Food and Agriculture Organization
of the United Nations


# Climate change and global market integration: Implications for global economic activities, agricultural commodities, and food security

Background paper for
The State of Agricultural Commodity Markets (SOCO) 2018

# Climate change and global market integration

## Implications for global economic activities, agricultural commodities, and food security

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The State of Agricultural Commodity Markets (SOCO) 2018

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# Acronyms

| | |
|---|---|
| GDP | Gross domestic product |
| GHG | Greenhouse gas |
| IPCC | Intergovernmental Panel on Climate Change |
| MAGNET | Modular Applied GeNeral Equilibrium Tool |
| RCP | Representative Concentration Pathways |
| SSP | Shared Socioeconomic Pathways |

## Executive summary

Four scenarios are developed in this paper including a baseline scenario, a climate change scenario, a climate change and trade liberalisation scenario, and a trade liberalisation scenario, to explore the impacts of climate change and trade liberalisation, and the adaptation potential of trade liberalisation in mitigating the adverse impact of climate change.

Compared to the baseline as characterised by the assumed shared socio-economic pathway (SSP3) and crop yields growth due to technological progress, the impacts of climate change are projected to be overall negative for food and agricultural production and gross domestic product (GDP) at the global scale. Global food and agricultural productions (incl. crops, livestock, processed food, and fish) are projected to decline by 0.28 percent on average by 2050, due to climate-induced crop yield losses, with the world GDP projected to fall by 0.18 percent accordingly. Consistent with the production decline, global calorie intake, an indicator of food availability, is expected to decline by 0.28 percent. This is connected with a worldwide decline of food purchasing power (2.9 percent), an indicator of food accessibility.

The impact of trade liberalisation, in the context of climate change, by removing border taxes for food and agricultural commodities in all countries, are expected to be modestly beneficial for economic growth, with the world GDP expected to increase by 0.38 percent. Food and agricultural productions, however, are expected to reduce by 0.36 percent due to liberalised trade, with global calorie intake expected to decline by 0.39 percent accordingly. The rise in wages and decline in food prices imply that food purchasing power will be higher in the trade liberalisation scenario. As measured by the unskilled wage in the agricultural sector relative to food prices, food purchasing power is projected to increase by 6.3 percent when trade is liberalised.

Adaptive effects of trade liberalisation are found, as it slightly mitigates the overall adverse impact of climate change at the global scale. The decline of the world GDP caused by climate change would be slightly smaller if food and agricultural trade is liberalised in the context of climate change. Also attributed to the adaptive effect of trade liberalisation, the climate-induced decline of global food and agricultural productions would be smaller and food security issues caused by climate change would be moderated, at the global scale.

# 1. Introduction

The 2018 edition of State of Agricultural Commodity Markets (SOCO) will analyse and quantify the impacts of climate change on the production and trade of agricultural commodities, and assess the potential of trade as an adaptation and mitigation tool.

A number of thematic papers were commissioned to inform the writing of the publication, including for instance papers on the legal aspects of trade and climate change, border measures, country/crop case studies, etc. Toward this end Wageningen Economic Research (WEcR) contributes a working paper that simulates (under baseline, climate change, and free trade scenarios) the effects of climate change on agricultural commodities and the global agricultural trade outlook to 2050, describing possible changes in bilateral trade flows.

The MAGNET computable general equilibrium modelling team at WEcR has conducted four simulations to explore the effects of climate change and trade liberalisation on food and agricultural commodities, productions and trade up to 2050.[1] The four simulations include three simulations that conform to the requirement of the Terms of Reference and one additional simulation that allows for identification of the adaptation potential of trade liberalisation.

# 2. Literature review

The Working Group II of the IPCC has provided ample scientific evidence in its fifth assessment report (IPCC, 2014) on a wide range of damages that climate change has caused and may continue to cause to the natural and human systems including, for example, melting snow and ice causing sea level to rise, more extreme weather such as heat waves, droughts, floods, cyclones, and wildfires, as well as overall negative impacts on crop yields and human health. The working group also surveyed the existing literature and found that global annual economic losses for additional temperature increases of ~2 °C are between 0.2 and 2.0 percent of income.

Given the multi-dimensional nature of the impacts that work through not only the earth's biophysical system but also inter-tangled social and economic domains, assessing precisely the impact of climate change has been among the most challenging tasks facing science communities around the world. While a growing body of literature has been developed to examine the impact of climate change on agriculture and the broader

[1] The four simulations cover all major food and agricultural (aggregated) commodities including paddy rice, wheat, other grains, oilseeds, sugar cane\sugar beet, vegetables\fruit, other crops, other agriculture, bovine animals (cattle\sheep\goats\horses), other animals (pig, poultry), raw milk, bovine meat products, other meat products, dairy products, sugar and molasses, crude vegetable oil, vegetable oil and fats, processed rice, other processed food, animal feed, fishery, forestry, and fertilizers.

economy, research findings vary significantly, depending on the framework and/or data being used in the assessment.

Broadly, there are two major types of framework being used to assess social and economic impacts of climate change – econometrics that estimates the direct relationship between observed climate/weather conditions (mainly represented by temperature and rainfall) and the corresponding farming performance (e.g. crop yield, land value, etc.); and economic modelling that explicitly models how climate-induced crop yield shocks work through the interactions between economic agents and typically integrates with process-based biophysical models which provide crop yield estimates for assumed climate conditions. The distinctions between these different approaches are also reviewed by Blanc and Reilly (2017).

Earlier econometric work relies on what was known as the "production function" approach that estimates the direct relationship between crop yields and climate variables such as temperature, precipitation, and carbon dioxide (See for example: Adams, 1989; Callaway *et al*., 1982). This approach, by its specification, does not take into account possible adaptation practices of farmers and thus has been criticized in later studies e.g. (Mendelsohn *et al*., 1994) for tending to overestimate crop yield losses from climate change. (Mendelsohn *et al*., 1994) instead propose what they called the "Ricardian approach" (also known as the "hedonic approach") that estimates the relationship between farm land value and observed climate variables using cross-sectional data that are believed to have factored in possible adaptations of farmers. Their results, compared to the earlier estimates using the production function approach, indicate potentially much lower negative and possibly small positive impacts of climate change on U.S. farming income. Being intuitively appealing, this approach became a standard for a while and has been followed, and modified, in many later studies including Schlenker *et al*. (2005), who claim that the pooling of rain fed and irrigated farmland data in Mendelsohn *et al*. (1994), was a misspecification that led to an underestimation of water input cost in irrigated areas. Based on an analysis focusing on rain fed farms, Schlenker *et al*. (2005), conclude that climate change will still have an overall negative impact on farm income in the United States of America (USA). In a another study applying the hedonic approach to Western Europe, Van Passel *et al*. (2017) find European farms are slightly more sensitive to warming than American farms, with both negative and positive impacts being possible depending on climate scenarios.

While a great advantage of the hedonic approach is that the full range of farmer adaptations has in principle been accounted for, some of the time-variant settings (e.g. technical change and policy change) and time-invariant characteristics (e.g. soil quality) that may have significant effects on farm's performance are not captured by this approach. This has received criticism from, for instance, Deschênes & Greenstone (2007), who employ a panel data approach to get around some of the limitations in the hedonic approach on the implicit assumption of time-invariant characteristics. Their panel data research indicates that agriculture in the USA will benefit from climate change.

While the advantage of the econometric approach lies in its capability in estimating directly the relationship between climate change and agricultural performance, one of the limitations with this approach is that all the estimations were based on historical observations which in turn were based on given economic situations. This approach thus cannot assess how changes in economic situations, e.g. changes in international trade flows and/or policies, may interfere with the impact of climate change. This is where economic models can come into play.

Unlike the econometric approach, the economic approach to estimating the impact of climate change is typically subject to explicit modelling of the optimization behaviour of economic agents and the interactions between these well-defined economic agents across different parts of the economy. In particular, economy-wide general equilibrium analytical frameworks model the interactions between the agricultural sector and the rest of the economy and thus are able to capture the flow-on impact of climate change throughout the economy and the indirect impact of climate change via changes in the rest of the economy, e.g. international trade, as demonstrated in several of the following reviewed publications.

In a recently completed study (Van Meijl *et al.*, 2017), MAGNET, a CGE model with global coverage, was used along with four other economic/biophysical models to assess the impact of climate change on global agriculture by 2050. The study examines a number of scenarios comprising different social economic pathways (SSP1-3), alternative climate conditions (Representative Concentration Pathways (RCP) 2.6 and RCP6), and possible mitigation measures. The MAGNET results show that the RCP6.0 forcing level has a small negative effect on the growth of GDP (approximately -0.22 percent) and the impact of mitigation on GDP is a bit more negative (approximately -0.32 percent). Overall across the participating models, crop prices are projected to increase under climate change while its effect on agricultural productions was projected to be a small negative at the global scale, with RCP6 and RCP2.6 showing very similar impacts, as the two selected pathways are not distinctively different around 2050.

Hsiang *et al.* (2017) developed a spatially-explicit integrated assessment framework incorporating a CGE model for the USA where potential damage of climate change on a range of sectors including agriculture, crime, coastal storms, energy, human mortality, and labour productivity are taken into account. They find the combined value of these market and nonmarket damages cost roughly 1.2 percent of GDP per +1 °C on average, with the damage being distributed unequally across locations. However, both studies, Van Meijl *et al.* (2017) and Hsiang *et al.* (2017), do not discuss how the impact of climate change may be affected by international trade.

The close relationship and possible interactions between climate change and international trade have been examined in a growing body of economic literature. A number of issues have been covered in earlier publications including: a) international trade and agricultural adaptation (e.g. Randhir & Hertel, 2000; Reilly & Hohmann, 1993; Rosenzweig & Parry, 1994; Tsigas *et al.*, 1997) to climate change  carbon leakages – an idea that if only a subset of countries tax carbon emissions, the level of emissions in non-taxing countries is likely to rise (e.g. Babiker, 2005; Elliott *et al*., 2010; Felder & Rutherford, 1993) b) the direct impact of international trade on the level of carbon emissions caused by international transportation (e.g. Cristea *et al*., 2013).

Cui *et al*. (2014) use the Global Trade and Environment Model (GTEM) to project impacts of climate change to Australian agriculture and consider whether global trade liberalisation can help in mitigating potential damage, and enhance any beneficial impacts, from climate change on Australia's agriculture. Their results show that in a liberalised world, Australia is projected to experience a slight improvement in the positive impact of climate change on its real GNP relative to the climate change impact under the status quo. Australia's major agricultural exports including wheat, other grains, and sugar are also projected to benefit in general in a liberalised world.

Costinot *et al*. (2016) developed a general equilibrium model with which they estimate that climate change over about 110 years, until the end of this century, may cause a 0.26 percent loss in global GDP. They also quantify the welfare impact of climate change interfered by adjustments in production and trade patterns, concluding that adjustments in production patterns (e.g. crop switches) contribute significantly to alleviations of the consequences of climate change while adjustments in trade patterns do little.

The ENV-Linkages model used in an OECD report (OECD, 2015) projects macroeconomic and sectoral economic consequences of climate change (i.e. climate damages) in absence of new climate policies, for a selected number of impacts: changes in crop yields, loss of land and capital due to sea level rise, changes in fisheries catches, capital damages from hurricanes, labour productivity changes and changes in healthcare expenditures from diseases and heat stress, changes in tourism flows, and changes in energy demand for cooling and heating. Based on these shocks, the modelling assessment suggests that if no further climate change action will be undertaken, the combined effect of the selected impacts (in the climate damages scenario) on global annual GDP are projected to rise over time to likely levels of 1.0 percent to 3.3 percent by 2060, with a central projection of 2 percent . This range reflects uncertainty on how sensitive the earth's climate reacts to a doubling of atmospheric $CO_2$ – using a likely range of 1.5 °C to 4.5 °C and a central projection of 3 °C. Assuming a wider range of 1 °C to 6 °C in the equilibrium climate sensitivity (ECS), GDP losses could amount to 0.6 percent to 4.4 percent in 2060.[2] Of the impacts modelled in the analysis, changes in crop yields and in labour productivity are projected to have the largest negative consequences, causing loss to annual global GDP of 0.9 percent and 0.8 percent, respectively, by 2060, for the central projection.

Dellink *et al*. (2017), also using the ENV-Linkage model, provide an analysis of how climate change damages may affect international trade and how international trade can help limit the costs of climate change, highlighting the differences in the effects that climate change will have on regional economic activities and trade competitiveness. They

[2] The OECD report also uses an integrated assessment model (AD-DICE) and its projections suggest that GDP may be negatively affected by between 2 percent and 10 percent by the end of the century relative to the no-damage baseline scenario.

assess both the direct impact of climate change on trade infrastructure, e.g. more frequent port closures due to extreme weather conditions, and the indirect impacts that work through interactions within the economic system. The authors show that, under climate change, world exports may decrease by 1.8 percent in 2060, relative to the baseline without climate damage (expressed in 2010 USD using purchasing power parity (PPP) exchange rates). By decomposing the changes in GDP to isolate different channels of climate impacts, the authors show that the negative impact of climate change comes mostly from domestic damage, and the effects of international trade in limiting the climate-induced damage are small in most regions.

## 3. Description of scenarios

Our research task in this report is based on the simulations of four pre-defined scenarios including: i) a baseline scenario that conforms to the SSP3 story line; ii) a climate change scenario; iii) a climate change and agricultural-food free trade scenario; and iv) an agricultural-food free trade scenario. A comparison of these different scenarios is provided in Table 1. All the scenario simulations project global developments up to 2050 using the parameters contained in Representative Concentration Pathways 6 (RCP6) and Shared Socioeconomic Pathways 3 (SSP3).

