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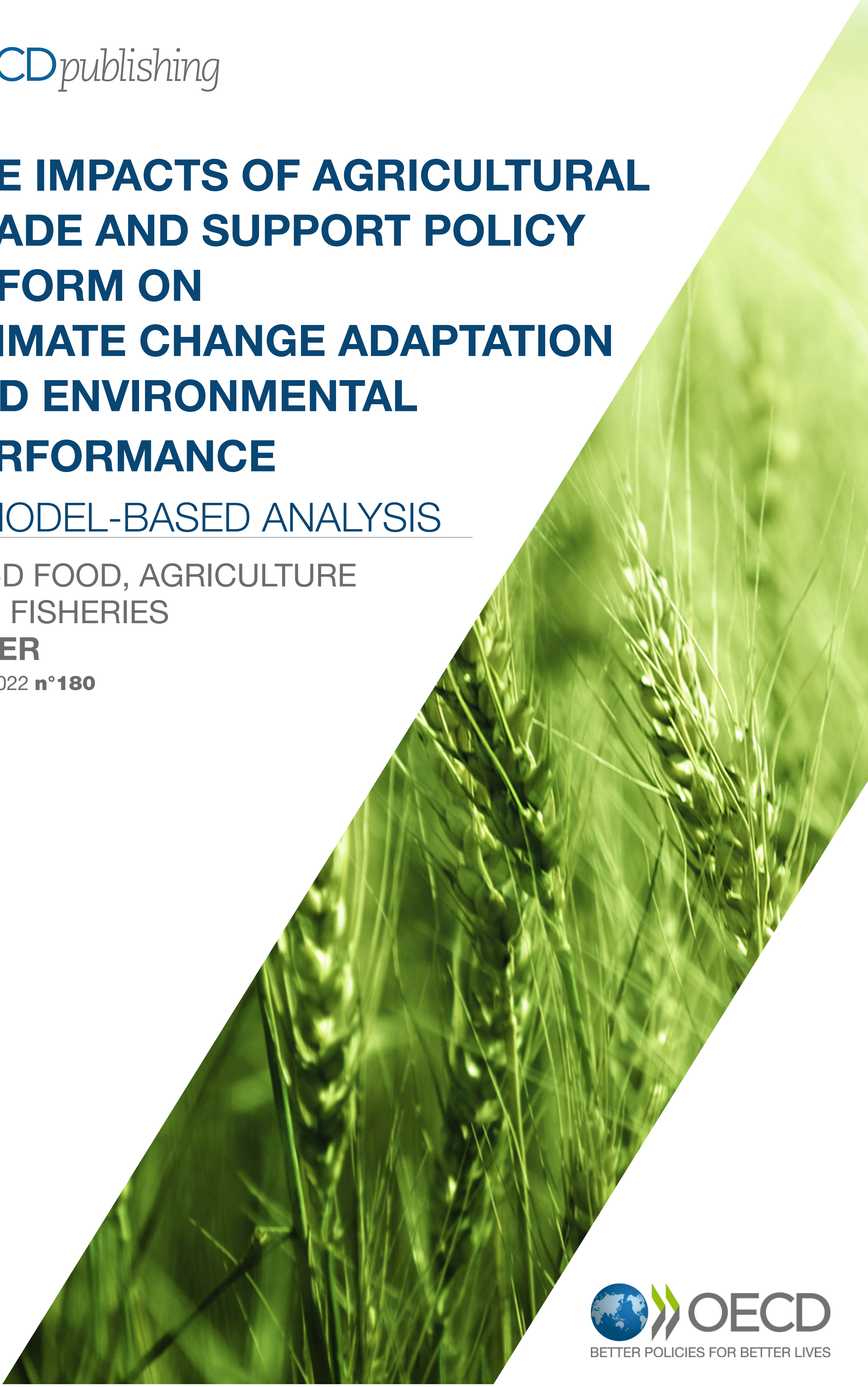
THE IMPACTS OF AGRICULTURAL TRADE AND SUPPORT POLICY REFORM ON CLIMATE CHANGE ADAPTATION AND ENVIRONMENTAL PERFORMANCE

A MODEL-BASED ANALYSIS

OECD FOOD, AGRICULTURE AND FISHERIES
PAPER

June 2022 **n°180**



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The Impacts of Agricultural Trade and Support Policy Reform on Climate Change Adaptation and Environmental Performance: A Model-Based Analysis

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This study investigates whether agricultural policy reforms could help cushion the impacts of climate change on agriculture by facilitating the relocation of production and international trade. The agricultural sector faces immense challenges in ensuring the provision of food, farm incomes, employment and environmental services in a changing climate. Its ability to meet these challenges depends, in part, on the flexibility with which agricultural production can be relocated in response to agro-ecological and market conditions being reshaped by climate change in a sustainable manner. To better understand these interactions, this study employs a quantitative model to assess the economic and environmental effects of removing market-distorting policies under climate change. The results suggest that the policy reforms could reduce the extent to which climate change increases agricultural commodity prices and undernourishment and, in that sense, contribute to global adaptation to climate change. Accompanying policy measures may however be required to prevent potential trade-offs associated with the reforms, including increases in land use emissions.

Key words: Adaptive capacity; trade policy; agricultural policy; tariffs; non-technical measures; producer support; land use change; water scarcity.

JEL codes: Q54, Q17, F18, C61, Q11, O13

Acknowledgements

The authors wish to acknowledge the valuable feedback provided by OECD delegations, which helped to improve the clarity and quality of this report. Thanks are also extended to Guillaume Gruère, Jonathan Brooks, Frank Van Tongeren, Jesús Antón, Martin von Lampe, Julia Nielson, and Marion Jansen for their constructive feedback. This report was funded by a joint voluntary contribution from Canada and New Zealand.

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Key messages

- Global economic modelling suggests that a broad package of agricultural policy reforms – in which a set of border measures and commodity-specific coupled payments are removed – could reduce the extent to which climate change can increase agricultural commodity prices and undernourishment, and in that sense could contribute to global adaptation to climate change. The reform package could achieve this by enabling production to shift to regions with a comparative advantage in production and by facilitating trade flows into regions negatively affected by climate change.
- Such reforms could also decrease global water demand from agriculture and slightly reduce the tendency of climate change to increase global greenhouse gas (GHG) emissions from the sector. The reforms would however only partly offset the adverse impacts of climate change on food security and environmental sustainability.
- The reforms themselves could generate trade-offs. The relocation of production due to the reforms could slightly increase global GHG emissions from land use change, and place additional strain on water resources in a few regions. Global average farm revenues could also fall as a consequence of the reforms. However, the reforms could stimulate an expansion in agricultural production and incomes in unsupported regions.
- Impacts of the reforms also differ, depending upon which type of agricultural support is removed. The removal of border measures, which dominates here, could decrease prices and undernourishment, but also slightly increase GHG emissions as agricultural production relocates and increases. On the other hand, removing commodity-specific coupled payments, would have the opposite effects, slightly reducing the supply of agricultural commodities and GHG emissions, and slightly raising food prices and undernourishment.
- Therefore, implementing the full package of reforms considered may require accompanying policy measures to ensure that economic gains do not come at the expense of the environment. For instance, the reform package could continue to deliver important benefits to consumers, without increasing global GHG emissions from land use change, if implemented alongside an effective ban on deforestation. Climate change adaptation and mitigation policies as well as social safety net programmes will also be needed to provide more inclusive and sustainable outcomes.
- The findings of this report illustrate some of the main interactions between support policies and climate adaptation, but modelled results are subject to their own set of assumptions and limitations. The representation of climate change impacts remains partial and does not consider the impact of temperature and precipitation extreme events, while the modelling approach focuses on a subset of stylised scenarios, sectors and support instruments, for which the chosen reference period also plays a role. The scope for further adaptation through the adoption of new technologies and practices should also be investigated in future research.

Executive Summary

The agricultural sector faces immense challenges in ensuring the provision of food, farm incomes, employment and environmental services in a changing climate. Its ability to meet these challenges depends, in part, on the flexibility with which agricultural production can be relocated in response to agro-ecological and market conditions being reshaped by climate change.

International trade plays an important role in this flexibility, by facilitating the shift of production across regions in response to climate-induced shifts in comparative advantage. With changes in climate varying among regions and over time, international trade could therefore help to cushion the impacts of climate change on global food production and consumption.

To better understand these interactions, this study employs the GLOBIOM model to quantitatively assess the economic, land use and environmental effects of removing market distorting policies under climate change, by 2050. GLOBIOM is a partial equilibrium model that represents the linkages between production, climate change impacts, and different sustainability variables at granular geographic and sectoral levels. Compared to alternative models, it allows in particular finer representation of land use changes response to climate and policy shocks, as well as related greenhouse gas (GHG) emissions.

Results from the modelling suggest that the removal of some forms of support could create benefits for food consumers across the world and could facilitate adaptation to climate change. At the same time, these reforms alone do not appear to be sufficient to reverse the adverse impacts of climate change on food security and environmental sustainability. The relocation of production due to the reforms could in addition slightly increase global GHG emissions due to land use changes. Land use conversion restrictions and climate mitigation measures are needed to reduce greenhouse gas emissions from the agriculture, forestry and other land use (AFOLU) sector. Additional climate adaptation policies will also be needed to enhance the resilience of the agricultural sector, along with social safety net programmes to ensure that the overall outcomes of the reform are inclusive.

Climate change, according to the scenarios considered, is projected to reduce crop and livestock production, increase commodity prices and undernourishment, and increase cropland and GHG emissions from the AFOLU sector. More specifically, the modelling results suggest that by 2050:

- The estimated effects of climate change on crop production could vary between -0.4% and -4.2% for crops and between -0.2% and -2.2% for livestock, depending on the severity of the climate change scenario.
- The increase in the number of undernourished people, calculated as the number of people whose food availability falls below the mean minimum dietary energy requirement, accounting for inequality of food distribution, ranges from 8 million in the mild climate change scenario, up to 112 million in the strong climate change scenario. This is caused by the tendency of climate change to raise commodity prices, which also improves revenues for many producers (mainly in the crop sector).
- Climate change could cause total GHG emissions from the AFOLU sector to change by +0.1% in the mild climate change scenario and by +0.5% in the strong climate change scenario, by inducing an expansion of agricultural land in regions with important forest and organic soil carbon stocks. By contrast, direct crop and livestock GHG emissions could decline, due to the fall in agricultural production caused by climate change.
- While agriculture water withdrawals are projected to decline, mainly due to increases in precipitation brought about by climate change in a number of irrigation dependent regions, the water exploitation index (a measure of overall pressure on freshwater resources) could increase with climate change due to lower freshwater availability.

Under the scenarios considered, global agricultural policy reforms could reduce the extent to which climate change can increase agricultural commodity prices and undernourishment, and in that sense could contribute to global adaptation to climate change. Specifically:

- The negative impact of climate change on global crop production changes from -4.2% under current policies to -4% under reformed policies in the strong climate scenario. The reforms facilitate the relocation of agricultural production from areas that are more negatively affected by climate change to others that are less affected (or even positively affected), according to the climatic model used. But these changes do not offset the overall negative effects of climate change on crop production.
- The modelled policy reforms also have the potential to reduce the extent to which climate change can increase agricultural commodity prices and undernourishment. For instance, the number of people who could become undernourished in the strong climate change scenario is lowered by -3.5 percentage points (11 million people), from 37.3% under current policies to 33.8% when all support analysed in the report is abolished. These gains in food security come from an increase in imports by food insecure areas, prompted by the removal of border measures.
- While agricultural policy reforms can potentially generate adaptation, economic and natural resources benefits, they also have the potential to slightly increase GHG emissions associated with land use change. Specifically, the full package of reforms is estimated to slightly increase GHG emissions relative to current policies (by 0.5%), with a negligible impact on climate change at the global level, triggered by the conversion of remaining forested areas to croplands and grasslands in regions that benefit from the removal of global agricultural support. That said, reforms could reduce GHG emissions growth from strong climate change by one-third, from a +0.5% increase with current policies into +0.35% increase with full reform. However, this would not offset the increased emissions caused by the reform.
- Global water demand by the sector may decrease; however, the relocation of production due to the reforms themselves could also generate trade-offs by placing additional strain on water resources in a few regions.
- Global average farm revenues could fall as a consequence of the reforms, although the reforms could stimulate an expansion in agricultural production and incomes in unsupported regions.

Impacts of the policy reforms would differ depending upon which type of agricultural support is removed. The removal of border measures could slightly increase agricultural production and GHG emissions, while decreasing farm revenues, prices, and undernourishment. GHG emission increases are in particular driven by land use changes in response to a reallocation in trade flows. This effect is typically missing in previous studies. Removing commodity-specific coupled payments would have a similar effect on farm revenues as the removal of border measures, but opposite impacts on market responses, with a decrease in production and GHG emissions, and an increase in prices and undernourishment.

Additional scenarios suggest that the full package of reforms could deliver similar benefits to consumers without increasing GHG emissions from land use change, if the reforms were implemented in a context where deforestation was prohibited effectively.

GLOBIOM has strong advantages for the forward-looking analysis of climate change impacts, as presented in this report. As with any model, it also has limitations. As a partial equilibrium model, it only focuses on land use and water sectors and excludes linkages with the rest of the economy. Furthermore, since consumers and producers are treated as separate agents, changes in farm income do not endogenously influence demand for agricultural commodities. Consequently, the potential changes in food security related to possible increases or decreases in farm income are not captured in this model framework.

Other limitations of the study include the partial and stylised representation of both climate change impacts and policy reforms. Climate change impacts are based on the best available data from crop production and global circulation models. However, this report only considers average gradual impacts of climate change, and disregards impacts from extreme climatic events that could be large for specific years, and could have long lasting effects. The options considered to adapt to climate change are based on adjustments to mix of production systems available locally. A larger set of adaptation technologies and practices could also be considered to provide a more complete assessment. The policy reform scenarios are also stylised and limited to a subset of instruments. For the removal of border measures, the analysis focuses on the role of import tariffs (including tariff rate quotas) and export taxes, while the inclusion of non-tariff measures is relatively simplified. More importantly, budgetary support measures focus on coupled payments linked to specific commodities. This includes output payments and a part of area-based payments coupled to production, irrespective of their implementation modalities. Input subsidies, which affect groups of commodities, are not considered here, due to the difficulty of allocating them across sectors. Finally, further analysis could be undertaken to disentangle structural support from more exceptional payments over the period of analysis. Consideration of longer historical periods for the analysis of agricultural support, and a higher level of granularity in the data used for the modelling would provide additional insights about the impacts of the reforms.

1. Introduction

Agriculture is highly vulnerable to climate change, due to its direct reliance on biophysical conditions that are being reshaped by climate change (IPCC, 2019[1]). The degree to which agriculture may be affected by climate change is dependent on the spatial and temporal distribution of climate impacts, as well as countries' mix of production systems, agro-ecological conditions, potential for adaptation, and policy settings (Rosenzweig and Parry, 1994[2]; Parry, Rosenzweig and Livermore, 2005[3]; OECD, 2015[4]; Ignaciuk and Mason-D'Croz, 2014[5]). For example, variations in water availability are expected to make agriculture in some world regions, such as northeast People's Republic of China (hereafter "China"), India and southwest United States, particularly vulnerable to climate change (OECD, 2017[6]). Temperature and precipitation changes from global warming are projected to be spatially heterogeneous, with areas near the Arctic experiencing the highest temperature increases and mid-latitude and subtropical dry regions experiencing precipitation reductions (IPCC, 2014[7]). These differentiated effects will modify regions' comparative advantage in the production of agricultural commodities (Dellink et al., 2017[8]) and hence their land use patterns, with some regions increasing agricultural intensification, others expanding their cropland area, and some abandoning production altogether (Riahi et al., 2017[9]; Nelson et al., 2014[10]; Schmitz et al., 2014[11]).

According to IPCC (2018[12]), adaptation is defined as "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities." Thus, adaptation options are defined as "the array of strategies and measures that are available and appropriate for addressing adaptation" (IPCC, 2018[12]). Hence, the purpose of adaptation options is to alleviate the damage or enhance the opportunities created by climate change.

Given their role in influencing production choices, agricultural policies will affect the capacity of the sector to adapt to climate change. For instance, these policies could play a fundamental role in determining the way in which agricultural activities will relocate both within and between countries, as well as the magnitude of intensification responses and land use changes resulting from climate change. This will have economic implications for both producers and consumers and may bring additional challenges for the sustainability of the agricultural sector and its contribution to GHG emissions and other environmental impacts.

This report uses GLOBIOM, a partial equilibrium model, to estimate the effects of climate change, agricultural policy reform and adaptation. To do so, the report considers four settings: (1) Current policies without climate change (CPnCC), (2) Current policies under climate change (CPCC), (3) Reformed policies without climate change (RFnCC) and (4) Reformed policies under climate change (RFCC). Table 1.1 displays the matrix of policy-climate scenarios presented in this report:

- *The effects of climate change, without any reform*, are given by the difference in current policies under climate change and current policies without climate change: CPCC-CPnCC.
- *The effects of reforms, without climate change*, are obtained by deducting the effects of current policies under no climate change effects from those of reformed policies under no climate change: RFnCC-CPnCC.
- *The effects of reform under climate change* are obtained by subtracting the effects of current policies under climate change from those resulting from reform under climate change: (RFCC-CPCC).
- *The adaptation effects* are given by the difference between climate change impacts under reformed policies and the climate change impacts under current policies: (RFCC-RFnCC)-(CPCC-CPnCC). This is mathematically equivalent to comparing the effects of reforms with and without climate change: (RFCC-CPCC)-(RFnCC-CPnCC). The report uses this later approach since it has the advantage of assessing the effects of reforms across different climate scenarios.

Table 1.1. Climate and policy scenarios matrix

Climate change/Policy settings	Current policies (CP)	Reformed policies (RF)
No climate change (nCC)	CPnCC (Baseline)	RFnCC
Climate change (CC)	CPCC	RFCC

In order to assess the environmental and economic effects of climate change and the potential role of agricultural policy reform on adaptation, the report is organised in three sequential steps. First, it simulates and discusses the potential economic, land use and environmental impacts of climate change on agriculture (effect 1 in the above list). Second, the report assesses the economic, land use and environmental impacts of removing particular forms of support in agriculture, not accounting for climate change impacts (effect 2). Lastly, based on the two previous steps, the report evaluates the adaptation potential of different policy regimes that remove policy support measures (effect 4) by discussing their two main components: the effects of reform under climate change (effect 3) and the effects of reform without climate change (effect 2).

The policy measures considered in this report include the elimination of all border measures including tariffs, quotas, tariff rate quotas (TRQs), a portion of the trade cost of technical non-tariff measures (NTMs),[1] all export taxes, as well as coupled payments to farmers linked to specific commodities (rice, wheat, maize, soybeans, barley, sorghum, rapeseed, sunflower, palm, sugar, milk, beef and veal, pig meat, eggs, poultry meat and sheep meat). These reform scenarios are not intended to be realistic,[2] instead, their purpose is to illustrate the trade-offs that may arise from removing different types of market distortions. To represent the impacts of more plausible reforms, a set of less ambitious scenarios is also modelled where border measures and coupled payments are partially reduced. Finally, a scenario that implements full reform in a context were deforestation is banned is also analysed.

The results of this modelling exercise need to be interpreted with care, given the model specifications and assumptions. There are three main limitations with respect to the representation of the impacts of climate change in this report. The first is that the impacts from extreme climatic events, such as droughts and floods, are not considered. Second, the impacts of climate change on livestock production are only incorporated via their impact on feed production. Third, being a partial equilibrium model, the supply of some production inputs (e.g. labour, fertiliser and others) is unaffected by climate change; if considered, those effects could increase the negative effects of climate change projected in this report.

The report is organised as follows. The following two subsections discuss the expected economic impacts from removing different support measures and results from the literature. Section 2 describes the modelling approach, policy, baseline and climate change scenarios. Section 3 presents the effects of climate change under current policies. Section 4 discusses the potential economic and environmental effects of policy reform, excluding climate change effects. Section 5 evaluates the adaptation potential to climate change of different policy setups. Finally, Section 6 offers conclusions and ideas to continue and improve this work.

[1] Technical non-tariff measures are requirements related to health and environmental protection, as well as processes followed in exporting countries prior to shipment. Non-tariff measures can increase trade costs but also boost demand as consumers have certainty that products that meet those requirements have lower health and environmental risks. Hence, when modelling the effects of removing trade costs associated with NTMs it is common practice to only partially eliminate those costs as fully removing them would also imply fully removing the demand-enhancing effects of NTMs (Cadot, Gourdon and van Tongeren, 2018[17]).

[2] In particular, substantial reforms are usually underpinned by structural transformations such as transitioning from rural to urban economies (Anderson, Rausser and Swinnen, 2013[80]).

1.1. Expected effects of removing market distorting measures

Over 60% of the transfers provided to the agricultural sector are provided through market distorting instruments, particularly market price support and subsidies linked to output or the unconstrained use of variable inputs (OECD, 2021[13]). Market price support comes from policy measures such as import border measures (import tariffs, export taxes) and minimum prices that create a wedge between domestic market prices and border prices (OECD, 2016[14]).

These instruments can potentially have different impacts on agricultural production, both at the country and global levels.[3] A tariff on a specific commodity increases its domestic price, incentivising domestic production. Removing that tariff lowers domestic production but the impact on international markets is ambiguous and depends, among other things, on the net importing position of that country (Laborde et al., 2021[15]) and on the elasticities of excess demand and supply.[4] Table 1.2 illustrates some of the potential impacts of removing tariffs in a country whose market is large enough to influence international prices. If the imposing country is a net importing country and the domestic demand elasticity is high (implying a high excess demand), global production will increase because the fall in domestic supply caused by the tariff removal is more than offset by imports, but if the demand elasticity in the imposing country is low, there will be a small impact on global production.

Table 1.2. Potential impacts of removing tariffs on global production

	Demand elasticity	
Trade position	High	Low
Net importing	High increase in global production: domestic price declines and production in importing country drops and demand for imports grows at higher rate than the drop in domestic supply	Small increase in global production: production in importing country drops and imports increase by a little more than the production decline.
Net exporting	No change in global production: drop in domestic production and potential replacement of domestic production by imports	No change in global production: small drop in domestic production and potential replacement of domestic production by imports

The impact on GHG emissions of removing tariffs will depend on different factors, such as the emission intensity differences between domestic and export markets, the commodities that are subject to tariff removal and the overall impact on global production. In general, if domestic supply is replaced by imports from countries with high emission intensities, GHG emissions would increase when tariffs are removed in net importing countries. When the imposing country is a net exporter, global production will not change significantly, independently of the elasticity of demand. However, if the elasticity of demand is high, there could be significant relocation effects, as domestic production could be partly replaced by imports. Undernourishment will tend to decrease when tariffs are removed due to lower prices.

An export tax has the opposite effect on market price support than a tariff, as it depresses the domestic price relative to the international market. The impact of removing the export tax will also depend on the trade position of the imposing country. If the imposing country is a net exporter, removing the export tax will have a boosting effect on that country's agricultural production and, hence, on global production. If the imposing country is net importing, the removal of the export tax will have no impact on domestic or global markets. The impact on GHG emissions will depend on the emission intensity profile of the country that removes the export tax, while the impacts on undernourishment will depend on the effects of removing the export tax on prices. Overall, since production increases and prices tend to decrease as a result of eliminating export taxes, GHG emissions may also increase and undernourishment may decrease.

Policies other than import and export taxes can drive a wedge between domestic and international prices. Notably, non-tariff measures (NTMs), defined as "policy measures, other than ordinary custom tariffs, that

[3] Other support instruments like payments decoupled from production, payments based on non-commodity criteria or those directed at general services can also have impacts on production but they are not considered in this analysis as the focus of this analysis is on the effects of removing most distorting forms of support.

[4] Other important factors are the cross elasticities of demand, which are omitted in this discussion to facilitate the analysis.

can potentially have an economic effect on international trade in goods, changing quantities traded, or prices or both" (UNCTAD, 2019[16]) not only impose trade costs but also can have demand-enhancing impacts by reducing market imperfections such as information asymmetries (Cadot, Gourdon and van Tongeren, 2018[17]). This means that it is not efficient to completely remove them but rather to find the instruments that can achieve the regulatory objective at the lowest trade cost.

In the modelling setup used in this report, removing the trade costs associated with NTMs is equivalent to that of removing a tariff. While there are different methodologies for assessing the trade costs associated with NTMs, the literature on assessing their demand-enhancing potential is scant. A common approach to estimating the trade costs associated with NTMs is to estimate their ad valorem equivalents (AVEs). The AVE of an NTM is the proportional rise in the domestic price of the goods to which it is applied, relative to a counterfactual where it is not applied, which is equivalent to imposing an import tariff.

The impacts of removing budgetary support policies will depend on the total support to producers, the type of support and the rates of support across commodities (Laborde et al., 2021[15]). Focusing on most distorting forms of budgetary support, three main instruments stand out: payments based on output, payments based on current area planted or animal numbers with production of specific commodity required, and payments based on variable inputs use without input constraints (OECD, 2021[13]). Payments based on output are highly distortive, considering they directly incentivise production. Payments based on variable inputs (fuel, water, fertiliser, pesticide) are also considered to be highly distortive, because they directly incentive greater use of these inputs or and decrease production costs. Furthermore, payments based on current area planted or on animal numbers, with production of specific commodity required, are usually considered to be coupled to production. Reducing coupled payments typically decreases production in the supported commodities at the global level. That said, at the regional level, there could be regions where production can expand as they become more competitive (Dellink et al., 2017[8]). While global production declines, GHG emissions will generally decrease, but they could also increase if those areas where offsetting production increases have high GHG emission intensities.

1.2. Results from previous literature

As discussed, the overall international impacts of removing distorting policies is an empirical question as some of those policies may have opposing effects on production at the regional and global level. The environmental impacts of removing those policies is also influenced by the impact of these policies on regional and global production which may differ by commodities and regions. An additional source of uncertainty is the model type, approach and the assumptions used to respond these questions. This section reviews some of the model-based key publications on the subject; a summary of their findings is shown in Table 1.3.

Previous work on the impacts of removing distorting support has focused on analysing the market impacts of policy reform, on their associated environmental effects and on the capacity for climate change adaptation. Two significant reports examine the effects of policy reform. Laborde et al. (2021[15]) model the impacts of removing coupled support and border measures on agricultural production, income and GHG emissions. They find that removing border measures has a small impact on agricultural production (-0.1%) and removing coupled support causes agricultural production to decline by -1%. Removing both has an almost additive impact, causing global agricultural production to decline by -1.1%. GHG emissions increase by 2% with the removal of border measures due to strong relocation effects from low emission intensities regions to high emission intensities areas. Removing domestic support induces an overall decline in GHG emissions of -0.6% due to reductions in crop and livestock production. OECD (2016[18]) estimates the impacts of different policy reform scenarios on economic outcomes and finds that removing both border measures and distorting payments to farmers has a small impact on agricultural production (-0.1%)[5] and increases the combined production of all sectors (agriculture and non-agriculture), labour income and total demand.

[5] OECD (2016[18]) finds significant changes in regional production with regions with low levels of protection such as Australia and New Zealand experiencing increases by more than 5% in their agriculture production due to the removal of support and regions with high levels of support such as Japan decreasing their production by more than 10%.

Springman and Freund (2022[19]) model the potential effects of repurposing agricultural subsidies on production, consumption, economic welfare, GHG emissions and health outcomes. According to their findings, removing all farmers' support would reduce the global production of fruits, vegetables and grains due to a production decline in subsidising regions. In particular, production of those commodities could decline between -1.1% and -2.8% in OECD countries, between -0.8% and -1.2% in non-OECD countries and increase by +0.6% in non-subsidised regions. GHG emissions would decline in OECD countries by -1.8% and global consumption would decline but diet-related mortality would increase. Repurposing those subsidies towards the production of healthy foods with lower GHG emission intensities could increase horticultural products, reduce GHG emissions and reduce diet-related mortality.

In a similar vein, Gautam et al. (2022[20]) examine the effects of removing market price support and budgetary support based on output and on the unconstrained use of variable inputs; as well as the potential impacts of repurposing agriculture support. Their findings show that eliminating budgetary support would reduce crop production by -1.3% and livestock production by -0.5%, while AFOLU GHG emissions would decrease by -1.5%. Different repurposing scenarios show contrasting effects on production, poverty and AFOLU GHG emissions. In this study, it appears possible to simultaneously reduce GHG emissions and poverty and increase production, by redirecting budgetary support towards the development and adoption of green technologies that can both increase productivity and reduce emissions.

Verburg et al. (2009[21]) model the impacts of trade liberalisation on AFOLU GHG emissions and find that removing trade barriers increases GHG emissions by 6% relative to the reference scenario of current policies, mainly due to the conversion of remaining vegetation areas to agricultural land in South America and Southeast Asia. Beckman et al. (2017[22]) simulate the effects on deforestation from removing tariffs on forest-risk products and find that removing tariffs on those products induces a loss on remaining global forest land due to major losses in South America and Southeast Asia.

The potential role of trade in helping agriculture adapt to climate change has been examined since the early 1990s, mainly in response to earlier work on the impacts of climate change that focused on one country or region and neglected trade flows (Adams et al., 1990[23]). By factoring trade into the analysis and expanding the geographic scope of study, these analyses found that with climate change: 1) overall agricultural production in developing countries is likely to decline, whereas that in developed countries is likely to increase (Rosenzweig and Parry, 1994[2]); 2) under full trade liberalisation, welfare losses from large potential reductions in yields in some regions of the world are estimated to be smaller than without trade liberalisation (Parry, Rosenzweig and Livermore, 2005[3]); and 3) distortionary agricultural support policies weaken the potential of the trading system to facilitate the relocation of food production according to changing comparative advantage (Tsigas, Frisvold and Kuhn, 1997[24]; OECD, 2021[13]; Randhir and Hertel, 2000[25]).

