sub-Saharan Africa	-59	662	41	1	53	4	-29	-14	-70	-24	-16	-16	0	0	0	0	0	0
Oceania	-48	-42	-45	-30	2	152	-42	-11	527	-3	-13	-12	0	0	-50	-48	-6	0

Table 2.d Changes in average crop land rent (%) at the AEZ level in the *TS+CY* Scenario

Region	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16	AEZ17	AEZ18
USA	0	0	0	0	0	0	44	233	163	721	540	702	774	1122	1414	1456	0	0
European Union	0	0	0	81	0	0	0	17248	424	151	437	402	90	127	91	99	0	0
Brazil	-96	-74	-42	1051	751	1366	0	0	0	-88	75	684	0	0	0	0	0	0
Canada	0	0	0	0	0	0	125	1860	609	656	631	0	287	577	593	571	0	0
Japan	0	0	0	0	0	0	0	0	399	287	556	761	0	0	450	0	0	0
China	0	0	0	-76	264	159	54	137	207	199	229	218	51	99	291	244	27	0
India	-81	106	336	724	529	1708	-42	76	88	119	229	463	55	54	58	50	0	0
Central America	70	416	622	528	619	736	46	316	180	368	497	356	0	0	0	0	0	0
South America	211	1292	450	205	358	1026	384	941	677	341	459	554	189	1228	1324	1650	1952	89
East Asia	0	0	0	0	0	0	51	22	661	278	263	0	83	330	353	0	0	0
Malaysia & Indonesia	0	0	0	64	11	209	0	0	0	0	0	0	0	0	0	0	0	0
South East Asia	0	0	0	198	132	156	0	0	0	206	187	249	0	0	-29	264	0	0
South Asia	30	0	325	612	573	127	31	33	22	208	393	21	7	15	-75	-57	0	0
Russia	0	0	0	0	0	0	4	17	-6	-13	28220	0	41	133	103	12	0	0
Other Central Europe	0	0	0	0	0	0	81	269	242	188	473	229	64	136	116	93	0	0
Other Europe	0	0	0	0	0	0	0	0	0	228	0	0	0	134	128	117	0	0
Middle East & N. Africa	210	-6	-35	497	0	0	219	347	632	1621	0	0	0	0	0	0	0	0
Sub-Saharan Africa	-70	255	700	998	1064	1227	-69	360	206	955	1134	1180	0	0	0	0	0	0
Oceania	17	26	1	697	2332	211	19	-24	26	965	2018	2154	0	0	7	162	2345	0

Annex 5 – Additional discussion of changes in regional output

There is heterogeneity in the changes of agricultural outputs under the ***Tax-Only*** regime. This outcome can be attributed to the burden of tax impact on production (including all goods and services), and income. It is not surprise that paddy rice, ruminant and dairy farm outputs decrease substantially in many regions due to their emissions (Supp. table 3a). In the ***Tax-Only*** regime, there is an overall increase in production for many crop commodities due to the fact of having more land available (land is moved away from paddy rice, but the regional harvested area remained constant). As a result, some regions, such as Canada, Japan, Oceania, and the European Union take advantage of this opportunity to export food commodities that are not GHG intensive emitters.

The situation in output is mixed when forest subsidy plays a role in the mitigation effort (***Tax-subsidy*** scenario). The reduction in cropland due to the forest expansion decreases output in developing economies (Supp. table 3b). Nevertheless, for many developed regions, the reduction of available cropland is compensated by improving efficiency/productivity of land and substituting this input with labor, leading to an increase in output.

Comparing both scenarios (***Tax-only*** vs. ***tax-subsidy*** scenarios), the situation is more adverse under the ***tax-subsidy*** regime for developing economies (India, Central and South America, South East Asia) because they have more land intensive production. Thus, the decrease in land due to the competition with forest drives lower outputs. This is opposite for emerging economies (Europe, Middle East & Northern Africa, and China) due to significant decreases in GDP and private consumption driven by the high tax in the ***Tax-Only*** scenario. The European Union has also a better situation under the tax-subsidy regime because this is a more efficient region and agriculture is a small share of its GDP; therefore it can take advantage of the situation and export food commodities encouraging increases of agricultural outputs.

In the presence of crop yield shocks, output for agricultural commodities gets reduced drastically in almost all sectors for both scenarios (***Tax+CY*** and ***TS+CY*** scenarios) (Supp. tables 1c and 1d). Furthermore, here we can observe more clearly an important consequence of implementing the tax-subsidy regime: further declines in output due to reduction of cropland, which also is suffering from adverse crop yields. Thus, because of the competition for land, many places with declines in output higher than 25% under the tax-subsidy regime (***TS+CY*** scenarios).