**Table 1 Description of Scenarios**

| Scenario Name | SSP3 Shocks | Crop exogenous Yield Shocks | Border Tariffs |
|---|---|---|---|
| Baseline | Population and Technological (latter swapped with GDP)[a] | Technological | As of 2011 |
| Climate Change | Population and Technological (latter swapped with GDP) | Technological and Climatic | As of 2011 |
| Climate Change and Trade Liberalisation | Population and Technological (latter swapped with GDP) | Technological and Climatic | Removed for Agriculture and Food |
| Trade Liberalisation | Population and Technological (latter swapped with GDP) | Technological | Removed for Agriculture and Food |

[a] The technology shocks are derived from FAO's GDP projections; they correspond to the technical change needed to reach the projected GDP in the baseline and are then kept constant across the alternative scenarios. This set-up allows us to keep GDP endogenous and thus responsive to climate and trade scenarios, while assuring that the baseline GDP development follows FAO's SSP3 storyline.

RCP6.0 is one of the four greenhouse gas (GHG) concentration trajectories adopted by the IPCC for its fifth Assessment Report. Under RCP6.0, global GHG emissions are expected to be at the intermediate level and the corresponding increase of global mean surface temperature by the end of this century (2081–2100) relative to the beginning of this century (1986–2005) is expected to be in the range of 1.4 °C to 3.1 °C with a mean of 2.2 °C (Pachauri *et al*., 2014).

SSP3 is also called the Regional Rivalry world, characterised with high mitigation and adaptation challenges within the SSP world views. It is a worldview in which the world is separated into regions characterized by extreme poverty, pockets of moderate wealth and a bulk of countries that struggle to maintain living standards for a strongly growing population. Regional blocks of countries have re-emerged with little coordination between them. Countries focus on achieving energy and food security goals within their own region. Population growth in this scenario is high as a result of limited improvements in education and low economic growth.

The Baseline Scenario (BS) is modelled on this Regional Rivalry world (SSP3), projecting developments in the world economy up to 2050. In this scenario, the world GDP, population, and crop yields due to technological change, are assumed to grow by 134.7 percent, 38.7 percent, and 38 percent, respectively, from 2011 to 2050.[3] The landscape however differs across regions and crops, as shown in Figures 1 and 2, where it can be seen that growth in population and GDP is especially high in developing regions (e.g. North, West and East Africa, Central Asia, Indonesia and Southeast Pacific) indicating a process of catching up although this catching up is much lower than in other SSP scenarios (e.g. SSP2).

[3] The data for GDP, population, and crop yield changes due to technological change and climate change, which are exogenous to the model, are provided by the FAO Global Perspectives Team, with the GDP and population data provided at the country level and crop yields data at the country and crop level. These country and crop level data are then aggregated using mappings for the MAGNET model.

**Figure 1 Assumed growth in GDP and population 2011-2050**

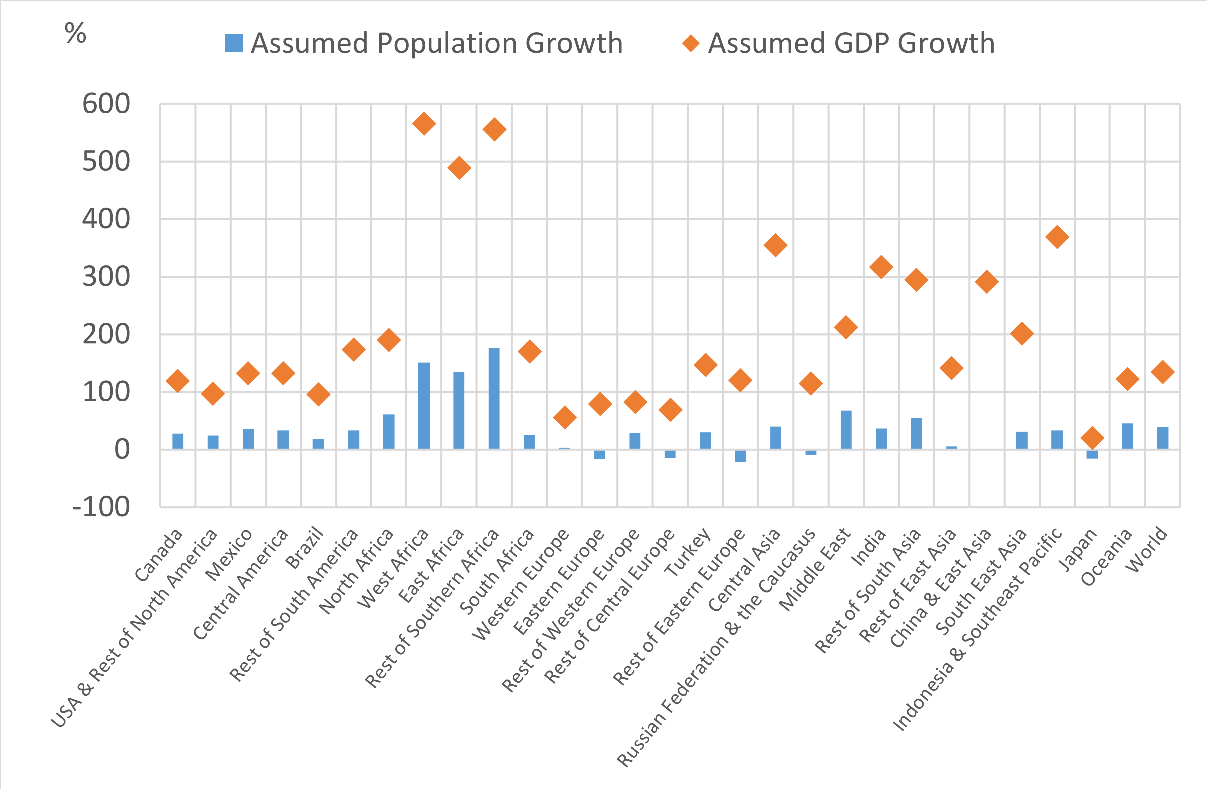
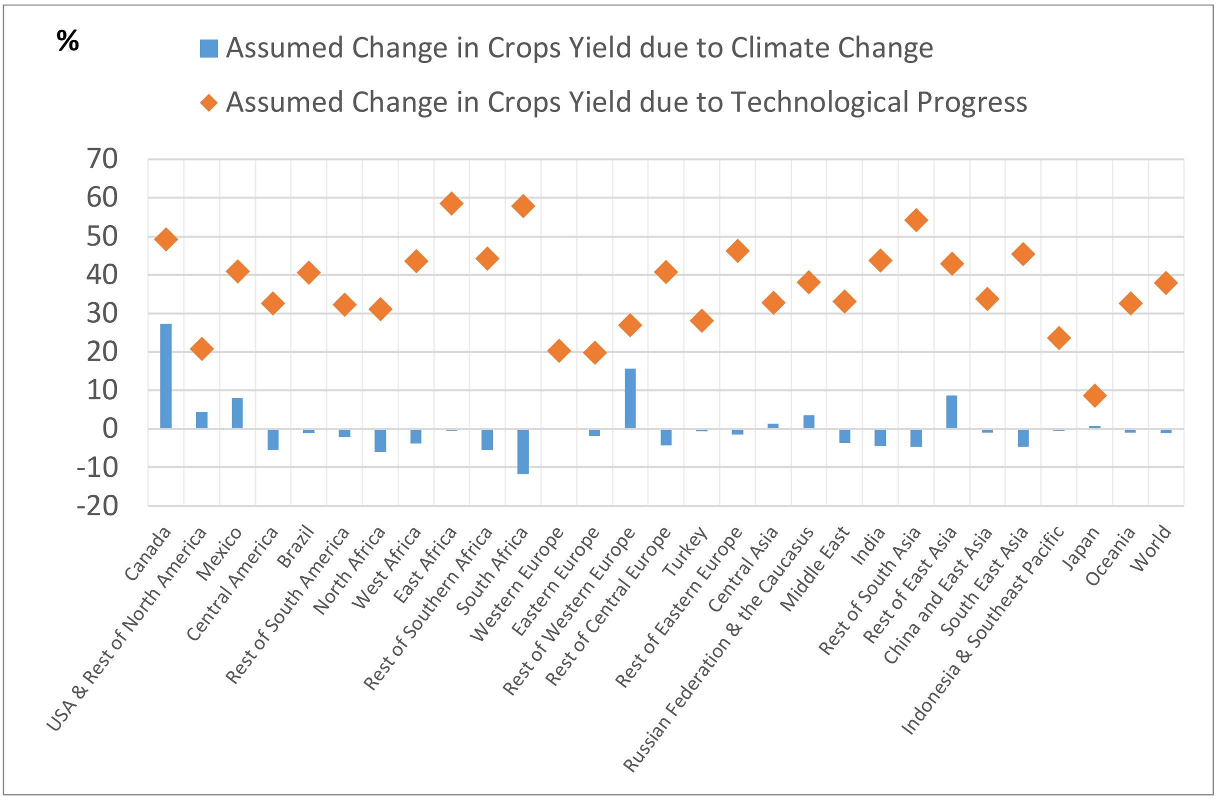



**Figure 2 Assumed change in crop yields 2011-2050**



On top of the baseline scenario, three alternative scenarios are developed to explore the implications of climate change and trade liberalisation.

The Climate Change Scenario (CC) is modelled in line with Representative Concentration Pathway 6.0 (RCP 6.0) which defines the changes in land productivity/crop yield due to climate change. This is essentially the only difference between the climate change scenario and the baseline as all the other shocks in the climate change scenario, including GDP, population, and exogenous crop yield growth due to technological progress, are taken from the baseline. Thus, the deviations of the Climate Change scenario from the Baseline measure the impact of climate change.

In the climate change scenario, the climate-induced crop yield shocks are crop and region-specific, with the aggregate crops yield assumed to decline by 1.13 percent at the global scale from 2011 to 2050. These exogenous yield shocks, as depicted in Figure 2, show that crop yields are rising in some regions (e.g. Canada, rest of Western Europe, Mexico, Rest of East Asia, USA and Rest of North America, and Russian Federation and the Caucasus) but declining in many other regions, with the highest yield declines being found in several developing economies (Africa, India, rest of South Asia and Southeast Asia).

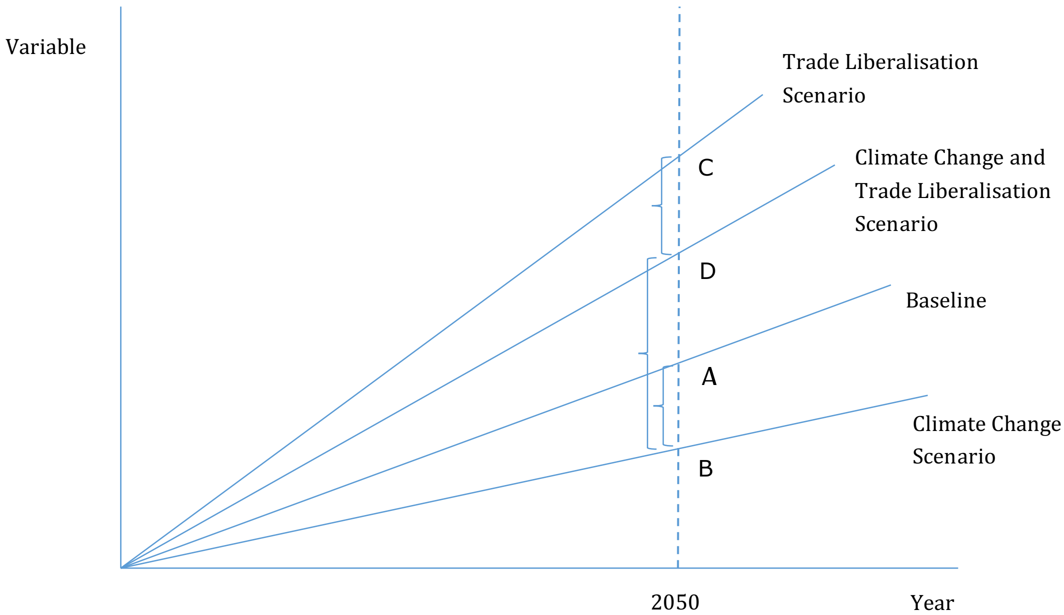
A Climate Change and Trade Liberalisation scenario (CCTL), modelled on the above Climate Change scenario (SSP3 and RCP6), includes further a removal of all border taxes including both import tariffs and export taxes/subsidies, for agricultural and food commodities. By design, this scenario is introduced to capture the free trade effect under climate change.

In addition to the above three scenarios, we introduce another counterfactual scenario in an attempt to shed light on the potential adaptation effects of trade liberalisation – that is, to what extent the impact of climate change may be mitigated by the impact of trade liberalisation. While the deviations of the Climate Change and Trade Liberalisation scenario from the Climate Change scenario, as described above, capture the effect of trade liberalisation, this effect per se does not reveal whether the pre-liberalisation climate change impacts (unaltered by trade liberalisation) may have been alleviated or aggravated by the introduction of trade liberalisation. In order to capture such a potential alteration from trade liberalisation, the post-liberalisation climate change impacts need to be isolated and compared with the pre-liberalisation climate change impacts.

To accomplish this isolation, a new scenario - Trade Liberalisation (TL) scenario without climate change impacts, is introduced and modelled on the baseline. In this new scenario the same trade liberalisation shocks as in the Climate Change and Trade Liberalisation scenario are included but the climate-induced crop yield changes are excluded. With this added scenario, we first compute the deviations of the Climate Change and Trade Liberalisation scenario results from the Trade Liberalisation scenario results – an isolation of the post-liberalisation climate change impacts. These deviations are then compared with pre-liberalisation climate change impacts, as measured by the deviations of the Climate Change scenario results from the Baseline results. The gap between these two groups of deviations, which we refer to as the interaction effect, essentially gauges to what extent climate change impacts may be altered by the introduced trade liberalisation. If a positive gap is found, that is, the post-liberalisation climate change impacts are less adverse than the pre-liberalisation ones, the adaptive effect of trade liberalisation may be declared – the interaction effect in this case may also be referred to as the adaptive effect.

Figure 3 provides an illustration of the scenarios as described above. Section 4 will report the projections of the baseline, which may be represented by the value of point A in this figure. Section 5 presents the unaltered climate change impacts, represented by the percentage deviation of point B from point A, denoted by (B/A-1)*100. Section 6 shows the trade liberalisation effects under climate change, as denoted by (D/B-1)*100. Section 7 discusses the interaction/adaptive effect, as denoted by ((D-C)-(B-A))/A*100.[4]

**Figure 3 An illustration of the relationship between scenarios**




# 4. Projections of the baseline

As mentioned earlier, the baseline scenario follows a particular shared social economic pathway (SSP3) as depicted in the input data from FAO where the world GDP, population, and exogenous crop yields attributed to technological progress are assumed to grow by 134.7 percent, 38.7 percent, and 38 percent, respectively, from 2011 to 2050.