Compared to previous efforts, more recent work on the adaptation effects of trade policies tends to model climate change impacts with greater geographical precision and includes land use changes not only between countries, but also within countries. While international trade has been recognised as a fundamental adaptation mechanism for climate change and agricultural water risks (OECD, 2017[6]), more recent studies tend to diverge in terms of the degree to which trade helps to alleviate the impacts of climate change on agriculture. These differences are most likely due to the modelling approach chosen (e.g. general vs. partial equilibrium), the policies simulated and the underlying data used to represent them, the assumptions and degree of detail used to represent the agriculture sector and, in the cases of climate change studies, the global climatic models and agronomic models used to simulate climatic shocks.

Randhir and Hertel (2000[25]) examine the welfare effects of removing trade and production distorting policies and of improving price transmission in international markets. The role of price transmission reflects the process of converting non-tariff measures to tariff measures as required by the Uruguay Round Agreement on Agriculture and are modelled by modifying the elasticities of substitution. Distorting policies consider border measures, output and export subsidies. They find that facilitating price transmission without removing distorting policies can have negative impacts on welfare. Removing distorting policies further supports adaptation of the agricultural sector to climate change, by helping relocation of food production to least affected regions.

Baldos and Hertel (2015[26]) find that fully integrated markets (absence of market barriers) can attenuate the effects of climate change on undernutrition rates, particularly in Sub Saharan Africa and South Asia. Cui et al. (2018[27]) find that removing all border taxes on agricultural and food products has beneficial impacts under climate change. In particular, they find that the negative impacts of climate change in a world without border taxes are smaller for food production, GDP, agricultural wages and calorie intake. GHG emissions also grow at a lower rate; however, they also find higher levels of GHG emissions from reforming policies. Gouel and Laborde (2018[28]) find that both improved price transmission (increasing the Armington elasticity) and fully integrated markets have a welfare improving effect and reduce the negative welfare impacts of climate change.

Other, related literature has also explored the role of trade on market and environmental performance under climate change, but not by directly estimating the impacts of reforming agricultural policies. Nelson et al. (2009[29]) indicate that trade will not be sufficient to compensate for the decline in yields of certain crops in developing regions, nor to prevent food insecurity and loss of welfare in poor and vulnerable areas of the globe. Costinot, Donaldson and Smith (2016[30]) use a general equilibrium model combined with gridded data on crop production, to show that production relocation within countries is more relevant than unrestricted trade for helping the agricultural sector adapt to climate change.

The sustainability implications of agricultural trade policies in the context of climate change have only recently been analysed. Liu et al. (2014[31]) find that a third of welfare losses attributed to trade restrictions are due to less efficient water and non-water resource allocations, but no specific effort is made in that study to understand the impacts on water resources. Beckman et al. (2017[22]) estimates that the global removal of tariffs on products linked to deforestation, such as oilseeds and beef, can lead to a reduction in forest area in South America, Indonesia and Malaysia. With forest area converted to pasture for beef production in South America and to oil palm plantations in Indonesia and Malaysia. Hanna et al. (2020[32]) project that adaptation to climate change through the expansion of the agriculture frontier to suitable areas for crop production may have large negative environmental impacts on water availability, biodiversity and soil organic carbon.

Table 1.3. Impacts of removing distorting policies in agriculture

Study	Focus	Total production	Farm income	Agricultural production	Trade flows	Environmental performance	Other variables	Climate change scenarios	Land use change
Springmann and Freund (2022)	Removal of budgetary support	+Economic welfare		-1.1% to -2.8% reduction of fruits, vegetables and grains in OECD countries, -0.8% to-1.2% in non-OECD countries and +0.6% in non-subsidised regions		−1.8% GHG emissions in OECD, −0.1% in non-OECD, +0.5% in non-subsidising countries	-11kcal/day to -21kcal/day energy intake +75K deaths	NA	NA
Gautam et al. (2022)	Removal of budgetary support	+0.05% real national income	-4.5%	-1.3% crop production, -0.5% livestock production		-1.5% GHG AFOLU emissions	+1.8% healthy food prices +0.01% poverty	NA	-0.05% of agricultural area
	Removal of budgetary support and market price support			-1.2% crop production, -0.35% livestock production		-0.55% AFOLU emissions			

Study	Focus	Total production	Farm income	Agricultural production	Trade flows	Environmental performance	Other variables	Climate change scenarios	Land use change
Laborde et al. (2021)	Removal of border measures	+0.3% total income	0.90%	-0.10%	NA	+2.10% GHG emissions	NA	NA	NA
	Removal of coupled support			-1%	NA	-0.60%	NA	NA	NA
	Removal of border measures and coupled support			-1.10%	NA	+1.70%	NA	NA	NA
OECD (2016)	Removal of border measures and coupled support	Increases total production		-0.10%	+5.30%	NA	Increases labour income and total demand	NA	NA
Randir and Hertel (2000)	Removal of border measures and coupled support under climate change	Increase in welfare	NA	NA	NA	NA	NA	Multiple GCMs and warming scenarios	NA
Cui et al. (2018)	Removal of border measures under climate change	+0.01 p.p. GDP	Increase in ag, wages	+0.03 p.p. food production	+12 of ag and food	-0.04 p.p. GHG emissions	Increases in calorie intake, labour an ag. wages	RCP6 scenario	Reduced ag land use
Gouel and Laborde (2018)	Full market integration under climate change	+1.15 p.p. global welfare						GAEZ A1F1 scenarios	Full market integration
Baldos and Hertel (2015)	Full market integration under climate change	NA	NA	NA	NA	NA	Reduction in the number of malnourished people in Sub Saharan Africa and South Asia	Multiple GCM for RCP8.5 scenario	NA

2. Model and scenarios

This section provides details about the modelling approach and scenario set-up used in this analysis. As highlighted in the above literature review, past analyses have relied alternatively on general and partial equilibrium modelling to study the relation of trade and climate change adaptation. General equilibrium models are usually appreciated for the comprehensiveness of their economic relations coverage, whereas partial equilibrium are capable of addressing more complex interactions within sectors, requiring more refined representation of production, market and environmental characteristics. For the present work, a partial equilibrium modelling framework is chosen, motivated by the need to represent climate change impacts in a spatially explicit framework (grid cells level) and by the ambition to include a large set of sustainability indicators, particularly on land use changes and water demand impacts, at a relatively high level of sectoral detail.

2.1. GLOBIOM, a partial equilibrium model

The analysis in this study is based on the Global Biosphere Management Model (GLOBIOM), developed at the International Institute for Applied Systems Analysis (IIASA).[6] GLOBIOM is partial equilibrium and recursive dynamic model, which has been designed to examine long-term trajectories of the agriculture and land use system. The model is run with 10-year time steps until 2050 with the following characteristics suitable for this work: (1) it covers all of the main land use sectors – agriculture (crop and livestock production), forestry and bioenergy; (2) the model supply functions are highly spatially disaggregated (in grid cells of 2x2 degrees), with different production systems (subsistence farming, low input rain fed, high input rain fed, and high input irrigated), which allows the use of spatially explicit climate change impact data to model crop productivity and management responses, and consideration of intraregional adaptation possibilities; (3) the model features a large number of crop and livestock activities, including 18 crops representing more than 70% of global harvested area, 7 meat and dairy primary products and two main processed wood products;[7] (4) the model features detailed GHG emissions (spatially and by source), including land use change emissions; (5) it incorporates water demand for irrigation and water availability variables, and can integrate the impact of climate change on the water cycle, as well as competition with other sectors for the water resource, through coupling with a hydrological model; (6) it represents bilateral trade flows in quantity terms, with a spatial equilibrium approach (Takayama and Judge, 1964[33]), which allow a high level of precision in the modelling of trade policies; and (7) production costs and farm gate prices are all expressed in absolute terms, which allows a consistent implementation of the domestic support information (IIASA, 2018[34]; Valin et al., 2013[35]). See Annex A for more detailed information on the crops, livestock and GHG accounting modelling approaches used in GLOBIOM.

Due to its capabilities, GLOBIOM has several advantages for the forward-looking analysis presented in this report, but it also has some limitations in comparison with CGE approaches. First, the model only considers the land use sectors and ignores the linkages with other parts of the economy. This could have implications, for instance, when modelling climate mitigation policies to reflect the impact of increased energy prices on agricultural inputs. Additionally, some other channels of impacts may be ignored such as the increased cost of transportation in regions exposed to more frequent flooding or electricity price increases due to climate shocks. A second limitation is the incomplete representation of factor markets and the absence of revenue cycling between farm income and food consumption. In the partial equilibrium representation, consumers and producers are represented as agents with separate objectives. This differs from a CGE approach where the emphasis is put on final agents' utility, taking into account household consumption, which is also influenced by farm revenues in rural areas.

In spite of these limitations, the partial equilibrium approach is well suited for this analysis due to its detailed representation and focus on the agriculture sector and its multiple sustainability dimensions. GLOBIOM is frequently used by researchers and modellers to analyse climate change scenarios for agriculture and its capabilities have been widely proved in cross-model comparisons (Schmitz et al., 2014[11]; Valin et al., 2014[36]; Nelson et al., 2014[37]; von Lampe et al., 2014[38]; van Meijl et al., 2018[39]). Additionally, GLOBIOM

[6] IIASA's team was selected to collaborate on this project from a pool of four modelling teams from internationally recognised institutions, following a competitive tender process.

[7] Crops covered include: rice, wheat, corn, soybean, barley, sorghum, millet, cotton, rapeseed, sunflower, groundnuts, palm, sugar cane, potatoes, sweet potatoes, cassava, chick peas, and dry beans. Livestock products include: dairy and other bovines, dairy and other sheep and goats, pigs, laying hens and broilers. Traded transformed products attached to these crop and livestock primary products (e.g. vegetable oils and meals, refined sugar, flour, or cheese), are accounted for in the supply utilisation accounts of the model, after conversion into primary crop and livestock equivalent. This version of the model does not feature a separate food transformation sector.

has been recently used in trade applications for estimating the role of trade in climate change adaptation and undernourishment[8] (Janssens et al., 2020[40]).

2.2. Trade and agriculture policy modelling assumptions

The model results of this analysis significantly depend on the data used, the assumptions, model calibration approach and parameterisation. For the representation of trade, GLOBIOM follows a spatial equilibrium approach and features each bilateral trade flow as a net quantity flow expressed in primary equivalent. The price for each imported commodity from region r to region s is expressed as follows:

$$P_s = P_r + \tau^{X}_{,r} + TC_{r,s}(x_{r,s}) + \tau^{M}_{r,s} + \tau^{NTM}_{r,s} + c_{r,s} \qquad \text{(Eq. 1)}$$

where P_r and P_s are domestic market prices for the regions r and s, respectively,

$\tau^{M}_{r,s}$ is the bilateral tariff applied by region s on exporter r,

$\tau^{X}_{,r}$ is the export tax applied by exporter r,

$\tau^{NTM}_{r,s}$ is the NTM equivalent trade cost,

$TC_{r,s}$ $(x_{r,s})$ is a variable transportation cost. It is composed of a fixed term, and a non-linear variable cost increasing with the quantity traded $x_{r,s}$ and defined by a trade cost elasticity,

$c_{r,s}$ is a calibration constant specific to each bilateral relation.

The *trade calibration process* of the model determines the values of $c_{r,s}$, P_r and P_s that minimise the deviation to currently observed bilateral trade flows and regional prices, keeping as constraints net trade flows of each region, as well as the trade costs structure – see conceptual approach in Jansson and Heckelei (2009[41]). The non-linear elements of the transportation cost function ensures smooth adjustments of trade according to the elasticity values, to the difference of a fully linear spatial equilibrium approach for which the number of trade flows are minimized in the optimal solution. Trade data are critical for the calibration process. The net trade of each region is based on FAOSTAT data for each GLOBIOM sector, after conversion of the product trade flows into raw primary equivalent. Net trade is then distributed across bilateral trade flows based on information from the harmonised trade database BACI (Gaulier and Zignago, 2010[42]).

Production functions in the model are constructed to represent explicit technologies associated with their inputs and production costs, and each management system in a given grid-cell is defined by its own Leontieff structure. The production function at the regional level is the result of the combination of these elementary production levels, defined per unit of land or animal head. Substitution among these spatially-referenced production units can occur and thereby affect overall production, depending on their relative profitability, which is also affected by climate change and policies. To represent a change in domestic support, payments are expressed as support per unit of land or animal head and are added within the Leontieff function of each production unit. The change in the mix of management systems in response to climate shocks or policy changes underpins the different variations in final yield and input mix, as well as the intraregional reallocation of production.

Considering this analysis explores the impact of removing border measures and coupled payments linked to specific commodities, information on the level of trade protection and agricultural support is essential. The report includes the following policy measures:

- *Tariff*: data on tariffs and TRQs come from the Market Access Map (MAcMap) database at the HS6 digit level (Guimbard et al., 2012[43]). The data used corresponds to an extraction of the tariff data for the year 2010, which is the most recent time-step for which these data were compiled in

[8] In this report, undernourishment is the number of people whose food availability falls below a mean minimum dietary energy requirement. Four parameters were used to measure undernourishment: a minimum dietary energy requirement, the coefficient of variation of the distribution within a country, the mean food availability in the country and total population (Janssens et al., 2020[40]).

GLOBIOM.[9] The choice of using tariffs instead of market price support (MPS) data from the OECD PSE database is justified by the possibility of differentiating the level of protection depending on the importer and by the global coverage of tariff data. Due to this difference in commodity representation and the specificities of the spatial equilibrium approach of GLOBIOM, calibrated prices used in the model differ from the reference prices used for MPS estimation in the PSE database and, therefore, the representation of protection may not be strictly equivalent between the two frameworks. A table is provided in Annex B showing the level of protection associated to the tariff data, using the MAcMap unit values as references. GLOBIOM then implements the tariff information in the model as specific-equivalent (cost per unit traded), using its calibrated prices.

- *Export taxes*: these are obtained from the Export Restrictions in Agriculture Database (Estrades, Flores and Lezama, 2017[44]) for the most recent period of available comparable data, 2013-15. Export taxes are applied to the domestic price of the exporting country as in equation 1, so that a reduction in the level of export taxes has similar effects as a tariff reduction in the importing country.
- *Technical NTMs*: Non-tariff measures are divided into technical and non-technical measures. For this analysis, only technical NTMs are included in the trade cost structure; they were obtained from the authors of Cadot, Gourdon and van Tongeren (2018[17]) for the year 2018. Technical NTMs are defined as regulations related to health and environmental protection, as well as processes followed in exporting countries prior to shipment (inspections, controls, etc.) (UNCTAD TRAINS, 2018[45]). They are classified as sanitary and phytosanitary measures (SPS), technical barriers to trade (TBT) and pre-shipment inspections and other formalities. SPS are measures that prohibit or limit the use of specific substances, impose hygienic requirements or any other measure that prevents disease dissemination (UNCTAD TRAINS, 2018[45]). TBT are measures such as inspection, testing, certification and labelling (UNCTAD TRAINS, 2018[45]). Pre-shipment inspections and other formalities are measures performed in the exporting country prior to shipment; these include inspections and other processes (UNCTAD TRAINS, 2018[45]). Non-technical measures include quantity control measures (e.g. licensing, quotas), price control measures (e.g. minimum import prices), finance requirements,[10] distribution restrictions, government procurement restrictions, measures affecting competition, rules of origin, subsidies and contingent trade-protective measures, such as anti-dumping duties (UNCTAD, 2019[16]).
- *Trade cost NTMs estimates* from Cadot et al. (2018[17]) are estimated at the commodity level using an Ordinary Least Square regression of Cost Insurance and Freight (CIF) unit values on a set of gravity variables (distance, contiguity, common language and Regional Trade Agreement dummies), a vector of number of NTMs from importing country by type and commodity, an interaction variable of the number of NTMs with the exporter's share in world trade of each commodity and an interaction variable of the number of NTMs with the importer's share in world trade of each commodity. The estimation was done for 5 000 products in 80 countries. Estimates obtained for individual products and countries were used as an input to generate trade costs associated with NTMs at the sector level in Cadot et al. (2018[17]). This report uses AVEs estimates at the commodity-country to construct sectoral trade costs in Cadot et al. (2018[17]), which can be imprecise and are rough proxies for trade costs associated with NTMs at that level of detail. Hence, the modelling trade costs associated with NTMs should be seen here as a coarse attempt to evaluate their impacts. The use of more consistent and precise estimates of AVE's NTMs should be considered in future research.

[9] More recent tariff datasets have been released since then but not incorporated in the model. Data comparison between 2010 and most recent years shows that the patterns of protection have remained relatively unchanged across regions and sectors. At the OECD level, the rate of protection has been relatively stable for the past 10 years, except for a few regions, such as Turkey where market price support significantly decreased over that period. For OECD countries as a whole, the nominal protection rate decreased from 1.11 in 2010 to 1.09 in 2020.

[10] According to UNCTAD (2019[16]), financial measures are those measures "that are intended to regulate the access to and cost of foreign exchange for imports and define the terms of payment".

- *Domestic support*: The model also implements coupled domestic support as a fixed subsidy per area cultivated or per animal entering the production function cost structure. Such payments affect the level of production in the country and, in turn, also affect market prices. Data on coupled payments were obtained from the Producer Single Commodity Transfers (PSCT) for the commodities studied in this report, excluding market price support, of the OECD Producer Support Estimate (PSE) database (OECD, 2020[46]). The PSCT is the annual monetary value of gross transfers from consumers and taxpayers to agricultural producers, measured at the farm gate level, arising from policies linked to the production of a single commodity (OECD, 2016[14]). The period 2017-2019 is used as a reference for this information.[11] PSCT categories in the model include payments based on output, based on input use and payments based on area (categories A2, B and C in PSE nomenclature). Other distorting forms of support also exist, such as payments based on variable input use or payments based on area requiring production and targeting multiple commodities. As these cannot be linked to a specific commodity, they are not included in this paper's framework, which means only a part of the coupled domestic support is considered in the analysis (Box 1).

Box 1. Domestic support coverage and implications for the results

According to OECD (2021[13]), in the most recent years, 80% of the most distorting policies in OECD countries correspond to policies supporting commodity output: most of which are market price support policies (USD 99 billion per year in 2017-2019, period used for this analysis), with a smaller contribution from direct payments based on output (USD 7 billion). Other most distorting policies also include payments to variable inputs (fuel, water, fertiliser, pesticides), when these are not associated to appropriate constraints (USD 9 billion). Other forms of agricultural support are also considered to be coupled to production, although they do not encourage the intensification of production – these include payments to farmers based on cultivated areas, number of animal heads, income or receipts, when production is required (Categories C and D of the OECD PSE nomenclature, totally USD 50 billion). Payments on other inputs such as fixed capital formation and on-farm services are also forms of coupled support (USD 19 billion). These latter forms of payments can be commodity specific, but a larger share is allocated to group of commodities (crops, livestock) or not targeted to any specific production.

In this analysis, we focus on the most distortive forms of payments as presented above, as well as the other coupled payments that target specific commodities. For the period 2017-2019 used for our support representation, the single commodity payments mostly include payments based on area from category C and a small share comes from payments based on output or input. During that period, the average annual global transfers to single commodities requiring production modelled in this report amounted to USD 28 billon (see Annex B for a detailed presentation of the support modelled in this report across regions and sectors). This figure includes commodity specific area payments but also more than 90% of output payments. A large proportion of payments based on variable input use are however excluded. Hence, during that period, an additional USD 150 billion per year were transferred to a group of commodities in the form of coupled transfers, but are not considered in this analysis because of the difficulty to assign them to specific commodities for the modelling. Including these additional payments would boost the effect of the domestic support removal in the reform scenarios. This would mean higher crop prices and undernourishment results, in particular in net food importing regions, in simulations where that form of support is removed. However, removing input subsidies would reduce resources extraction (e.g. water) and associated emissions (e.g. from fertilisers), exacerbating the trade-offs from removing those policies. Such additional scenarios could be explored in future research.

The report also fully acknowledges that payments based on area/animals/receipts or income are not as distorting as those based on output or input. However, these payments are considered because in most

[11] In contrast to the data on border measures data, the data on agriculture support is continuously monitored and updated by the OECD (OECD, 2021[13]). Thus, for payment support measures the most recently available data was used. The three year period selected, however, also includes exceptional payments that are not necessarily representative of farm programs compared to previous periods (see Box 1).

cases they still have an impact on the extensive margin of production. Area payments can also come with additional conditions or implementation modalities that are not considered here and may require a more refined analysis in future work, to better represent the link between payment and production response.

Last, it should be noted that support payments can vary significantly on a year-to-year basis, and using a three-year average may not be fully representative of the business as usual situation for some countries. For instance, in the case of the United States, an exceptional transfer of USD 12 billion was paid in 2018 to support farmers in the context of the *ad hoc* Market Facilitation Program, a large part to the benefit of soybean producers. This payment is considered in this analysis and, therefore, is reflected in the relatively high level of support for US soybean used in the analysis, relying on a 2017-19 average. This implies a much stronger soybean production and price response for the policy reform scenario in that region, compared to a scenario based on a different reference period. More details on the results implications can be found in Section 4.2.

2.3. Scenario framework

The analysis focuses on the interaction of climate change and different policy reform scenarios, covering the following dimensions: i) climate change scenarios, determined by the level of warming and the climate models used, ii) agricultural policy reforms, based on reduction of border measures and coupled payments, iii) baseline assumptions.

2.3.1. Policy reform scenarios

The policy scenarios consider different levels of cuts in border measures and agricultural support measures coupled to production. As described in the previous sub-section, the border measures analysed are tariffs, technical NTMs and export taxes. Coupled support policies considered are commodity-specific transfers other than market price support, based on the OECD PSE database. These include output payments and area- or animal-based based payments for which production is required. Input payments are here not considered due to their cross-sectoral nature (see Box 1 for details).

The report considers for removal of border measures scenarios that tariffs and export taxes are fully removed. In the case of NTMs, however, as these can have both benefits and costs, a standard practice when modelling their removal is to reduce them only partially (Flaig et al., 2018[47]). This study follows the approach from Flaig et al. (2018[47]) and considers a reduction of 15% of the trade costs associated with NTMs, a level estimated “actionable” as it represents half the reduction needed to bring the level of global NTMs’ trade costs to the remaining intra-EU trade costs.

More specifically, the main policy scenarios considered in the report are the following:

- *Current Policies*: policies as in Baseline
- *No Border Measures*: 100% removal of tariffs and export taxes and 15% removal of trade costs associated to NTMs
- *No Coupled Payments*: 100% removal of coupled payments linked to specific commodities
- *Full Reform*: 100% removal of tariffs and export taxes and 15% removal of trade costs associated to NTMs. 100% removal of coupled payments

In addition, two alternative scenarios with more limited scope reforms, following OECD’s previous work on the subject that explored plausible reform paths (OECD, 2016[18]), and one additional scenario that implements full reform under a deforestation ban are briefly explored:

- Differentiated Partial Reform (OECD, 2016[18]):
    - Border measures on all agriculture products in developed countries (excluding Japan) are reduced by 50% with the same cut applied to coupled payments. For some developed countries, some sectors are subject to less ambitious reforms: tariffs and coupled payments

are reduced by 25% in Japan. The rice sector faces a 5% cut. Sugar in the United States is subject to a 5% cut. Dairy faces a 5% cut in Canada.

  - Tariffs and coupled payments on all agriculture products in other regions are reduced by 10%.

- General Partial Reform (OECD, 2016[18]): 50% cut in both border measures and coupled payments in all regions and sectors (OECD, 2016[18]).
- Full Reform and deforestation ban: 100% removal of tariffs and export taxes and 15% removal of trade costs associated to NTMs. 100% removal of coupled payments. This scenario includes a constraint on forest conversion by completely restricting deforestation.

The policy scenarios above take a long term perspective and the effect of short-term support measures are limited by the use of a three-year time-window for the reference period. Furthermore, measures taken in subsequent years in response to the COVID-19 crisis are not considered in the analysis. It is also important to note that the scenarios modelled do not include the adoption of specific mitigation policies or the adoption of environmental regulations by specific countries.

2.3.2. Climate change scenarios

The climate change scenarios distinguish different levels of climate warming, structured around the Representative Concentration Pathways (RCP) 2.6, 4.5 and 8.5, depicting diverse trajectories of GHG concentration levels in the atmosphere and associated climate forcing (van Vuuren et al., 2011[48]). Throughout the report, the climate change scenarios based on RCPs 2.6, 4.5 and 8.5 are referred to as mild, moderate and strong levels of climate change. The impact of the RCPs on temperature and precipitation patterns in different regions of the world depend on the Global Circulation Model (GCM) used. For the core set of scenarios analysed, the results are based on the HadGEM2-ES GCM, based on the data compiled in the context of the ISIMIP fast-track study. These results are then processed in the crop model EPIC that simulates the impact of climate variation on crop productivity (Rosenzweig et al., 2014[49]). For crop productivity impacts, the report includes CO_2 concentration effects that can offset some of the negative impacts of temperature or precipitation changes. More details of the climate change scenario are presented in Annex B.

Results from the HadGEM2-ES GCM was chosen as a central case for representing climate impacts as this model is among the most used in the literature and EPIC crop yield data are available for all RCPs for that GCM. However, other GCMs provide different responses to emission concentration. The HadGEM2-ES results show for instance that temperature increases are accompanied by drier conditions when compared to some other models (Warszawski et al., 2013[50]). Sensitivity analyses were also performed using four additional GCMs focusing on the impacts of the strongest climate change scenario (RCP 8.5): GFDL-ESM2M, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M. The sensitivity analysis uses the same policy scenarios but the GMCs differ in the distribution and magnitude of the climatic effects brought by climate change, compared to HadGEM2-ES. The influence of the GCM choice on the results of the main outcome variable is shown in Annex C.

The time period considered for climate change analysis is mid-term century, and the focus of the report is on slow onset impact of climate change, based on 30-year average of annual weather future realisations under each climate scenario. This means the results only consider average temperature and precipitation climatic impacts but not extreme weather events, which could lead to more contrasted outcomes when focusing on a specific year, and have long lasting impacts for the sector.

2.3.3. Baselines with and without deforestation

All the scenarios above are implemented in the model on the top of a dynamic baseline represented by the Shared Socioeconomic Pathway "Middle of the Road" (SSP2). The SSPs are scenarios of global development trajectories that depict five different pathways.[12] SSP2 combines the trends observed over

[12] SSP1-Sustainability (low challenges to mitigation and adaptation), SSP2-Middle of the road (medium challenges to mitigation and adaptation), SSP3-Regional rivalry (high challenges to mitigation and adaptation), SSP4-Inequality (low challenges to mitigation, high challenges to adaptation), SSP5-Fossil-fueled development (high challenges to

the past century regarding technological development with future scenarios that are consistent with middle-of-the-road challenges to mitigation and adaptation of GHG emissions (Fricko et al., 2017[51]). In this scenario, by default, climate conditions remain at their 1980-2010 average level to capture both historical and current conditions and policy conditions are set at their most recent levels according to the sources used. Tariffs, including TRQs, are kept at their historical level (the model uses data from 2010), as well as NTMs technical measures and export taxes. Annex B presents the details of the socioeconomic pathways and the agricultural policy scenarios in baseline.

Future impact of climate change and policy reform can be greatly influenced by the assumptions in the baseline. One of the impacts of the policy and climate shock is a substantial variation in emissions related to land use changes. To better understand the role played by deforestation regulations at the intersection of the policy reform and climate change scenarios, the report also considers as an alternative baseline a SSP2 scenario without deforestation (SSP2 No Def). Under this scenario, land use conversion from cropland or grassland to forested areas is prevented from occurring in the model, reflecting a scenario of deforestation ban. Under such alternative baseline, a policy reform scenario does not lead to deforestation in other parts of the world due to production relocation.

Changing the baseline has some notable implications on the underlying dynamics of main variables. In the baseline with deforestation, cropland expands globally by 118.8 Mha, between 2020 and 2050, whereas the increase is only 113.0 Mha when deforestation is stopped. Grassland expansion is affected more substantially with a slowdown in the expansion from 207.6 Mha with deforestation to 152.7 Mha without deforestation. Conversion of forest by agricultural expansion is cut by 104.1 Mha in the no deforestation baseline, although further expansion in other natural land expands by 43.6 Mha. As a result of land expansion restrictions, agricultural prices are higher in the baseline without deforestation by 0.4% globally, with higher impacts in Brazil (+1.1%), rest of Latin America (+1.8%) and Africa (+1.1%), compared to the baseline with deforestation. This leads to an increase by 5.5 million persons undernourished by 2050, mostly in Africa.

Note that using a deforestation ban is only one possible mitigation strategy to reduce the harmful land use change impacts of the policy reform scenarios. The report does not consider alternative approaches such as targeting low-efficiency areas abandoned due to the policy reform that could instead be converted into forests or into productive areas, reducing the pressure to deforestation in other regions. A mandate to afforest or restore those areas following a trade policy reform could reduce some of the negative environmental effects of reform without the large losses on food security induced by a deforestation ban. However, afforestation would not be able to offset the emissions from forest clearance in tropical areas as afforested land would take many years to sequester carbon and, for most regions, would not reach similar stocks as those released through primary forest conversion (World Resources Institute, 2021[52]).

2.4. Scenario outcome variables

In the following sections, we present the modelling results of different combinations of the scenarios above. The outcomes analysed comprise crop and livestock production and prices, farm revenues, undernourishment, land use change, AFOLU GHG emissions,[13] water demand for the irrigation of crops and the water exploitation index, which is a ratio of water use in all sectors to total freshwater availability.

Results are simulated in the resolution of the global version of the model (gridded regional production, 37 trading markets, 18 crops and 7 livestock products), and presented at a more aggregated level for sake of clarity. Results tables and figures are structured around the following sectors and regions:

- *14 regions*: AFR=Africa, Middle East and Turkey, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=

mitigation, low challenges to adaptation). SSPs were established by the research community as a basis to perform climate change assessments (Riahi et al., 2017[9]).

[13] GHG emissions results exclude emissions coming from the transportation of agricultural goods and the energy use in this sector.

Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States. See Annex A for the correspondence to the model regions and countries.

- *8 crop groups*: RIC=Rice, WHT=Wheat and its products, CGR=Coarse grains (maize, barley, sorghum, millet) and their products, SGC=Sugar cane and its products, SOY=Soybean and its products, PLM=Palm fruit and its products, OSN=Other oilseeds (rapeseed, sunflower, groundnuts), CRP=All crops aggregate,
- *7 livestock product groups*: BEF=Beef, LMB=Lamb, PRK=Pig meat, PTM=Poultry meat, EGG=Eggs, DRY=Milk and dairy products, LSP=All livestock products.

3. The economic, land use and environmental effects of climate change on agriculture

This section analyses the potential effects of climate change on agricultural production, prices, farm revenues, undernourishment, land use, AFOLU GHG emissions, water withdrawals and the water exploitation index. As indicated in the introduction, the climate change effect is isolated by subtracting the current policies without climate change (CPnCC) scenario (baseline) from the scenario of current policies with climate change (CPCC). All outcomes, except for AFOLU emissions, are presented relative to the baseline scenario without climate change by 2050. The effects on AFOLU emissions are also compared to baseline emissions, but in cumulative terms for the period 2010-2050, as land use emissions change over time and vary according to the regions that experience land use changes.

3.1. Summary of results

Climate change is projected to cause, globally, negative effects on crop and livestock production, higher commodity prices and undernourishment. The estimated effects on crop production vary between -0.4% and -4% for crops and between -0.2% and -2% for livestock, relative to the baseline, depending on the climate change scenario. On average, the price impacts vary from -0.03% in a mild climate change scenario (RCP 2.6) to +9% in the strong climate change scenario (RCP 8.5). Average farm revenues may increase due to higher producer prices. At the regional level, some countries will expand their production due to improved climatic conditions, or due to the relocation of production from more adversely affected regions.

The impacts of climate change on the environment are mixed. On the one hand, land use change and organic soil emissions increase. Land use change emissions (LUC) increase due to the conversion of forested areas to croplands and grasslands in regions that increase their agricultural production, while organic soil emissions (ORS) are caused by the expansion of palm oil plantations into peatlands. On the other hand, direct crop and livestock emissions decline due to lower agricultural production. Total AFOLU GHG emissions increase by +0.13% in the mild climate change scenario (RCP 2.6) and by +0.5% in the strong climate change scenario (RCP 8.5) relative to baseline AFOLU emissions. However, the total AFOLU GHG estimated emissions are not robust to the choice of climatic model (GCM), as some models show negative global AFOLU emissions due to stronger negative effects of crop and livestock emissions and lower increases in LUC and ORS emissions (Figure A C.7). Agriculture water withdrawals are projected to decline by -7% in the strong climate change scenario, mainly due to increases in precipitation rates in specific regions. Despite these reductions in water withdrawals, the water exploitation index (WEI), which measures total freshwater stress, increases due to climate change. That said, the effect on the WEI is also sensitive to the choice of climatic model (Figure A C.8).

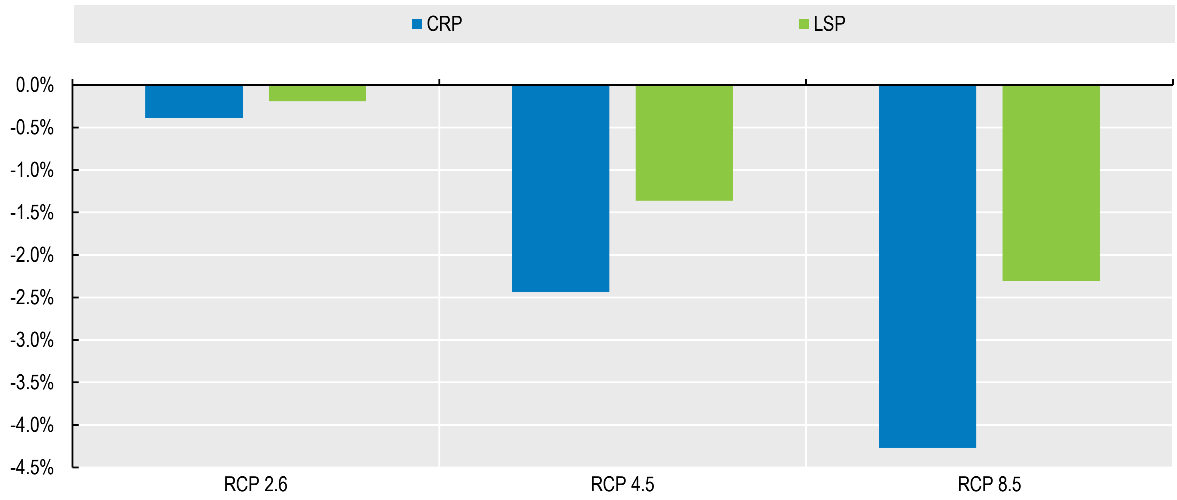
3.2. Economic impacts

According to this model, climate change has a detrimental impact on global crop and livestock production. The projected impacts by 2050 across the three climate change scenarios analysed in this report are negative and vary between -0.4% and -4% for crops and between -0.2% and -2% for livestock (Figure 3.1).

Agricultural production is expected to decline in most regions due to climate change and those loses are expected to be exacerbated under stronger climate change scenarios.

The global impacts on production are underpinned by negative effects on AFR, CHN, IND, RAS and USA (Table A D.1 and Table A D.2). In CHN, RAS and USA, the impacts are concentrated in a few commodities, while AFR and IND see negative impacts across the board. In CHN, the affected sectors are coarse grains (CGR), sugar cane (SGC) and eggs (EGG); in RAS, rice (RIC) and dairy (DRY); in USA, coarse grains (CGR), soybeans (SOY), wheat (WHT) and poultry meat (PLM). At the global level, the crops that contribute the most to global losses are coarse grains (CGR), sugar cane (SGC) and rice (RIC) and the most affected livestock products are dairy (DRY), egg (EGG) and poultry meat (PLM). Egg and poultry meat are mostly affected by the increase in corn prices, while dairy production is affected by the increase in soybeans prices.[14] Some regions like BRA, CIS, EUR and NZL, are projected to increase their production of both crops and livestock under global warmer conditions due to better crop growing conditions.

Figure 3.1. Climate change impacts on agricultural production (%)

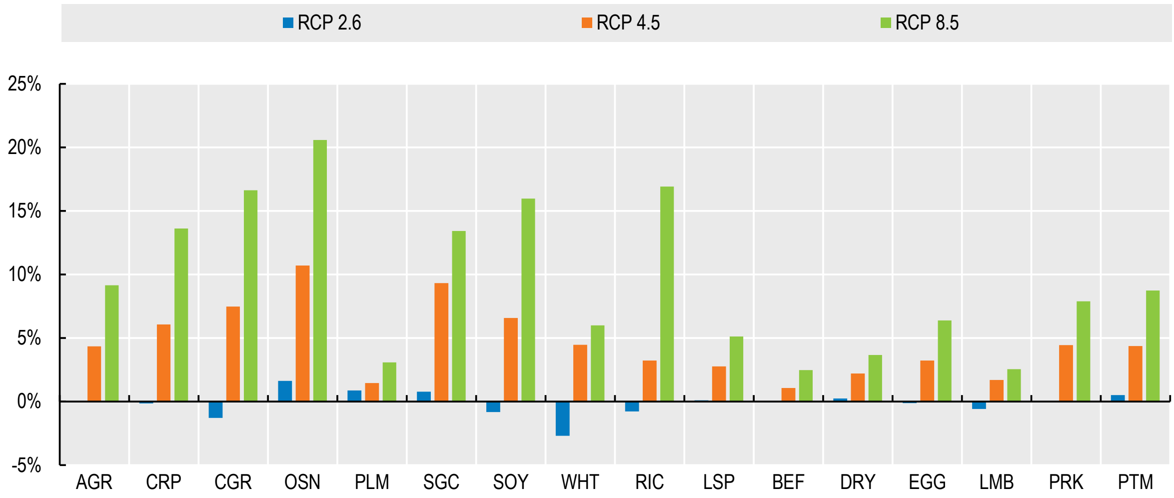


Note: CRP=All crops aggregate, LSP=All livestock products.

Climate change increases the prices of all commodities, particularly under stronger climate change scenarios (RCP 4.5 and 8.5) due to a decline in global production (Figure 3.2). On average, the price impacts on the sector (AGR) vary from -0.03% in a mild climate change scenario (RCP 2.6) to +9% in the strongest climate change scenario (RCP 8.5), relative to the baseline scenario. Crop prices (CRP) increase by 14% in the strongest climate change scenario (RCP 8.5), due to its effect on a number of products: coarse grains (CGR) (+17%), other oilseeds (OSN) (+21%), soybeans (SOY) (+16%), rice (RIC) (+17%) and sugar cane (+13%). The price of livestock products (LSP) increases by +5% in the strongest climate change scenario (RCP 8.5). Pork and poultry meat prices observe the highest increase induced by climate change due to the higher reliance of those sectors on feed. Such strong price increases are consistent with other modelled findings from that literature (Nelson et al., 2014[10]). In the mild climate change scenario (RCP 2.6) the prices of some commodities such as coarse grains, soybeans, wheat and rice decline due to better growing conditions.

[14] In GLOBIOM, the main channel by which climate change impacts livestock production is by the impact it has on feed crops.

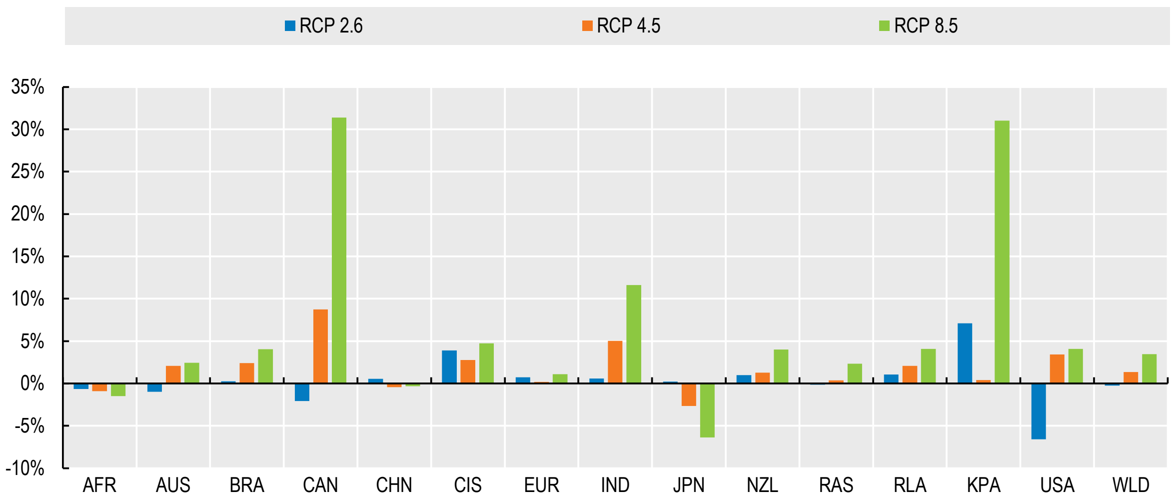
Figure 3.2. Climate change impacts on prices (%)



Note: Global price variations are calculated as production-weighted average of regional domestic price variations, using baseline weights. AGR=All agricultural products, CRP=All crops aggregate, CGR=Coarse grain (maize, barley, sorghum, millet), OSN=Other oilseeds (rapeseed, sunflower, groundnuts) and their products, PLM=Palm fruit and its products, SGC=Sugar cane and its products, SOY=Soybean and its products, WHT=Wheat, RIC=Rice, LSP=All livestock products, BEF=Beef, DRY=Milk and dairy products, EGG=Eggs, LMB=Lamb, PRK=Pig meat, PTM=Poultry meat.

Climate change also increases farm revenues at the global level (+3.5% in the strong climate change scenario relative to baseline). However, this aggregate result is underpinned by different regional impacts, with farm revenues rising in most regions and falling mostly in AFR and JPN (Figure 3.3). The negative impacts of climate change on farm revenues observed in those regions are more than offset by increases in the rest of the regions. This overall increase in farm revenue is due to the interaction of a supply shock induced by climate change and the relative low elasticities of demand of the analysed products that results in price changes larger than the decline in quantity supplied. Cui et al. (2018[27]) report a similar finding for most regions of the world.

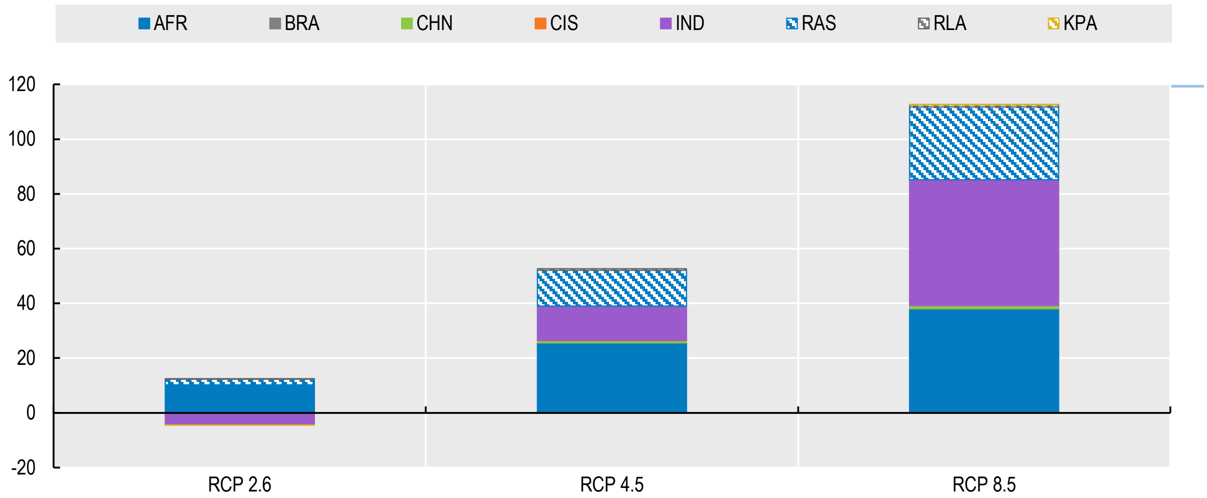
Figure 3.3. Climate change impact on farm revenues (%)



Note: AFR=Africa, Turkey and the Middle East, BRA=Brazil, CAN=Canada, CHN=China, JPN=Japan, RLA=Rest of Latin America, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, RAS= Rest of Asia, AUS=Australia, NZL=New Zealand, KPA=Korea and Pacific Islands, USA=United States.

The increase in agriculture prices for all commodities induced by climate change can in turn increase the number of undernourished people worldwide (Figure 3.4). These effects become more pronounced in stronger climate change scenarios. Globally, the number of undernourished people is projected to increase from 8 million (+3% of global population living undernourished in the baseline scenario) in a scenario of mild climate change (RCP 2.6) to 112 million in a scenario of strong climate change (+37% of the global population living undernourished in the baseline scenario). The regions of AFR and RAS face increases in undernourished people in all climate change scenarios, while there is a small decrease in IND under the mild climate change scenario (RCP 2.6) due to higher crop production in that region under that scenario.

Figure 3.4. Climate change impact on undernourishment (million people)



Note: AFR=Africa, Turkey and the Middle East, BRA=Brazil, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, IND=India, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands.

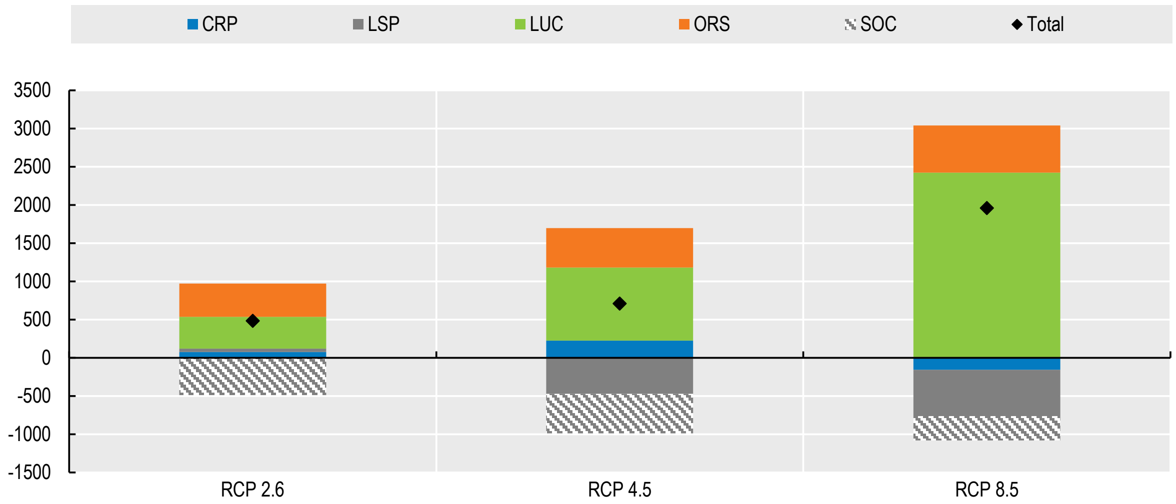
3.3. Land use and environmental impacts

Greenhouse gas (GHG) emissions from the AFOLU sector increase as a consequence of climate change due to land use change (Figure 3.5). Most of those emissions come from the conversion of grasslands and forested areas into cropland and organic soils emissions caused by the expansion of palm oil plantations into peatlands. Cropland area expands due to lower yields induced by climate change. Nevertheless, cropland expansion is not sufficient to offset production loses caused by climate change. AFOLU GHG emissions grow between +0.4 $GtCO_2$ in a mild climate change scenario (RCP 2.6) and +2 $GtCO_2$ in the strong climate change scenario (RCP 8.5) in a 50-year period, representing, respectively, between +0.13% and +0.5% of cumulative GHG emissions from the AFOLU sector during the same period in the baseline scenario without climate change. Roughly, those total GHG emissions are equivalent to +9 $MtCO_2$/year and +39 $MtCO_2$/year, respectively.[15] Emissions from livestock production decline in stronger climate change scenarios (RCP 4.5 and RCP 8.5) due to lower livestock production induced by climate change. Soil carbon emissions decline in all climate change scenarios due to lower crop production, while crop emissions experience small changes due to climate change.[16]

[15] While these estimated emissions are small relative to estimated global AFOLU GHG emissions (10-12 $GtCO_2$eq/year) and may not have additional impacts on global warming, they could impose additional challenges to reduce sectoral emissions for meeting the Paris Agreement target of stabilising global warming at 2ºC, estimated at 8 $GtCO_2$eq/year by 2050 (Henderson et al., 2021[79]).

[16] These emissions estimates only consider the impact of climate change on crop yield, but not the impact on forest, where carbon stocks could increase significantly considering the effect of CO_2 fertilisation (positive) but could also be lost due to increased risk of forest fire and tree mortality rate due to a warmer climate.

Figure 3.5. Climate change impacts on cumulative AFOLU GHG emissions 2010-2050 (Mt CO_2eq)



Note: CRP=emissions from crop production, LSP= emissions from livestock production, LUC= land use change emissions, ORS=Organic soils emissions, SOC= soil organic carbon.

The conversion of forest areas (FOR) in BRA, RAS and RLA to croplands (CRP) and grasslands (GRS) (Table A D.3) to compensate for declined production in other areas of the world drives most of the LUC emissions prompted by climate change. Land use emissions from forest conversion (LUCF) explain more than 60% of total emissions from those regions in climate change scenarios RCP 4.5 and RCP 8.5 (Table A D.4). Overall, climate change is expected to decrease forested area by -28 000 km^2 in RCP 2.6 (nearly the size of Belgium) and by -62 000 km^2 in RCP 8.5 (almost the size of Latvia). However, other natural vegetation areas (ONV) increase in all climate change scenarios, mainly due to a reduction of croplands and/or grasslands areas in some regions. In EUR and CIS, cropland areas decline and are replaced by natural vegetation areas (ONV) while in USA and CHN, grasslands are replaced by other natural vegetation. Those effects cause a decrease in both land use emissions from other natural areas (LUCN) and a decline in soil organic carbon emissions due to lower crop area in EUR and CIS.

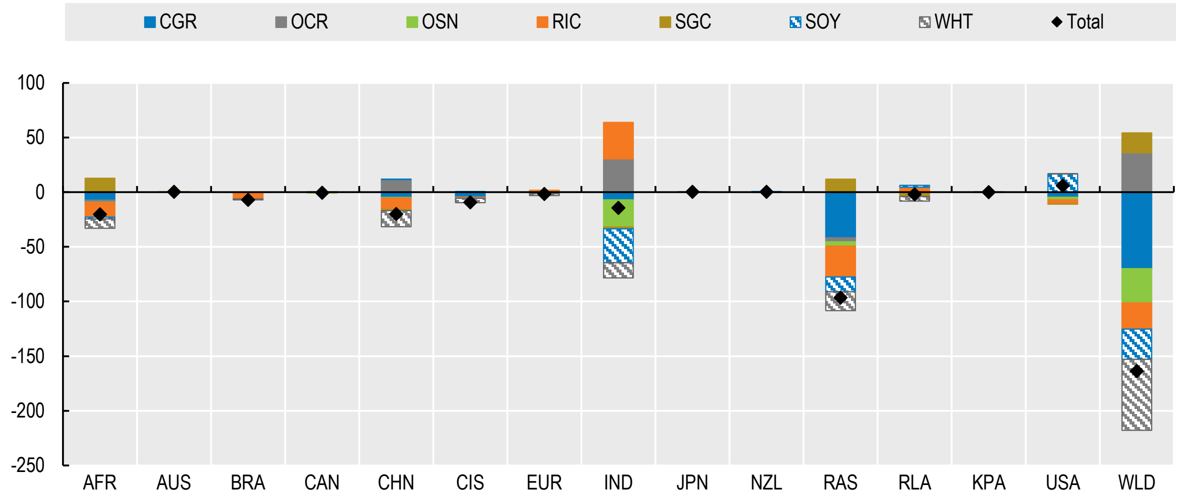
Climate change causes small changes on crop emissions due to the strong decline in emissions from fertiliser use by crops in USA, where climate change from the GCM model used in this study is projected to severely impact cereals production; those reductions are more than compensated by increases in crop emissions from other regions.

Livestock emissions from enteric fermentation and manure management experience strong declines in CHN, IND and RAS due to lower dairy production.

Water demand for irrigation of coarse grains (CGR), other crops (OCR), other oilseeds (OSN), rice (RIC), sugar cane (SGC), soybeans (SOY) and wheat (WHT) is expected to decline with climate change by -164 km^3 (-7% of agriculture water withdrawals in baseline scenario by 2050) as a result of reduced demand from areas where precipitation is projected to increase and from lower irrigation water demand in areas where climate change is projected to have a strong and negative impact on yields. Water withdrawals for irrigation decrease strongly in particular for the group of coarse grains and wheat (Figure 3.6).

Most of the decrease in global water demand for irrigation is driven by net reductions in AFR, CHN, IND and RAS. In IND and RAS the net reduction in water demand for agriculture is induced by higher precipitation rates. In the United States, water demand increases for the production of soybeans, while the production of coarse grains falls due to strong impacts of climate change on coarse grain yields, particularly corn.

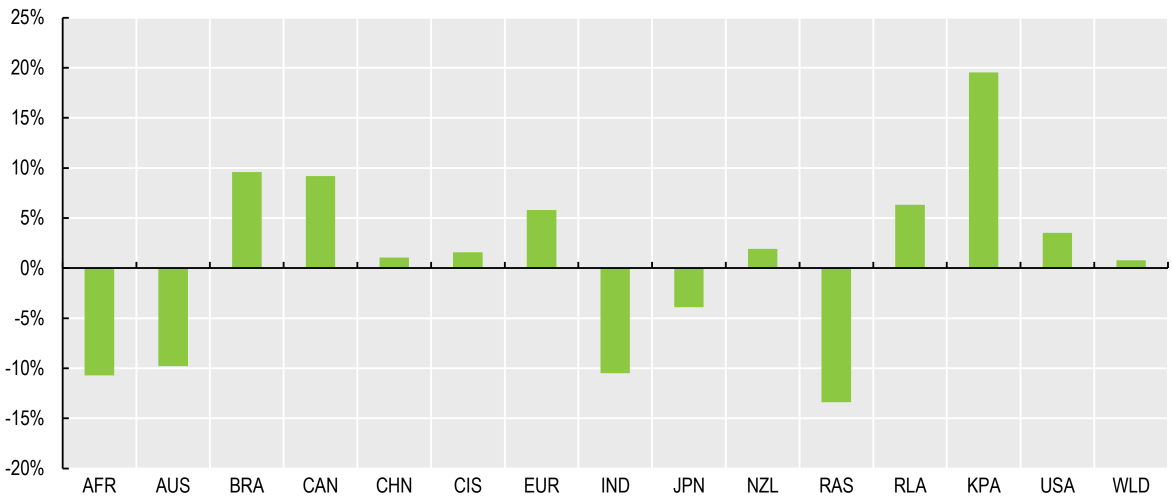
Figure 3.6. Climate change impacts on agriculture water withdrawals (km³)



Note: CGR=Coarse grain (maize, barley, sorghum, millet), OCR: Other crops, OSN=Other oilseeds (rapeseed, sunflower, groundnuts), RIC=Rice, SGC=Sugar cane and its products, SOY=Soybean and its products, WHT=Wheat. AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States.

While global water use for agriculture declines due to climate change, climate change increases the pressure on total available freshwater as reflected by the increase in the Water Exploitation Index (WEI).[17] The WEI decreases in AFR, AUS, IND and RAS but increases in the rest of the regions analysed (Figure 3.7).

Figure 3.7. Climate change impacts on water exploitation index (%)



Note: The water exploitation index is the ratio of total water withdrawals to total freshwater resources. AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States.

[17] The water exploitation index is the ratio of total water withdrawals in all sectors of the economy to total freshwater resources.

4. The economic, land use and environmental effects of reforming agricultural policies

This section analyses the potential impacts of implementing policy reforms by removing both border measures and coupled payments linked to specific commodities, in a scenario without climate change, to understand the main economic, land use and environmental effects of policy reform. As indicated in the Introduction, the effects of the reforms are calculated by subtracting the baseline scenario (CPnCC) from the policy reform without climate change (RFnCC) scenarios. More specifically, these reforms focus on three core policy reform regimes:

- No Border Measures: 100% removal of tariffs, 100% removal of export taxes and 15% removal of trade costs associated to NTMs.
- No Coupled Payments: 100% removal of payments coupled to the production of specific commodities.
- Full Reform: No Border Measures + No Coupled Payments.

Finally, a subsection summarises the effects of three additional policy scenarios, two of partial reforms and one full reform with a deforestation ban.

4.1. Summary of results

The specified agricultural policy reforms have mixed impacts, depending upon which category of agricultural support is removed. Removing all border measures (100% import tariffs, 15% of trade costs associated to NTMs and 100% export taxes) could increase global crop and livestock production by a small fraction (+0.3% relative to baseline), whereas removing coupled payments could reduce global crop and livestock production by an equally limited amount (-0.5% and -0.4%, respectively). According to the model, fully reforming agricultural policies by removing both border measures and coupled payments causes a net -0.2% change in global crop production and a near-zero change in livestock production. Those global impacts are driven by more significant changes at the regional level, with production increasing in some regions and declining in others. The regions where production falls are those regions where support including both border measures and coupled payments linked to specific commodities is more prevalent such as AFR, CIS, CHN, EUR, JPN and USA, while production expands in regions that have less support and have a comparative advantage in the production of agricultural commodities like AUS, BRA, NZL, RAS and RLA.

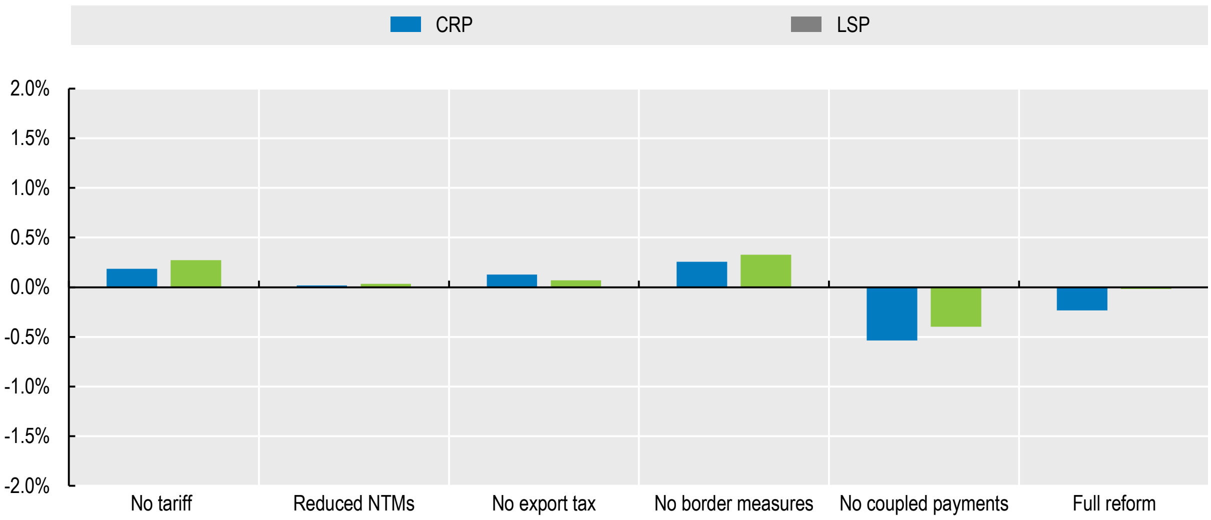
Unsurprisingly, the removal of agricultural support has the effect of lowering farm revenues (-3%); however, the impact of the reforms on producer prices differs, depending on which type of support is removed. The removal of border measures deflates producer prices, while the removal of coupled budgetary support increases them, but by less (in absolute value); thus, the full package of the reforms has a net negative impact on producer prices. Given their tendency to lower domestic agricultural commodity prices, the full package of policy reforms has the potential to reduce the number of undernourished (-3%). At the same time, the reforms and can lower water demand (-2%) and, in the absence of GHG mitigation policies, they could slightly increase AFOLU GHG emissions (+0.5%), despite lowering agricultural production. These increases stem from LUC emissions. In contrast, the full package of reforms leads to no change in direct GHG emissions from crop and livestock production (excluding LUC). The increase in total GHG emissions caused by policy reforms could be prevented if the reforms were implemented in a context where deforestation is banned. Reforming policies in the presence of these land use constraints could also lower undernourishment, by inducing reductions in agricultural commodity prices, particularly of crops, compared to a baseline with these constraints in place.