Supp. table 3a Output changes (%) per region under *Tax-Only* scenario

Region	Rice	Wheat	Sorg.	Oth. Gr.	Soy	Palm	Raps.	Oth. Oilsd.	Sugar crops	Oth. Agri. Prod.	Dairy Farms	Rumn	Non Rumn.
USA	-9	-14	-7	-3	5	0	1	1	-2	-4	-5	1	-7
European Union	47	-2	0	1	7	0	3	4	-2	-2	-3	11	-1
Brazil	-4	-54	-6	-6	-23	-17	-28	-28	15	-5	-13	-48	-46
Canada	0	-10	0	-2	-17	0	-15	-25	0	-7	-3	-1	11
Japan	2	19	0	15	14	0	23	15	-1	0	-1	4	2
China	-28	-27	-9	-10	-10	-9	-9	-10	-7	-11	-10	-26	-16
India	-7	-6	-3	-3	1	0	1	2	-3	-2	-9	-11	-6
Central America	16	49	0	-3	4	-4	1	-10	-2	5	-12	-33	-6
South America	-17	-9	-5	-6	-20	-16	-16	-31	-2	-5	-12	-34	-13
East Asia	4	-23	1	-5	5	0	5	7	-4	-5	-6	-10	-11
Malaysia & Indonesia	-9	0	0	4	10	10	0	5	1	3	-17	-33	-4
South East Asia	-27	90	-5	-3	29	18	0	23	-4	7	-2	-61	-14
South Asia	-10	-15	-3	-6	-28	0	-13	-14	0	-1	-5	-13	-7
Russia	-16	23	7	7	8	0	14	20	-3	-1	-14	-8	-9
Other Central Europe	-35	3	-1	1	10	0	9	11	-2	-2	-8	-8	-3
Other European countries	0	1	0	2	-6	0	10	15	0	0	-5	3	0
Middle East & N. Africa	29	-2	-9	-9	1	0	3	9	-8	0	-12	-23	-11
Sub-Saharan Africa	-39	1	-6	-6	21	-2	14	21	-8	-1	-23	-53	-23
Oceania	16	36	10	14	24	8	22	13	0	-2	-19	-14	-13

Supp. table 3b Output changes (%) for commodities under the *Tax-Subsidy* scenario

Region	Rice	Wheat	Sorg.	Oth. Gr.	Soy	Palm	Raps.	Oth. Oilsd.	Sugar crops	Oth. Agri. Prod.	Dairy Farms	Rumn	Non Rumn.
USA	-1	-16	-3	-7	-3	0	-4	-1	-2	-4	-4	0	-5
European Union	49	5	-2	3	19	0	12	17	-1	5	-2	9	0
Brazil	-4	-43	-10	-10	-16	-8	-26	-23	2	-9	-11	-40	-39
Canada	0	-3	0	2	-2	0	-6	4	0	2	-3	-2	7
Japan	0	11	0	9	7	0	11	8	-1	1	-2	3	1
China	-20	-19	-5	-6	-8	-8	-11	-9	-4	-9	-7	-22	-10
India	-7	-8	-7	-6	-6	0	1	-9	-6	-7	-10	-13	-6
Central America	-4	18	-4	-9	-6	-11	-10	-20	-5	-11	-11	-29	-5
South America	-16	-28	-13	-15	-25	-20	-22	-35	-5	-22	-15	-31	-12
East Asia	-3	-23	-7	-8	-20	0	-12	-12	-3	-9	-6	-11	-9
Malaysia & Indonesia	-8	0	0	-2	-5	-2	0	-8	-3	-6	-17	-28	-3
South East Asia	-19	79	-3	-2	15	16	0	11	-3	5	-1	-45	-9
South Asia	-8	-9	-2	-3	-33	0	-3	-11	-1	-3	-5	-10	-5
Russia	-9	15	7	5	9	0	12	19	-1	1	-10	-5	-6
Other Central Europe	-25	5	0	3	16	0	11	15	-1	2	-5	-5	-1
Other European countries	0	5	0	4	-4	0	35	29	1	5	-4	3	0
Middle East & N. Africa	21	3	-3	-3	11	0	15	15	-5	4	-7	-15	-6
Sub-Saharan Africa	-27	-3	-5	-6	3	-6	3	4	-6	-7	-18	-43	-16
Oceania	20	13	3	8	-5	4	10	4	0	-1	-15	-5	-7