[4] The percentage deviations of variables reported in Section 7 for gauging the interaction effects and the associated climate change impacts and trade liberalisation effects are all expressed in baseline values, in order to make a common denominator for comparison.

Due to both the assumed demand increase driven by the growth in GDP and population, and to the assumed technological progress that boosts crop yields worldwide, global crops and livestock productions in the baseline are projected to grow respectively by 58 percent and 47 percent from 2011 to 2050, underpinned respectively by a 10 percent expansion in agricultural land (6 percent for cropland and 11 percent for pasture land).

Agricultural trade roughly mirrors the expansion of agricultural productions as global trade in crops increases by 59 percent and trade in livestock increases by 70 percent. The increase in livestock trade is faster than the increase in livestock productions since there is a mismatch between regions that experience a fast increase in livestock productions, e.g. China and East Asia, and Middle East, and regions that see a strong growth in demand, e.g. India and West Africa. A faster increase in trade relative to productions essentially reflects the flexibility of the global livestock market that reallocates increased supply to meet the growing demand.

The growing demand and expanding agricultural sectors drive both input prices and output prices higher. By 2050, global crop prices (2011 constant price) are projected to increase by 24 percent, and global livestock prices to increase by 18 percent. Notably, these input and output price increases in the SSP3 context are higher than in the SSP2 world where MAGNET results indicate relatively moderate price increases (see, Van Meijl *et al*., 2017). At the regional level, changes in agricultural prices vary significantly across regions in this SSP3 as they increase more in developing regions.

As an immobile input, agricultural land prices increase sharply, with prices for cropland and pasture land expected to increase over four times and five times, respectively, over this projection period. The SSP3 scenario also leads to particular stress on land markets in developing countries and especially Africa. This induces a sharp increase in land prices in these regions. In MAGNET, the rise in land price relative to other endowment prices (e.g. labour, capital) also triggers an endogenous yield response as land will be substituted by labour and capital. In addition to the 38 percent assumed exogenous growth in crop yields globally, the simulated endogenous growth in crop yields – as measured by the change in crop outputs relative to the change in land use, is approximately 14 percent at the global scale in the Baseline.

## 5. The implications of climate change

As mentioned earlier, the only difference in the Climate Change scenario, compared to the Baseline, is the climate-induced crop yield shocks. The deviations of the climate change scenario simulation results from the baseline simulation results thus capture the impacts of climate change through the changing crop yields.

### Food and agricultural productions, prices, and sectoral income

Given the overall negative changes in crop yields induced by climate change at the global scale, the climate change scenario is expected to feature relatively lower outputs compounded with higher prices globally. The simulation results confirm that, relative to the baseline, global food and agricultural productions in the climate change scenario are expected to decline by 0.28 percent at 2050, including crops (0.66 percent), livestock (0.12 percent), processed food (0.16 percent), and fish (0.03 percent)[5]. Unsurprisingly, the declining food productions drive food prices higher, with the world average food prices (domestic real market price for private consumptions) expected to rise by 2.6 percent, due to the impact of climate change.

The climate-induced decline in crop yields coupled with the growing demand as specified by the SSP3 storyline, triggers an increase in agricultural inputs at the global scale. As a result, cropland expands by 0.6 percent worldwide, at the cost of a small decline in pasture land (0.01 percent). This crop-bias is caused primarily by all climate-related exogenous yield shocks being imposed on crops only.[6]

The sectoral income of crops and broadly the sectoral income of agriculture including livestock are projected to increase by 5.9 percent and 4.8 percent, respectively, due to the impact of climate change. These seemingly counterintuitive results essentially reflect how the global demand system works on food consumption. Given the relatively low price elasticities of demand on food consumption, compared to non-food consumptions, the decline in agricultural productions due to climate change have been more than offset by the rise in prices of agricultural produce, leading to improved sectoral income in agriculture at the global scale.

The improved agricultural sectoral income under climate change also occurs at the regional level, with almost all regions, including both climate-resilient and climate-vulnerable regions, showing an improved sign in agricultural income. Since both types of regions improve on agricultural income, this implies that the story behind the improvements would be different for individual regions. While climate-vulnerable regions are still subject to the aforementioned law of demand elasticities, i.e., reduced agricultural productions overshadowed by rising food prices, regions having increased agricultural productions under climate change typically are not bounded by the same rule since the production increases in these regions are typically absorbed by increased foreign demand, which helps buffer an otherwise depression of domestic prices in agricultural produce.

The only region that suffers a loss in agricultural income while experiencing an increase in agricultural productions under climate change is Rest of East Asia, as it is the only region where prices of agricultural products decline under climate change. To help

[5] Fish productions reduce modestly in the climate change scenario since the feed inputs to aquaculture become less available and thus more expensive.

[6] Our simulations use climate-related yield shifters provided by the FAO. Since no livestock yield shifters are provided from FAO, all the climate-related yield shifters in the present simulations are limited to crop yields only.

understand what has occurred to agriculture in this region, we compare this region with another similar region, Rest of Western Europe (RWE), as both regions are positively affected by climate change and thus both have increased agricultural productions in the climate change scenario. Moreover, both are relatively small regions having a similar export size (approximately USD 3-4 billion) at 2050 in the baseline. However, faced with different trade barriers to food and agricultural commodities, represented by import tariffs levied by destination countries, agriculture in the two regions fares very differently under climate change. The RWE region, with its food and agricultural exports on average levied 25 percent by destination regions, can manage to get majority (82 percent) of the increased agricultural productions disposed of via export. The Rest of East Asia region, by contrast, faces a hefty 81 percent corresponding import tariffs on average levied by its trading partners. Under the high trade barrier, Rest of East Asia can only dispose of a small portion of the increased agricultural productions (39 percent) via export, with the remaining majority forced to be absorbed in the domestic market. This creates a dampening effect on domestic agricultural prices and effectively hurts agricultural income within the region.

The overall negative changes in crop yields, both exogenous and endogenous, at the global scale indicate that climate change causes agricultural land less productive. Our simulation shows that, while global agricultural productions are declining under climate change, agricultural land use on average goes up (0.16 percent) at the global scale, a mixture of an increase from cropland (0.59 percent) and a minor decrease from pasture land (0.01 percent). Again, this bias towards cropland use reflects that climate-induced yield shocks are implemented only for crops. The magnitudes of the increase in cropland use and the decrease in crop productions roughly mirror the magnitude of the built-in crop yield shocks at the global scale (1.1 percent).

Climate change also causes less efficient use of resources in agriculture, particularly in the cropping sector, as far as greenhouse gas (GHG) emissions are concerned.[7] Contrary to the reduced crop productions, GHG emissions in this sector increase by about 1 percent globally, in the climate change scenario relative to the baseline. By contrast, GHG emissions from the livestock sector reduce by 0.25 percent globally, largely in line with the contracted productions in this sector. Taking all sectors into account, global GHG emissions reduce by 0.13 percent globally, consistent with the broad contractions in macroeconomic growth at the global scale.

### Food and agricultural trade

While global agricultural productions are expected to decline due to the impacts of climate change, global trade in food and agricultural products is projected to rise by 0.9 percent under climate change, including rises in trade for crops (2.2 percent), livestock (0.7

[7] The emissions accounting in MAGNET includes all major greenhouse gases: $CO_2$, $CH_4$, $N_2O$, and F-Gases. However, GHG emissions from induced land use change are excluded.

percent), and processed food (0.5 percent), with an exception for fish trade which is found to barely change at the global scale. Rises in global food and agricultural trade are characterized not only by the increase in food exports/imports from climate-resilient/vulnerable regions, but also by the increase in net exports/imports from these regions. Due to the impact of climate change, food exports from climate-resilient regions are expected to increase by 1.6 percent, met by the corresponding increase (0.6 percent) in food imports from climate-vulnerable regions. Along with the increase in food exports, net food exports (exports minus imports) also increase by 1.9 percent in climate-resilient regions, matched by the corresponding 0.5 percent increase in net food imports (imports minus exports) by climate-vulnerable regions.

These changes in trade flows driven by climate change essentially reflect the role of global trade as a double-edged sword under climate change: reallocating food and agricultural products around the world to minimize climate-induced welfare losses, and on the other hand, strengthening the trade competitiveness of climate-resilient regions, making climate-vulnerable regions as a whole even less competitive in global food trade.

This global climate-trade linkage is also mirrored at the regional level. Canada and United States of America and Rest of North America, for example, have their trade competitiveness strengthened by favourable climate change, with food exports in the two countries increasing by 5.2 percent and 0.7 percent, respectively, and net food exports increasing by 5.3 percent and 1.1 percent, respectively. By contrast, food imports in India and West Africa increase by 6.1 percent and 5.8 percent, respectively, and net food imports in these two regions also increase by 10.3 percent and 6.7 percent, respectively.

The increase in global food and agricultural trade under climate change, as projected in our simulations, meets a common expectation that in principle increased trade flows are necessary to compensate for production losses in economies affected adversely by climate change. However, our results are in contrast with the results of Dellink *et al*. (2017) which instead show a contraction in global trade under climate change and the authors attribute the contraction in trade to the contraction in global final demand as indicated by the loss in world GDP. While linking GDP with trade sounds intuitive, our simulations reveal that a GDP loss at the global scale may also be sustained by an expansion in global trade, as will be shown below. Thus, the GDP loss, even if it may be a source, should not be the main source, at least not the single source, of the contraction in global trade as projected in their study.

### Macroeconomic growth

While the sectoral income in agriculture may benefit from climate change, as explained earlier, the other sectors of the economy which consume agricultural products or use agricultural products as inputs directly or indirectly are expected to be hurt by the falling supply and rising price of agricultural inputs. Consequently, the gross product at the world level, the world GDP, is expected to be negatively affected under climate change.

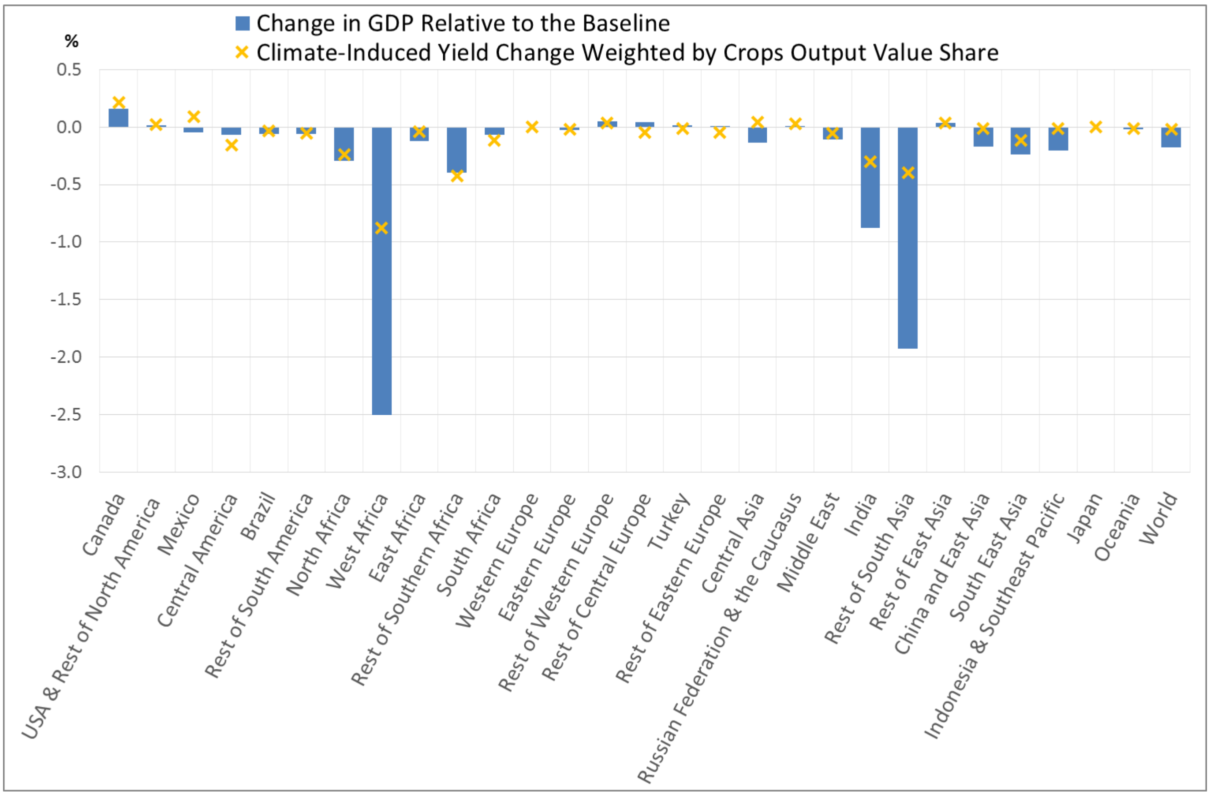
Relative to the baseline, the world GDP in the climate change scenario is projected to decline by 0.18 percent at 2050, which translates to some USD 150 billion (in 2011 constant prices). This result is roughly at the lower bound of the economic loss estimates (0.2-2 percent) surveyed by the IPCC (IPCC, 2014) for an assumed 2°C increase in temperature. However, it should be noted that, first, our projection period only extends to 2050 (under RCP6.0 global mean temperature increase would be markedly less than 2°C by 2050); and second, different assumptions on climate-induced changes in the economy would potentially lead to very different estimates. For instance, the much higher OECD estimate, with a mean value of 2 percent loss in global GDP (OECD, 2015), was based on many assumed climate-related changes in the economy including crop yield losses, loss of land and capital due to sea level rise, changes in fisheries catches, capital damages from hurricanes, labour productivity changes and changes in healthcare expenditures from diseases and heat stress, changes in tourism flows, and changes in energy demand for cooling and heating. By contrast, our present modelling exercise focuses only on crop yield losses induced by climate change.