Removing all forms of support generates water savings due to a more efficient worldwide allocation of crops. However, some regions currently experiencing water stress, such as AUS, experience higher pressure on their water resources due to an expansion of crop production. The increase in AFOLU GHG emissions in the model is due to the conversion of forested areas and other natural areas to grasslands and croplands in the BRA and RLA regions and, to a lesser extent, due to a shift in livestock production from low emission intensity areas to high emission intensity areas, and in the absence of any mitigation effort.

4.2. Economic impacts

Border measures and coupled payments have opposite impacts on global production and domestic prices. Removing border measures (No Border Measures) tends to depress farm prices and could increase global agricultural production, while removing coupled payments (No Coupled Payments) depresses production and could increase prices. According to this model, reforming agricultural policies by removing border measures and coupled payments (Full Reform) has a negative albeit small impact on global crop production (-0.2%), a near-zero effect on livestock production (-.02%) (Figure 4.1) and a negative impact on agricultural prices (AGR) (-2%) (Figure 4.2). Removing tariffs, some (15%) trade costs associated with NTMs and export taxes, each has a positive impact on global crop and livestock production. The removal of trade costs associated with NTMs has the lowest impact mainly because only a small fraction of those costs was removed.[18] The global effects on production and prices of removing both border measures and coupled payments are roughly additive. In the case of production, the resulting impacts of removing both types of measures is dominated by the removal of coupled payments and, in the case of prices, by the removal of tariffs. Sugar cane and rice prices are the most affected by the removal of border measures and coupled payments. The model suggests that sugar cane prices decline by -12% and rice prices decline by -5% when all policy measures are removed. These effects are explained by the high tariffs in those sectors.

Figure 4.1. Policy reform impacts on agricultural production (%)



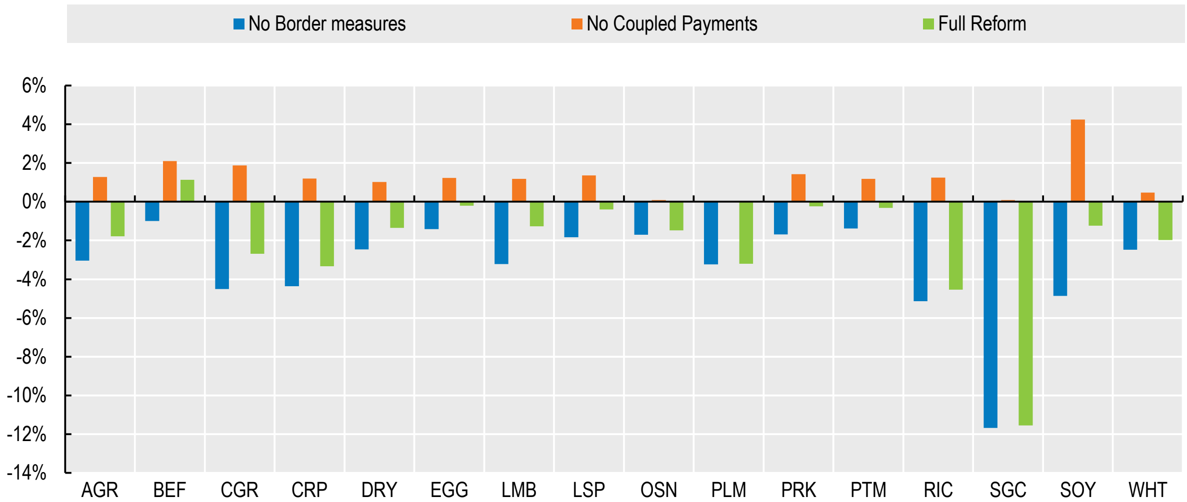
Note: CRP= All crops aggregate, LSP= All livestock products. No Tariff scenario: 100% removal of tariffs. Reduced NTMs scenario: 15% reduction of trade costs associated with NTMs. No Export Tax: 100% removal of export taxes. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments.

The net global effects of reforming agricultural policies result from regions that increase production and regions that decrease production (Table A D.5 and Table A D.6). Overall, regions with low levels of border measures and coupled payments and that have a comparative advantage in the production of agricultural products, such as AUS, BRA, NZL, RAS and RLA experience the largest production increase following the removal of these measures, while regions with higher levels of border measures, coupled payments or

[18] As mentioned in the Introduction section, there are some uncertainties regarding the trade costs of NTMs estimates used in this modelling exercise. However, because the reform scenario assumes a small reduction of those trade costs, the overall impacts of this scenario are small and excluding them does not change the overall impacts of removing border measures. For instance, only removing tariffs increases crop production by 0.19%, while removing all border measures, including trade costs associated with NTMs, tariffs and export taxes, increases crop production by 0.26%.

both such as AFR, CIS, CHN, EUR, JPN and USA tend to experience production losses. Overall, those regions that gain from improved terms of trade due to the removal of border measures increase their exports to those markets that reduce their domestic production (Figure 4.3). The production of most agricultural commodities increases when border measures are removed (No Border Measures), while removing coupled payments (No Coupled Payments) has a strong and negative impact on the production of coarse grains (CGR), soybeans (SOY) and most livestock products. The production of livestock products declines when coupled payments are removed because support for livestock products in some regions is abolished and also because feed becomes more expensive due to higher soybeans and coarse grains prices. Removing all forms of support has a net negative impact on crop and livestock production, due mainly to the removal of payments linked to the production of maize and soybeans in USA and to beef (BEF) in EUR.[19]

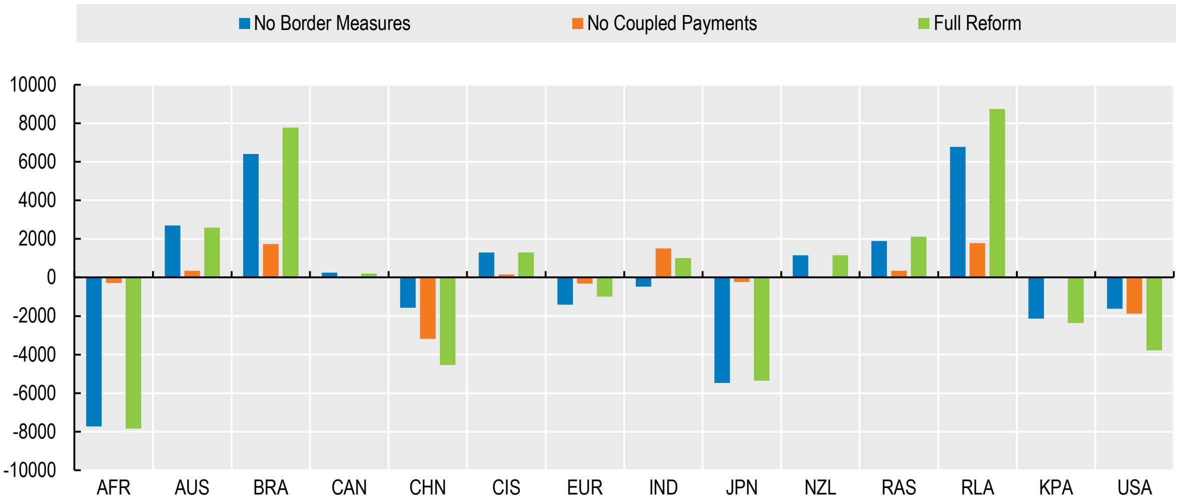
Figure 4.2. Policy reform impacts on agriculture prices (%)



Note: Global price variations are calculated as production-weighted average of regional domestic price variations, using baseline weights. AGR=All agricultural products, CRP=All crops aggregate, CGR=Coarse grain (maize, barley, sorghum, millet), OSN=Other oilseeds (rapeseed, sunflower, groundnuts) and their products, PLM=Palm fruit and its products, SGC=Sugar cane and its products, SOY=Soybean and its products, WHT=Wheat, RIC=Rice, LSP=All livestock products, BEF=Beef, DRY=Milk and dairy products, EGG=Eggs, LMB=Lamb, PRK=Pig meat, PTM=Poultry meat. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments.

[19] Support based on the area coupled to production is particularly high for soybeans in the US in the baseline scenario. This is due to the inclusion of the year 2018, during which an exceptional payment to soybean producers (Box 1). As a consequence of including this year, the reported price change for soybean is 80% higher than it would have been if this payment did not take place, and US soybean production declines by 4% in the “No coupled payments” scenario. The market impact on soybean in turn causes a decline in livestock production in the US for animals consuming large amount of soybean meal, in particular poultry (-2%). The contribution of the exceptional payment on global prices and production is however limited, as the US soybean payment considered only represents 18% of the total support removed for all US crops in the reform scenario (USD 21.3 billion). The livestock production impact is buffered by the use of other feed inputs, in particular grazing for ruminants, and the livestock sector is also directly affected by the removal of USD 7.4 billion of coupled targeted support (Table A B.4). The results would however change at the regional level if a different reference period was chosen for measuring domestic support, particularly for the poultry sector in the United States. This sector does not receive single commodity payments and would likely benefit from the reform under an alternative reference period, whereas it suffers losses under the current scenario.

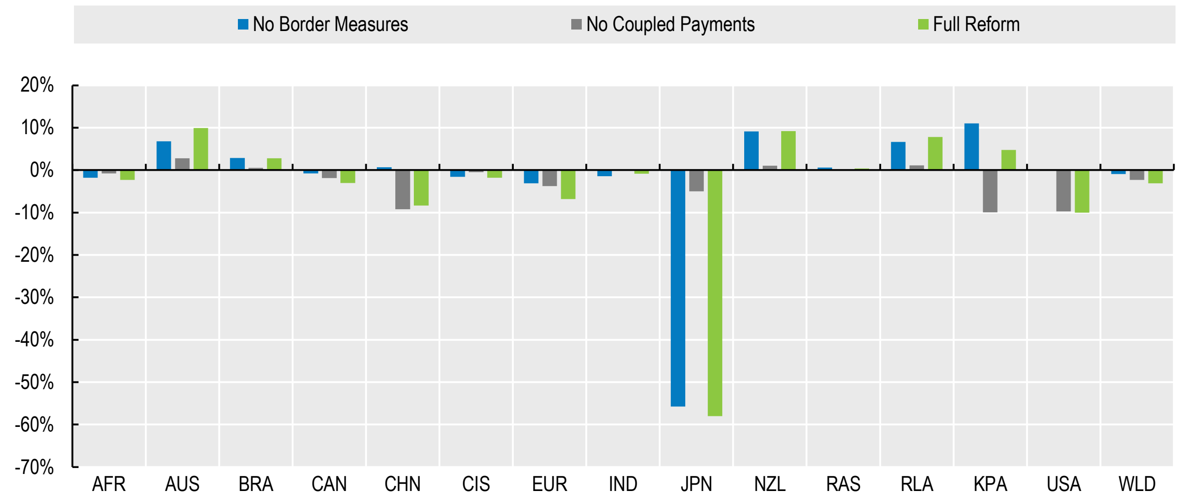
Figure 4.3. Policy reform impacts on net trade (1 000 t)



Note: AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA= Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. Full Reform No Def: No Trade Restrictions + No Coupled Payments + ban on deforestation.

Some forms of support are important sources of farm revenue in particular regions. Fully removing border measures and coupled payments (Full Reform) may negatively impact global farm revenues (-3%); particularly in areas that use payments coupled to the production of specific commodities such as in CHN, EUR, JPN and USA. However, farm revenues increase in regions such as AUS, BRA, NZL, RLA and KPA, where production increases as a result of policy reform (Figure 4.4).

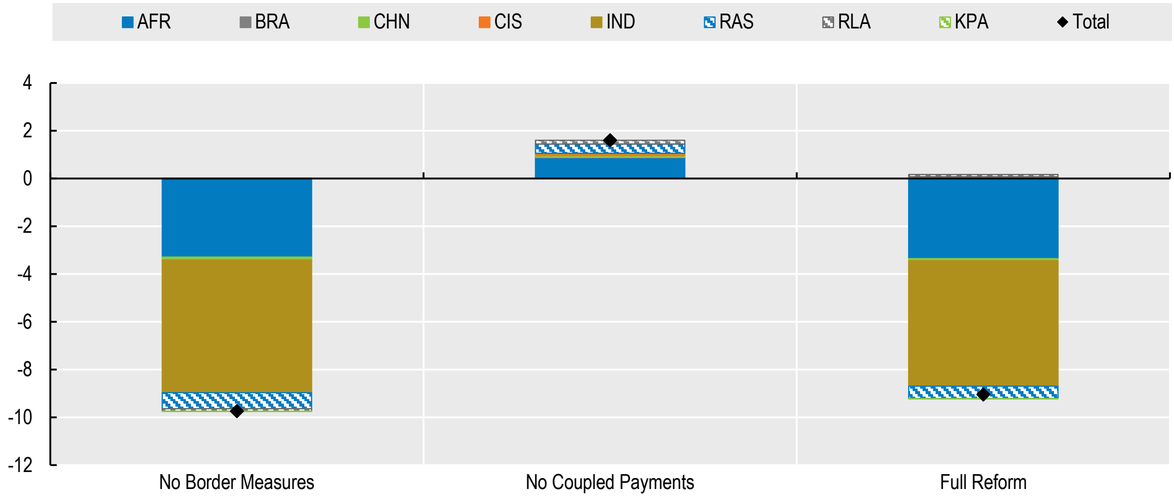
Figure 4.4. Policy reform impacts on farm revenues (%)



Note: AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA= Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments.

Removing all forms of support (Full Reform) may lower the total number of undernourished by 9 million (-3% of the world population living undernourished in the baseline scenario of current policies), of which 5 million are in IND and 3 million in AFR (Figure 4.5) The bulk of this effect is driven by the removal of border measures, which causes a decline in prices. Only removing coupled payments (No Coupled Payments) may increase undernourishment as prices tend to increase, affecting areas where undernourishment prevalence is high, such as AFR.[20] The extent of this undernourishment increase directly depends on the volume of domestic support removed, which can vary depending on the reference period considered (Box 1).

Figure 4.5. Policy reform impacts on undernourishment (million people)



Note: AFR=Africa, Turkey and the Middle East, BRA=Brazil, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, IND=India, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments.

4.3. Land use and environmental impacts

Reforming agricultural policies in the absence of GHG mitigation policy efforts (or land use regulation) can increase AFOLU GHG emissions, due to land use change in some regions. Removing border measures could increase AFOLU GHG emissions by +2 000 Mt CO_2eq, while removing coupled payments may decrease AFOLU GHG emissions by -124 Mt CO_2eq (Figure 4.6). Overall, the model suggests that reforming all agricultural policies raises AFOLU GHG emissions by +1 900 Mt CO_2eq emissions, which is equivalent to +0.5% of global AFOLU emissions in the baseline scenario with current policies by 2050.

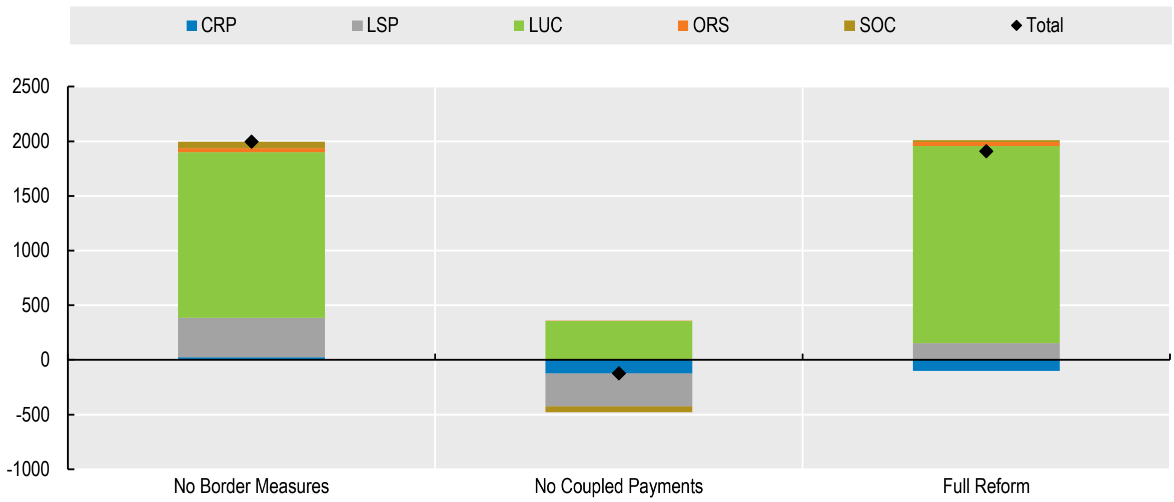
The significant difference in the AFOLU GHG emissions produced by removing border measures and those produced by removing coupled payments is explained by the relocation effects of those policies. Removing border measures causes a large production shift from areas with high levels of protection to other regions that improve their terms of trade, inducing an increase in global production. On the contrary, the relocation effects from removing coupled support are comparatively smaller, due to a lower impact on the terms of trade of most regions; production declines due to the removal of coupled payments in regions where that

[20] These numbers do not consider the potential effect that these policies may also have on smallholder farmers located in the analysed regions, who may also face higher food security risks due to the reduction in prices (Hertel, Burke and Lobell, 2010[82]). This is due to the fact that farm revenue and household income are calculated separately in a partial equilibrium setting. However, the large proportion of net-food buyers in poor farm households still supports the final direction of these effects (Ivanic and Martin, 2008[81]). This share would also increase over time due to the urbanisation trend in low and middle-income regions.

form of support is prevalent. The decline in production induced by the removal of coupled payments is reflected in the decline of both crop and livestock emissions. Nevertheless, a fraction of the increase in production in unsupported areas comes from land use conversion. Thus, the net effect on AFOLU GHG emissions from removing coupled support is almost zero. Notably, the combined effects of removing both border measures and coupled payments on AFOLU GHG emissions are roughly additive.

Relocation effects from fully reforming policies plays a crucial role in the resulting AFOLU GHG emissions. The bulk of those emissions (97%) comes from the conversion of forested areas to cropland and grasslands (Table A D.8), primarily occurring in BRA and RLA, where crop and livestock production increases at the expense of forest loss (Table A D.7). Those areas also contribute the most to soil organic carbon emissions (SOC) due to increased crop production. Despite the fact that livestock production declines as a result of removing all forms of support, livestock emissions increase by +152 Mt CO_2eq. This effect is driven by the relocation of beef production from low emission intensity areas such as EUR to higher emission intensity areas like certain regions in BRA and RLA[21]. GHG emissions from the crop sector (CRP) decline by -100 Mt CO_2eq, mainly due to reductions in rice production in JPN and KPA and to a decline in coarse grains production in CIS.

Figure 4.6. Policy reform impacts on AFOLU GHG emissions (Mt CO_2eq)



Note: CRP=emissions from crop production, LSP= emissions from livestock production, LUC= land use change emissions, ORS= Organic soils emissions, SOC= soil organic carbon. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments.

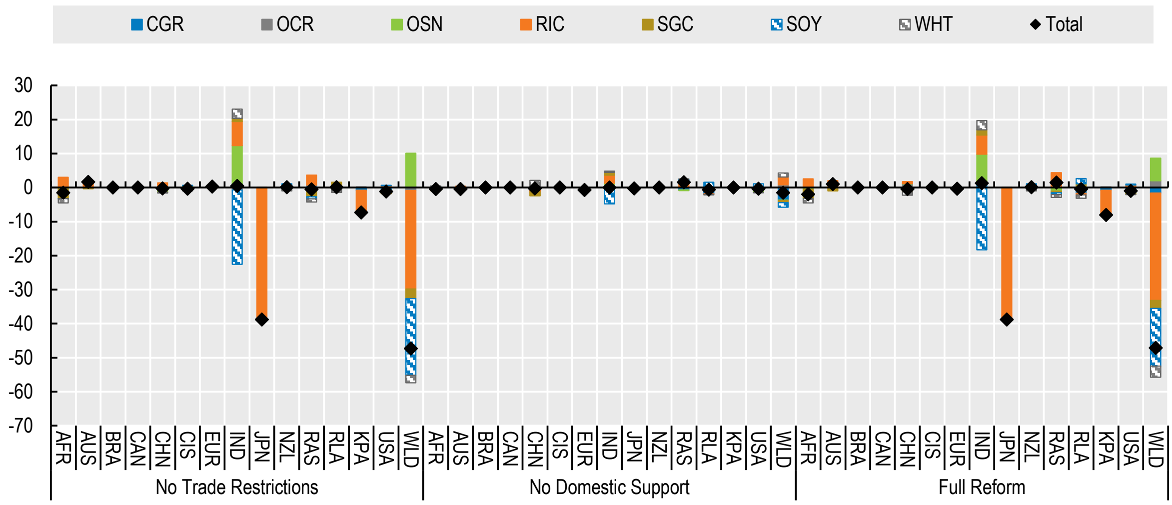
Water demand for irrigation is expected to decline with agriculture reform, reflecting more efficient crop allocation. Fully reforming agriculture (Full Reform) may reduce agriculture water withdrawals by 47 km^3 (-2% of baseline water withdrawals under current policies), mainly due to reductions in water withdrawals for rice production. Those reductions are caused by the removal of border measures (No Border Measures) (Figure 4.7).

The water use reduction caused by reforming policies also contributes to diminishing the pressure on total water resources from all sectors in the economy (Figure 4.8). The WEI decreases globally by -0.1 percentage points, due to decreasing indices in JPN and KPA. However, in AUS, a region that gains from policy reform, the WEI increases by 10 percentage points, indicating stronger pressure on water resources in a region that currently faces water shortages risks.

[21] Some of the most relevant factors explaining emission intensities are diet composition and quality. Developed regions tend to have more intensive livestock production systems with high quality diets that rely on grain use and emit less GHG emissions per kilogram of protein produced (Herrero et al., 2013[56]).

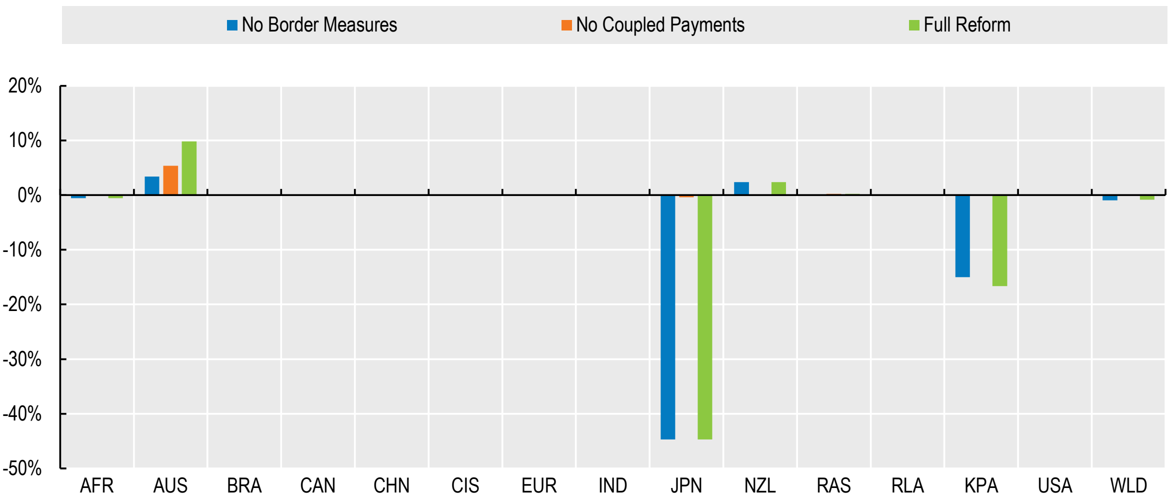
Reforming all policies while imposing a deforestation ban does not significantly affect water demand relative to the scenario where policies are reformed without a deforestation ban.

Figure 4.7. Policy reform impacts on agriculture water withdrawals (km³)



Note: CGR=Coarse grain (maize, barley, sorghum, millet), OCR: Other crops, OSN=Other oilseeds (rapeseed, sunflower, groundnuts), RIC=Rice, SGC=Sugar cane and its products, SOY=Soybean and its products, WHT=Wheat. AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments.

Figure 4.8. Reform impacts on water exploitation index (%)



Note: AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments.

4.4. Alternative reforms

This subsection explores the impacts of alternative reform scenarios that impose limits and constraints to the Full Reform scenario by analysing the impacts of three specific reforms: (1) removing up to 50% of distorting support in developed countries and removing 10% in developing ones, (2) removing 50% of all distorting support in all countries and (3) implementing full reform with a deforestation ban.

Table 4.1 shows the estimated economic and environmental impacts of the full reform scenario (Full Reform) and of the alternative reforms relative to current policies. In the partial reform scenarios (Differentiated Partial Reform and General Partial Reform), the production impacts are similar as in the full reform scenario but the resulting price reductions are much smaller. Due to the milder impacts on prices observed in the partial reform scenarios, farm revenues also decline by a lower proportion.

Partial reforms have a moderate impact on undernourishment: relative to a scenario where policies are fully reformed, it falls by 1 million (9% of the undernourishment effect from Full Reform) and in General Partial Reform the decline is of 3 million (39% of the undernourishment from Full Reform).

Implementing partial reforms that limit the scope of the cuts in border measures and coupled payments generate between 34% and 46% of the AFOLU GHG emissions caused by the full reform and generate low reductions in water demand.

Reforming policies in a context where deforestation is banned (Full Reform-No Def) has a negative impact on prices, particularly on crop prices. This price effect reduces undernourishment and, at the same time, prevents any increase in land use emissions and dramatically constrains the increase in total AFOLU emissions compared to the full and partial reform scenarios.[22]

Table 4.1. The economic and environmental impacts of alternative reforms at the global level

Variable	Variable (units)	Full reform	Differentiated partial reform	General partial reform	Full reform (no Def)[1]
Economic					
Production	CRP (%)	-0.2%	-0.2%	-0.2%	-0.2%
	LSP (%)	0.0%	-0.1%	-0.1%	-0.0%
Prices	AGR (%)	-1.8%	0.0%	-0.3%	-1.6%
	CRP (%)	-3.3%	-0.4%	-0.7%	-3.2%
	LSP (%)	-0.4%	0.4%	0.1%	-0.3%
Farm revenues	(%)	-3.1%	-0.9%	-1.5%	-3.0%
Undernourishment	Million people	-9	-1	-3	-9.9
Environmental					
GHG emissions	Total (Mt CO_2eq)	1909	882	657	9
	CRP (Mt CO_2eq)	-101	-30	-79	-116
	LSP (Mt CO_2eq)	152	-90	-135	101.6
	LUC (Mt CO_2eq)	1805	1005	882	-40
	ORS (Mt CO_2eq)	35	1	16	36
	SOC (Mt CO_2eq)	18	-5	-26	27
Water	Water use (km^3)	-47	0	-6	-50
	Water exploitation Index (percentage points)	-0.1 %	0.0 %	0.0 %	-0.8%

1. For comparability, the baseline scenario used for assessing the Full Reform (no Def) scenario includes a deforestation ban. All impacts are estimated relative to baseline projection in 2050.

[22] It is important to recall that in this case the baseline scenario includes current policies and a ban on deforestation.

5. The climate change adaptation potential of policy reform

This section focuses on the climate change adaptation potential of reforming agricultural policies. To isolate the adaptive capacity of the reforms it is necessary to compare the effects of reform under climate change (for mild (RCP 2.6), semi-strong (RCP 4.5) and strong climate change (RCP 8.5) scenarios) to those effects without climate change (presented in Section 4). Following the scenario notation from the Introduction, the effect of reform under climate change is expressed as RFCC − CPCC, while the effect of reform without climate change is denoted as RFnCC − CPnCC. Thus, the adaptation effect is computed as (RFCC − CPCC) − (RFnCC − CPnCC).

More specifically, this section presents results for four policy setups, with and without climate change:

- Current Policies: Policies as in Baseline
- No Border Measures: 100% removal of tariffs and export taxes and 15% removal of trade costs associated with NTMs
- No Coupled Payments: 100% removal of coupled payments
- Full Reform: Scenarios 100% removal of tariffs and export taxes and 15% removal of trade costs associated to NTMs. 100% removal of coupled payments

A subsection in the end covers the adaptation effects of alternative reforms that either partially cut border measures and coupled payments or that implement full reforms where land use change is constrained by banning deforestation.

5.1. Summary of results

A world without distorting support (without border measures and coupled payments) may adapt better to climate change, as the impact of climate change is lower on agricultural production, prices and undernourishment than in a world with the current levels of border measures and coupled payments linked to specific commodities reflected in the baseline scenario. Nevertheless, the adaptation benefits for the agricultural sector from fully removing distorting support appear to be relatively small: they could increase crop production by +0.1% in the mild climate change scenario (RCP 2.6) and by +0.2% in the strong climate change scenario (RCP 8.5), while the adaptation benefits in the livestock sector are near-zero. These adaptation gains are explained by the removal of border measures and coupled payments that relocates crop production from AFR, CIS, EUR, USA and JPN to AUS, BRA, NZL, RAS and RLA. According to the GCM used in this report, some of the regions where crop production moves from, particularly AFR and USA, experience worse climate conditions for crop production due to climate change. In contrast, some regions where crop production moves to, due to globally reforming policies, in particular BRA and RLA, may benefit from better crop growing conditions due to climate change. Thus, the overall adaptation effect on agricultural production is positive. The estimated effects on sectoral production are consistent across climatic models (GCMs) (see Figures in Annex C).