Supp. table 3c Output changes (%) for commodities under the *Tax+CY* scenario

Region	Rice	Wheat	Sorg.	Oth. Gr.	Soy	Palm	Raps.	Oth. Oilsd.	Sugar crops	Oth. Agri. Prod.	Dairy Farms	Rumn	Non Rumn.
USA	10	-6	-4	-11	-12	0	-33	9	-3	-5	-6	0	-9
European Union	21	-22	-14	-10	-29	0	5	-12	-4	-8	-4	9	-2
Brazil	-3	-14	2	4	-14	28	-11	1	17	6	-13	-48	-46
Canada	0	24	0	-11	-6	0	1	-19	1	1	-4	-3	10
Japan	1	32	0	13	6	0	29	-12	-1	0	-1	3	1
China	-29	-10	-11	-6	-6	-4	31	4	-5	-5	-9	-26	-16
India	-21	-8	-12	-11	2	0	-26	-19	-10	-21	-18	-19	-14
Central America	-6	-13	6	-2	-1	-4	20	-26	-1	2	-13	-34	-6
South America	-18	6	-4	1	-19	-15	6	-25	-2	-5	-12	-35	-14
East Asia	-17	-2	2	-4	-10	0	-20	-37	-11	-16	-11	-18	-16
Malaysia & Indonesia	-15	0	0	-11	-33	-11	0	-20	-4	-3	-23	-40	-6
South East Asia	-31	114	-22	-10	-15	-14	0	-19	-5	8	-5	-63	-16
South Asia	-16	-13	-1	-5	-30	0	-4	-15	-4	-1	-8	-15	-9
Russia	-21	-19	33	6	29	0	43	-18	-9	-14	-16	-9	-12
Other Central Europe	-24	-9	-10	-12	-9	0	-8	-4	-5	-2	-11	-11	-7
Other European countries	0	11	0	15	4	0	20	10	-1	1	-6	2	-1
Middle East & N. Africa	43	-6	-2	-10	11	0	3	-14	-10	-4	-14	-26	-13
Sub-Saharan Africa	-34	-19	-14	-8	6	2	26	-18	-8	4	-25	-54	-24
Oceania	21	-5	8	-22	24	-13	-16	-8	4	1	-18	-10	-11

Supp. table 3d Output changes (%) for commodities under the *TS+CY* scenario

Region	Rice	Wheat	Sorg.	Oth. Gr.	Soy	Palm	Raps.	Oth. Oilsd.	Sugar crops	Oth. Agri. Prod.	Dairy Farms	Rumn	Non Rumn.
USA	-9	-11	-6	-30	-29	0	19	16	-5	-10	-8	-2	-12
European Union	14	-28	-21	-15	-36	0	29	-10	-5	3	-5	7	-2
Brazil	-14	-43	-33	-24	-36	-19	-36	-34	-11	-22	-16	-45	-44
Canada	0	21	0	-14	-29	0	3	7	-4	2	-9	-12	3
Japan	-6	18	0	4	-1	0	20	-14	-4	-1	-6	-3	-5
China	-27	-13	-8	-11	-16	-9	2	-9	-7	-12	-11	-28	-17
India	-24	-20	-24	-23	-33	0	1	-42	-23	-25	-26	-26	-19
Central America	-50	3	-4	-31	-32	-36	-17	-57	-16	-32	-27	-38	-15
South America	-30	-47	-28	-32	-41	-48	-32	-50	-15	-42	-22	-37	-20
East Asia	-24	-27	-18	-17	-43	0	-28	-36	-6	-15	-17	-29	-23
Malaysia & Indonesia	-20	0	0	-18	-28	-32	0	-39	-15	-12	-32	-44	-8
South East Asia	-31	140	-23	-16	-28	-10	0	-30	-7	6	-7	-56	-17
South Asia	-28	-9	18	-9	-58	0	18	-24	-10	-4	-13	-18	-13
Russia	-21	-21	27	-1	57	0	73	-8	-13	-15	-16	-11	-13
Other Central Europe	5	-9	-19	-20	7	0	-3	7	-10	8	-13	-14	-11
Other European countries	0	17	0	22	12	0	51	30	-1	9	-6	-1	-6
Middle East & N. Africa	61	-7	16	-10	38	0	8	-18	-12	-3	-17	-26	-15
Sub-Saharan Africa	-56	-39	-21	-22	-44	-33	-5	-40	-18	-31	-26	-52	-27
Oceania	71	-7	-29	-16	-68	-10	-23	-27	0	-25	-16	2	-2

Notes: Sorg: Sorghum. Oth Gr: Other Coarse Grains. Soy: Soybeans. Raps: Rapeseed. Rumn: Ruminants.