In this sense, our GDP estimate is more comparable with Costinot *et al*. (2016) who also focus on crop yield losses caused by climate change. Using FAO's Global Agro-Ecological Zones field level data collected from about 1.7 million grid cells, Costinot *et al*. (2016) estimate that climate change over 110 years until the end of this century would cause a 0.26 percent loss of GDP (2009 value). In order to compare our estimate of 0.18 percent loss of world GDP with their estimate, we need to first factor in the difference in the projected climate change time span. On a "comparing apple with apple" basis, if we stretch our projection time span from 40 years to 110 years and assume climate-induced crop yield changes following the existing trend, a back of the envelope calculation shows that our model may project nearly half a percent loss of GDP. However, it is also necessary to take the very different modelling frameworks being used in the respective studies into account. For instance, capital supply has been endogenized in our current policy runs while it was not modelled in Costinot *et al*. (2016). In an earlier modelling exercise where we assume exogenous capital supply, which may be regarded as being closer to Costinot *et al*.'s assumptions, the projected world GDP loss due to climate change was 0.09 percent for the 40 year projection period, which amounts to about 0.25 percent loss of GDP for 110 years with the same back of the envelope calculation, very close to Costinot *et al*.'s estimate.

While the world GDP is expected to experience a loss under climate change, the effects on regional GDPs do not appear to be homogenous. As Figure 3 shows, the deviations of GDP in the climate change scenario relative to the baseline vary significantly across regions. While the GDP growth in a number of regions has been affected negatively, these effects are positive in some other regions. Moreover, the GDP deviations in some regions are too small to even be visible. Among the regions that are found to be hit particularly hard by climate change are regions located mainly in Africa and South Asia. West Africa, for example, sees the GDP falling by 2.5 percent under climate change relative to the baseline.

These cross-regional variations of the GDP response to climate change can largely be understood by taking into account the joint effect of two major contributing factors: a) the directions and magnitude of climate change impacts on crops as defined by the climate-induced crop yield shocks (See, also Figure 2) and b) how important the cropping sector is to the economy, represented by the value share of the cropping sector in all sectors. The joint effect of the two factors implies that the positive or negative climate-induced crop yield shocks may be magnified or moderated depending on how much an economy is reliant on the cropping sector. Technically, this joint effect can be quantified by multiplying the exogenous crop yield changes with the sectoral value share of crops. In Figure 4, the share weighted crop yield shocks are plotted against the deviations of regional GDPs. The two variables trace each other very well in most regions, suggesting that deviations of regional GDPs are, to a great extent, predictable by the two known factors.

**Figure 4 Changes in GDP in the climate change scenario relative to the baseline at 2050**




Developing economies, as Figure 4 shows, are found to be hit harder compared to their developed counterparts due partly to higher climate-induced crops yield losses, and partly to the economic structure as the cropping sector typically accounts for a relatively large portion in the developing economies. At 2050, the output value of crops in the developing economies accounts for an average of 3.5 percent in the output value of all sectors, compared to only 0.6 percent on average in the developed economies. West

Africa, for example, has over 23 percent of its sectoral output value generated from crops at 2050. The heavy reliance on the cropping sector renders these developing economies more vulnerable to a negative crop yield shock.

Impacts in several regions fail to be explained by the factors stated above as the direction of GDP changes in these regions has a small yet opposite deviation from what is indicated by the direction of crop yield changes. These regions can be divided into two groups: a negative crop yield shock but a positive GDP change (Rest of Central Europe, Turkey, and Rest of Eastern Europe); and a positive crop yield shock but a negative GDP change (Mexico, Central Asia, and Japan). These inconsistences between crop yield shocks and GDP changes tell us that despite playing a major role in explaining the direction of GDP changes, crop yield itself is not the only driver guiding where GDP is heading, even if crop yield shocks are the only shocks in defining climate change. The directions of the GDP response to climate change may be complicated by other factors that reflect to what extent a region will be affected by climate change relative to other regions. In other words, "relativity" also matters (Dellink *et al*., 2017).

To figure out how crop yields and the so-called relativity may interact with each other in affecting the direction of GDP movements, we hereby define the crop yield effect as the "first order" effect since the direction of yield changes determines the direction of GDP changes in most of the cases where the joint magnitudes of crop yield shocks and crops shares in GDP are significant. The relativity, here we refer to as the "second order" effect, can however become prominent and even dominate the first order effect especially where the yield-share joint magnitudes are small, as is the case of the six "defected" regions (See, again, Figure 4).

Relativity may work through multiple channels, with an important one being reflected by the terms of trade (relative price of imports in terms of exports) of a country in agri-food commodities. Climate change drives crop prices up in global markets, and the 2050 baseline results show that the three regions with "negative yield but positive GDP" are all net crop exporters (total crop exports exceed imports) and therefore face a positive terms of trade effect due to the higher price of their exports. This positive terms of trade effect dominates the small negative yield effect. An improvement in terms of trade benefits GDP in these regions in the sense that they can buy more imports for any given level of exports. The implied increase in real purchasing power of domestic productions is equivalent to a transfer of income from the rest of the world and this can have large impacts on domestic consumptions, savings and investment. The three regions with "positive yield but negative GDP" are all net crop importers facing a negative terms of trade effect as their crop (agri-food) imports become more expensive. For the given level of exports they can buy less imports and thus their GDPs will be effected negatively. This negative terms of trade effect in this case dominates the small positive yield effect in these regions.

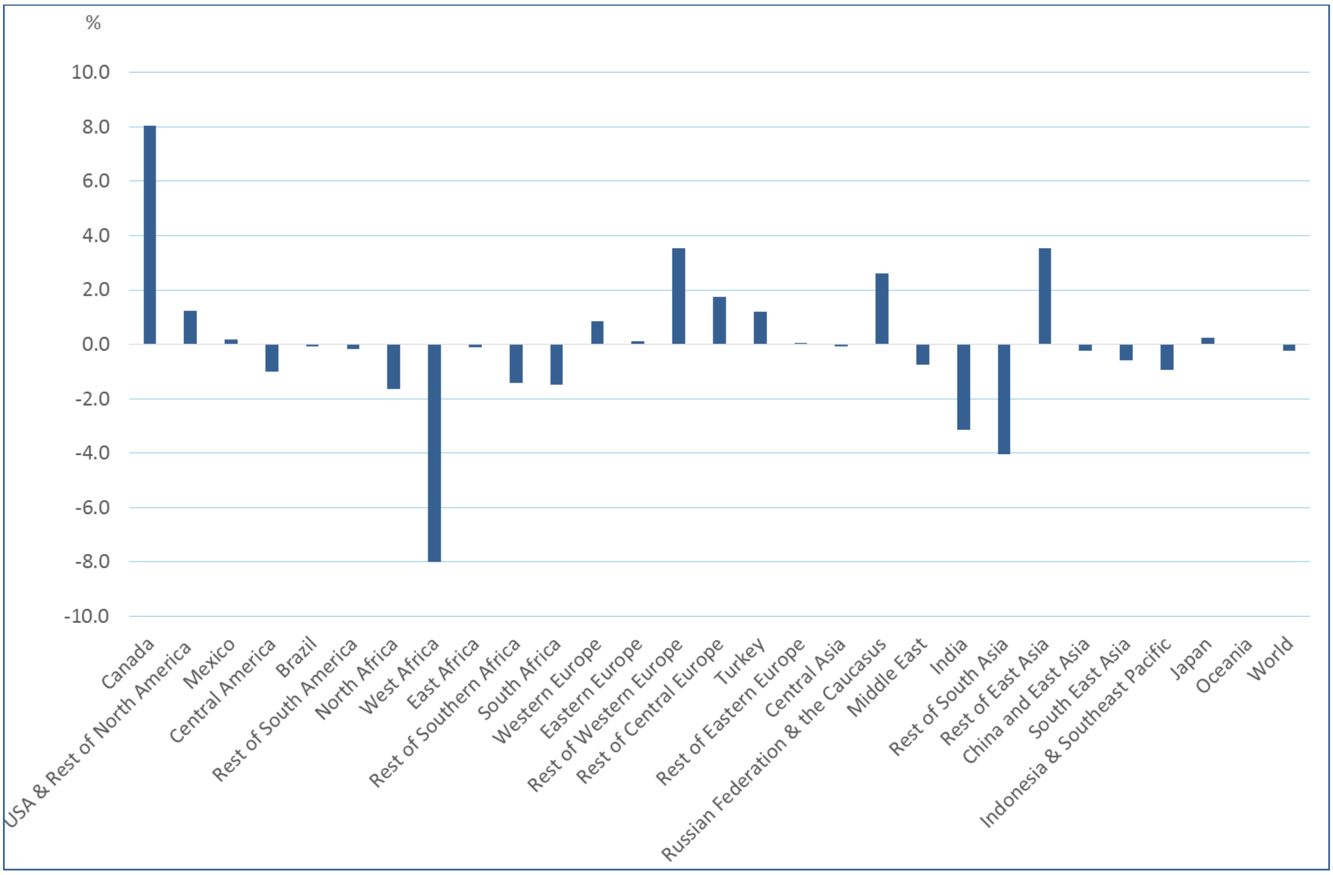
### Food security

Since less food and agricultural products will be produced globally under climate change, it follows that climate change may cause food security issues around the world, as warned by Wheeler and Von Braun (2013). Relative to the baseline, our projections show that calorie intake in the climate change scenario will drop 0.28 percent globally, in line with the production reductions in all food commodities including crops, livestock, processed food, and fish.

At the regional scale, developing regions in total are projected to have a slightly greater reduction in calorie consumption (0.283 percent) under climate change than developed regions (0.265 percent) but individual regions differ significantly. While most regions experience a fall in calorie consumptions, regions showing an increase in calorie consumptions are mostly developing regions including: Mexico, Rest of South America, North Africa, and Rest of South Asia.

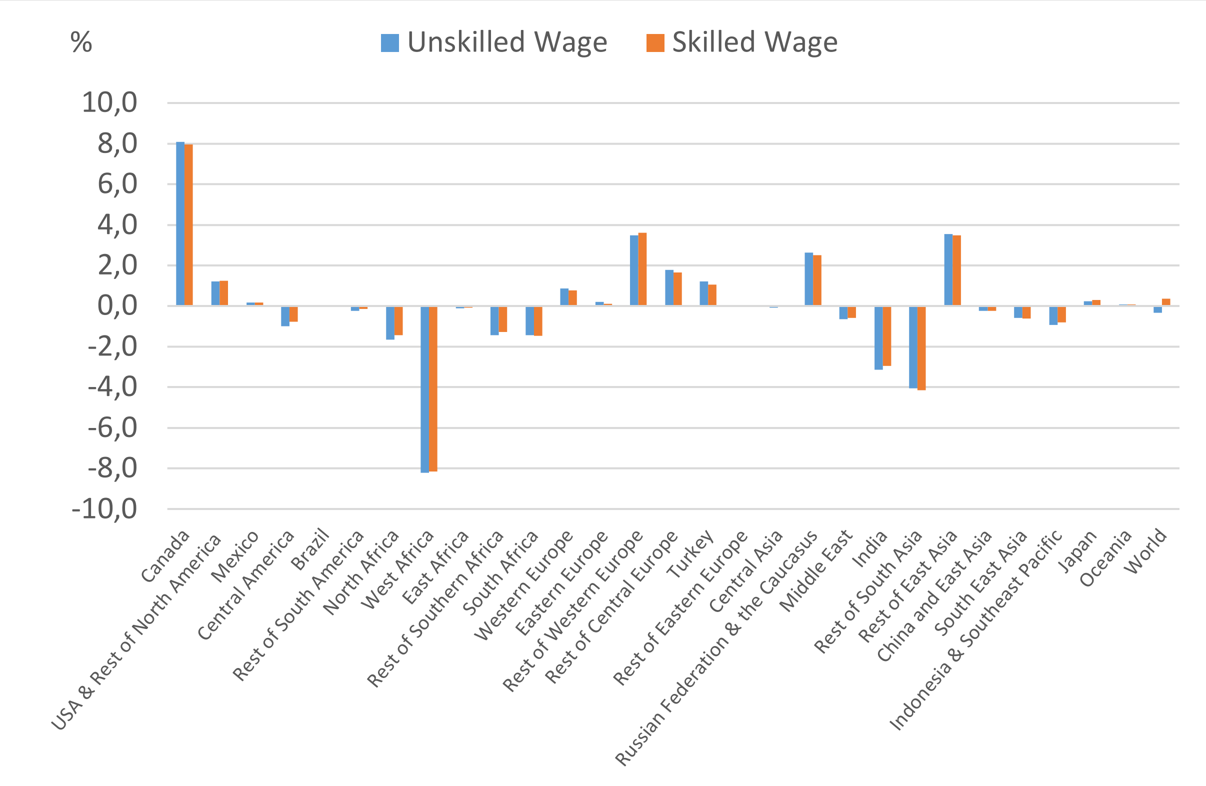
Along with food availability indicated by reduced calorie consumptions, food accessibility, as measured by the relative change between wages and food prices and the resulting change in food purchasing power, will also be adversely affected by climate change. In the climate change scenario relative to the baseline, the world average wage is expected to fall by 0.34 percent, with the average wage in agricultural sectors (incl. both crops and livestock) expected to decline by 0.24 percent. However, the decline in agricultural wage mostly occurs in developing regions (Figure 5). Most developed regions experience an increase in agricultural wage, due mostly to the favourable trade positions under climate change.

**Figure 5 Changes in agricultural wage under climate change relative to baseline**




While wages earned by skilled workers and unskilled workers are expected to decline by about the same degree when all sectors are taken into account, skilled wage in agricultural sectors are expected to rise by 0.35 percent globally, in contrast to the falling unskilled wage (0.33 percent) in agricultural sectors. This divergence in the global average is somewhat misleading since at the regional scale, as shown in Figure 6, it is evident that changes in skilled and unskilled wages in agricultural sectors are very similar in each of these global regions.