The policy setup that removes coupled payments (No Coupled Payments) may provide the most adaptation gains in terms of production relative to other policy regimes, mainly because it discourages production in CHN and USA, where the GCM used in this report projects negative impacts due to climate change. However, only removing coupled payments has the least benefits for undernourishment because border measures remain in place and limit trade flows to areas that face undernourishment risks due to climate change. By contrast, removing border measures (No Border Measures) has the least adaptation gains for production, but the highest adaptation gains for undernourishment.

Alternative policy reforms, that partially cut border measures and coupled payments have more limited impacts on prices and, consequently, on undernourishment. In contrast, when the full reform is implemented in a context where deforestation is banned, the reforms can be particularly beneficial for reducing undernourishment.

In a world without border measures and coupled payments, the environmental effects from climate change could be lower than in the current policy setup. According to this simulation, policy reform cuts one third of the AFOLU GHG emissions growth caused by strong climate change, reducing it from +0.5% under current policies to +0.35% under full reform. The effects on water are near-zero. These estimated environmental effects are consistent across climatic models (GCMs) (Figure A C.13 and Figure A C.14). This would however have only a minor effect on climate change and would not be sufficient to offset the increased emissions caused by these reforms.

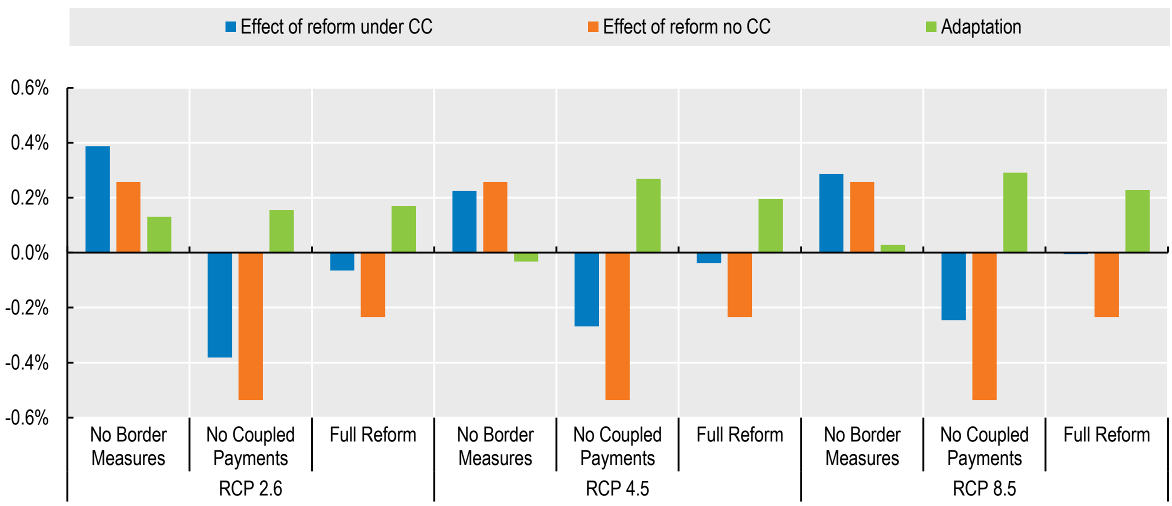
5.2. Economic impacts

Crop production may adapt better to climate change and may be subject to lower negative impacts in a world without border measures and coupled payments linked to specific commodities (Full Reform) than in a world with current policies (Figure 5.1). Those adaptation benefits are, nevertheless, relatively small, as they benefit crop production by +0.1% in the mild climate change scenario (RCP 2.6) and +0.2% in the strong climate change scenario (RCP 8.5). The reason is that the policy effects on crop production under climate change are similar to those without climate change. The (modest) adaptation effect mainly comes from the smaller impact that removing coupled payments has on lowering production in the presence of climate change than when those policies are removed in the absence of climate change (Figure 5.2).

By contrast, livestock production does not appear to generate adaptation benefits mainly because the effects of removing border measures under climate change are less strong than the effect of removing those policies without climate change (Figure 5.2).

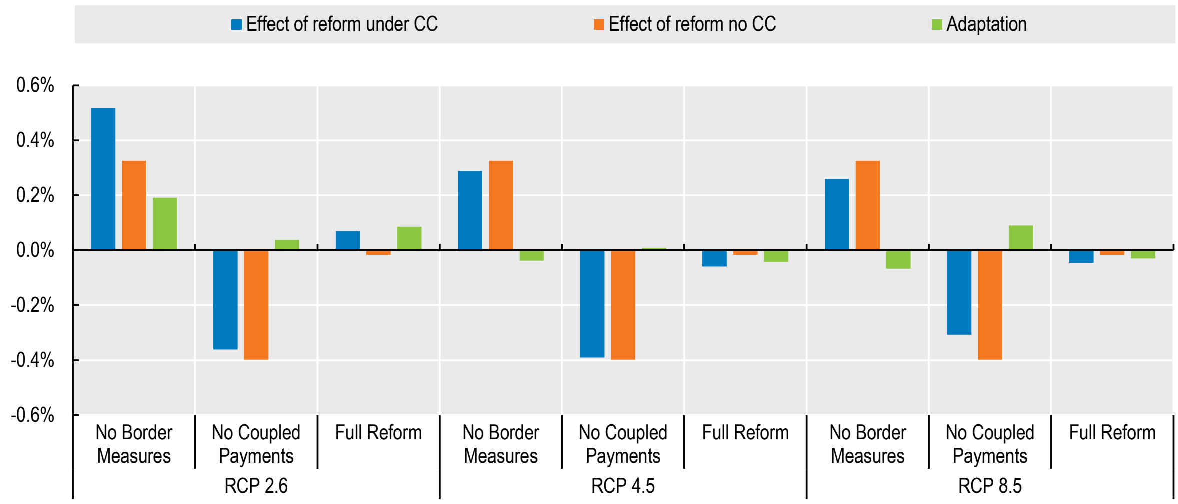
The policy setup that removes coupled payments (No Coupled Payments) provides the largest adaptation gains relative to other policy regimes in climate change scenarios RCP 4.5 and RCP 8.5, mainly because it discourages production in areas where climate change is projected to have negative impacts on production, according to the GCM used in this report. By contrast, removing border measures (No Border Measures) provides the least adaptation benefits on global production under climate change scenarios RCP 4.5 and RCP 8.5.

Figure 5.1. Adaptation effects of policy regimes on crop production (%)



Note: No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. Effect of reform under CC=RFCC-CPCC. Effect of reform no CC=RFnCC-CPnCC. Adaptation= (RFCC-CPCC) – (RFnCC-CPnCC).

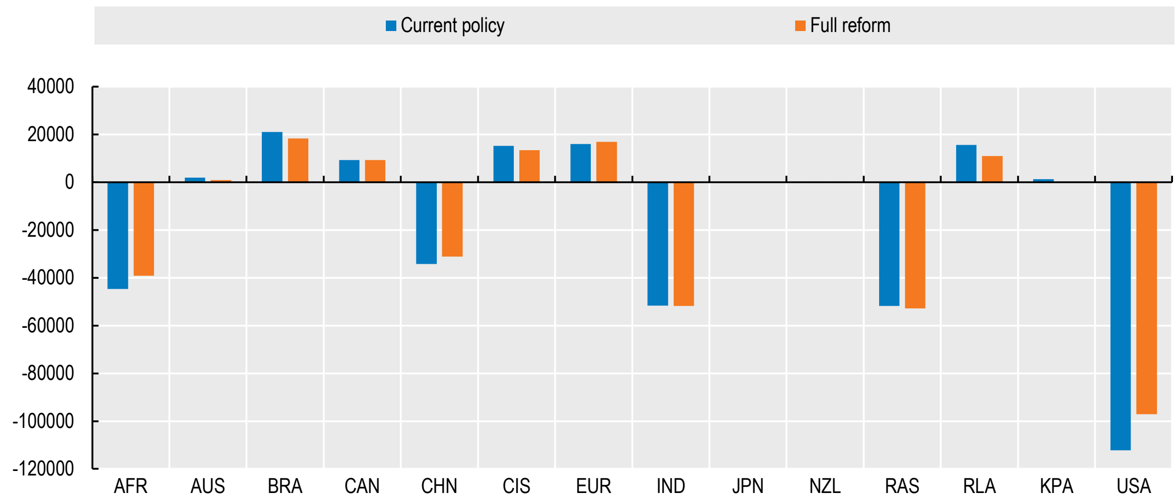
Figure 5.2. Adaptation effects of policy regimes on livestock production (%)



Note: Current policies: policies as in baseline. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. Effect of reform under CC=RFCC-CPCC. Effect of reform no CC=RFnCC-CPnCC. Adaptation= (RFCC-CPCC) – (RFnCC-CPnCC).

The adaptation effects of removing border measures and coupled payments diverge across policy regimes and climate scenarios because they depend on both the relocation effect of removing those policies and on the geographic distribution of climatic shocks. To clarify how these two effects interact, Figure 5.3 plots the projected climate change impacts on crop production under the strong climate change scenario (RCP 8.5) for all regions. AFR, CHN, IND and USA, all expected to face negative climate change impacts under current policies, are also less impacted by climate change under fully reformed policies. This is because fully reforming policies relocates part of the crop production in those regions to AUS, BRA, NZL, RAS and RLA, where climate change also may have a positive effect (Table A D.5).

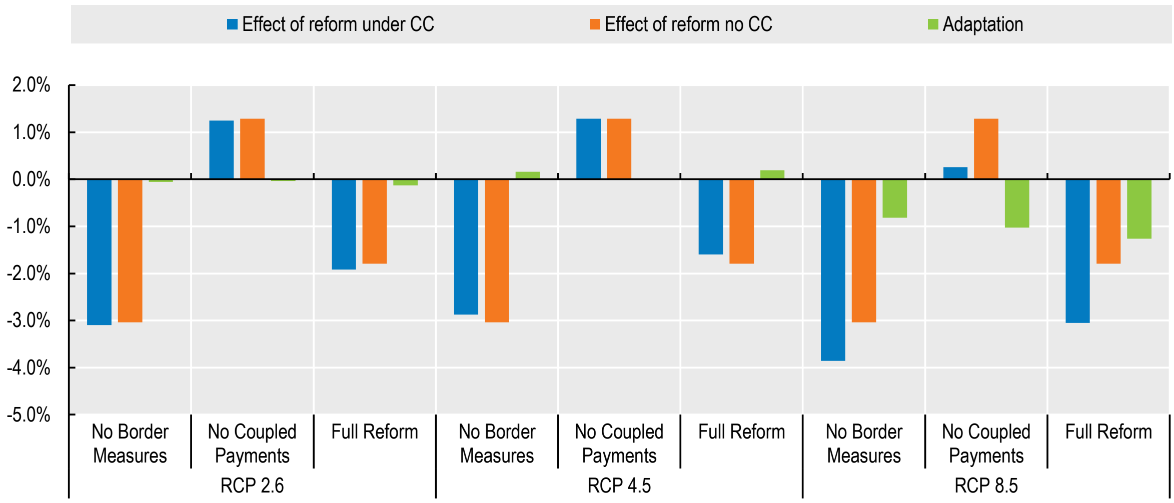
Figure 5.3. Climate change effects on regional crop production under different policy regimes (1000 t dm)



Note: AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS=Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States. Full Reform: No Trade Restrictions + No Coupled Payments. Climate change scenario is RCP 8.5.

The positive effect that the strong climate change scenario (RCP 8.5) exerts on agriculture prices is moderated in policy settings that remove border measures and coupled payments (Full Reform) (Figure 5.4). This is because removing coupled payments sees climate change increase agriculture prices by less, and removing border measures reduces prices by more in protected regions under climate change than in the absence of climate change. These effects however can be different for some exporters where prices increase when the border measures they face are removed. Therefore, the adaptation effect can be different at the global level in the case of milder scenario due to different spatial patterns of the climate change impact. In the RCP 4.5 climate change scenario, the price effects of removing border measures (No Border Measures) are less strong under climate change than without climate change conditions and, thus, revert the adaptation benefits. For that climate change scenario, however, removing coupled payments (No Coupled Payments) still generates adaptation benefits with respect to agriculture prices.

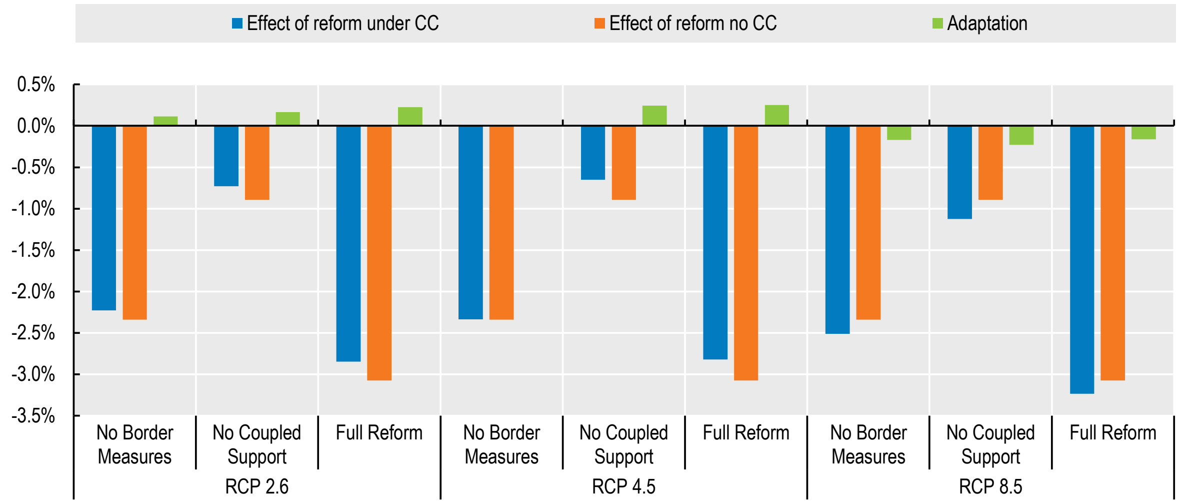
Figure 5.4. Adaptation effects of policy regimes on agriculture prices



Note: Global price variations are calculated as production-weighted average of regional domestic price variations, using baseline weights. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. Effect of reform under CC=RFCC-CPCC. Effect of reform no CC=RFnCC-CPnCC. Adaptation= (RFCC-CPCC) – (RFnCC-CPnCC).

In general, the impacts of the strong climate change scenario (RCP 8.5) on farm revenues are similar to the effect on prices, implying lower revenues in policy setups that remove support measures (Figure 5.5). In the strong climate change scenario (RCP 8.5), farm revenues decline -0.2% when removing coupled support. However, in milder climate change scenarios (RCP 2.6 and RCP 4.5), farm revenues increase by more in all policy reform settings than in the current policy settings. This divergence is explained by the reduced effect that removing either border measures or coupled payments has on farm revenues under the milder climate change scenarios.

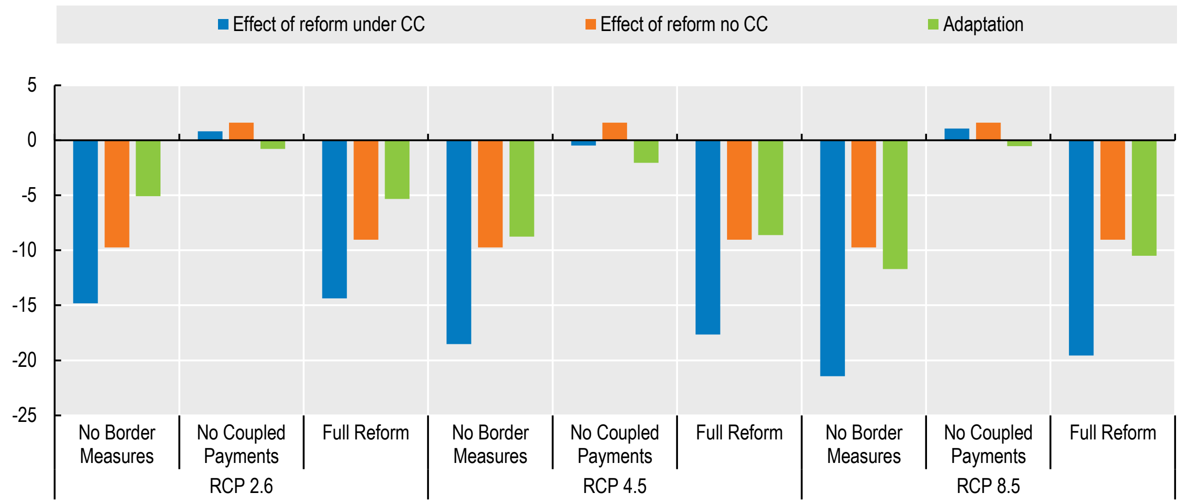
Figure 5.5. Adaptation effects of policy regimes on farm revenues



Note: No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. Effect of reform under CC=RFCC-CPCC. Effect of reform no CC=RFnCC-CPnCC. Adaptation= (RFCC-CPCC) – (RFnCC-CPnCC).

Reforming agricultural policies can mitigate the negative effects of climate change on undernourishment based on the model results (Figure 5.6). In particular, the policy setting that removes border measures (No Border Measures) generates the most adaptation gains: between -5 million people in the mild climate change scenario (RCP 2.6) and -11 million people under the strong climate change scenario (RCP 8.5). The reduction in the number of undernourished in the strong climate change scenario turns the undernourishment growth of +37.3% (+112 million people) under current policies into +33.8% (+102 million people) under full reform. Fully removing border measures reduces undernourishment by more in the presence of climate change conditions than in the absence of climate change, due to the stronger effects that removing those measures has on prices under climate change.

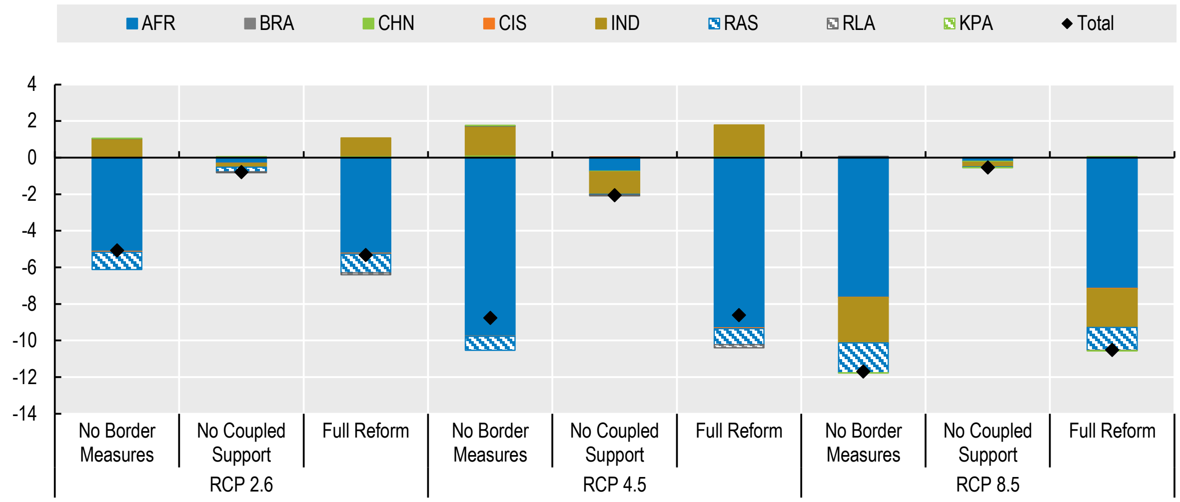
Figure 5.6. Adaptation effects of policy regimes on undernourishment (million people)



Note: No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. Effect of reform under CC=RFCC-CPCC. Effect of reform no CC=RFnCC-CPnCC. Adaptation= (RFCC-CPCC) – (RFnCC-CPnCC).

At the regional level, removing border measures can help areas that have high levels of undernourishment such as AFR, IND and RAS to cushion the negative effects of climate change on agricultural production by reducing food prices and facilitating imports (Figure 5.7). Only removing coupled payments (No Coupled Payments) has limited adaptation benefits on undernourishment.

Figure 5.7. Adaptation effects of policy regimes on regional undernourishment (million people)



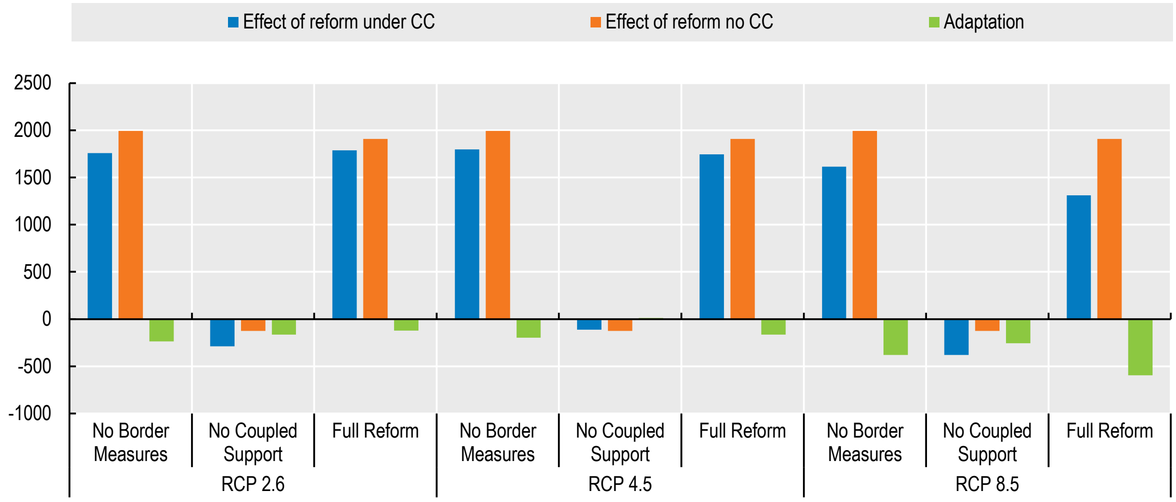
Note: AFR=Africa, Turkey and the Middle East, BRA=Brazil, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, IND=India, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments.

5.3. Environmental impacts

Removing border measures and coupled payments (Full Reform) under a strong climate change scenario (RCP 8.5) may bring environmental benefits as total AFOLU GHG emissions are -600 Mt CO_2eq less than in the current policy setup (Figure 5.8). Hence, full reform cuts one third of AFOLU GHG emission growth under climate change, turning the effect of climate change from a +0.5% increase under current policies into +0.35% increase under full reform, bringing total emissions from +1 900 Mt CO_2eq to +1 300 Mt CO_2eq over 50 years, equivalent to +26 Mt CO_2eq per year. However, those emissions will have negligible impacts on global warming (roughly increasing global temperature by approximately 0.002 degrees according to the relationship between annual GHG emissions and global warming (Rogelj et al., 2016[53])). These positive effects on emissions result from the more moderate effect that removing border measures has on AFOLU GHG emissions in the presence of climate change than without climate change.

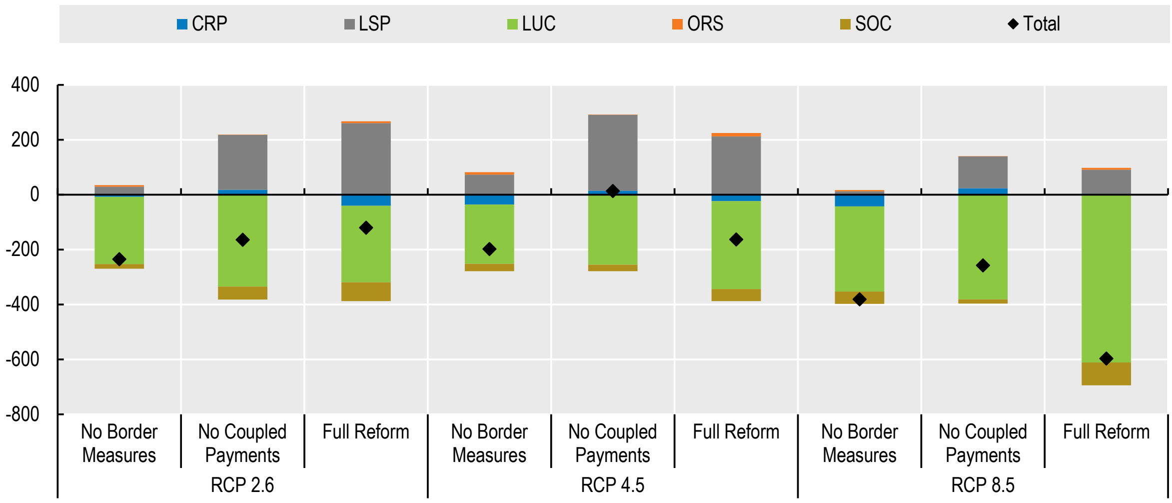
Most of those avoided emissions accrue to decreasing land use emissions, and are observed despite increased livestock emissions due to the shift of livestock production to more emission intensive areas (Figure 5.9). Land use emissions growth is lower in a world without border measures and coupled payments due to lower soybeans production in BRA and RLA relative to a world with current policies because under fully reformed policies soybean production is less affected by climate change in a setup without those policies in place.

Figure 5.8. Adaptation effects of policy regimes on cumulative AFOLU GHG emissions 2030-2050 (Mt CO_2eq)



Note: No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. Full Reform No Def: Full Reform and deforestation ban. Effect of reform under CC=RFCC-CPCC. Effect of reform no CC=RFnCC-CPnCC. Adaptation= (RFCC-CPCC) – (RFnCC-CPnCC).

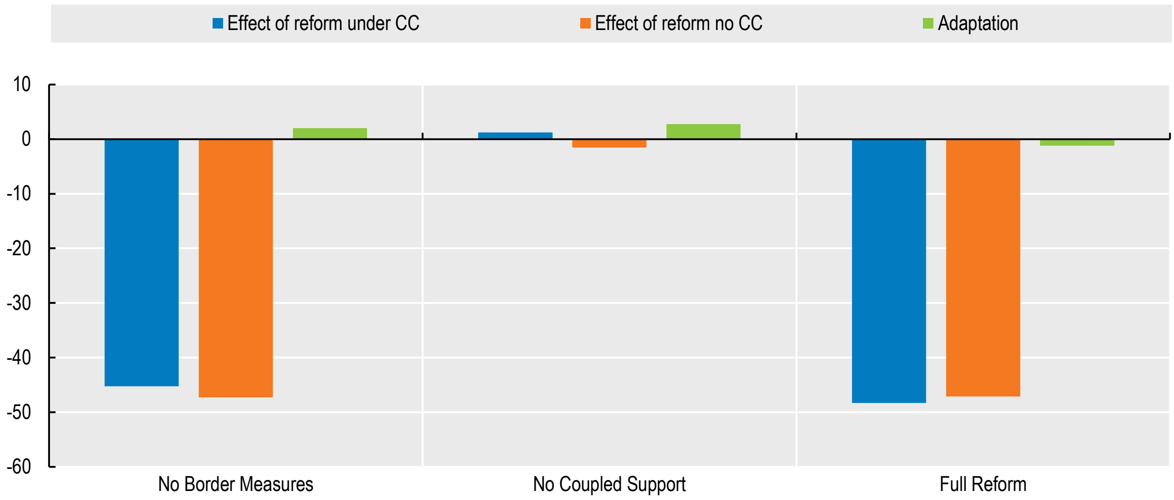
Figure 5.9. Adaptation effects of policy regimes on cumulative AFOLU GHG emissions by source 2030-2050 (Mt CO_2eq)



Note: CRP=emissions from crop production, LSP= emissions from livestock production, LUC= land use change emissions, ORS=Organic soils emissions, SOC= soil organic carbon. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. Full Reform No Def: Full Reform and deforestation ban.

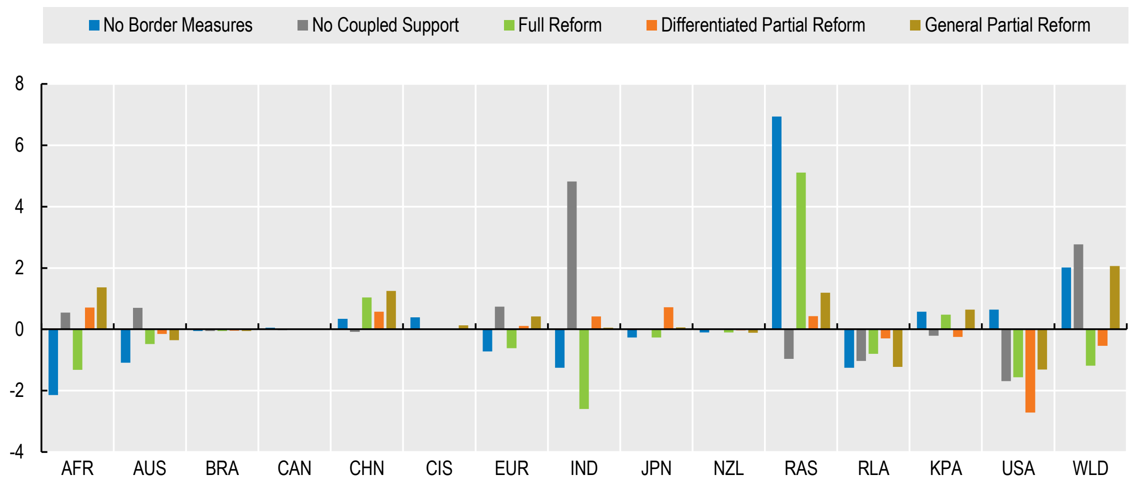
Removing all forms of support (Full Reform) may bring near-zero reductions in irrigation water withdrawals relative to those induced by the strong climate change scenario under current policies (RCP 8.5) (Figure 5.10). The estimated reduction is of -1 km^3, a decline of -0.05%. The apparent low adaptation gain with respect to water reductions reflects the similar effects that removing both border measures and coupled support have both with and without climate change. Water demand reductions are underpinned by lower demand for irrigation in AFR, IND, RLA and USA (Figure 5.11).