Annex 6 – Additional discussion on changes in regional domestic food price

As expected, the rise in price occurs mainly in 'dirty' agricultural commodities such as paddy rice and livestock sectors (***Tax-Only*** scenario). This occurs because of the imposition of the high tax regime (\$150t/CO_2e) penalizes severely GHG emissions, especially in countries with land-intensive production (Supp. table 4a).

The implementation of the FCS subsidy provides more uniform consequences for the entire agricultural sector. Thus, prices for the non-carbon intensive emitter agricultural products increase in the ***Tax-Subsidy*** compared to the ***Tax-Only*** scenario. Land competition between with forestry and rise in land rent are two possible explanations for this outcome (Supp. table 2b).

In terms of regions, for emerging economies (Russia and Brazil), the food prices do not go up as high as under the ***tax-only*** regime. These places take advantage of the FCS subsidy which partially offsets the negative impacts of the tax on emissions. Thus, with no sequestration subsidy, private consumption and GDP are lower (***Tax-Only*** scenario) which drives up the prices by a higher amount than in the ***Tax-Subsidy*** regime.

For developed regions such as the EU and other European countries, the \$150/tCO_2e tax on emissions also reduces significantly the energy and livestock production which drives down the consumption and GDP by more than doubled than imposing the \$80/tCO_2e tax-subsidy. At the same time, terms of trade (i.e. price of exports relative to imports) favors EU increasing the price more significantly in the ***Tax-Only*** scenario. In contrast, for developing regions, changes in land use together with increases in land rent (by more than 100% in many AEZs) provoked by the FCS subsidy play a more relevant role in the boost in prices than the tax regime.

In addition, the situation gets worse when the overall negative crop yields are included. More land is required for crop production increasing abruptly land rent (for both ***Tax+CY*** and ***TS+CY*** scenarios). Particularly, in the ***TS+CY*** scenario, due to the fact that less land is available for crop production, the prices for most agricultural and livestock products are often more than double (+200%) their original value, for almost all regions of the world. This reflects that under climate change effects, FCS can drive global increases in food prices which can be unsustainable for many economies.

Supp. table 4a Price changes (%) per region under *Tax-Only* scenario

Region	Rice	Wheat	Sorg.	Oth. Gr.	Soy	Palm	Raps.	Oth. Oilsd.	Sugar crops	Oth. Agri. Prod.	Dairy Farms	Rumn	Non Rumn.
USA	76	29	39	39	27	18	27	26	21	19	31	48	29
European Union	35	24	26	26	24	24	22	22	26	18	34	47	26
Brazil	56	41	34	34	41	42	41	41	40	18	139	520	62
Canada	22	29	36	38	33	33	33	32	15	23	31	79	22
Japan	17	16	16	16	14	15	17	14	14	15	25	36	24
China	155	59	46	46	29	29	28	29	40	29	48	147	35
India	84	32	15	15	14	18	14	14	8	13	59	89	18
Central America	44	14	6	6	28	26	29	26	8	12	39	159	13
South America	120	29	32	32	42	43	43	40	32	21	66	243	45
East Asia	32	38	34	33	20	14	21	20	34	21	40	79	32
Malaysia & Indonesia	93	15	11	10	12	13	17	11	12	12	32	118	24
South East Asia	139	2	4	6	12	6	22	10	14	12	36	378	41
South Asia	81	39	44	43	23	29	27	27	27	17	28	116	40
Russia	91	10	7	7	9	10	10	10	7	9	30	41	25
Other Central Europe	94	18	25	25	20	9	17	17	23	17	46	60	20
Other European countries	14	20	33	22	32	28	18	22	19	16	35	38	17
Middle East & N. Africa	32	18	25	25	19	15	11	11	10	7	36	82	26
Sub-Saharan Africa	140	23	26	26	7	5	6	7	43	14	235	479	58
Oceania	72	20	17	18	18	17	18	17	21	19	47	90	31

Supp. table 4b Price changes (%) for commodities under the *Tax-Subsidy* scenario