**Figure 6 Changes in skilled and unskilled wages in agriculture in climate change scenario relative to baseline at 2050**




Rising food prices and falling wages indicate that food purchasing power would deteriorate under climate change. At 2050, food purchasing power, used to assess the poverty level as measured by the ratio of unskilled wage in agriculture to cereal prices, is expected to decline by 4.7 percent globally due to the impact of climate change.[8] At the regional scale, food purchasing power in almost all regions is expected to decline, with the only exception for Rest of East Asia. Again, as explained earlier for the falling sectoral income in agriculture in this region, this is the only region where food prices decline under climate change and accordingly food purchasing power in this region rises.

[8] Another food purchasing power indicator can be derived by taking the ratio of the average wage in all sectors to the average price of all foods, and this indicator would decline by 2.9 percent globally due to climate change. While both indicators would decline in response to climate change, they have very different trajectories over time. Over the projection period up to 2050, the all-sector wage/food price indicator is expected to rise in both Baseline (88 percent) and the Climate Change scenario (82 percent), in contrast with the agri-unskilled wage/cereal price indicator which declines in both Baseline (-30 percent) and the Climate Change scenario (-34 percent). The rise in the all-sector wage/food price indicator is driven by the faster economy-wide wage growth relative to food price growth, as opposed to the agri-unskilled wage/cereal price indicator driven by the slower growth in agri-unskilled wage relative to the growth in cereal prices. Clearly, compared to the broad all-sector wage/food price indicator, the agri-unskilled wage/cereal price indicator used in this paper to assess food accessibility of the poor as they may be represented by unskilled workers in agriculture who are considered consuming mainly cereal-based staple food, captures not only the vulnerability of the poor to climate change but also their vulnerability to broad economic growth – their food purchasing power may be deteriorating even if the economy is growing.

# 6. The implications of trade liberalisation

As noted earlier, the Climate Change and Trade Liberalisation scenario is modelled on the Climate Change scenario by removing all border taxes (incl. both import tariffs and export taxes) for all agricultural and food commodities including all edible crops, livestock, processed food, and fish, while keeping climate-induced crop yield shocks the same as in the Climate Change scenario. The free trade effects under climate change can thus be captured by the deviations of the simulation results of the Climate Change and Trade Liberalisation scenario from the simulation results of Climate Change scenario.

## Food and agricultural trade

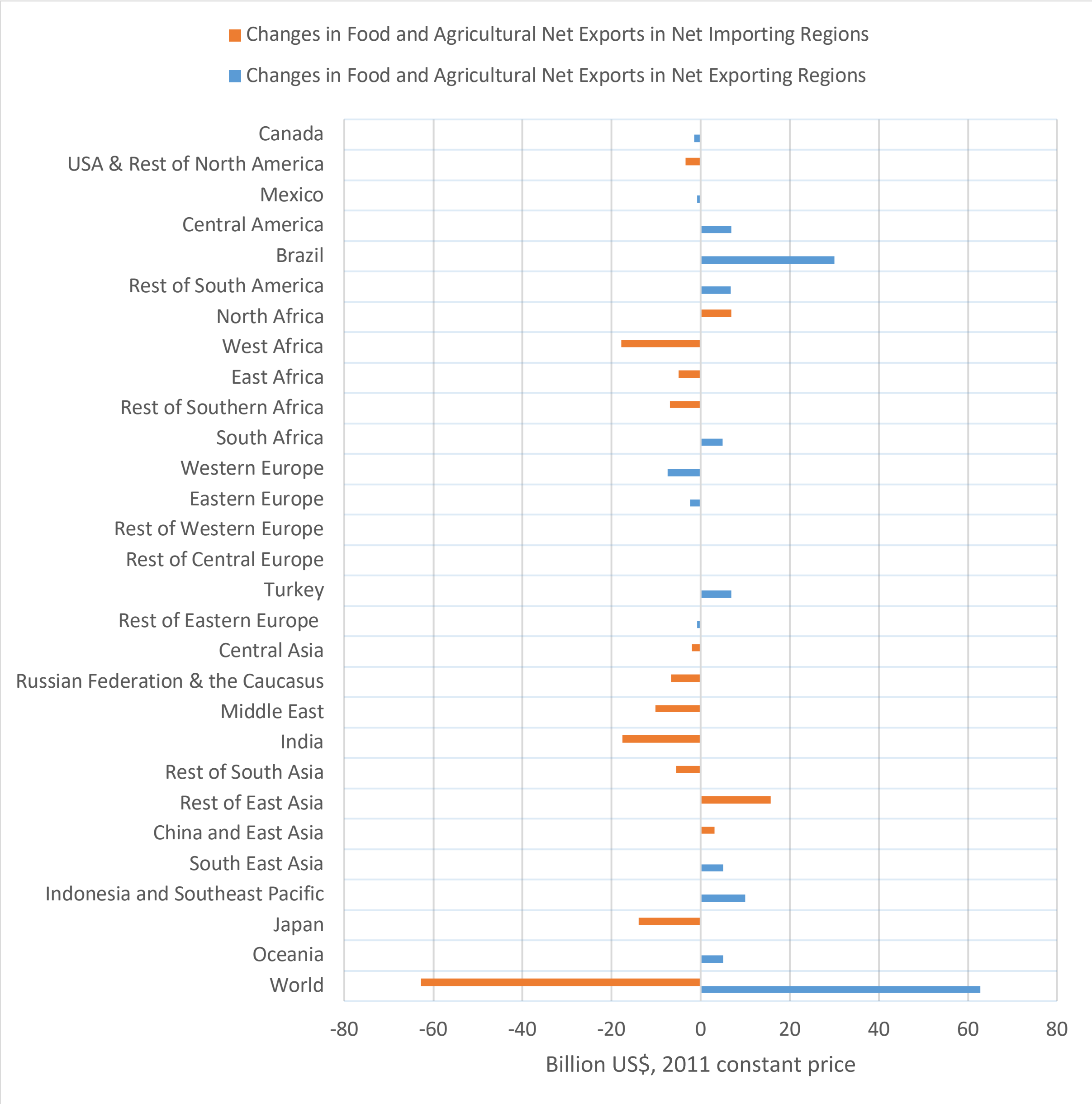
An immediate effect of removing border taxes in all countries is expected to be an expansion of global trade. Under the liberalised regime, global trade in agricultural and food commodities is projected to increase by 12 percent, relative to the Climate Change scenario. While this increase has been shared by all major food commodity groups including crops (5.3 percent), livestock (4.4 percent), processed food (16 percent), and fish (2.4 percent), the increase of trade in processed food is the leading contributor partly because the majority of food commodity trade (61 percent) is trade in processed food and partly because processed food tends to have higher initial (i.e. pre-liberalisation) protection levels compared to primary agriculture.

An expected consequence at the regional scale is that when trade is liberalised, food exporting regions are, in general, able to export more and food importing regions are in general able to import more. Figure 7 shows that the existing net food exporting regions, as identified in the Climate Change scenario at 2050, including all South America regions, South Africa, Turkey, Southeast Asia, and Oceania, will have an increase in net exports. On the other hand, the existing net food importing regions including United States of America and Rest of North America, most regions in Africa (East, West, and Rest of Southern Africa), regions around South and Central Asia and Middle East, Russian Federation and the Caucasus, and Japan, will have an increase in net food imports (i.e. decrease in net exports).[9] In total, food and agricultural net food exporting regions are expected to have an increase of USD 63 billion (2011 constant price) in net food exports, which is balanced by the same amount of increase in net food imports by net food importing regions.[10] This implies that overall, the existing comparative advantages in most regions, as characterized by changes in net food exports/imports, are maintained in the liberalised world.

[9] The net food trade issue discussed here also demonstrates that regions benefiting from climate change may not benefit from trade liberalisation in the sense that these regions (e.g. United States of America and Rest of North America, Russian Federation and the Caucasus, and Japan) experiencing a growth in net food exports due to climate change impacts would experience a decline in net food exports due to trade liberalisation.

[10] The balance in global trade needs to be evaluated using the same price metric. Here we use world exporter prices (F.O.B) to reach the trade account balance.

**Figure 7 Changes in food and agricultural net exports in net exporting/importing regions: CCTL vs. CC**




Several regions, however, show a reversal in their trading positions under trade liberalisation, including several of the existing net food exporting regions experiencing a decline in net food exports (e.g. Western and Eastern Europe) and several of the existing net food importing regions seeing a rise in net food exports (e.g. North Africa and Rest of East Asia). These reversals may be caused by, among other things, the relative border taxes, including border taxes a region levies relative to that levied by trading partners, and border taxes faced by a region relative to that faced by the other regions. Western Europe, for example, faces a negative net border tax – aggregate border taxes for food and agricultural imports levied by Western Europe exceeds the corresponding border taxes levied by all regions on the food exports of Western Europe, and this to a large extent explains why this region experiences a decline in net food exports after border taxes are removed.

### Food and agricultural productions, land use, and GHG emissions

In principle, trade liberalisation may cause an increase or decrease in food and agricultural productions depending on where trade has been liberalised more or less. In the Climate Change and Trade Liberalisation Scenario relative to the Climate Change Scenario, agricultural productions are projected to decline by 0.28 percent worldwide, with a decrease of 0.64 percent in crops productions compensated by an increase of 0.43 percent in livestock produce. The increase in global livestock productions is driven by lower input costs since livestock feed are cheaper now at the global level.

The overall contraction in agricultural productions also leads to the productions of processed foods declining by 0.42 percent globally. Consistent with the increase in livestock, productions of fish also increase (0.13 percent) globally as fishes are closer food substitutes with livestock than with crops. When all edible commodities (incl. edible crops, livestock, processed food, and fish) are counted in, global productions contract by approximately 0.36 percent under the liberalised trading regime.[11] This contraction essentially reflects a structural adjustment in the economy as a result of trade liberalisation. The lower prices of food and agricultural products boost non-food sectors, as will be shown in the next section on the macroeconomic effect, since these sectors may use agri-food products as inputs directly or indirectly. The expansion in non-food sectors demands more primary inputs and thus reallocates mobile primary factors, e.g. labour, from agri-food sectors to the rest of the economy. Among other things, reallocation of primary inputs contributes directly to the contraction of agricultural productions.[12]

In a liberalised world, regions such as Western Europe, India, and Japan, are projected to experience a significant decline in food and agricultural productions, and given the substantial shares that food and agricultural productions in these regions account for in global productions, the production decline in these regions weighs heavily on the global decline of food productions (

Figure 8 8). By contrast, a number of other regions, particularly Brazil and Rest of East Asia, see a substantial increase in food productions, offsetting to some extent this declining momentum, as illustrated by the production-share weighted changes in food productions. Developed regions on average experience a greater decline in food and agricultural productions (0.9 percent) than developing regions (0.1 percent).

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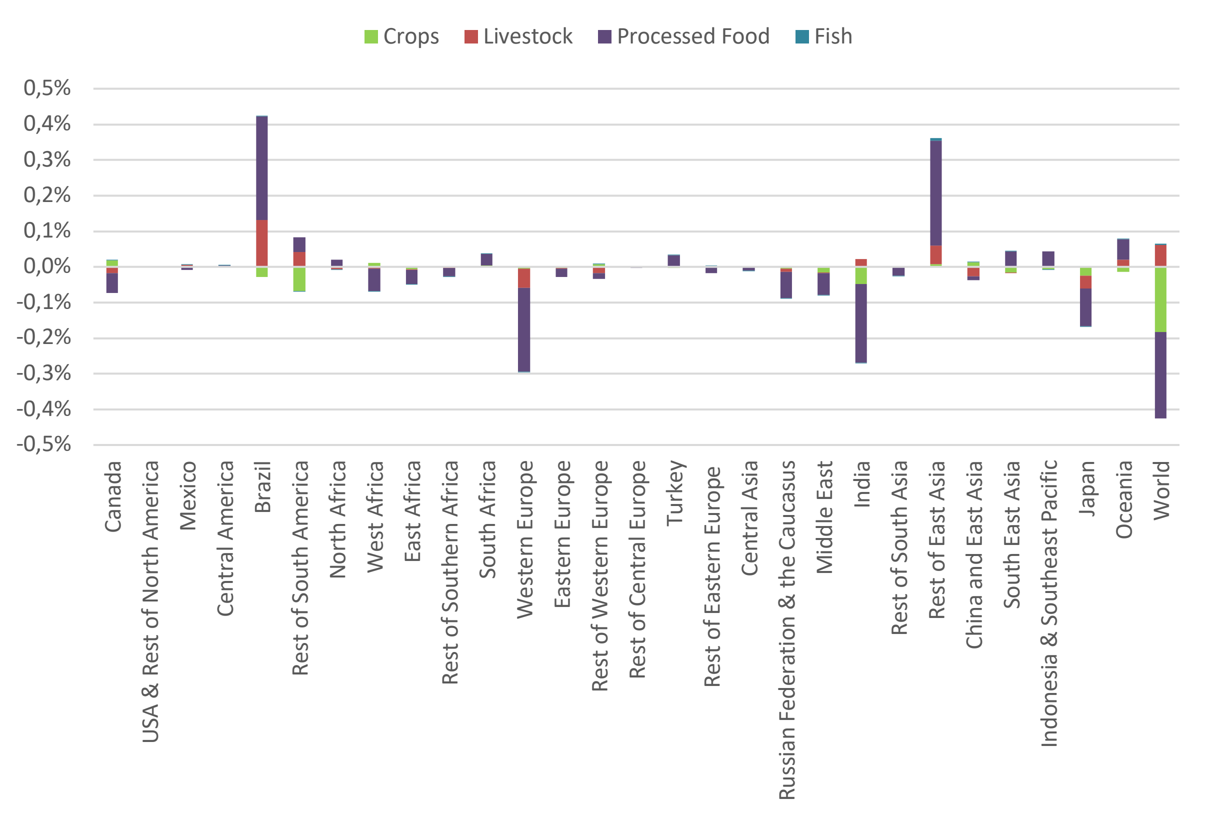
[11] Contraction in productions caused by trade liberalisation is also found by Langley *et al*. (2003) who use a global partial equilibrium to analyse the international dairy supply and trade.

[12] Our simulation shows that employment in agri-food sectors will shrink by 0.6 percent globally, with a corresponding employment increase in the other sectors. This employment reallocation is driven by a higher wage increase in non-food sectors (0.62 percent) relative to the wage increase in agri-food sectors (0.46 percent).