Figure 5.10. Adaptation effects of policy regimes on agriculture water withdrawals (km³)



Note: No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. Full Reform No Def: Full Reform and deforestation ban. Effect of reform under CC=RFCC-CPCC. Effect of reform no CC=RFnCC-CPnCC. Adaptation= (RFCC-CPCC) – (RFnCC-CPnCC).

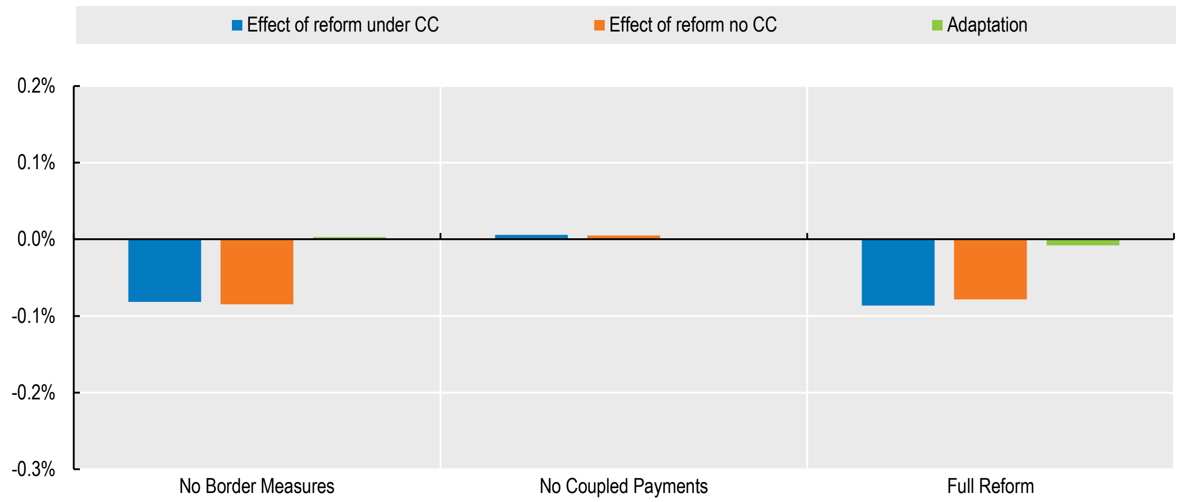
Figure 5.11. Adaptation effects of policy regimes on regional agriculture water withdrawals (km³)



Note: AFR=Africa, Turkey and the Middle East, BRA=Brazil, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, IND=India, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. Full Reform No Def: Full Reform and deforestation ban.

Removing all distorting policies (Full Reform) has a limited impact at reducing the WEI under the strong climate change scenario (RCP 8.5) relative to the effects of climate change on WEI under current policies (Figure 5.12) due to the small effects that the reform has on WEI with and without climate change.

Figure 5.12. Adaptation effects of policy regimes on water exploitation index (percentage points)



Note: No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. Full Reform No Def: Full Reform and deforestation ban.

5.4. Alternative Reforms

This subsection briefly explores the effects of alternative reform scenarios that impose limits and constraints to the Full Reform scenario by analysing the adaptation impacts of three specific reforms: (1) removing up to 50% of distorting support in developed countries and removing 10% in developing ones, (2) removing 50% of all distorting support in all countries and (3) implementing full reform in a context where deforestation is banned. Section 2 describes these alternative scenarios in detail. Alternative scenarios are contrasted with the Full Reform scenario without constraints presented in previous sections.

Alternative reforms do not have substantially different impacts on agriculture production than those prompted by Full Reform (Table 5.1). The partial reforms scenarios have more limited effects on prices, GHG emissions and undernourishment. In the case where border measures and coupled payments removals are combined with a ban on deforestation (Full Reform-No Def, compared to the baseline where deforestation is also removed), adaptation impacts on prices are comparable to those under Full-Reform with deforestation, and the reductions in undernourishment remain, although they are slightly lower (-8 million instead of -11 million for Full Reform). Overall, undernourishment is however higher by 5.5 million people in the alternative baseline without deforestation compared to the initial baseline (see Section 2.4). The benefits of the reforms on moderating emissions growth also appear much lower when deforestation is banned, which is simply due to the much lower land use change emissions under that alternative baseline.

Table 5.1. The adaptation effects of alternative reforms at the global level

Variable	Variable (Units)	Full Reform	Differentiated Partial Reform	General Partial Reform	Full Reform (no Def)[1]
Economic					
Production	CRP (%)	0.2%	0.2%	0.2%	0.2%
	LSP (%)	0.0%	0.0%	0.0%	-0.1%
Prices	AGR (%)	-1.3%	-0.6%	-1.0%	-1.4%
	CRP (%)	-2.3%	-1.1%	-1.9%	-2.3%
	LSP (%)	-0.3%	-0.2%	-0.1%	-0.5%
Farm revenues	(%)	-0.2%	-0.1%	0.0%	-0.2%
Undernourishment	Million people	-11	-1	-2	-8
Environmental					
GHG emissions	Total (Mt CO_2eq)	-597	9	9	-77
	CRP (Mt CO_2eq)	-2	16	7	3
	LSP (Mt CO_2eq)	91	325	310	125
	LUC (Mt CO_2eq)	-610	-304	-202	-121
	ORS (Mt CO_2eq)	6	0	-1	9
	SOC (Mt CO_2eq)	-83	-28	-18	-94
Water	Water use (km^3)	-1	-1	2	-3
	Water Exploitation Index (percentage points)	0.0%	0.0%	0.0%	-0.2%

1. For comparability, the baseline scenario used for assessing the Full Reform (no Def) scenario includes a deforestation ban. All impacts are estimated relative to baseline projection in 2050, based on the RCP 8.5 scenario with HadGEM2-ES.

6. Conclusions

The agricultural sector faces immense challenges in ensuring the provision of food, farm incomes, employment and environmental services in the face of accelerating climate change, which is modifying comparative advantage in production across regions and constraining global agricultural output.

At the same time, trade protection measures and other forms of support to agricultural producers have influenced production choices and contributed to a global pattern of production that is not fully aligned with the underlying comparative advantages in production that countries might have without this support.

The impacts of reforms to agricultural trade and support policies have been well-researched from the perspective of increasing economic welfare, along with its implications for competitiveness and trade performance. However, the impact that these policy reforms could have on agriculture's capacity to adapt and continue to provide food and incomes in a sustainable way in the face of accelerating climate change has been under-explored.

This study aimed to explore this issue by using the GLOBIOM model to quantitatively assess the economic, land use and environmental effects of removing border measures and coupled payments linked to specific commodities under climate change, by 2050. This analysis suggests that a broad package of agricultural policy reforms – in which a set of support policies, including border measures and coupled payments linked to specific commodities, are removed – could reduce the extent to which climate change can increase agricultural commodity prices and undernourishment, and in that sense could contribute to global adaptation to climate change. The modelling suggests that the reform package could achieve this by enabling production to shift to regions with a comparative advantage in production and by facilitating trade flows into regions negatively affected by climate change. Such a package of reforms could also reduce global water demand, although it may place additional strain on water resources in a few regions. Modelling shows that the reforms may generate trade-offs themselves, such as slightly increasing global GHG emissions from land use change. Global average farm revenues could also fall as a consequence of the reforms, although the reforms could stimulate an expansion in agricultural production and incomes in unsupported regions.

This analysis show that policy reforms have different impacts, depending upon which type of agricultural support is removed. The removal of border measures and commodity-specific coupled payments have opposite effects on production, prices, undernourishment and GHG emissions. This demonstrates the need for a careful assessment of the individual policies under consideration to design reform packages that are coherent with policymakers' objectives.

While the global modelling results in this study suggest that the removal of some forms of support could facilitate adaptation to climate change and create benefits for food consumers across the world, the reforms alone do not appear to be nearly sufficient to mitigate the impact of climate change on food security and the environment. The reforms would need to be accompanied with appropriate regulations such as land use conversion restrictions to mitigate potential harmful side effects. Deeper transformation policies could help to ensure broader adaptation success and social safety nets would also be needed to deliver more inclusive outcomes. Such transformations could also generate synergies with climate mitigation efforts when combined with technical measures such as improved feeding techniques, pasture management, genetic resource management and more precise fertiliser use.

The findings of this report need be considered in view of the various uncertainties and limitations related to this type of analysis at the global scale. These limitations include the partial and stylised representation of climate change and of the specific policy measures used in the analysis. Although the climate change impacts are based on the best available data from crop production and global circulation models, the impacts are based on multiple year averages and therefore exclude the extreme events which can significantly disrupt agricultural production in specific seasons or years. The policy reform scenarios are also stylised and partial. For instance, with regard to trade protection measures, an approximate approach is used to estimate trade costs associated with NTMs as an initial attempt to complement the more available and robust data on tariff measures, but more refined estimates quantifying the impacts of NTMs would be needed to confirm the results. The study also considers reforms to single commodity payments linked to the production of a set of commodities (rice, wheat, maize, soybeans, barley, sorghum, rapeseed, sunflower, palm, sugar, milk, beef and veal, pig meat, eggs, poultry meat and sheep meat), based on output, area cultivated or animal numbers, and does not capture the larger share of coupled budgetary support targeting inputs or broader commodity groups, nor possible implementation modalities attached to the payments. Other limitations relate to the use of partial equilibrium modelling framework which, on the one hand provides a high-level of detail on agricultural production activities and its interaction with land use and water resources, but does not consider interactions with other sectors of the economy, neither possible introduction of novel adaptation technologies and practices.

Future research to address some of the limitations of this study could provide further insights into the potential for agricultural policy reforms to facilitate adaptation to climate change, or to offset the impacts of climate change. The inclusion of extreme events in specific years would reveal how policy reforms perform in the face of more severe disruptions to production. A more complete set of policy reforms, including in particular all types of budgetary support that are coupled to production or variable input use, and better consideration of their policy design, including environmental compliance, could also change the magnitude and distribution of impacts from the full reform package and should therefore be explored further. This additional research will help to further disentangle the complex interactions between agricultural support policies and climate change adaptation.

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Annex A. Description of GLOBIOM's sectors and GHG accounting

Crops

GLOBIOM explicitly covers production of each of the 18 world major crops representing more than 70% of the total harvested area and 85% of the vegetal calorie supply as reported by FAOSTAT. These crops are: rice, wheat, corn, soybean, barley, sorghum, millet, cotton, rapeseed, sunflower, groundnuts, palm, sugar cane, potatoes, sweet potatoes, cassava, chick peas, and dry beans. Each crop can be produced under different management systems depending on their relative profitability: subsistence, low input rain-fed, high input rain-fed, and high input irrigated, when water resources are available. For each of the four systems, crop yields are calculated at the Simulation Unit level on the basis of soil, slope, altitude and climate information using the EPIC model (Williams, 1995[54])). Within each management system, input structure is fixed following a Leontief production function. But crop yields can change in reaction to external socio-economic drivers through switch to another management system or reallocation of the production to a more or less productive Supply Unit. Besides the endogenous mechanisms, an exogenous component representing long-term technological change is also considered.

Livestock

GLOBIOM includes a particularly detailed representation of the global livestock sector. Animal species distinguish between dairy and other bovines, dairy and other sheep and goats, pigs, and poultry, with further distinction of laying hens and broilers. Livestock production activities are defined in several alternative production systems adapted from Seré and Steinfeld (1995[55]): grass based (arid, humid, temperate/highlands), mixed crop-livestock (arid, humid, temperate/highlands), and other, for ruminants; smallholders and industrial for monogastrics. For each species, production system, and region, a set of input-output parameters is calculated based on the approach by Herrero et al. (2013[56]). Feed rations are defined consisting of grass, stovers, feed crops aggregates and other feedstuff. Outputs include four meat types, milk and eggs, and environmental factors (manure production, N-excretion, and GHG emissions). The initial distribution of the systems is based on Robinson et al. (2011[57]). Switches between the across systems allow for feedstuff substitution and for intensification or extensification of livestock production.

Forestry

The forestry sector is represented in GLOBIOM with five categories of primary products (pulp logs, saw logs, biomass for energy, traditional fuel wood, and other industrial logs) which are consumed by industrial energy, cooking fuel demand, or processed and sold on the market as final products (wood pulp and sawn wood). These products are supplied from managed forests and short rotation plantations. Harvesting cost and mean annual increments are informed by the G4M global forestry model (Kindermann et al., 2006[58]) which in turn calculates them based on thinning strategies and length of the rotation period.

Representation of market and trade equilibrium

The structure of GLOBIOM is very similar to mathematical programming model applied to agriculture such as US FASOM (Schneider, McCarl and Schmid, 2007[59]). In GLOBIOM, market representation if based on FAOSTAT commodity balances for agriculture and for forestry products. Market prices are calibrated to farm gate prices from FAOSTAT, and market equilibrium and trade is determined through mathematical optimization which allocates land and other resources to maximize the sum of consumer and producer surplus (McCarl and Spreen, 1980[60]). As in other partial equilibrium models, prices are fully endogenous for the markets covered and exogenous for factors or inputs provided by other sectors of the economy (energy, fertilisers, machinery, etc.).

International trade is represented in GLOBIOM through Enke-Samuelson-Takayama-Judge spatial equilibrium assuming homogenous goods (Takayama and Judge, 1964[33]). Bilateral trade flows between the 37 economic regions are determined by the initial trade pattern, relative production costs of regions, and the minimization of trading costs. Trade costs are composed of tariffs from the MAcMap-HS6 database (Bouët et al., 2008[61]) and transport costs (Hummels, 2005[62]). A non-linear element is added in which trade costs increase with traded quantity to model persistency in trade flows via a constant elasticity function for trade flows observed in the base year, and a quadratic function for new trade flows. The non-linear element reflects the cost of trade expansion in terms of infrastructure and capacity constraints in the transport sector and is reset after each 10-year time step. Trade flows for the base year are calibrated following the calibration method proposed in Jansson and Heckelei (2009[41]). The bilateral trade flow distribution for GLOBIOM is based on data from the BACI database (Gaulier and Zignago, 2010[42]). Compared to other global economic models, GLOBIOM's trade representation is positioned between the rigid Armington approach of general equilibrium models and the flexible world pool market approach of many partial equilibrium models. Further information on the international trade representation in GLOBIOM is documented in Baker et al. (2018[63]).

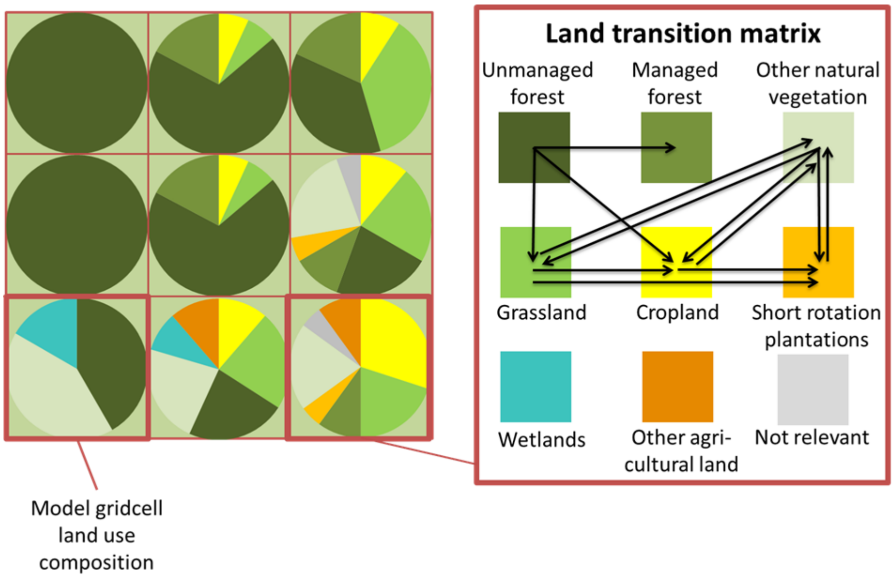
Representation of environmental accounts

GLOBIOM uses the globally gridded simulated crop yields and resource requirements (fertiliser, water, costs) from the crop model EPIC. Supply side activities are modelled in EPIC using a global grid of 212,707 grid cells which are based on the heterogeneity in land characteristics and thus vary in size between 5 x 5 arcminutes (10 km by 10 km square at the equator) and 30 x 30 arcminutes pixels (50 x 50 km at the equator). This information is then aggregated to determine input requirements and aggregated represented the model at 2 x 2 degrees resolution. The main inputs to crop and livestock are as follow:

Land

EPIC determines the land area needs for the crops, whereas ruminant pasture area needs depend on the grazing requirements as determined by the RUMINANT digestibility model, for the different livestock production systems. G4M also computes the harvest efficiency of managed forest and the area needs for plantation expansions. All these economic activities are then associated with their three respective land cover types: cropland, pasture land, managed forest, and short rotation plantations for newly planted areas with woody or lignocellulosic feedstock. These compete with two other land cover types: primary forest and other natural land. Three additional land cover types are also represented in the model: other agricultural land, wetlands, and not relevant areas (bare areas, water bodies, snow and ice, and artificial surfaces), but these are kept constant in the model. The base year spatial distribution of land cover is based on the Global Land Cover 2000 (GLC2000). Land conversion over the simulation period is endogenously determined for each *Supply Unit* within the available land resources. Such conversion implies a conversion cost – increasing with the area of land converted – that is taken into account in the producer optimisation behaviour. Land conversion possibilities are further restricted through biophysical land suitability and production potentials, and through a matrix of potential land cover transitions Figure A A.1.

Figure A A.1. Land cover representation in GLOBIOM and the matrix of endogenous land cover change possibilities



Source: Havlik et al. (2014[64]).

Water

The representation of irrigated cropland production systems considers both the biophysical suitability and irrigation water requirements of crops at a monthly level which is simulated by EPIC and harmonised with the country-level FAO AQUASTAT statistics for water withdrawn for irrigation available from AQUASTAT (FAO, 2015[65]). Four irrigation systems are modelled at a high spatial resolution for irrigated cropland: sprinkler, basin, drip and furrow irrigation (Sauer et al., 2010[66]). The final irrigation water demand for crops for a given land unit depends on the application efficiency of each system. The source of water supplying that supplies irrigation water demand is split into three categories: irrigation sourced by surface water, irrigation sourced by groundwater, and irrigation sourced by non-renewable sources. Surface water availability is sourced from mean monthly runoff estimated by LPJml (Bondeau et al., 2007[67]) and re-distributed according to the average discharge rates in each river basin to have a good spatial representation of water availability aggregated to the land units of GLOBIOM (Schewe et al., 2014[68]). Irrigated areas from groundwater are sourced from spatially explicit data from Siebert and Döll (2010[69]), from which we determine the share of irrigated area at the 0.5 degree level sourced by surface water and groundwater.

The impact of the different scenarios on water use is implemented in the model through a detailed representation of rain fed and irrigated systems (Palazzo et al., 2019[70]). Water needs of these systems are estimated through the EPIC crop model and used to drive the demand for irrigation water. Change in precipitation in rain fed systems directly affect crop yield in the biophysical modelling, whereas it affects irrigation water demand in the case of irrigated systems. In the case of GLOBIOM, water availability information is preserved as a monthly constraint for the management of the water cycle and irrigation water demand. The monthly irrigation water demand at aggregated land units is based on globally gridded crop model projections of crop water requirements and monthly cropping calendars and is limited by the water available at the monthly level from all sources at aggregated land units (Pastor et al., 2014[71]). Irrigated area that cannot be supplied with water is converted to rain fed area. This method has the benefit of capturing the impact of water scarcity for low flow months, with the limitation that water storage strategies to redistribute the flow between months are not here considered. The model however represents the conjunctive use of water from surface and groundwater sources to supplement during low flow months. Because GLOBIOM solves for the full year at once, it is also assumed that farmers have perfect foresight about whether water will be available for each month before deciding using an irrigated system instead of a rain fed one.

GLOBIOM also captures the constraints related to the full water cycle and the impact of climate change on the water run-off to determine water availability for irrigation. This takes into account the withdrawals of other sectors than agriculture (domestic demand, industry), though the linkage with a global hydrological model PCRGLOB (Wada, Wisser and Bierkens, 2014[72]). For the present analysis, we consider the change of water availability associated with the expansion of these other sectors over time (Wada, Wisser and Bierkens, 2014[72]), but the interaction effect of climate change on the water supply is not included. This means water available for use by irrigation is only impacted by the change of water withdrawals from irrigation, for a fixed amount of available water for the year considered.

GHG emissions and soil organic carbon

The different activity models used for GLOBIOM input data allow for a precise account of GHG emissions, most of the time corresponding to the Tier 2 criteria of the IPCC AFOLU guidelines (Valin et al., 2013[73]). For crops, rates of synthetic fertiliser use are calculated using the output from the EPIC model, after harmonization with the consumption statistics from the International Fertilizer Association. Methane emissions from rice cultivation are computed using area harvested and the emission factor provided by EPA. Livestock emissions are sourced from the RUMINANT model which has been applied in each country to the different livestock systems from the Sere and Steinfeld classification. Three GHG sources are considered: enteric fermentation (CH4), manure management (CH_4 and N_2O), and manure applied to pasture (N_2O). Land use change emissions are provided through carbon stock data from the G4M model, consistent with FAO inventories. Forest conversion to agricultural land or plantation is considered to release all the carbon contained in above- and below-ground living biomass into the atmosphere. Carbon stocks for land use types other than forests are sourced from the Ruesch and Gibbs database (Ruesch and Gibbs, 2008[74]). Soil organic carbon balance follows IPCC Tier 1 methodology and, hence, it assumes that converting cropland to grassland leads to SOC sequestration. However, grassland remaining grassland for more than 20 years are considered with constant SOC.

Regional aggregation

The version of GLOBIOM used for this analysis is structured around 37 regional markets, but the results have been aggregated at the level of 14 macroregions to better describe the distribution of the effects. Table A A.1 below indicates the correspondences between the level of results reporting (first column), the model initial regions (second column) and the individual countries represented in the model.

Table A A.1. List of regions used in the study, and mapping with model regions and countries

Macro region	GLOBIOM regions	Countries
EU and EFTA (EUR)	EU Baltic	Estonia, Latvia, Lithuania
	EU Central East	Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia
	EU Mid-West	Austria, Belgium, Germany, France, Luxembourg, Netherlands
	EU North	Denmark, Finland, Ireland, Sweden, United Kingdom
	EU South	Cyprus,[1] Greece, Italy, Malta, Portugal, Spain
	ROWE	Gibraltar, Iceland, Norway, Switzerland
Commonwealth of Independent States and Rest of Eastern Europe (CIS)	Russia	Russian Federation
	Other Former USSR	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Tajikistan, Turkmenistan, Uzbekistan
	Ukraine	Ukraine
	RCEU	Albania, Bosnia and Herzegovina, Croatia, Macedonia, Serbia-Montenegro
United States of America (USA)	United States of America	United States of America
Canada (CAN)	Canada	Canada
Brazil (BRA)	Brazil	Brazil
Rest of Latin America (RLA)	Mexico	Mexico
	Argentina	Argentina

Macro region	GLOBIOM regions	Countries
	RCAM	Bahamas, Barbados, Belize, Bermuda, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Netherland Antilles, Panama, St Lucia, St Vincent, Trinidad and Tobago
	RSAM	Argentina, Bolivia, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela
China (CHN)	China	China
Australia (AUS)	Australia	Australia
New Zealand (NLZ)	New Zealand	New Zealand
Japan (JPN)	Japan	Japan
Korea and the Pacific (KPA)	Korea	Korea
	Pacific Islands	Fiji Islands, Kiribati, Papua New Guinea, Samoa, Solomon Islands, Tonga, Vanuatu
India (IND)	India	India
Rest of Asia (RAS)	Indonesia	Indonesia
	Malaysia	Malaysia
	RSEA OPA	Brunei Daressalaam, Singapore, Myanmar, Philippines, Thailand
	RSEA PAC	Cambodia, Korea DPR, Laos, Mongolia, Viet Nam
	RSAS	Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka
Africa, Middle East and Turkey (AFR)	Congo Basin	Cameroon, Central African Republic, Congo Republic, Democratic Republic of Congo, Equatorial Guinea, Gabon
	Eastern Africa	Burundi, Ethiopia, Kenya, Rwanda, Tanzania, Uganda
	South Africa	
	Southern Africa (Rest of)	Angola, Botswana, Comoros, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Swaziland, Zambia, Zimbabwe
	West and Central Africa	Benin, Burkina Faso, Cape Verde, Chad, Cote d'Ivoire, Djibouti, Eritrea, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Somalia, Sudan, Togo
	North Africa	Algeria, Egypt, Libya, Morocco, Tunisia
	Middle East	Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen
	Turkey	Turkey

1. Note by Turkey: The information in this document with reference to “Cyprus” relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the “Cyprus issue”.
Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

Annex B. Modelling scenarios description

Baseline Scenario

Under SSP2 technical change is assumed to continue but no specific adaptation technologies are considered other than endogenous responses on management, crop switching, area expansion and crop reallocation. Some projections under this pathway are (Fricko et al., 2017[51]):

- By 2100, final energy demand is 2.7 times higher than its value in 2010.
- Global population reaches 9.4 billion people (44% higher than global population in 2010) by 2070, and slowly declines thereafter.
- Per capita GDP increases by a factor of 6 by the end of the century as compared to 2010 levels, reaching USD 60 000/year.
- Human consumption of crops is projected to increase by 41% until 2050 and return to this level by 2100, after peaking around 2070.
- Global crop production increases by 84% in 2100 relative to 2010.
- Crop production expands because of increased intensification and additional cropland, which is projected to increase by 25% relative to 2010.
- Biomass demand (and production) for energy increases by 8% in 2050, relative to 2010.

Tariff data from the Market Access Map (MAcMap) database at the HS6 digit level (Gaulier and Zignago, 2010[42]) is the most comprehensive harmonised database at the HS6 digit level on tariff measures available for a large number of countries and covering most of the tariff lines. The overview of protection levels, as implied by tariffs (including TRQs) in the reference year 2010 are illustrated in Table A B.1. As the figure shows, the level of protection varies strongly depending on the regions and sectors. Crop markets are usually relatively open, except for rice and sugar crops. However, the level of protection for crops is concentrated in Japan (JPN) and Korea and Pacific Islands (KPA). In the case of the livestock sectors, higher level of protection are observed in many regions, in particular, the European Union and EFTA (EUR), Africa, Turkey and the Middle East (AFR), India (IND) and the United States (USA).

Table A B.1. *Ad valorem* tariffs in baseline scenario in importing regions (%)

	WHT	RIC*	CGR	SOY	PLM	OSN	SGC	**CRP**	BEF	LMB	PRK	PTM	EGG	DRY	**LSP**	**AGR**
AFR	12.7	10.5	16.2	8.6	10.2	8.0	23.5	**11.9**	41.5	32.3	30.6	20.6	10.7	29.1	**31.2**	**18.3**
AUS	3.3	0.0	0.7	0.5	0.6	2.9	0.8	**1.4**	1.8		0.2			3.3	**1.6**	**1.5**
BRA	5.8	8.5	7.3	3.3	9.1	7.8	11.2	**6.8**	9.6	9.3	8.9	8.0	2.6	14.9	**10.9**	**8.2**
CAN	14.6	0.2	16.1	1.2	1.4	3.3	0.3	**7.0**	12.2	0.1	2.1	46.4	23.5	112.7	**49.2**	**21.3**
CHN	40.9	43.9	26.2	2.5	7.9	7.1	34.7	**21.9**	12.4	12.4	12.9	6.6	14.1	10.1	**10.7**	**18.1**
CIS	10.1	8.0	6.0	5.2	3.0	5.9	26.7	**8.1**	18.7	10.6	21.3	25.1	5.1	11.6	**17.6**	**11.3**
EUR	10.3	21.1	12.9	4.8	4.6	4.5	22.5	**9.8**	51.6	18.5	24.6	31.4	15.1	19.3	**31.6**	**17.0**
IND	27.8	50.5	23.3	3.8	45.7	11.7	50.9	**24.0**	53.9		93.2	77.7	26.6	49.0	**61.2**	**36.4**
JPN	56.4	300.5	26.0	3.7	0.1	4.7	27.1	**45.9**	33.5		29.6	8.3	14.6	47.6	**32.0**	**41.0**
NZL	2.1	0.1	3.2	2.1	0.4	0.0	0.4	**1.5**	0.5		3.8	2.0		1.6	**1.7**	**1.6**
RAS	6.3	12.4	6.1	6.4	3.7	5.0	9.6	**6.2**	7.2	3.3	8.6	13.1	7.6	7.9	**8.7**	**7.0**
RLA	11.6	9.2	10.2	5.1	7.5	6.3	18.6	**9.4**	13.9	3.1	14.6	46.8	13.2	24.3	**23.4**	**14.1**
KPA	4.5	371.2	153.5	80.5	4.2	8.0	8.2	**78.3**	24.6	13.4	16.3	19.8	12.9	32.7	**24.6**	**60.2**
USA	2.4	1.3	1.9	1.1	0.2	13.6	12.4	**3.0**	2.8	0.1	0.3	3.3	2.9	19.2	**7.8**	**4.6**
WLD	**12.0**	**40.5**	**19.3**	**9.5**	**6.6**	**6.1**	**19.1**	**14.1**	**26.6**	**13.2**	**20.6**	**24.3**	**11.0**	**23.1**	**23.5**	**17.3**

Note: AGR=All agricultural products, BEF=Beef, CGR=Coarse grain (maize, barley, sorghum, millet), CRP=All crops aggregate, DRY=Milk and dairy products, EGG=Eggs, LMB=Lamb, LSP=All livestock products, OSN=Other oilseeds (rapeseed, sunflower, groundnuts) and their products, PLM=Palm fruit and its products, PRK=Pig meat, PTM=Poultry meat, RIC=Rice, SGC=Sugar cane and its products, SOY=Soybean and its products and WHT=Wheat. AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA= Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States, WLD=World.
All data are based on MAcMap estimates for the year 2010, except for the exception of rice below.
* For rice, the high ad valorem tariffs are the result of the TRQ instruments in Japan and Korea. For Japan, the TRQ is based on ad valorem equivalent for the TRQ as calculated in MAcMap for 2010. For Korea, quantitative restrictions on rice imports were reflected in 2000 MacMap data but were not in 2010, as quotas had been progressively increased in line with the Marrakesh Agreement, before being replaced by a tariffication of rice in 2015. For the modelling, the initial MAcMap 2000 ad valorem equivalent estimate was used for model calibration to represent market access restrictions over the period instead of 2010 data with the lower ad valorem equivalent estimate. That estimate would have been different if an ad valorem equivalent of the TRQ had been used based on more recent trade data.
Source: MAcMap database (Guimbard et al., 2012[43]).