Region	Rice	Wheat	Sorg.	Oth. Gr.	Soy	Palm	Raps.	Oth. Oilsd.	Sugar crops	Oth. Agri. Prod.	Dairy Farms	Rumn	Non Rumn.
USA	54	25	33	34	31	19	25	28	31	25	22	33	18
European Union	20	14	15	15	16	17	13	13	15	11	20	29	14
Brazil	45	34	34	34	36	42	34	35	39	27	98	309	35
Canada	16	23	23	27	27	20	27	26	22	22	23	55	13
Japan	17	16	8	17	17	11	19	17	15	16	20	25	14
China	92	42	36	37	29	29	29	29	35	29	41	107	22
India	76	34	33	32	31	10	30	33	32	32	64	79	11
Central America	48	15	29	32	35	35	30	32	34	28	42	110	8
South America	91	38	42	43	45	50	45	42	49	41	74	183	31
East Asia	39	36	36	36	32	17	30	31	24	34	35	64	22
Malaysia & Indonesia	67	20	6	23	20	26	12	22	27	25	37	82	15
South East Asia	80	2	11	13	19	16	14	17	16	17	28	222	25
South Asia	58	29	33	35	24	21	27	27	26	20	23	81	24
Russia	54	8	6	7	9	13	9	9	5	7	22	30	16
Other Central Europe	60	11	15	15	17	16	12	12	14	12	31	40	11
Other European countries	6	14	21	14	28	27	15	18	12	10	21	23	9
Middle East & N. Africa	18	12	14	15	16	16	8	8	5	5	21	51	14
Sub-Saharan Africa	88	21	26	26	18	19	17	16	35	21	151	288	34
Oceania	45	20	20	19	25	21	20	21	22	21	34	57	17

Supp. table 4c Price changes (%) for commodities under the *Tax+CY* scenario

Region	Rice	Wheat	Sorg.	Oth. Gr.	Soy	Palm	Raps.	Oth. Oilsd.	Sugar crops	Oth. Agri. Prod.	Dairy Farms	Rumn	Non Rumn.
USA	106	57	64	67	63	40	72	60	74	35	36	53	35
European Union	87	76	82	75	71	29	42	61	64	40	40	53	32
Brazil	79	60	39	39	60	54	61	66	35	22	146	540	66
Canada	28	54	44	72	52	38	53	61	27	33	36	87	26
Japan	36	35	18	37	36	28	34	58	27	25	29	42	28
China	172	51	47	45	31	28	29	32	12	18	50	152	36
India	470	42	51	49	72	22	120	84	33	108	91	150	27
Central America	96	58	6	6	62	58	42	63	5	28	46	164	15
South America	168	48	45	43	67	97	57	68	36	39	72	253	52
East Asia	134	49	39	41	45	33	66	70	349	55	62	102	41
Malaysia & Indonesia	164	27	14	59	63	69	25	59	41	29	46	133	32
South East Asia	194	17	37	33	61	83	28	68	27	25	46	398	46
South Asia	161	57	51	56	45	48	73	63	59	33	36	136	46
Russia	132	68	8	11	34	28	33	69	74	43	34	44	31
Other Central Europe	110	61	61	62	63	28	55	65	65	32	58	71	28
Other European countries	16	51	41	29	47	40	56	51	57	31	40	44	21
Middle East & N. Africa	57	48	33	38	37	28	41	54	19	27	44	91	32
Sub-Saharan Africa	171	59	70	53	37	33	29	64	42	27	245	497	64
Oceania	141	55	54	73	38	65	64	56	12	30	48	93	33

Supp. table 4d Price changes (%) for commodities under the *TS+CY* scenario

Region	Rice	Wheat	Sorg.	Oth. Gr.	Soy	Palm	Raps.	Oth. Oilsd.	Sugar crops	Oth. Agri. Prod.	Dairy Farms	Rumn	Non Rumn.
USA	250	134	154	167	194	105	127	191	150	130	39	51	41
European Union	147	158	149	143	191	62	89	147	108	94	38	48	29
Brazil	213	159	154	147	199	349	193	223	140	152	149	415	59
Canada	54	128	54	150	160	36	140	150	184	113	47	96	34
Japan	98	101	18	110	118	59	109	150	88	82	45	53	33
China	184	91	111	115	120	116	120	122	56	95	69	145	43
India	517	140	200	192	252	19	248	333	255	191	149	190	27
Central America	316	121	135	177	263	286	153	215	173	165	106	145	17
South America	367	174	184	187	205	328	219	196	194	210	117	239	69
East Asia	216	124	139	141	154	141	143	163	50	132	87	119	52
Malaysia & Indonesia	211	89	12	117	130	179	54	151	150	116	74	121	33
South East Asia	222	62	113	113	184	229	48	178	96	103	62	299	45
South Asia	290	99	74	120	126	81	195	157	114	95	40	134	46
Russia	141	133	28	32	90	69	87	148	132	90	40	50	39
Other Central Europe	108	117	112	114	156	158	123	152	117	77	67	72	37
Other European countries	10	113	55	68	142	203	157	142	117	83	40	43	23
Middle East & N. Africa	95	111	56	78	120	135	123	147	47	90	50	84	38
Sub-Saharan Africa	299	152	184	187	224	313	285	219	105	157	181	357	55
Oceania	160	127	169	148	190	184	177	156	114	170	46	74	27

Notes: Sorg: Sorghum. Oth Gr: Other Coarse Grains. Soy: Soybeans. Raps: Rapeseed. Rumn: Ruminants.