**Figure 8 Production-share weighted changes in food productions: CCTL vs. CC**




The relative change between crop productions and livestock productions naturally leads to a relative change in the input use in the respective sector. Globally, 0.8 percent cropland moves out of this sector, mostly being converted to pasture land which increases by 0.4 percent at the global scale. The percentage increase of global cropland, doubling that of pasture land, reflects that global pasture land area doubles global cropland area in the baseline since on average agricultural land barely changes.

The changing sectoral activities within agriculture are also mirrored by changes in GHG emissions. GHG emissions from the cropping sector reduce by 2.2 percent globally, consistent with the contracted activities in this sector. By contrast, livestock emissions increase by 1.8 percent around the world. Total GHG emissions from all sectors increase by 0.3 percent globally due to the liberalisation-induced expansion in economic activities.

## Macroeconomic growth

The contribution of trade liberalisation to macroeconomic growth has been well explained and tested in many earlier studies (See, for example, Bhagwati, 1978; Dollar, 1992; Krueger, 1978; Sachs *et al.*, 1995). Consistent with these earlier findings, the world GDP in the Climate Change and Trade Liberalisation scenario is projected to grow by 0.38 percent, relative to the Climate Change scenario. Two major findings here though, are at the regional scale.

First, compared to net food exporting regions, net food importing regions, as a whole, appear to benefit more in macroeconomic growth from liberalised trade, with the average GDP increase in net food importing regions (0.48 percent) more than double the average GDP increase in net food exporting regions (0.21 percent)[13]. This is primarily because, among other things, Net food importing regions on average face a higher food border tax rate (13.9 percent), compared to the rate faced by net food exporting regions (8.8 percent), (Table 2). Notably, this macroeconomic result is in stark contrast with the above results focused only on agricultural trade, where the net food exporting regions in general experience a greater expansion in food and agricultural exports under trade liberalisation, which apparently suggests that trade liberalisation would benefit food exporting regions more. The finding here however sheds light on the importance of both sides of international trade through which trade liberalisation may contribute to economic growth: the export side where lowered trade costs make food export easier and thus contributes directly to GDP growth through increased exports; and the import side as cheaper food imports lower domestic food prices and the resulting income and substitution effects are expected to trigger an expansion of the domestic economy.

Second, developing economies on average benefit more in GDP growth than their developed counterparts. On average, the GDP increase in developing economies (0.61 percent) is much greater than the GDP increase in developed economies (0.15 percent). The increase in GDP in developing economies should be attributed not only to the generally higher border tax rates for food and agricultural commodities faced by developed economies (13.6 percent) than that faced by developed economies (8.1 percent), but also to the heavier involvement of food related economic activities in the developing economies. Measured by both food productions and consumptions, the food activity/GDP ratio in developing economies (23 percent) almost doubles that ratio in developed economies (12 percent). The heavier presence of food related economic activities enables developing economies to take better advantage of the benefits from liberalised food and agricultural trade.

[13] Again, net food exporting and importing regions are identified in the Climate Change Scenario.

**Table 2 Regional economic characteristics and GDP change in Climate Change and Trade Liberalisation scenario relative to Climate Change scenario at 2050**

| | Exporting/ Importing Region | Developed/ Developing Economy | GDP Change (%) | Food Border Tax Rate (%) | Food Activity/ GDP Ratio (%) |
|---|---|---|---|---|---|
| Canada | Exporting | Developed | 0.32 | 9.5 | 11 |
| USA & Rest of North America | Importing | Developed | 0.00 | 7.6 | 9 |
| Mexico | Exporting | Developing | 0.06 | 3.6 | 22 |
| Central America | Exporting | Developing | 0.84 | 12.1 | 40 |
| Brazil | Exporting | Developing | 0.32 | 12.8 | 27 |
| Rest of South America | Exporting | Developing | -0.27 | 8.0 | 27 |
| North Africa | Importing | Developing | 1.13 | 10.7 | 40 |
| West Africa | Importing | Developing | 2.14 | 13.7 | 41 |
| East Africa | Importing | Developing | 0.40 | 12.2 | 57 |
| Rest of Southern Africa | Importing | Developing | 0.58 | 13.4 | 35 |
| Southern Africa | Exporting | Developed | 0.36 | 16.6 | 21 |
| Western Europe | Exporting | Developed | 0.14 | 4.1 | 13 |
| Eastern Europe | Exporting | Developed | 0.06 | 3.8 | 18 |
| Rest of Western Europe | Exporting | Developed | 0.49 | 16.4 | 12 |
| Rest of Central Europe | Exporting | Developed | 0.44 | 7.3 | 20 |
| Turkey | Exporting | Developing | 1.27 | 19.8 | 25 |
| Rest of Eastern Europe | Exporting | Developed | -0.03 | 7.6 | 28 |
| Central Asia | Importing | Developing | 0.66 | 7.0 | 20 |
| Russian Federation and the Caucasus | Importing | Developed | 0.11 | 11.2 | 16 |
| Middle East | Importing | Developing | 0.33 | 8.9 | 16 |
| India | Importing | Developing | 2.14 | 50.6 | 27 |
| Rest of South Asia | Importing | Developing | 2.28 | 12.9 | 56 |
| Rest of East Asia | Importing | Developed | 1.67 | 68.5 | 11 |
| China and East Asia | Importing | Developing | 0.25 | 10.3 | 15 |
| Southeast Asia | Exporting | Developing | 0.61 | 14.1 | 34 |
| Indonesia and Southeast Pacific | Exporting | Developing | 0.10 | 31.6 | 21 |
| Japan | Importing | Developed | 0.04 | 15.2 | 14 |
| Oceania | Exporting | Developed | 0.03 | 10.6 | 14 |
| **World** | | | **0.38** | **10.8** | **18** |

### Food security

Since global food and agricultural productions are expected to decline under trade liberalisation, the availability of food declines at the global level. Our simulations project that global calorie intake would drop 0.4 percent due to liberalised trade, roughly in line with the decline of food productions (0.36 percent) – with the small gap reflecting the adjusted food consumption structure in the liberalisation scenario.

The global reduction in calorie intake however masks the fact that developed regions as a whole essentially gain an increase in calorie intake (1.4 percent) but this gain has been dwarfed by a decline in developing regions (0.8 percent) since the total calorie intake in developing regions, driven by a relatively large and fast growing population in these regions, are more than four times higher than that in developed regions.

In terms of food access we see another picture. The economic growth driven by trade liberalisation pushes wages higher at the global scale, with an average wage increase of 0.16 percent in the agricultural sector and 0.62 percent in non-agricultural sectors, globally. Within the agricultural sector, wages earned by skilled workers experience a faster increase (0.28 percent), compared to a 0.16 percent increase for unskilled workers.

The rise in wages and decline in food prices imply that food purchasing power will be higher in the trade liberalisation scenario. As measured by the unskilled wage in the agricultural sector relative to food prices, food purchasing power is projected to increase by 6.3 percent when trade is liberalised.

## 7. The adaptive effect of trade liberalisation

As stated earlier, climate change impacts may be altered by the introduction of trade liberalisation and the alterations, if any, reflect whether and to what extent trade liberalisation can mitigate the impact of climate change. Identifying the potential mitigation and adaptation effects of trade liberalisation requires, as explained earlier, an isolation of the liberalisation-altered climate change impacts from the unaltered impacts. The liberalisation-altered climate change impacts are measured by the deviations of the Climate Change and Trade Liberalisation scenario simulation results from the newly introduced Trade Liberalisation scenario results (without climate change). The difference between these deviations and the deviations reported in Section 5 “The implications of climate change” captures the interaction effect - to what extent trade liberalisation has altered the impacts of climate change.

Therefore, the interaction effects reported in this section are substantially different from the trade liberalisation effects reported in the last section where the deviations of the Climate Change and Trade Liberalisation scenario simulation results from the Climate Change scenario simulation results are used to capture the implications of trade liberalisation under climate change. However, the two effects - the interaction effects reported below and the trade liberalisation effects reported above, are closely related since computing the interaction effects is equivalent to decompose the trade liberalisation effects reported in the last section into two parts: the pure trade liberalisation effect, as captured by the deviations of the Trade Liberalisation scenario results from the Baseline, and the interaction effect. Thus, the interaction effect may be interpreted from two different but associated perspectives – two sides of the same coin.

### Macroeconomic growth

Broadly, the simulation results show that, with the introduction of trade liberalisation, the overall adverse impacts of climate change at the global scale will be slightly moderated. The first and most important indicator used to measure this adaptive effect is the world GDP, which was projected to decline by 0.18 percent due to the impact of climate change (unaltered by trade liberalisation). However, this decline is expected to lower to 0.17 percent if food and agricultural trade is liberalised. The improvement on world GDP, small yet positive, signals an overall liberalisation-induced alleviation of the globally negative climate change impacts. [14]

At the regional scale, the interaction effects on GDP do not appear to be uniform. While for many regions the interaction effects are not very different from the global average, several regions experience quite large positive or negative changes in GDP due to the interaction effect. These effects in India, West Africa, and North Africa, for example, are particular large and positive, with the climate-induced GDP losses in these regions reduced by 0.11 percent, 0.04 percent, and 0.04 percent, respectively. By contrast, Rest of Eastern Europe and Rest of South America, the only two regions expected to be negatively affected by trade liberalisation as reported in Section 6.3, are also subject to an adverse interaction effect which makes the original climate change impacts in these two regions worsen by 0.02 percent and 0.01 percent, respectively.

### Food and agricultural productions, land use, and GHG emissions

As far as food and agricultural productions are concerned, the globally negative impacts of climate change on food productions are moderated by nearly 0.03 percent, the percentage difference between the negative pre-liberalisation climate change impact (a 0.28 percent reduction in food productions) and the negative post-liberalisation climate change impact (a 0.25 percent reduction in food productions), as shown in

Figure **9**. The moderation in the broad food category is mainly driven by the moderation in the crops and processed food sectors (both sectors experience about a 0.03 percent moderation) and to a lesser extent, a moderation from the livestock sector (slightly over

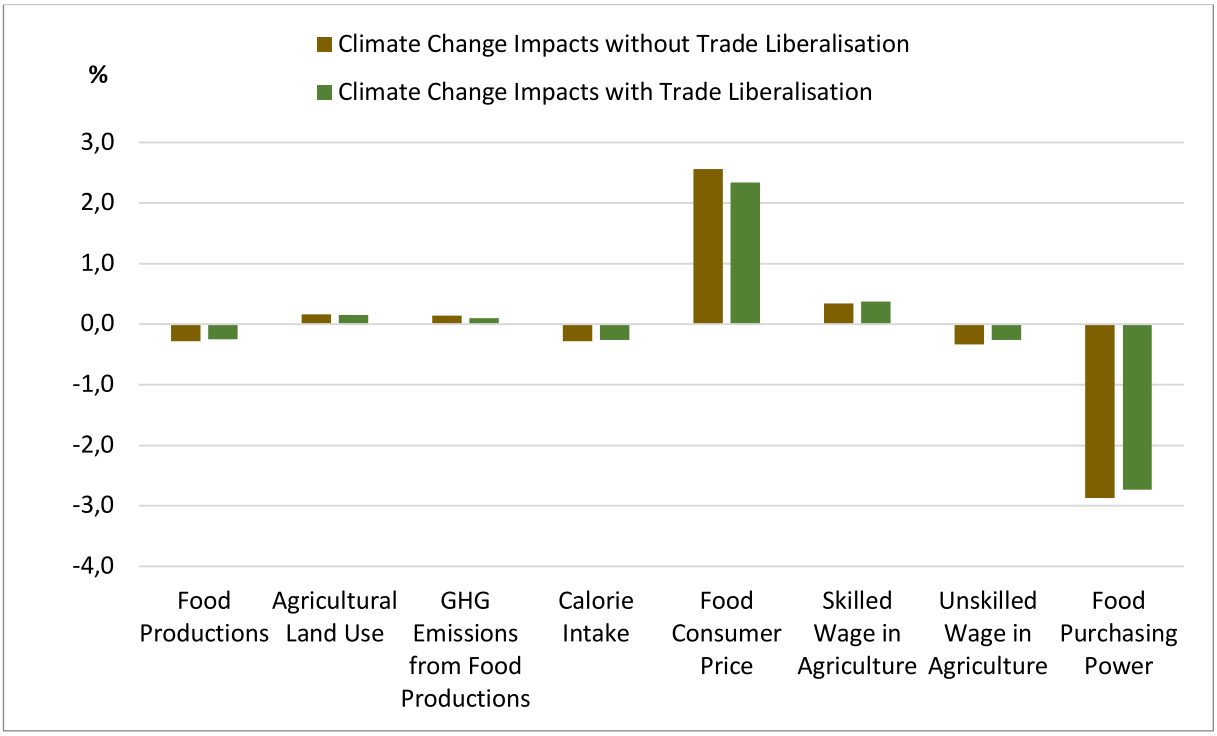
[14] It should be noted, again, that in our simulation exercise, the projection time horizon is limited to 2050, the exogenous climate-related shocks are limited to crop yields, and trade liberalisation is implemented only for food and agricultural commodities. The adaptive effect defined in this paper may be different if these limitations change.

0.01 percent). The fish sector barely changes, meaning that trade liberalisation is not expected to alter the initial climate change impacts on fish productions at the global scale.

A small efficiency gain on input uses in the agricultural sector is also found as a result of the interaction/adaptation effects. Cropland uses, which increases by 0.59 percent globally due to climate change, are expected to increase by only 0.56 percent if food and agricultural trade is liberalised. The land use increase in the overall agricultural sector due to climate change would reduce by some 0.01 percent as the interaction effect for pasture land is largely negligible.

While the adaptive effects for GHG emissions at the macro (all-sector) level are not observed, the emissions from food productions are mitigated by 0.04 percent, with emissions from crop productions, in particular, mitigated by 0.13 percent - down from a 1.05 percent increase to a 0.91 percent increase, indicative of some liberalisation-induced corrections for climate-induced inefficiencies on GHG emissions at the global scale.