The export taxes data were obtained from the Export Restrictions in Agriculture Database (Estrades, Flores and Lezama, 2017[44]) for the most recent period of available data (2013-15). Export taxes concentrate in a few crop markets and regions (Table A B.2): the rice sector in Africa, Turkey and the Middle East (AFR), wheat (WHT), coarse grains (CGR), soybeans (SOY) and other oilseeds (OSN) in Rest of Latin America (RLA).

Table A B.2. Export taxes (% of domestic price)

Based on the 2013-15 period

	WHT	RIC	CGR	OCR	SOY	PLM	OSN	BEF	CRP	LSP	AGR
AFR	0.0%	51.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	3.7%
RLA	9.6%	0.9%	14.2%	0.4%	26.7%	0.0%	17.5%	7.2%	19.0%	3.9%	16.2%
CIS	6.6%	0.0%	0.0%	0.0%	0.2%	5.8%	2.1%	0.0%	3.2%	0.0%	2.5%
RAS	0.0%	0.0%	0.0%	1.5%	0.0%	3.8%	0.0%	0.0%	2.4%	0.0%	2.1%
WLD	1.3%	2.0%	1.3%	0.3%	8.0%	3.2%	3.8%	0.7%	3.4%	0.2%	1.9%

Source: Author’s calculations based on Estrades, Flores and Lezama (2017[44]).

Table A B.3 shows the trade costs associated with NTMs technical measures estimated by Cadot, Gourdon and van Tongeren (2018[17]) for the agricultural commodities considered in this report. NTM's trade costs tend to be high in livestock sectors and vary considerably by region.

Table A B.3 Trade costs of non-tariff measures (NTMs) in agriculture (% of domestic price)

	AFR	AUS	BRA	CAN	CHN	CIS	EUR	IND	JPN	NZL	RAS	RLA	KPA	USA	WLD
WHT	1.9	20.5	2.1	6.8	16.3	0.4	4.4	18.9	9.6	6.5	3.2	9.6	n.a.	20.9	5.4
CGR	28.8	34.9	12.6	69.3	0.2	19.4	20.6	4.6	11.1	9.4	26.5	35.7	n.a.	84.2	25.2
RIC	6.0	3.6	29.9	14.4	11.4	0.5	1.8	0.4	0.6	0.7	12.1	17.3	n.a.	0.8	6.8
SGC	18.3	82.0	82.7	50.7	4.4	3.8	41.6	4.8	17.9	46.3	15.4	48.9	n.a.	90.6	28.7
SOY	6.6	27.9	8.4	8.0	0.0	0.0	13.1	1.3	7.7	6.6	11.2	10.6	n.a.	4.4	7.9
PLM	0.5	0.9	0.4	0.7	5.7	0.0	3.9	3.1	1.1	0.0	4.0	3.5	n.a.	0.1	2.0
OSN	3.4	5.8	17.9	23.3	0.1	0.3	0.3	0.6	20.0	1.3	1.9	0.9	n.a.	7.0	3.1
CRP	8.4	23.6	15.3	23.5	7.0	3.0	12.7	7.1	9.6	9.4	12.4	16.7	n.a.	25.3	11.0
BEF	5.9	76.7	0.6	20.2	1.5	2.3	5.8	21.3	3.5	26.7	8.3	6.6	n.a.	17.0	8.8
LMB	6.9	6.1	11.1	11.1	0.0	0.0	0.5	0.0	0.0	0.0	4.1	1.2	n.a.	2.9	3.1
PRK	17.1	117.5	4.4	32.6	126.8	2.1	10.3	23.7	82.7	107.1	64.6	76.4	n.a.	40.4	37.4
PTM	24.2	93.9	72.9	86.3	19.8	2.4	20.4	35.8	81.6	56.2	23.9	27.8	n.a.	93.6	29.6
EGG	3.8	56.3	0.3	41.8	46.1	1.6	3.6	0.0	76.7	41.9	30.3	3.2	n.a.	32.2	14.0
DRY	25.9	76.5	29.8	36.3	86.7	2.3	3.0	31.8	10.9	20.7	42.3	34.9	n.a.	56.4	25.2
LSP	18.5	84.1	27.7	41.4	52.0	2.3	8.1	27.8	34.1	40.5	31.0	29.7	n.a.	51.0	22.7
AGR	12.1	45.0	19.8	29.7	23.0	2.8	11.1	14.5	18.3	20.4	19.0	21.4	n.a.	34.9	15.1

Note: Import-weighted ad-valorem equivalent estimates of NTMs. Regions with no data (n.a.) does not necessarily indicate that there are no trade costs or no relevant NTMs in those regions but rather that the estimation method did not produce any statistically significant results. AFR=Africa, Turkey and the Middle East AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States. WHT=Wheat, CGR=Coarse grain (maize, barley, sorghum, millet), RIC=Rice, SGC=Sugar cane and its products, SOY=Soybean and its products, PLM=Palm fruit and its products, OSN=Other oilseeds (rapeseed, sunflower, groundnuts) and their products, CRP=All crops aggregate, BEF=Beef, LMB=Lamb, PRK=Pig meat, PTM=Poultry meat, EGG=Eggs, DRY=Milk and dairy products, LSP=All livestock products, AGR=All agricultural products.
Source: Cadot, Gourdon and van Tongeren (2018[17]).

Table A B.4 shows the product specific commodity transfers excluding market price support from the OECD PSE database. The support presented in the table comes from the commodities studied in this report: barley, sorghum, wheat, beef and veal, eggs, maize, milk, poultry meat, rice, rapeseed, sunflower, sheep meat, cotton, soybeans, sugar, pig meat, palm oil and rye. Most of this type of support is concentrated in large economies such as CHN, EUR, JPN and USA and are particularly significant for coarse grains (CGR), soybeans (SOY), and beef (BEF) and dairy products (DRY).

Table A B.4. Single commodity transfer payments considered for the reform scenarios (million USD)

Based on 2017-19 PSE data. Market price support is not included.

	WHT	RIC	CGR	SGC	SOY	OSN	BEF	LMB	DRY	PRK	PTM	EGG	CRP	LSP	AGR
AFR	183		48	47		117	0		2		8	14	825	25	849
CAN	110		68		35	120	37		35	53			360	124	484
BRA	26	15	119	20	199		68		1	3	5		389	77	465
CHN			1492		1892								8421		8421
IND				116			58		16				116	74	190
AUS				143					2				143	2	145
JPN	309	413	89	275	216		112		396			27	1302	535	1837
EUR	95	64	1	213			2115	722	1444	46	13		379	4341	4720
RLA	44	9	124	14	21		83		42	5	0		212	130	342
CIS		3					118	12	377	24	38	27	12	595	607
RAS		267	39	1	5		41		1	0	14		311	55	367
KPA		675											675		675
USA	720	57	2423	33	3866		1	0	351	263			8061	615	8676
WLD	1495	1504	4414	897	6234	237	2728	864	3303	406	79	69	21260	7448	28708

Note: AFR=Africa, Turkey and the Middle East AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States. WHT=Wheat, CGR=Coarse grain (maize, barley, sorghum, millet), RIC=Rice, SGC=Sugar cane and its products, SOY=Soybean and its products, OSN=Other oilseeds (rapeseed, sunflower, groundnuts) and their products, CRP=All crops aggregate, BEF=Beef, LMB=Lamb, PRK=Pig meat, PTM=Poultry meat, EGG=Eggs, DRY=Milk and dairy products, LSP=All livestock products, AGR=All agricultural products.
Source: OECD (2020[46]).

Climate change scenario

This report focuses on climate change scenarios RCP 2.6, RCP 4.5 and RCP 8.5. RCP 2.6 is the scenario with the least warming potential, where emissions start declining by 2020 and radiative forcing levels (GHG emissions) peak at 3 W/m^2 and decline up to 2.6 W/m^2 by 2100. RCP 4.5 is a medium warming scenario, where radiative forcing levels reach 4.5 W/m^2 by 2100 and remain stable afterwards. RCP 8.5 is the strongest climate change scenario, where radiative forcing increases up to 8.5 W/m^2 by 2100. Climate change is projected to the year 2100, but the results in this report are shown for the year 2050. GLOBIOM takes uses the temperature and precipitation data from GCMs for projecting changes in yields and production.

Projected temperature and precipitation changes in this GCM model vary widely by region and by season (Müller and Robertson, 2014[75]). By 2050, regional temperature increases range from a maximum of 5.5 degrees to a minimum of 1.45 degrees. Higher latitudes are projected to experience the largest temperature increases. Projected changes in annual precipitation also vary widely by region, with some regions experiencing a 49% increase and others a 29% decline (Müller and Robertson, 2014[75]). The information from climate models is available at the 0.5 x 0.5 degrees of spatial resolution and used in combination with the agronomic model Environmental Policy Integrated Climate (EPIC) to project the change in yields under different management assumptions (low input, high input, irrigated). Two alternative set-ups are available: with and without CO_2 fertilisation effects. Most of the literature that looks at the impacts of climate change on crop yields and production agrees that higher CO_2 atmospheric concentration levels have beneficial impacts on yields (Rosenzweig et al., 2018[76]). For long-term horizons, they tend to disagree on the magnitude of that effect, while for near-term horizons the discrepancies are less apparent (Rosenzweig et al., 2014[49]). In this study the climate change scenario inclusive of CO_2 fertilisation is considered to be the default climate change scenario.

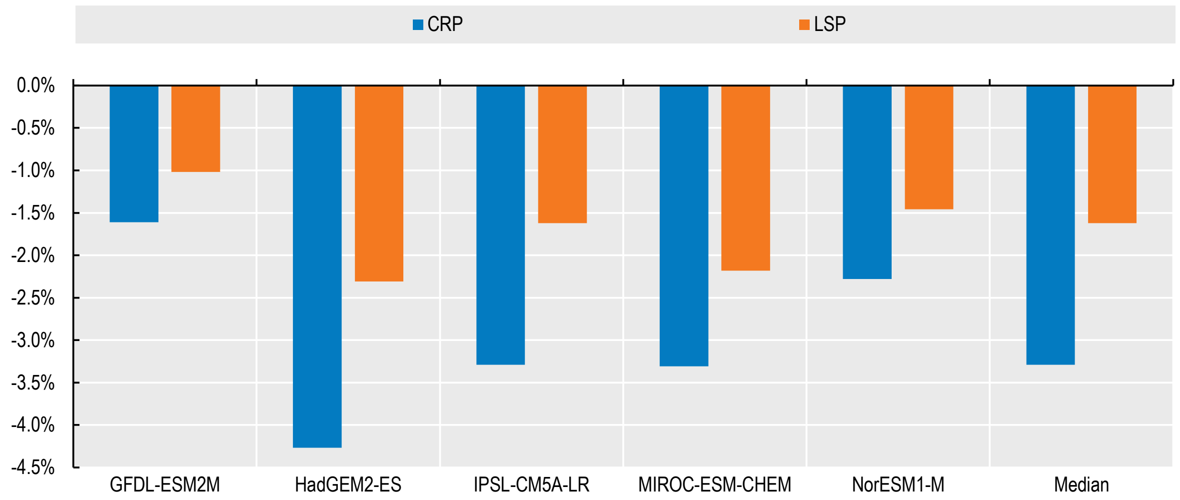
Annex C. Sensitivity analysis

Climate change impacts

This section analyses the sensitivity of climate impacts on key economic and environmental outcomes. It focuses on the impacts of the strongest climate change scenario (RCP 8.5) using five climatic models: GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M.

The climate change impacts on global crop and livestock production are negative in all GCMs but vary from as low as -1.6% for CRP and -1% for LSP up to -4.2% for CRP and -2.3% for LSP (Figure A C.1). The median effect is of -3.3% for CRP and -1.6% for LSP. Overall, the HadGEM2-ES GCM used throughout this report tends to report stronger impacts of climate change, in particular due to the lower precipitation response to temperature changes in that model (Warszawski et al., 2013[50]). The response of the EPIC crop model to the climatic and CO_2 concentration patterns are illustrated in more details in Leclère et al. (2014[77]).

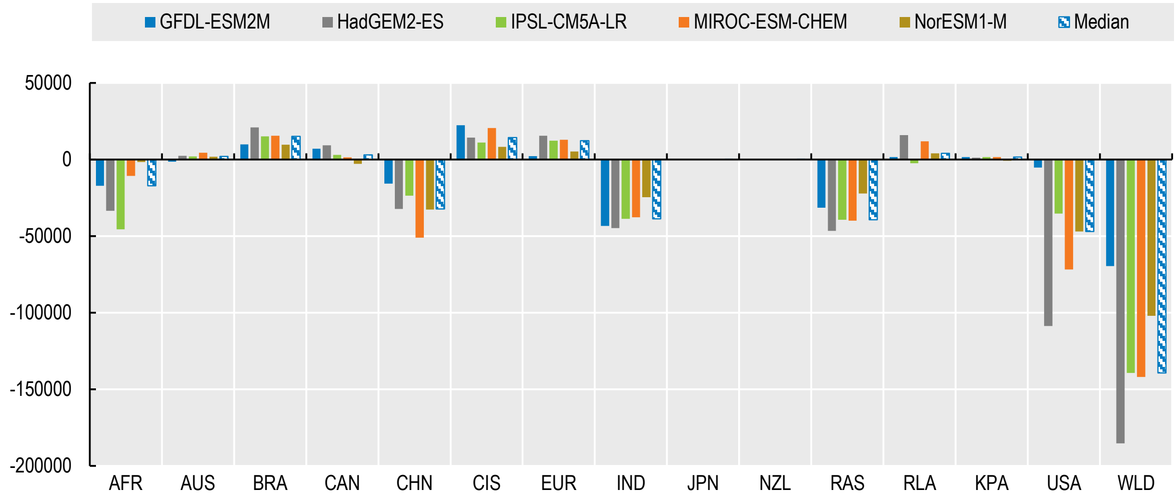
Figure A C.1. Climate change impacts on crop and livestock production across GCMs (%)



Note: CRP=All crops aggregate, LSP=All livestock products. The reference climate change scenario is RCP 8.5.

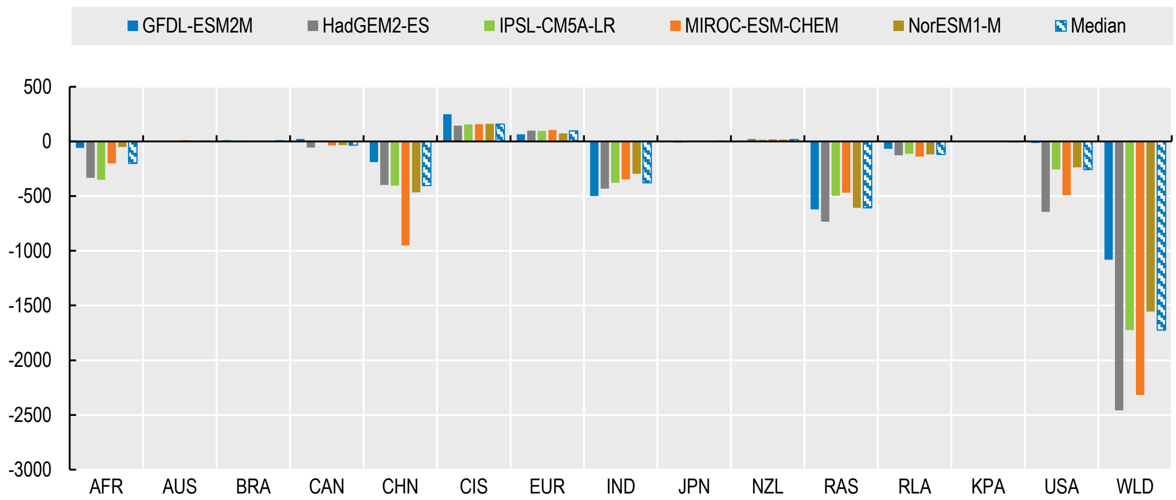
Models tend to show more variability on the regional production impacts of climate change. However, most of the models tend to report crop and livestock impacts in the same direction for the analysed regions (Figure A C.2 and Figure A C.3). The model HadGEM2-ES GCM reports stronger impacts on RAS and USA regions, while the model GFDL-ESM2M shows the lowest impacts for most regions. These differences relate to different spatial patterns in temperature increase, as well as in precipitation response across the models. In the case of the USA, in particular, temperature increases are strong in HadGEM2-ES around the corn belt and combined with relatively dry patterns compared to other models. This leads to dramatic decline in yield by 2050 for maize (-37%) and soybean (-35%) in North America under RCP 8.5 (see Supplementary information table ST3 in Leclere et al., 2014). This impact is not as strong with other climate models. More recent analysis using a broad spectrum of climate and crop models still suggests decline in maize and soybean yield would be among the strongest in the USA region compared to other world regions (Jägermeyr et al., 2021[78]). These impacts would still be strong by second half of the century for maize (stronger than -30%) but more moderate for soybean (lesser than -20%) according to these more recent simulations.

Figure A C.2. Climate change impacts on regional crop production across GCMs (1000 t dm)



Note: AFR=Africa, Turkey and the Middle East, BRA=Brazil, CAN=Canada, CHN=China, JPN=Japan, RLA=Rest of Latin America, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, RAS= Rest of Asia, AUS=Australia, NZL=New Zealand, KPA=Korea and Pacific Islands, USA=United States. The reference climate change scenario is RCP 8.5.

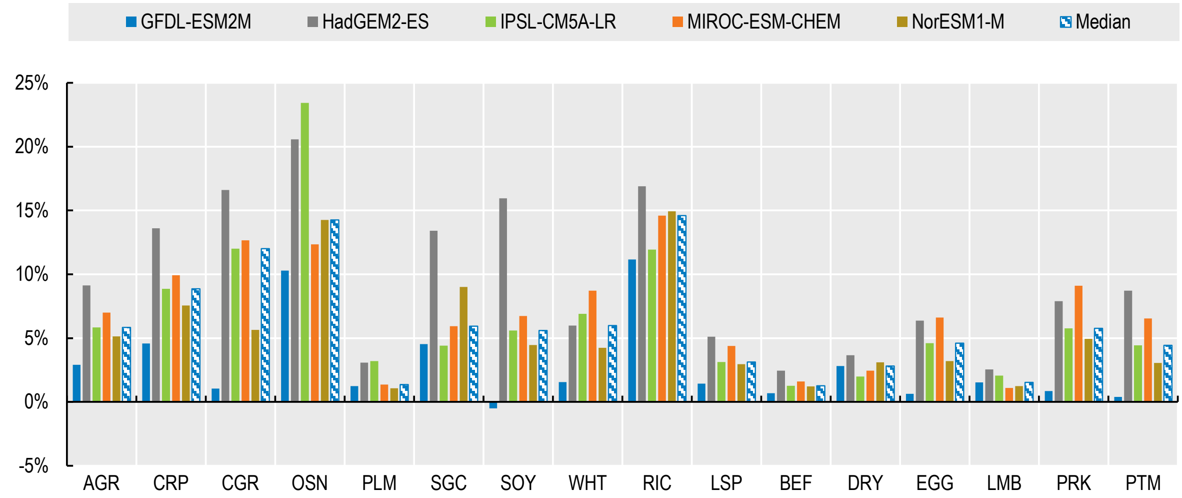
Figure A C.3. Climate change impacts on regional crop livestock production across GCM models (1000 t protein)



Note: AFR=Africa, Turkey and the Middle East, BRA=Brazil, CAN=Canada, CHN=China, JPN=Japan, RLA=Rest of Latin America, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, RAS= Rest of Asia, AUS=Australia, NZL=New Zealand, KPA=Korea and Pacific Islands, USA=United States, WLD=World. The reference climate change scenario is RCP 8.5.

Most models coincide on the direction of climate effects on aggregate agriculture prices (AGR) and across commodities. The estimated effects of climate change on agriculture prices (AGR) vary from as low as +3% to as high as +9%. The models also concur on reporting stronger effects for coarse grains (CGR), other oilseeds (OSN) and rice (RIC) (Figure A C.4).

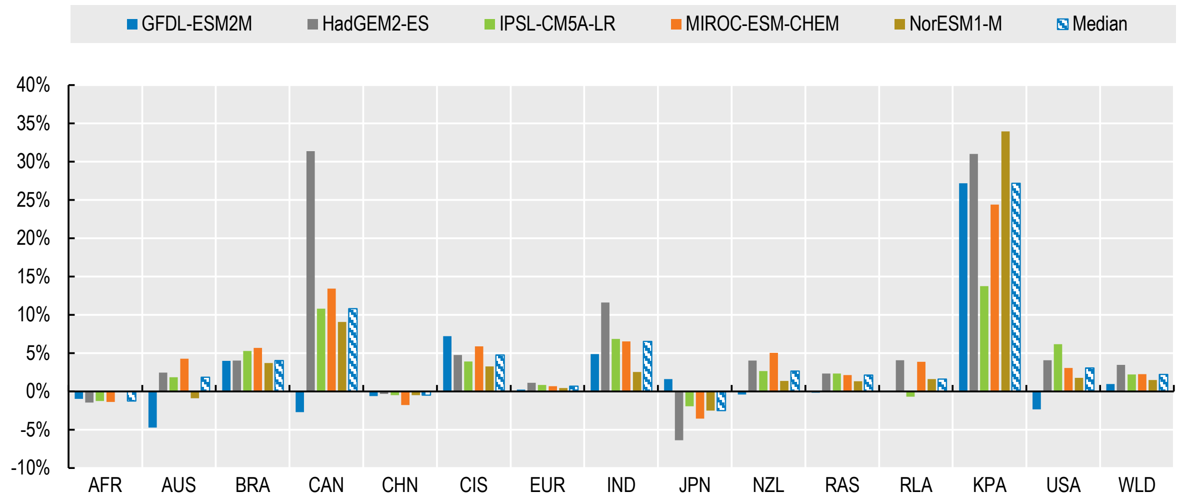
Figure A C.4. Climate change impacts on agriculture prices across GCMs (%)



Note: AGR=All agricultural products, CRP=All crops aggregate, CGR=Coarse grain (maize, barley, sorghum, millet), OSN=Other oilseeds (rapeseed, sunflower, groundnuts) and their products, PLM=Palm fruit and its products, SGC=Sugar cane and its products, SOY=Soybean and its products, WHT=Wheat, RIC=Rice, LSP=All livestock products, BEF=Beef, DRY=Milk and dairy products, EGG=Eggs, LMB=Lamb, PRK=Pig meat, PTM=Poultry meat. The reference climate change scenario is RCP 8.5.

All models show an increase in world farm revenues and most of them also coincide on the direction of the climate change effects on regional farm revenues (Figure A C.5). AFR, CHN and JPN will experience a decline on farm revenues while farm revenues in the other regions are expected to grow, with CAN and KPA experiencing the strongest growth.

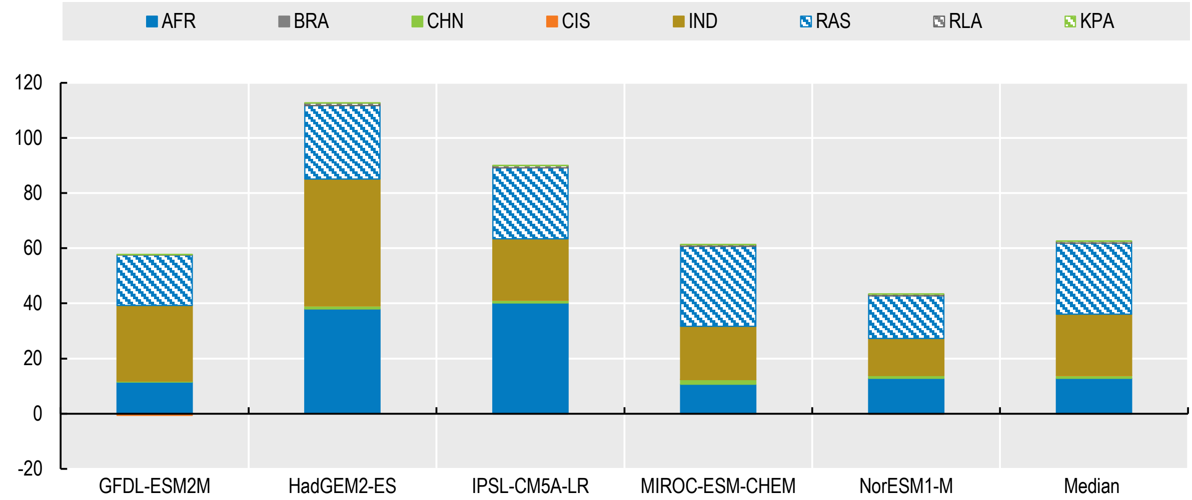
Figure A C.5. Climate change impacts on farm revenues across GCMs (%)



Note: AFR=Africa, Turkey and the Middle East, BRA=Brazil, CAN=Canada, CHN=China, JPN=Japan, RLA=Rest of Latin America, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, RAS= Rest of Asia, AUS=Australia, NZL=New Zealand, KPA=Korea and Pacific Islands, USA=United States, WLD=World. The reference climate change scenario is RCP 8.5.

The estimate effects of climate change on undernourishment are positive in all GCMs but vary in terms of magnitude from 43 million people to 112 million people (Figure A C.6). There are also some differences in the effects across regions.

Figure A C.6. Climate change impacts on undernourishment across GCMs (million people)

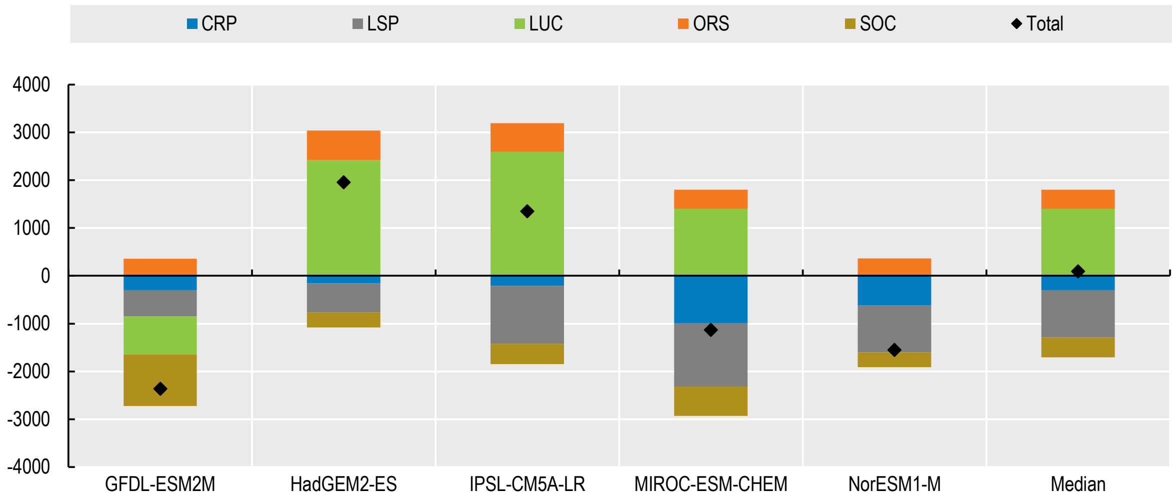


Note: AFR=Africa, BRA=Brazil, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, IND=India, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands. The reference climate change scenario is RCP 8.5.

The environmental effects of climate change tend to be less consistent across GCMs. AFOLU GHG emissions are reported to increase in two models and to decrease in the rest (Figure A C.7). The median effect is slightly positive, driven by LUC and ORS emissions. All models except one report an increase in LUC and ORS emissions and all models report declines in crop (CRP) and livestock (LSP) emissions. However, there are significant differences in the magnitude of those emissions.

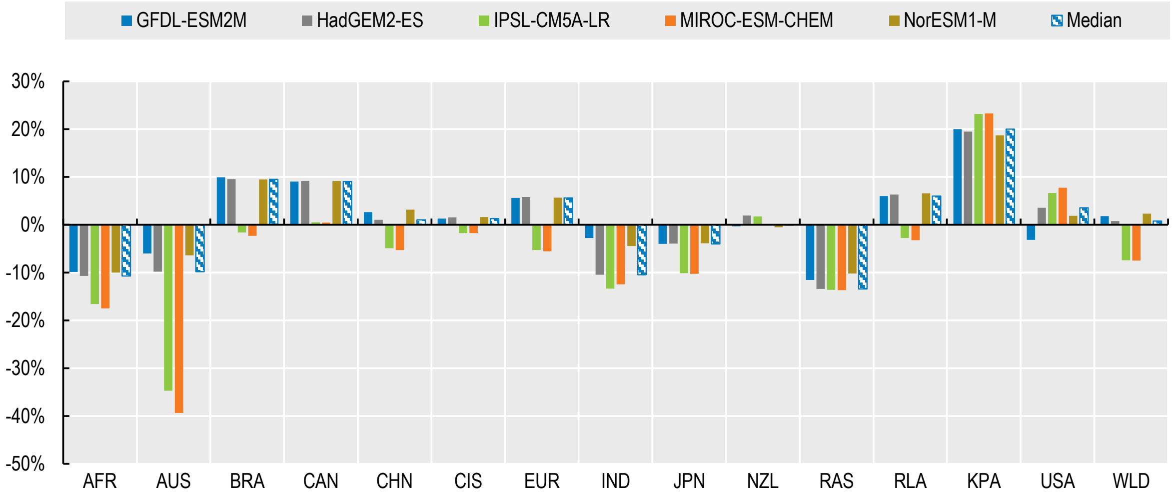
Models also show divergent impacts on the WEI at the global level (Figure A C.8), with three of them showing increases in the WEI and two showing declines. The median effect on the WEI is positive though, indicating an overall increase in water stress. The divergences in the global effects are driven by some differences across regions.