Annex 7 – Additional remarks about the macroeconomic variables

The ***tax-only*** regime causes consumer price index (CPI) to increase more substantially than imposing a ***tax-subsidy*** policy. This is the case, because these policies are implemented in the whole economy (i.e., manufacture and services) and not only in agriculture. Thus, the 150$/t$CO_2$e tax on emissions drives up the prices for sectors such as coal, oil, gas and energy intensive products higher than in the 80$/t$CO_2$e tax-subsidy case for all the regions(figure 4).

As expected, the incorporation of climate changes effects on agriculture into the picture shows that the CPI increase even higher mainly due to the increase of the carbon taxes and tax-subsidy regimes to achieve the same level of emissions together with the high food prices. Similar situation happens when comparing the scenarios with and without climate change effects, especially for developing and emerging economies such as India and Malaysia and Indonesia, Sub-Saharan Africa and Middle East & Northern Africa.

In terms of GDP, both policies then decrease real GDP for all regions with and without the presence of climate change. Here we first compare both policies without any climate change effect, which has been a common practice in the literature. We find that the economy for all the regions are driven down more drastically under the carbon tax regime due, especially due to the decrease in energy production as well as consumption compared to the ***Tax-subsidy*** scenario. Many regions, especially with vast forest and sequestration intensity, are able to take advantage of the subsidy and thus their GDP does not decrease as much as in the Tax-Only scenario.

Nevertheless, the picture changes when we incorporate the adverse crop yield losses. The tax increase is higher in the tax-subsidy case (100$/t$CO_2$e, which is a 25% increase from the $80/t$CO_2$e) making the difference with the tax-only regime smaller ($155/t$CO_2$e). Considering also the negative effect of land competition and increases in rent, many places in the world face a lower real income in the ***TS+CY*** scenario. This outcome indicates that FCS implementation becomes less attractive with the inclusion of climate change effects on agriculture. There are few exceptions such as Canada, Russia and Central Europe in which the situation looks better situation under the tax-subsidy regime (***TS+CY*** scenario). This is partially because these are places that received beneficial yield shocks for several crop sectors at the AEZ level (figure 4).

Supp. table 5 Changes in CPI (%) and real GDP (%) per region and scenario

Region	Tax-only regime		Tax-subsidy		Tax + CY		TS + CY scenario	
	Δ%CPI	Δ%GDP	Δ%CPI	Δ%GDP	Δ%CPI	Δ%GDP	Δ%CPI	Δ%GDP
United States	10.4	-1.2	4.1	-0.7	10.5	-1.4	4.9	-1.3
European Union	12.0	-0.4	4.9	-0.2	12.5	-0.8	7.6	-1.4
Brazil	15.4	-3.0	7.6	-2.2	17.3	-3.1	15.5	-6.1
Canada	10.0	-1.6	4.1	-0.8	10.3	-1.7	5.6	-1.7
Japan	12.2	-0.3	5.1	-0.2	12.6	-0.4	7.0	-0.6
China	19.9	-9.8	11.2	-5.7	19.5	-9.7	19.9	-9.4
India	17.7	-5.5	13.4	-5.1	35.7	-11.2	50.7	-14.9
Central America	10.3	-4.7	4.0	-3.3	10.6	-5.2	5.4	-7.4
South America	14.0	-2.9	7.4	-2.9	15.7	-3.2	16.0	-6.9
East Asia	12.7	-1.7	6.1	-1.1	14.6	-2.1	10.7	-1.9
Malaysia & Indonesia	17.9	-3.7	10.0	-2.8	22.1	-5.5	22.5	-7.6
South East Asia	18.9	-3.9	9.4	-2.3	20.9	-4.6	16.6	-4.9
South Asia	21.9	-4.4	13.4	-3.2	28.5	-6.2	33.5	-9.1
Russia	17.9	-7.8	8.9	-3.2	20.1	-8.9	15.6	-6.5
Other Central Europe	15.5	-8.4	7.8	-4.8	18.2	-9.9	18.0	-9.6
Other European countries	10.7	-0.4	4.0	-0.2	11.0	-0.5	5.4	-0.6
Middle East & N. Africa	19.7	-3.5	8.8	-1.8	22.4	-4.3	19.5	-4.5
Sub-Saharan Africa	19.7	-6.0	12.3	-4.4	23.7	-7.0	36.2	-11.4
Oceania	10.6	-1.7	4.4	-1.0	10.9	-1.9	6.9	-2.4

Annex 8 – Further discussion on welfare impacts

Table 2 shows an overall decline in the welfare (a measure of economic well-being in $ of equivalent variation [EV]) due to the 150$/t$CO_2$e tax for almost all of the countries. In this ***Tax-only*** scenario United States, China and Middle East & North Africa suffer the highest losses (e.g. EV losses are higher than $100 billion) due partially to negative impacts from reallocating resources. The two least affected regions are Japan and the European Union due to favorable terms of trade (TOT) which eliminates the adverse impacts of other components of welfare.