**Figure 9 The adaptive effect measured by the difference between climate change impacts with and without trade liberalisation at 2050**




## Food security

Compared to the adaptive effects of trade liberalisation on food production, the adaptive effects on food prices are more substantial (see

Figure 9). The price rises due to climate change at the global scale will be moderated in almost all major food categories including crops (0.69 percent), livestock (0.47 percent), and processed food (0.19 percent), with an exception of fishes for which the adaptive effect is not visible. On average, food and agricultural prices are moderated by 0.35 percent, down from the climate-induced 2.6 percent increase to 2.2 percent increase.

The increase in food productions and decrease in food prices at the global scale, thanks to the adaptive effect, imply that the climate-induced food security issue will be moderated accordingly. The decline of global calorie intake due to climate change is expected to reduce by 0.02 percent - a reduction from the initial decline of 0.28 percent to 0.26 percent. The improvements on food security are most significant in India and Turkey, where the calorie intake is expected to rise by 0.42 percent and 0.15 percent, respectively, attributed to the adaptive effect. The calorie intake however is expected to decline most in Rest of East Asia (0.47 percent), Japan (0.38 percent), North Africa (0.32 percent), and Middle East (0.23 percent), also due to the interaction effect.

The interaction effect also causes a rise in wages for unskilled workers at the global scale, although the wage for skilled workers does not seem to be affected globally. Unskilled wages in agricultural sectors (crops and livestock) also have a greater improvement (0.08 percent), relative to the improvement of unskilled wages in non-agriculture sectors (0.05 percent). Accordingly, food purchasing power, measured by the unskilled wage in agriculture relative to food consumption prices, improves by 0.15 percent globally, down from the climate-induced initial decline of 2.88 percent to 2.73 percent.

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# Appendix

**Table A. 1 Average ad valorem import tariffs on agricultural and food commodities at 2011 (%)**

| | Canada | USA & Rest of North America | Mexico | Central America | Brazil | Rest of South America | North Africa | West Africa | East Africa | Rest of Southern Africa | South Africa | Western Europe | Eastern Europe | Rest of Western Europe | Rest of Central Europe | Turkey | Rest of Eastern Europe | Central Asia | Russian Federation & the Caucasus | Middle East | India | Rest of South Asia | Rest of East Asia | China and East Asia | South East Asia | Indonesia & Southeast Pacific | Japan | Oceania | World |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Canada | 0 | 1 | 2 | 8 | 7 | 8 | 21 | 9 | 22 | 12 | 5 | 7 | 14 | 40 | 14 | 18 | 1 | 14 | 31 | 4 | 44 | 5 | 21 | 8 | 12 | 6 | 22 | 1 | 7 |
| USA & Rest of North America | 12 | 9 | 1 | 10 | 17 | 14 | 8 | 7 | 14 | 9 | 4 | 8 | 8 | 20 | 8 | 27 | 7 | 32 | 26 | 4 | 29 | 14 | 155 | 4 | 9 | 5 | 22 | 0 | 17 |
| Mexico | 1 | 0 | 0 | 6 | 7 | 9 | 6 | 8 | 9 | 8 | 7 | 3 | 2 | 32 | 8 | 33 | 3 | 27 | 21 | 10 | 63 | 29 | 38 | 8 | 10 | 11 | 25 | 1 | 2 |
| Central America | 2 | 2 | 9 | 6 | 10 | 11 | 21 | 18 | 22 | 12 | 4 | 3 | 10 | 3 | 4 | 64 | 12 | 21 | 16 | 6 | 39 | 13 | 19 | 27 | 30 | 9 | 8 | 1 | 7 |
| Brazil | 13 | 3 | 20 | 36 | 0 | 5 | 10 | 12 | 19 | 13 | 16 | 12 | 13 | 42 | 11 | 32 | 10 | 17 | 20 | 8 | 26 | 6 | 139 | 6 | 9 | 8 | 6 | 0 | 12 |
| Rest of South America | 4 | 1 | 6 | 10 | 0 | 3 | 11 | 10 | 6 | 9 | 10 | 8 | 4 | 25 | 8 | 48 | 4 | 17 | 12 | 6 | 20 | 17 | 48 | 4 | 5 | 12 | 9 | 1 | 6 |
| North Africa | 3 | 2 | 13 | 7 | 9 | 7 | 0 | 16 | 3 | 30 | 12 | 5 | 15 | 21 | 8 | 16 | 2 | 11 | 6 | 1 | 22 | 13 | 7 | 10 | 3 | 6 | 7 | 2 | 5 |
| West Africa | 0 | 0 | 12 | 6 | 10 | 4 | 21 | 11 | 14 | 14 | 3 | 0 | 0 | 2 | 4 | 3 | 0 | 1 | 5 | 7 | 4 | 11 | 36 | 6 | 3 | 5 | 1 | 0 | 3 |
| East Africa | 1 | 1 | 10 | 11 | 5 | 4 | 2 | 21 | 2 | 1 | 19 | 0 | 0 | 28 | 5 | 36 | 6 | 1 | 11 | 4 | 45 | 9 | 12 | 5 | 6 | 5 | 5 | 0 | 4 |
| Rest of Southern Africa | 0 | 2 | 23 | 4 | 4 | 7 | 4 | 23 | 3 | 9 | 0 | 0 | 0 | 90 | 8 | 22 | 1 | 0 | 1 | 27 | 12 | 7 | 2 | 8 | 34 | 5 | 0 | 1 | 7 |
| South Africa | 3 | 1 | 6 | 13 | 17 | 17 | 18 | 20 | 28 | 13 | 0 | 4 | 2 | 12 | 8 | 7 | 2 | 7 | 6 | 15 | 10 | 33 | 367 | 11 | 5 | 9 | 23 | 3 | 19 |
| Western Europe | 19 | 3 | 8 | 16 | 15 | 14 | 20 | 13 | 28 | 15 | 2 | 0 | 0 | 25 | 5 | 24 | 10 | 16 | 20 | 15 | 60 | 21 | 36 | 9 | 17 | 7 | 25 | 3 | 4 |
| Eastern Europe | 16 | 4 | 17 | 9 | 13 | 8 | 11 | 13 | 14 | 7 | 2 | 0 | 1 | 48 | 3 | 38 | 13 | 20 | 19 | 11 | 33 | 5 | 149 | 10 | 9 | 8 | 36 | 3 | 5 |
| Rest of Western Europe | 48 | 3 | 12 | 6 | 7 | 9 | 86 | 12 | 20 | 20 | 13 | 5 | 4 | 8 | 6 | 14 | 3 | 11 | 11 | 16 | 37 | 23 | 13 | 12 | 11 | 8 | 3 | 3 | 8 |
| Rest of Central Europe | 10 | 5 | 8 | 8 | 11 | 12 | 33 | 9 | 18 | 12 | 10 | 5 | 3 | 7 | 2 | 9 | 9 | 14 | 16 | 21 | 31 | 7 | 13 | 15 | 28 | 9 | 15 | 2 | 7 |
| Turkey | 2 | 11 | 23 | 13 | 10 | 12 | 14 | 16 | 16 | 13 | 18 | 2 | 4 | 8 | 19 | 0 | 6 | 18 | 7 | 16 | 22 | 17 | 18 | 10 | 20 | 6 | 5 | 3 | 9 |
| Rest of Eastern Europe | 47 | 3 | 3 | 21 | 0 | 33 | 7 | 10 | 11 | 11 | 11 | 4 | 4 | 27 | 2 | 45 | 2 | 0 | 0 | 9 | 3 | 7 | 248 | 9 | 14 | 8 | 7 | 1 | 7 |
| Central Asia | 0 | 1 | 4 | 0 | 1 | 1 | 6 | 1 | 36 | 0 | 5 | 11 | 5 | 83 | 5 | 46 | 0 | 0 | 0 | 9 | 15 | 5 | 11 | 8 | 15 | 1 | 0 | 0 | 5 |
| Russian Federation & the Caucasus | 3 | 1 | 24 | 6 | 2 | 3 | 3 | 6 | 8 | 5 | 1 | 6 | 5 | 20 | 2 | 44 | 2 | 1 | 0 | 5 | 41 | 5 | 13 | 12 | 10 | 9 | 4 | 2 | 7 |
| Middle East | 13 | 3 | 7 | 6 | 7 | 6 | 1 | 15 | 14 | 28 | 9 | 3 | 2 | 17 | 11 | 27 | 6 | 33 | 11 | 4 | 29 | 11 | 17 | 4 | 17 | 9 | 9 | 2 | 6 |
| India | 2 | 1 | 9 | 62 | 12 | 9 | 12 | 13 | 13 | 21 | 17 | 4 | 6 | 4 | 6 | 21 | 6 | 5 | 8 | 10 | 0 | 12 | 180 | 7 | 10 | 6 | 3 | 0 | 10 |
| Rest of South Asia | 1 | 3 | 1 | 10 | 6 | 8 | 9 | 11 | 11 | 10 | 25 | 4 | 2 | 5 | 9 | 44 | 6 | 15 | 11 | 7 | 10 | 9 | 46 | 6 | 16 | 7 | 5 | 0 | 9 |
| Rest of East Asia | 8 | 4 | 6 | 8 | 5 | 8 | 12 | 10 | 35 | 8 | 14 | 3 | 1 | 16 | 4 | 11 | 3 | 20 | 17 | 45 | 30 | 11 | 3 | 17 | 17 | 17 | 15 | 3 | 15 |
| China and East Asia | 4 | 3 | 19 | 16 | 11 | 9 | 30 | 15 | 15 | 14 | 8 | 9 | 11 | 19 | 12 | 21 | 7 | 11 | 11 | 15 | 36 | 14 | 51 | 5 | 10 | 4 | 11 | 2 | 13 |
| South East Asia | 6 | 2 | 22 | 9 | 11 | 10 | 18 | 14 | 13 | 13 | 5 | 8 | 9 | 8 | 5 | 27 | 3 | 9 | 16 | 9 | 60 | 15 | 29 | 5 | 11 | 7 | 13 | 0 | 11 |
| Indonesia & Southeast Pacific | 3 | 1 | 9 | 10 | 66 | 10 | 24 | 27 | 5 | 15 | 14 | 6 | 6 | 5 | 3 | 97 | 0 | 13 | 33 | 10 | 135 | 21 | 45 | 16 | 7 | 14 | 3 | 1 | 28 |
| Japan | 6 | 3 | 12 | 3 | 10 | 6 | 12 | 14 | 10 | 13 | 6 | 8 | 10 | 9 | 5 | 10 | 6 | 4 | 19 | 7 | 33 | 12 | 29 | 13 | 8 | 12 | 0 | 2 | 12 |
| Oceania | 14 | 4 | 21 | 17 | 13 | 25 | 10 | 11 | 17 | 6 | 8 | 23 | 9 | 36 | 11 | 57 | 7 | 11 | 17 | 4 | 26 | 17 | 43 | 12 | 5 | 8 | 24 | 0 | 14 |
| World | 12 | 2 | 3 | 12 | 6 | 7 | 13 | 13 | 14 | 13 | 7 | 2 | 2 | 25 | 5 | 32 | 7 | 7 | 15 | 9 | 60 | 13 | 81 | 7 | 10 | 7 | 16 | 1 | 9 |

Note: values in diagonal cells are generally zero for a single country but maybe non-zero for a multi-country region, indicative of an intra-regional import tariff.
Source: calculated from GTAP data base 2011.

## Table A. 2 Average ad valorem export taxes on agricultural and food commodities at 2011 (%)

| | Canada | USA & Rest of North America | Mexico | Central America | Brazil | Rest of South America | North Africa | West Africa | East Africa | Rest of Southern Africa | South Africa | Western Europe | Eastern Europe | Rest of Western Europe | Rest of Central Europe | Turkey | Rest of Eastern Europe | Central Asia | Russian Federation & the Caucasus | Middle East | India | Rest of South Asia | Rest of East Asia | China and East Asia | South East Asia | Indonesia & Southeast Pacific | Japan | Oceania | World |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Canada | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| USA & Rest of North America | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mexico | 0.0 | 0.0 | 0.0 | -0.3 | 0.0 | -1.3 | -6.6 | 0.0 | -0.1 | 0.0 | 0.0 | -0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.1 |
| Central America | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Brazil | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Rest of South America | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| North Africa | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| West Africa | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| East Africa | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Rest of Southern Africa | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| South Africa | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Western Europe | -0.6 | -0.1 | -1.1 | -1.1 | -0.3 | -0.5 | -4.2 | -2.1 | -1.0 | -1.1 | -0.6 | 0.0 | -0.1 | -1.9 | -1.2 | -0.4 | -0.6 | -2.8 | -3.4 | -6.2 | -0.6 | -1.6 | -1.6 | -1.0 | -1.8 | -3.1 | -1.6 | -0.6 | -0.6 |
| Eastern Europe | -0.4 | -0.4 | -0.1 | -0.1 | 0.0 | -0.1 | -0.9 | -0.3 | -0.1 | 0.0 | -0.3 | 0.0 | 0.0 | -0.6 | -0.7 | 0.0 | -1.6 | -8.7 | -4.2 | -3.4 | -0.1 | 0.0 | -1.7 | -0.5 | -0.2 | 0.0 | -1.7 | -0.2 | -0.5 |
| Rest of Western Europe | -1.0 | -0.5 | -0.5 | -0.3 | -0.5 | -1.4 | -0.6 | -0.2 | -1.2 | -0.1 | -0.9 | -1.0 | -0.3 | 0.0 | -0.4 | -0.8 | -0.4 | -0.7 | -0.3 | -0.2 | -1.4 | -1.5 | -0.6 | -0.4 | -0.7 | -1.0 | -0.1 | -1.2 | -0.6 |
| Rest of Central Europe | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Turkey | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Rest of Eastern Europe | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Central Asia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Russian Federation & the Caucasus | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 |
| Middle East | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| India | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Rest of South Asia | -0.2 | -0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.2 | 0.0 | -0.1 | 0.0 | 0.0 | -0.2 | -0.8 | -0.3 | -0.1 | -3.6 | -0.3 | 0.0 | -3.8 | -0.4 | -0.1 | 0.0 | 0.0 | -0.5 |
| Rest of East Asia | -0.7 | -0.5 | -0.1 | 0.0 | -0.1 | 0.0 | 0.0 | -0.2 | 0.0 | -0.4 | -0.1 | -0.2 | 0.0 | -0.1 | 0.0 | -2.7 | 0.0 | 0.0 | -0.2 | 0.0 | 0.0 | 0.0 | 0.0 | -0.7 | -0.2 | -0.2 | -1.2 | -0.4 | -0.6 |
| China and East Asia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| South East Asia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Indonesia & Southeast Pacific | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Japan | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oceania | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| World | -0.1 | 0.0 | 0.0 | -0.1 | -0.1 | -0.1 | -1.2 | -0.4 | -0.2 | -0.2 | -0.2 | 0.0 | -0.1 | -1.3 | -0.8 | -0.1 | -0.4 | -0.6 | -1.3 | -1.0 | -0.2 | -0.1 | -0.2 | -0.1 | -0.2 | -0.2 | -0.2 | -0.1 | -0.2 |

Note: negative values are export subsidies instead of taxes.
Source: calculated from GTAP data base 2011.

**Table A. 3 Changes in agricultural and food trade in the Climate Change and Trade Liberalisation scenario relative to the Climate Change scenario at 2050 (million US$, 2011 constant price)**

| | Canada | United States | Mexico | Central America | Brazil | Rest of South America | North Africa | West Africa | East Africa | Rest of Southern Africa | South Africa | Western Europe | Eastern Europe | Rest of Western Europe | Rest of Central Europe | Turkey | Ukraine | Central Asia | Russian Federation & the Caucasus | Middle East | India | Rest of South Asia | Rest of East Asia | China | South East Asia | Indonesi a | Japan | Oceania | World |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Canada | 0 | 3228 | 520 | 579 | 16 | 271 | 3015 | 72 | 183 | 247 | 49 | 507 | 38 | 445 | 0 | -136 | -2 | 51 | 1506 | -247 | 1519 | -1078 | 497 | 862 | 904 | -107 | 3989 | 250 | 17178 |
| USA & Rest of North America | 1154 | 29 | -1587 | 357 | 285 | 1178 | 206 | 26 | 223 | 376 | 4 | 1284 | 96 | -27 | -1 | 104 | 0 | 85 | 259 | -1402 | 14 | 121 | 3251 | 509 | 1933 | -512 | 857 | 0 | 8820 |
| Mexico | 37 | -949 | 0 | -340 | 14 | 171 | -42 | 1 | -1 | 75 | 3 | 37 | 3 | 363 | 1 | 29 | -1 | 3 | 134 | -4 | 94 | 6 | 128 | 25 | 16 | 8 | 2461 | 1 | 2273 |
| Central America | -20 | 847 | 1670 | -1348 | 18 | 2579 | 159 | 4193 | 43 | 19 | -7 | 321 | 72 | -111 | 0 | 125 | -2 | 20 | 72 | -49 | 235 | -76 | -39 | 344 | 396 | 8 | 377 | 29 | 9874 |
| Brazil | 8156 | -1101 | 503 | 3370 | 0 | 720 | -493 | 46 | -352 | -1122 | 766 | 21738 | 660 | 4893 | -69 | 280 | -57 | 0 | 693 | 331 | -349 | -2020 | 1252 | -3097 | 316 | -319 | -3273 | -93 | 31382 |
| Rest of South America | -837 | -2005 | -242 | -676 | -376 | -1556 | 4888 | -1837 | -186 | -167 | 160 | 12011 | 179 | 333 | 0 | 1217 | -14 | -4 | 161 | -803 | 28 | 1679 | -424 | 272 | -431 | -84 | 1484 | -48 | 12722 |
| North Africa | 30 | 210 | 20 | 4 | 32 | 26 | -919 | 1136 | -1147 | 862 | 26 | 2841 | 181 | -16 | 5 | 9 | 6 | 7 | 37 | -296 | 13853 | 3 | -52 | 48 | -12 | 17 | -1 | 47 | 16956 |
| West Africa | -85 | 114 | 14 | -8 | 28 | 7 | 114 | 234 | 43 | 101 | 0 | 171 | 21 | -60 | -2 | -174 | -3 | -3 | -36 | -9 | 0 | 32 | -14 | 267 | -152 | 18 | -60 | 5 | 559 |
| East Africa | -25 | 59 | 51 | 1 | 6 | 7 | -142 | 426 | -872 | -752 | -2 | 61 | 2 | 64 | 0 | 52 | 1 | -6 | 2 | 171 | 858 | -716 | -17 | 94 | -13 | 14 | 9 | 11 | -656 |
| Rest of Southern Africa | 0 | 16 | 28 | 0 | 2 | 6 | -34 | 471 | -151 | 70 | -57 | -36 | -2 | 6 | 1 | 6 | 5 | -1 | -14 | 665 | 51 | -46 | -7 | 42 | 74 | 36 | -1 | 6 | 1136 |
| South Africa | -18 | -23 | 42 | -1 | 9 | 16 | -4 | 603 | 2488 | 1097 | 0 | 58 | -10 | -28 | 0 | -4 | -2 | -4 | -19 | 287 | -293 | 140 | 155 | 565 | -75 | 12 | 1095 | 10 | 6096 |
| Western Europe | 6695 | 3173 | 378 | 569 | 780 | 987 | 2676 | 1980 | 3468 | 1879 | -323 | -34054 | -728 | 4976 | -56 | 608 | 420 | 147 | 3300 | 595 | 2695 | 1736 | 1094 | 2823 | 1388 | -3 | 2689 | 665 | 10556 |
| Eastern Europe | 99 | 420 | 137 | 15 | 11 | 23 | -14 | 266 | -21 | -3 | 3 | -4848 | -1085 | 274 | -89 | 1076 | 460 | 89 | 708 | 313 | 9 | -193 | 181 | 89 | 80 | 63 | 399 | 66 | -1473 |
| Rest of Western Europe | 1932 | 645 | 130 | -17 | 50 | 23 | 663 | 383 | 52 | 582 | 28 | 3333 | 123 | -70 | 3 | 233 | 3 | 17 | 142 | 2337 | 98 | 15 | -51 | 256 | 96 | 50 | -125 | 116 | 11048 |
| Rest of Central Europe | -2 | 210 | 5 | 0 | 4 | 10 | 77 | -178 | 3 | 0 | 1 | 339 | 20 | 15 | -11 | -8 | 3 | 0 | 16 | 80 | -18 | -8 | -3 | 90 | 17 | 0 | 7 | 4 | 674 |
| Turkey | 55 | 1087 | 33 | 5 | 57 | 53 | -183 | 436 | 448 | 354 | 28 | 721 | 207 | -55 | 863 | 0 | 50 | 413 | 64 | 6914 | -217 | 227 | -27 | 194 | 370 | 12 | 46 | 109 | 12263 |
| Rest of Eastern Europe | 237 | -11 | -9 | 110 | 1 | 290 | 192 | -107 | 18 | 13 | 4 | 227 | 101 | -3 | -1 | 253 | -101 | -318 | -923 | 848 | -2095 | -239 | 26 | 484 | 1056 | -3 | -18 | 5 | 36 |
| Central Asia | -9 | -5 | -2 | -1 | 1 | 1 | -3 | -25 | 15 | -2 | 0 | 17 | 13 | -4 | 0 | 16 | -4 | -322 | -20 | 11 | -21 | -75 | 0 | 3 | 37 | 0 | -11 | 2 | -386 |
| Russian Federation & the Caucasus | -8 | 93 | 7 | 19 | 5 | 32 | -1617 | -180 | -891 | 139 | 20 | 760 | 114 | 15 | 2 | 948 | -49 | -286 | -334 | 754 | 477 | 57 | -215 | 367 | 37 | 4 | -71 | 9 | 206 |
| Middle East | 194 | 201 | 0 | -5 | 23 | 24 | -468 | 1913 | 28 | 1642 | 29 | 431 | 77 | 18 | 4 | 74 | 5 | 1401 | 70 | -1439 | 159 | 209 | -75 | 0 | 369 | 6 | -5 | 41 | 4926 |
| India | 60 | 869 | 40 | 328 | 25 | 20 | 158 | 736 | 195 | 675 | 59 | 644 | 44 | 9 | 1 | 38 | 15 | 7 | 63 | 1490 | 0 | 1722 | 414 | 188 | 1639 | 334 | 72 | 57 | 9901 |
| Rest of South Asia | 0 | 55 | 3 | 3 | 1 | 5 | -32 | 120 | 99 | 79 | 11 | 241 | 8 | 7 | 1 | 154 | 6 | 39 | 54 | -24 | -295 | 275 | 135 | 6 | 503 | 20 | 7 | 18 | 1501 |
| Rest of East Asia | 323 | 2606 | 94 | 63 | 70 | 143 | 52 | 1264 | 215 | 347 | 107 | 1062 | 73 | 115 | 7 | 60 | 27 | 189 | 421 | 4098 | 815 | 576 | 19 | 3578 | 3019 | 423 | 6089 | 790 | 26642 |
| China and East Asia | -81 | 1061 | 525 | 129 | 244 | 146 | 478 | 779 | 203 | 221 | 95 | 2668 | 239 | 109 | 4 | 63 | 25 | -17 | 179 | 736 | 575 | 472 | 769 | 115 | 529 | 355 | 392 | 159 | 11171 |
| South East Asia | 196 | 2097 | 450 | -308 | -8 | 107 | 1103 | 1863 | 255 | 1000 | 52 | 2951 | 251 | -21 | 0 | 14 | 43 | 55 | -67 | 424 | 1721 | 2395 | 230 | -1398 | 3370 | 218 | 643 | 290 | 17928 |
| Indonesia & Southeast Pacific | 4 | -2 | 90 | -8 | 18 | 26 | 287 | 771 | -246 | 378 | 51 | -160 | 29 | -19 | 1 | 13 | -22 | 16 | 199 | 79 | 7726 | 1231 | 1705 | 178 | -1164 | 120 | -111 | 11 | 11199 |
| Japan | 9 | 163 | 3 | -2 | 5 | 6 | -3 | 3028 | 22 | 18 | -1 | 267 | 2 | -1 | 0 | 1 | 0 | 0 | 10 | -11 | 5 | -87 | 73 | 581 | 2 | 19 | 0 | 20 | 4131 |
| Oceania | 534 | -824 | 184 | 195 | 17 | 601 | -68 | -77 | 158 | -107 | 26 | 4433 | 82 | -33 | 1 | 329 | 0 | -12 | 131 | -794 | -177 | 610 | 1926 | 572 | -1470 | 429 | 1047 | -510 | 7201 |
| World | 18630 | 12265 | 3085 | 3032 | 1340 | 5922 | 10047 | 18341 | 4289 | 8018 | 1131 | 18026 | 811 | 11192 | 664 | 5382 | 812 | 1566 | 6809 | 15054 | 27467 | 6967 | 10931 | 8058 | 12833 | 1138 | 17985 | 2067 | 233863 |

Source: calculated from MAGNET simulation results.

**Table A.4 Regional aggregation**

| Regional aggregate | Countries |
|---|---|
| Brazil | Brazil |
| Canada | Canada |
| Central America | Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Cayman Islands, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Montserrat, Netherlands Antilles, Nicaragua, Panama, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, Turks and Caicos Islands, British Virgin Islands, American Virgin Islands |
| Central Asia | Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan |
| China and East Asia | China, Hong Kong, Macao, Mongolia, Taiwan Province of China |
| East Africa | Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Mauritius, Mayotte, Rwanda, Seychelles, Somalia, Sudan, South Sudan, Uganda |
| Eastern Europe | Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia |
| Western Europe | Åland Islands, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Guadeloupe, Ireland, Italy, Luxembourg, Malta, Martinique, Netherlands, Portugal, Réunion, Spain, Sweden, United Kingdom |
| India | India |
| Indonesia and Southeast Pacific | American Samoa, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Federated States of Micronesia, Indonesia, Nauru, New Caledonia, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Pitcairn, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, United States Minor Outlying Islands, Vanuatu, Wallis and Futuna |
| Japan | Japan |
| Rest of East Asia | Democratic People's Republic of Korea, Republic of Korea |
| Mexico | Mexico |
| Middle East | Bahrain, Islamic Republic of Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen |
| North Africa | Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, Tunisia, Western Sahara |
| Oceania | Antarctica, Australia, Bouvet Island, British Indian Ocean Territory, Christmas Island, Cocos (Keeling) Islands, French Southern Territories, Heard Island and McDonald Islands, New Zealand, Norfolk Island |
| Rest of Central Europe | Albania, Andorra, Bosnia and Herzegovina, Faroe Islands, Gibraltar, Guernsey, Holy See (Vatican City State), Isle of Man, Jersey, the former Yugoslav Republic of Macedonia, Monaco, Montenegro, San Marino, Serbia |
| Rest of Southern Africa | Angola, Botswana, the Democratic Republic of the Congo, Lesotho, Malawi, Mozambique, Namibia, Swaziland, United Republic of Tanzania, Zambia, Zimbabwe |
| Rest of South America | Argentina, Plurinational State of Bolivia, Chile, Colombia, Ecuador, Falkland Islands (Malvinas), French Guiana, Guyana, Paraguay, Peru, South Georgia and the South Sandwich Islands, Suriname, Uruguay, Bolivarian Republic of Venezuela |
| Rest of South Asia | Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka |
| Rest of Western Europe | Iceland, Liechtenstein, Norway, Svalbard and Jan Mayen, Switzerland |
| Russian Federation and the Caucasus | Armenia, Azerbaijan, Georgia, Russian Federation |
| South Africa | South Africa |
| Southeast Asia | Brunei Darussalam, Cambodia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, Viet Nam |
| Turkey | Turkey |
| Rest of Eastern Europe | Belarus, Republic of Moldova, Ukraine |
| United States of America and Rest of North America | Bermuda, Greenland, Saint Pierre and Miquelon, United States |
| West Africa | Benin, Burkina Faso, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Côte d'Ivoire, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Saint Helena, São Tomé and Principe, Senegal, Sierra Leone, Togo |

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