Implementing the 80 $/t$CO_2$e ***tax-subsidy*** regime drives a global welfare loss of about $457 billion (table 2), which is lower than the EV loss from applying the ***tax-only*** regime ($-760 billion). This shows that FCS, under no presence of crop yield losses, seems to be a more cost effective alternative compared to the other options, which is consistent with the literature.

For both policy regimes, the addition of crop yield losses reduces welfare across the world. Nevertheless, the impact is more dramatic in the TS+CY regime because the already scarcer agricultural land due to competition with forestry sequestration. In particular, climate change (in the ***TS+CY*** scenario) provokes adverse impacts in technical efficiency due to crop yield losses in all regions representing a global decline of approximately $514 billion in welfare (47% of $1,107 billion welfare loss). This suggests a significant underestimation of social welfare losses if the agricultural productivity variation is not included in the FCS modeling.

Likewise, adjusting for population, EV per capita results show that, independently of the policy regime and development, both emerging and developed economies suffer losses under the presence of climate change on average of more than $150 per capita.

Table 6.a Welfare decomposition for the *Tax-Only* scenario (in $ millions of EV)

Region	Carbon Trading	Allocation Efficiency	Endowment Efficiency	Technical Efficiency	Terms of trade	Investment Saving	ΔEV
United States	0	-147,503	-21	471	34,657	-3,211	-115,607
European Union	0	-57,549	-68	1,516	57,740	-2,368	-729
Brazil	0	-18,706	-23	-55	2,730	799	-15,255
Canada	0	-15,514	-6	99	407	-243	-15,257
Japan	0	-16,442	-1	326	27,909	-3,393	8,400
China	1	-176,353	-68	-2,444	-18,172	3,297	-193,740
India	0	-34,721	-32	-181	3,213	-315	-32,037
Central America	0	-45,062	-11	1	-7,742	-172	-52,986
South America	2	-16,468	-20	-25	-3,286	453	-19,344
East Asia	0	-17,709	-5	54	5,264	-515	-12,911
Malaysia & Indonesia	0	-13,702	-7	-13	-1,892	-584	-16,198
South East Asia	0	-15,765	-19	-394	2,153	-232	-14,257
South Asia	0	-7,966	-12	-47	-210	-126	-8,361
Russia	0	-43,414	-14	-330	-23,186	6,405	-60,539
Other Central Europe	0	-46,726	-24	166	623	-782	-46,743
Other Europe	0	-2,255	0	72	-6,282	-1,006	-9,471
Middle East & N. Africa	0	-38,362	-9	-51	-66,731	2,151	-103,002
Sub-Saharan Africa	20	-30,470	-54	-247	-14,942	175	-45,517
Oceania	-867	-12,934	-8	11	7,316	-289	-6,771
Global	**-844**	**-757,621**	**-400**	**-1,072**	**-433**	**44**	**-760,326**

Table 6.b Welfare decomposition for the *Tax-Subsidy* scenario (in $ millions of EV)

Region	Carbon Trading	Allocation Efficiency	Endowment Efficiency	Technical Efficiency	Terms of trade	Investment Saving	ΔEV
United States	1	-76,866	-16	-3,690	29,789	-1,714	-52,497
European Union	0	-22,133	-57	-2,720	37,221	-1,415	10,897
Brazil	-87	-13,164	-20	-678	3,815	625	-9,509
Canada	0	-7,533	-5	-236	160	-180	-7,794
Japan	0	-9,297	-1	-1,621	17,065	-2,305	3,841
China	0	-98,203	-59	-7,206	-9,262	1,264	-113,466
India	0	-27,650	-30	-4,602	2,735	-291	-29,839
Central America	0	-30,495	-9	-1,404	-5,383	-34	-37,324
South America	12	-15,569	-18	-1,409	-1,036	456	-17,564
East Asia	0	-9,431	-4	-1,359	3,737	-443	-7,499
Malaysia & Indonesia	0	-8,532	-6	-1,993	-912	-269	-11,713
South East Asia	0	-8,425	-16	-1,063	2,546	-170	-7,128
South Asia	0	-5,245	-11	-668	-202	-94	-6,220
Russia	0	-18,316	-11	335	-18,359	4,263	-32,088
Other Central Europe	0	-26,004	-20	-587	1,390	-584	-25,805
Other Europe	0	-1,265	0	-1	-6,166	-534	-7,966
Middle East & N. Africa	0	-19,114	-7	-467	-52,819	1,504	-70,903
Sub-Saharan Africa	-2	-20,768	-49	-1,753	-10,173	111	-32,634
Oceania	4	-7,722	-7	342	5,547	-159	-1,994
Global	**-72**	**-425,734**	**-347**	**-30,781**	**-305**	**33**	**-457,206**

Table 6.c Welfare decomposition for the *Tax+CY* scenario (in $ millions of EV)

Region	Carbon Trading	Allocation Efficiency	Endowment Efficiency	Technical Efficiency	Terms of trade	Investment Saving	ΔEV
United States	-1	-152,528	-21	-10,552	43,594	-5,623	-125,131
European Union	0	-64,265	-69	-34,109	52,448	-3,443	-49,437
Brazil	0	-18,813	-23	-704	6,137	491	-12,911
Canada	0	-16,151	-6	-797	1,817	-186	-15,322
Japan	0	-17,883	-1	-1,751	25,880	-3,233	3,013
China	0	-182,351	-69	4,476	-21,321	4,220	-195,044
India	0	-39,423	-34	-32,313	2,868	-425	-69,327
Central America	0	-48,036	-11	-2,023	-8,172	-180	-58,422
South America	-1	-16,622	-20	-2,124	102	339	-18,326
East Asia	0	-17,253	-5	-4,028	2,859	82	-18,346
Malaysia & Indonesia	0	-14,760	-8	-5,734	-1,431	4	-21,928
South East Asia	0	-16,624	-19	-2,635	2,815	-44	-16,508
South Asia	0	-8,764	-12	-2,651	-876	-218	-12,521
Russia	0	-45,686	-14	-4,112	-24,817	7,225	-67,404
Other Central Europe	0	-48,255	-24	-6,534	1,326	-834	-54,321
Other Europe	0	-2,565	0	-243	-7,049	-771	-10,629
Middle East & N. Africa	0	-41,015	-10	-5,499	-71,346	2,695	-115,174
Sub-Saharan Africa	-11	-31,571	-54	-4,368	-14,464	245	-50,223
Oceania	-9	-13,165	-8	-1,324	9,434	-349	-5,422
Global	**-23**	**-795,730**	**-408**	**-117,024**	**-194**	**-4**	**-913,382**

Table 6.d Welfare decomposition for the *TS+CY* scenario (in $ millions of EV)

Region	Carbon Trading	Allocation Efficiency	Endowment Efficiency	Technical Efficiency	Terms of trade	Investment Saving	ΔEV
United States	0	-98,976	-18	-52,889	71,531	-14,944	-95,295
European Union	0	-53,755	-58	-127,540	24,128	-5,227	-162,452
Brazil	12	-17,239	-21	-21,457	17,305	1,373	-20,028
Canada	0	-10,083	-5	-6,841	5,574	53	-11,301
Japan	0	-13,470	-1	-14,263	4,318	-1,166	-24,582
China	0	-129,254	-65	-43,354	-21,787	5,564	-188,896
India	0	-32,525	-33	-65,750	2,559	-565	-96,314
Central America	0	-50,814	-10	-21,387	-13,170	-76	-85,458
South America	-116	-20,023	-19	-20,732	8,752	836	-31,302
East Asia	0	-11,391	-5	-8,333	-7,211	2,119	-24,821
Malaysia & Indonesia	0	-11,390	-8	-17,177	-2,190	1,649	-29,117
South East Asia	0	-11,617	-19	-8,865	5,963	564	-13,974
South Asia	0	-6,373	-12	-10,578	-2,034	-497	-19,493
Russia	0	-28,190	-12	-8,608	-25,803	7,097	-55,516
Other Central Europe	0	-31,786	-22	-22,337	9,189	-939	-45,895
Other Europe	0	-2,373	0	-1,574	-9,834	485	-13,296
Middle East & N. Africa	0	-27,964	-9	-20,869	-69,837	3,351	-115,328
Sub-Saharan Africa	12	-26,326	-52	-33,423	-10,955	614	-70,130
Oceania	9	-9,714	-7	-8,388	14,569	-515	-4,046
Global	**-84**	**-593,262**	**-377**	**-514,365**	**1,067**	**-225**	**-1,107,245**

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