Figure A C.7. Climate change impacts on cumulative AFOLU GHG emissions (2010-2050) across GCMs (Mt CO_2eq)



Note: CRP=emissions from crop production, LSP= emissions from livestock production, LUC= land use change emissions, ORS=Organic soils emissions, SOC= soil organic carbon emissions. The reference climate change scenario is RCP 8.5.

Figure A C.8. Climate change impacts on Water Exploitation Index across GCMs (%)



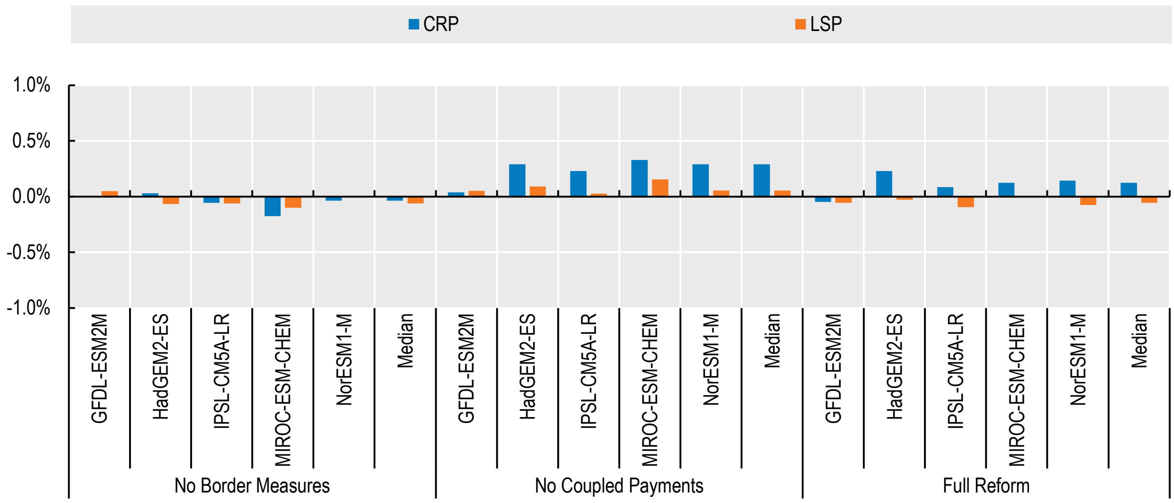
Note: AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States, WLD=World. The reference climate change scenario is RCP 8.5.

Adaptation effects of policy reform

This section analyses the sensitivity of adaptation effects on key economic and environmental outcomes. It focuses on the strongest climate change scenario (RCP 8.5) and on climate change impacts obtained from five climatic models: GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M.

All models project production adaptation gains from removing coupled payments (No Coupled Payments) (Figure A C.9). The effects of border measures are less consistent across models with some predicting gains and others predicting loses. Most models also project adaptation gains in agricultural production from fully removing distorting support.

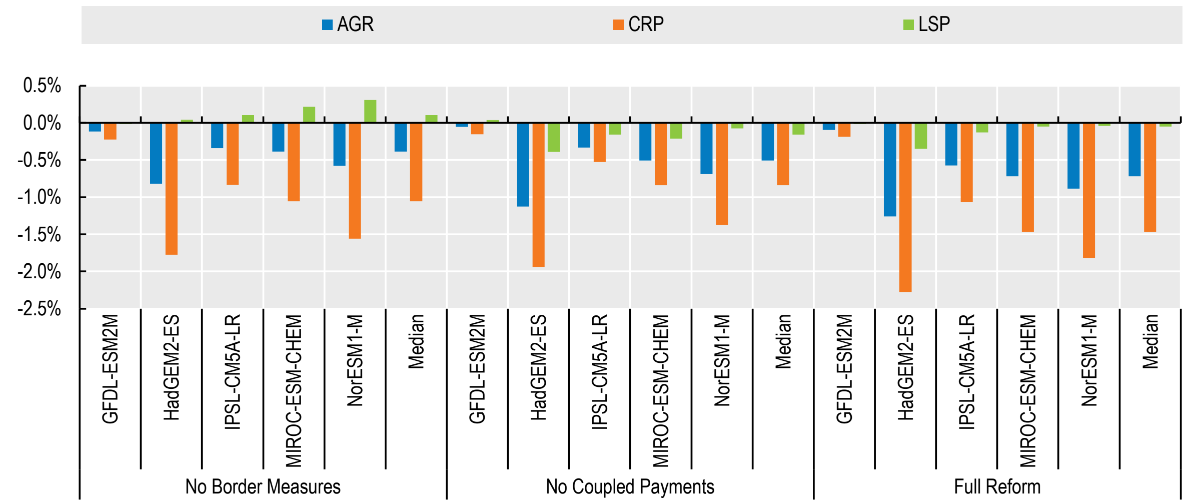
Figure A C.9. Adaptation effects of policy regimes on agricultural production across GCMs (percentage points)



Note: CRP=All crops aggregate, LSP=All livestock products. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. The reported outcome is the difference between the climate change effects under different policy regimes (the resulting economic and environmental outcomes with and without climate change under a given policy regime) and those obtained under current policies.

All models project lower price impacts in policy regimes that remove all distorting support (Full Reform) (Figure A C.10). The majority of the models also predict higher livestock price increases in the policy regime that removes all border measures (No Border Measures).

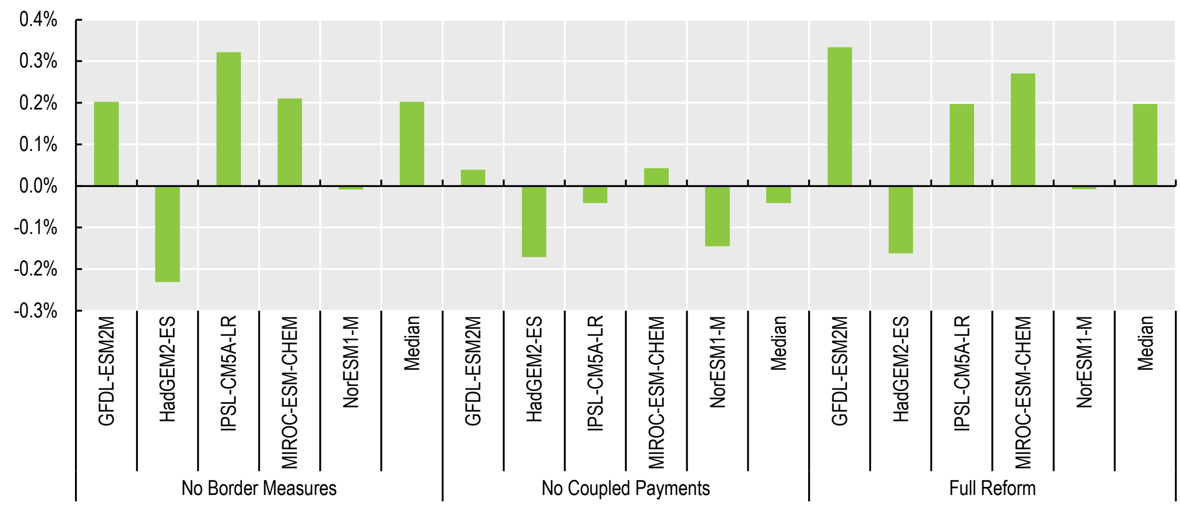
Figure A C.10. Adaptation effects of policy regimes on agriculture prices across GCMs (percentage points)



Note: AGR=All agriculture products, CRP=All crops aggregate, LSP=All livestock products. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. The reported outcome is the difference between the climate change effects under different policy regimes (the resulting economic and environmental outcomes with and without climate change under a given policy regime) and those obtained under current policies.

While most models predict higher growth of farm revenues under alternative policy regimes, the GCM uses in this report reports declines in alternative policy regimes than in current policies (Figure A C.11). The median effect is positive for No Border Measures and Full Reform scenarios.

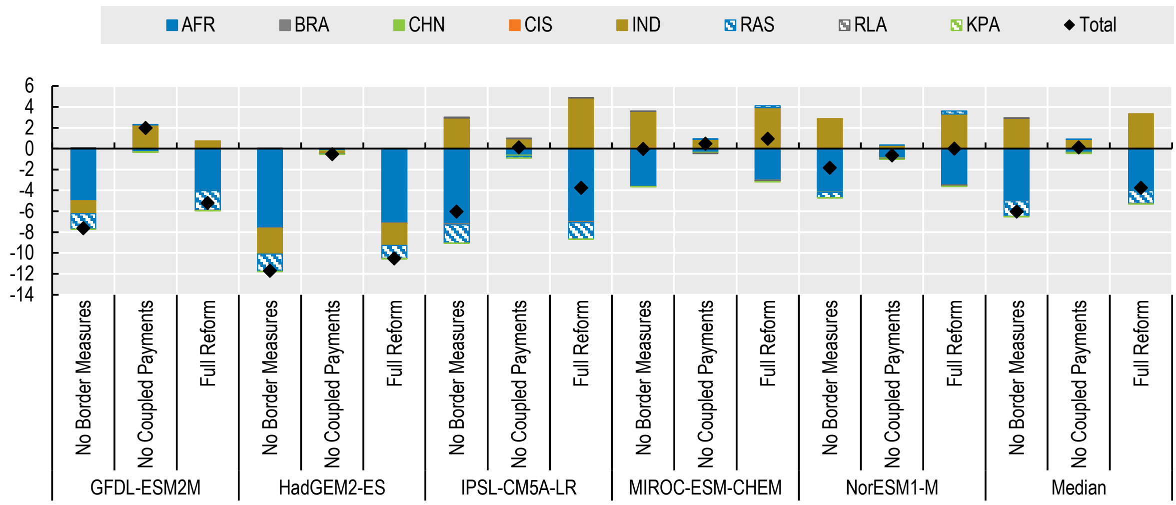
Figure A C.11. Adaptation effects of policy regimes on farm revenues across GCMs (percentage points)



Note: No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. The reported outcome is the difference between the climate change effects under different policy regimes (the resulting economic and environmental outcomes with and without climate change under a given policy regime) and those obtained under current policies.

The majority of models predict undernourishment adaptation gains from removing border measures (No Border Measures) and low gains or even loses for No Coupled Payments regimes (Figure A C.12). The median effect is negative for removing all distorting policies (Full Reform).

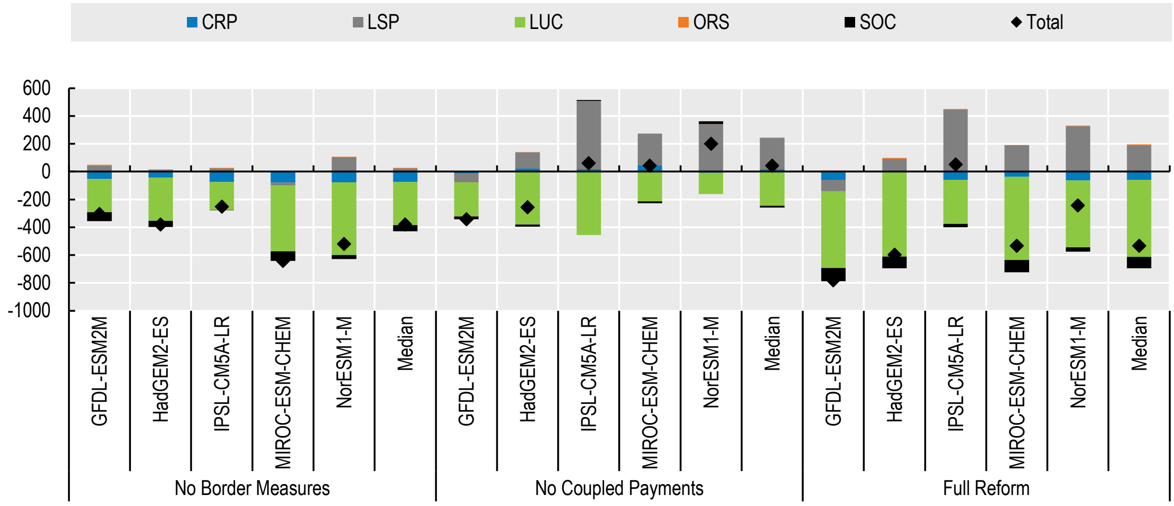
Figure A C.12. Adaptation effects of policy regimes on undernourishment across GCMs (million people)



Note: AFR=Africa, Turkey and the Middle East, BRA=Brazil, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, IND=India, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. The reported outcome is the difference between the climate change effects under different policy regimes (the resulting economic and environmental outcomes with and without climate change under a given policy regime) and those obtained under current policies.

The adaptation effects on AFOLU GHG emissions are consistent as most models observe lower AFOLU emissions growth in policy regimes that fully remove distorting support (Full Reform) (Figure A C.13). All models predict lower LUC emissions and SOC emissions in Full Reform. However, the models show divergent results on livestock emissions, with some models predicting strong increases while others predicting small increases and even negative effects.

Figure A C.13. Adaptation effects of policy regimes on cumulative AFOLU GHG emissions across GCMs (Mt CO_2eq)



Note: CRP=emissions from crop production, LSP= emissions from livestock production, LUC= land use change emissions, ORS=Organic soils emissions, SOC= soil organic carbon. Current policies: policies as in baseline. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. The reference climate change scenario is RCP 8.5. The reported outcome is the difference between the climate change effects under different policy regimes (the resulting economic and environmental outcomes with and without climate change under a given policy regime) and those obtained under current policies.

All models predict no significant adaptation gains from reform on water availability (the water exploitation index remains unchanged), except when border measure alone are removed (Figure A C.14).

Figure A C.14. Adaptation effects of policy regimes on WEI across GCMs (percentage points)

Note: No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments. The reference climate change scenario is RCP 8.5. The reported outcome is the difference between the climate change effects under different policy regimes (the resulting economic and environmental outcomes with and without climate change under a given policy regime) and those obtained under current policies.

Annex D. Regional effects

The following tables provide more insights into model results at regional level for production, land use change and greenhouse gas emissions. More results are available directly by the authors upon request.

Table A D.1. Climate change impacts on regional crop production (1000 t dry matter)

	CGR	OSN	PLM	RIC	SGC	SOY	WHT	Total
RCP 2.6	**1254**	**-8035**	**-2365**	**1803**	**-3872**	**-2652**	**-3620**	**-17487**
AFR	-4903	-3246	-1051	-2949	-4003	-13	6496	-9667
AUS	2	1393		36	122	31	910	2493
BRA	3965	-16	8	31	1906	-14	87	5967
CAN	-478	-1323				-572	3946	1573
CHN	-1823	-1216	92	443	-321	-9	-1355	-4189
CIS	3127	1735		16	0	162	9995	15035
EUR	3015	952		169	0	-237	5669	9568
IND	3183	340		8785	474	5540	503	18825
JPN	0	0		11	0	0	0	11
NZL	92	12					57	161
RAS	-1826	-734	-236	-3770	-3977	-55	-1782	-12379
RLA	1729	260	-62	768	297	2142	2079	7213
KPA	-34	-3	-68	9	1985	0		1889
USA	-4795	-518		-1747	-355	-9628	-30225	-47268
RCP 4.5	**-29884**	**-16148**	**-8477**	**-18003**	**-17945**	**-9377**	**-15417**	**-115251**
AFR	-12682	-6276	-1680	-4835	-5334	-79	4486	-26399
AUS	-139	407		17	155	92	515	1047
BRA	2527	43	25	-168	2521	5882	259	11089
CAN	-406	-934				-303	1353	-290
CHN	-7678	-1864	-157	-2130	-10140	-15	-1853	-23837
CIS	2364	1088		-9	0	160	5050	8652
EUR	4048	1626		274	0	-564	4201	9585
IND	-2271	-1358		-84	-2764	-2785	-2615	-11878
JPN	0	0		27	0	0	0	27
NZL	109	12					20	141
RAS	-4064	-1011	-126	-10017	-4297	-1562	-5941	-27018
RLA	-636	489	-278	1032	220	3790	1283	5900
KPA	10	-5	-55	92	2122	0		2163
USA	-11067	-693		-2203	-427	-13993	-22175	-50556
RCP 8.5	**-65609**	**-13624**	**-4328**	**-36927**	**-32472**	**-15977**	**-16429**	**-185366**
AFR	-16523	-8283	-2675	-6035	-7859	-183	8020	-33537
AUS	-161	687		106	245	95	1568	2540
BRA	5087	71	72	-120	2737	13322	-119	21050
CAN	-1895	-1481				-1047	13791	9368
CHN	-11024	-3146	-159	-3895	-11149	-15	-2787	-32175
CIS	3479	1735		1	0	75	9088	14377
EUR	5653	2178		855	0	424	6512	15623
IND	-7541	-3028		-8892	-9862	-8130	-7268	-44722
JPN	0	0		29	0	0	0	29
NZL	182	18					8	208
RAS	-7677	-1668	-1364	-16148	-8118	-2232	-9412	-46618
RLA	2116	1021	-151	1778	490	7918	2818	15990
KPA	-106	-7	-51	-534	1966	0		1268
USA	-37199	-1720		-4073	-920	-26206	-38648	-108766

Note: Colour shading indicates results magnitude (green = positive, red = negative). CGR=Coarse grain (maize, barley, sorghum, millet), OSN=Other oilseeds (rapeseed, sunflower, groundnuts) and their products, PLM=Palm fruit and its products, RIC=Rice, SGC=Sugar cane and its products, SOY=Soybean and its products, WHT=Wheat, CRP=All crops aggregate. AFR=Africa, Turkey and the Middle East, BRA=Brazil, CAN=Canada, CHN=China, JPN=Japan, RLA=Rest of Latin America, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, RAS= Rest of Asia, AUS=Australia, NZL=New Zealand, KPA=Korea and Pacific Islands, USA=United States.

Table A D.2. Climate change impacts on regional livestock production (1000 t protein)

	BEF	DRY	EGG	LMB	PRK	PTM	Total
RCP 2.6	**-55**	**-154**	**-17**	**-16**	**57**	**-22**	**-207**
AFR	-14	-4	-28	-9	-13	-67	-135
AUS	2	0	0	1	1	3	8
BRA	1	0	0	0	-3	-3	-5
CAN	-3	-8	0	-1	-4	0	-15
CHN	-17	-5	-7	-3	61	4	32
CIS	2	5	3	1	26	57	93
EUR	-3	5	10	2	38	17	70
IND	-11	-127	19	-5	27	0	-98
JPN	0	0	0	0	3	-2	0
NZL	2	4	0	4	1	0	11
RAS	-12	-19	-4	-5	-48	-12	-101
RLA	6	3	-4	-1	-5	-1	-2
KPA	0	0	0	0	2	1	4
USA	-7	-9	-6	-1	-30	-17	-70
RCP 4.5	**-86**	**-485**	**-282**	**-63**	**-198**	**-329**	**-1443**
AFR	-18	-12	-56	-17	-29	-129	-261
AUS	2	3	0	0	-2	0	2
BRA	7	0	0	0	-1	1	7
CAN	-4	-5	1	0	-9	-6	-23
CHN	-17	-6	-140	-21	-57	-19	-260
CIS	3	2	0	-1	18	100	123
EUR	-4	16	5	1	36	15	68
IND	-17	-196	-35	-12	-28	0	-288
JPN	0	0	-1	0	3	-2	-1
NZL	1	8	0	2	1	0	11
RAS	-35	-287	-22	-11	-53	-56	-464
RLA	4	-1	-13	-2	-27	-36	-74
KPA	0	-1	0	0	-1	1	-1
USA	-6	-7	-20	-1	-49	-200	-283
RCP 8.5	**-142**	**-715**	**-512**	**-78**	**-372**	**-639**	**-2459**
AFR	-18	-26	-66	-20	-34	-167	-332
AUS	4	5	-1	-1	-5	-4	-2
BRA	8	2	-3	0	-6	9	11
CAN	-9	-16	-1	-1	-16	-15	-57
CHN	-31	-46	-195	-26	-83	-17	-398
CIS	4	8	2	0	27	104	145
EUR	-3	20	-1	1	64	18	100
IND	-14	-212	-96	-17	-92	0	-432
JPN	0	0	-2	0	-2	-6	-11
NZL	3	12	0	6	2	0	22
RAS	-49	-398	-69	-14	-59	-143	-732
RLA	2	-7	-25	-4	-41	-52	-127
KPA	0	-1	0	0	-2	0	-3
USA	-39	-57	-53	-3	-126	-366	-644

Note: Colour shading indicates results magnitude (green = positive, red = negative). BEF=Beef, DRY=Milk and dairy products, EGG=Eggs, LMB=Lamb, PRK=Pig meat, PTM=Poultry meat. AFR=Africa, Turkey and the Middle East, BRA=Brazil, CAN=Canada, CHN=China, JPN=Japan, RLA=Rest of Latin America, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, RAS= Rest of Asia, AUS=Australia, NZL=New Zealand, KPA=Korea and Pacific Islands, USA=United States.

Table A D.3. Climate change impact on land use change (1000 ha)

	CRP	GRS	FOR	ONV
RCP 2.6	**-6678**	**-5798**	**-2847**	**15313**
AFR	2016	-1714	301	-604
AUS	-342	-108	0	450
BRA	-398	55	-346	688
CAN	-2655	1247	0	1409
CHN	315	-384	0	-89
CIS	-1784	80	0	1704
EUR	-2302	-330	0	2631
IND	1114	-1611	0	498
JPN	-38	1	0	37
NZL	-12	112	0	-100
RAS	4989	-1469	-1527	-1844
RLA	1497	65	-1265	-298
KPA	54	-7	-11	-36
USA	-9132	-1737	0	10868
RCP 4.5	**7025**	**-13396**	**-2845**	**9192**
AFR	3909	-5090	651	535
AUS	559	-559	0	0
BRA	210	664	-410	-465
CAN	-346	477	0	-131
CHN	498	-1741	0	1295
CIS	-1703	-2	0	1705
EUR	-3606	-334	0	3938
IND	2563	-2264	0	-257
JPN	-86	2	0	84
NZL	-27	-37	0	64
RAS	1764	-1058	-1621	794
RLA	2236	92	-1450	-878
KPA	82	-20	-16	-46
USA	970	-3524	0	2553
RCP 8.5	**17891**	**-18437**	**-6295**	**6823**
AFR	6226	-6455	683	-455
AUS	630	-630	0	0
BRA	1522	-672	-1003	152
CAN	1877	-422	0	-1455
CHN	346	-2302	0	2000
CIS	-2610	43	0	2567
EUR	-3903	-310	0	4213
IND	4789	-2931	0	-1856
JPN	-105	3	0	102
NZL	-31	158	0	-127
RAS	1368	-570	-3130	2270
RLA	3519	516	-2829	-1206
KPA	-38	-10	-16	64
USA	4299	-4853	0	553

Note: Colour shading indicates results magnitude (green = positive, red = negative). CRP=Cropland, GRS=Grassland, FOR=Forest, ONV=Other natural vegetation areas. AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States.

Table A D.4. Climate change impacts on regional GHG emissions (Mt CO_2eq)

	CRP	LSP	LUCF	LUCG	LUCN	ORS	SOC	Total
RCP 2.6	**76**	**45**	**949**	**91**	**-627**	**437**	**-487**	**485**
AFR	-23	-57	-116	31	47		-8	-127
AUS	19	20	0	1	-23		-14	3
BRA	14	137	165	-2	-80		-38	196
CAN	-62	-23	0	-15	-18		-38	-156
CHN	20	-203	0	3	4		18	-158
CIS	66	34	0	-2	-22		-72	4
EUR	197	-20	0	7	-84		-114	-13
IND	75	-41	0	14	-62		-72	-86
JPN	-4	-3	0	0	-1		4	-3
NZL	8	18	0	-4	10		0	32
RAS	46	-26	572	37	241	437	60	1366
RLA	8	123	326	-2	48		38	541
KPA	-8	0	3	0	14		1	11
USA	-280	85	0	23	-701		-251	-1125
RCP 4.5	**226**	**-474**	**1015**	**177**	**-238**	**517**	**-515**	**708**
AFR	-73	-70	-265	76	-7		53	-286
AUS	6	8	0	6	0		-11	9
BRA	8	46	196	-20	54		-36	249
CAN	-23	-6	0	-6	2		3	-30
CHN	-1	-290	0	14	-63		23	-317
CIS	68	23	0	-1	-22		-82	-15
EUR	192	14	0	8	-142		-208	-136
IND	193	-218	0	20	32		-167	-140
JPN	-7	0	0	0	-2		0	-9
NZL	6	9	0	1	-7		-1	9
RAS	-74	-141	642	29	-84	517	-82	808
RLA	-5	61	437	4	152		50	698
KPA	-1	-1	5	1	15		0	18
USA	-63	90	0	46	-165		-57	-149
RCP 8.5	**-157**	**-605**	**2225**	**253**	**-55**	**618**	**-318**	**1960**
AFR	-15	-82	-295	99	110		88	-96
AUS	13	16	0	7	0		-5	30
BRA	19	93	479	20	-18		-13	581
CAN	37	-20	0	5	18		59	100
CHN	-107	-473	0	18	-98		21	-638
CIS	104	18	0	-1	-36		-113	-29
EUR	270	16	0	7	-137		-212	-56
IND	70	-174	0	26	232		-157	-3
JPN	-10	-3	0	0	-2		3	-12
NZL	8	25	0	-6	13		-1	40
RAS	-143	-168	1222	20	-308	618	-91	1149
RLA	74	187	814	-5	193		95	1359
KPA	-8	0	5	0	14		0	12
USA	-469	-41	0	63	-36		8	-475

Note: Colour shading indicates results magnitude (green = positive, red = negative). CRP=emissions from crop production, LSP= emissions from livestock production, LUCF= land use change emissions from forests, LUCG= land use change emissions from grasslands, LUCN= land use change emissions from other natural areas, ORS=Organic soils emissions, SOC= soil organic carbon. AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States.

Table A D.5. Policy reform impacts on regional crop production (1000 t dry matter)

	CGR	OSN	PLM	RIC	SGC	SOY	WHT	Total
No Border Measures	**3537**	**451**	**1571**	**2745**	**5448**	**2504**	**-3558**	**12906**
AFR	-3909	-664	-244	940	-4504	-251	-571	-9717
AUS	176	155		987	219	-11	84	1534
BRA	3351	-61	-122	-591	2465	1326	1817	8098
CAN	-43	-131				20	-28	-190
CHN	-235	-261	-1133	3460	-245	0	-350	1281
CIS	-1855	350		-170	0	-29	-1124	-3442
EUR	528	254		809	0	-1499	-1337	-1083
IND	870	519		3439	1879	-7539	920	1161
JPN	0	0		-7810	0	0	0	-7810
NZL	47	0					-69	-28
RAS	100	-175	3224	4541	1612	-123	-514	8626
RLA	668	1501	-155	-346	2164	11749	-2266	13232
KPA	-547	-60	0	-3362	2578	0		-1351
USA	4387	-976		849	-720	-1139	-120	2596
No Coupled Payments	**-16095**	**-438**	**0**	**-1124**	**-385**	**-4701**	**-912**	**-26867**
AFR	-5	-170	1	-109	16	0	-103	-1441
AUS	6	-32		195	-183	59	60	479
BRA	-246	13	0	-5	0	2231	-318	2056
CAN	-18	-164				32	381	187
CHN	-3032	57	0	-348	-51	0	55	-8166
CIS	69	29		0	0	10	299	469
EUR	-447	-119		-166	0	55	-450	-980
IND	-112	-32		-51	-46	-1179	279	-41
JPN	0	0		-64	0	0	0	-66
NZL	4	0					-3	2
RAS	-587	-27	-1	-488	-120	122	-6	-1097
RLA	-29	-328	0	113	16	3844	-99	4086
KPA	0	0	0	-292	0	0		-294
USA	-11698	334		90	-17	-9875	-1006	-22063
Full Reform	**-11181**	**172**	**1481**	**2093**	**5154**	**-2084**	**-4989**	**-11728**
AFR	-4027	-844	-244	745	-4472	-166	-890	-11366
AUS	169	118		987	7	47	-84	1598
BRA	3081	-55	-122	-592	2468	3002	1332	9379
CAN	-112	-344				55	453	-1
CHN	-1300	59	-1133	3758	-235	0	-36	-3095
CIS	-1768	358		-149	0	-37	-947	-3126
EUR	-264	116		738	0	-704	-1806	-1618
IND	746	461		3410	1846	-7680	888	1812
JPN	0	0		-7810	0	0	0	-7810
NZL	48	-3					-70	-31
RAS	-181	-201	3134	4123	1590	-109	-470	7897
RLA	532	1350	-155	-350	2128	14723	-2149	16556
KPA	-547	-60	0	-3677	2578	0		-1668
USA	-7560	-782		911	-755	-11214	-1209	-20255

Note: Colour shading indicates results magnitude (green = positive, red = negative). CGR=Coarse grain (maize, barley, sorghum, millet), OSN=Other oilseeds (rapeseed, sunflower, groundnuts) and their products, PLM=Palm fruit and its products, RIC=Rice, SGC=Sugar cane and its products, SOY=Soybean and its products and WHT=Wheat. AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA= Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments.

Table A D.6. Policy reform impacts of on regional livestock production (1000 t protein)

	BEF	DRY	EGG	LMB	PRK	PTM	Total
No Border Measures	**-13**	**189**	**30**	**21**	**43**	**79**	**347**
AFR	-39	-79	-7	2	14	-16	-125
AUS	28	75	0	-3	-1	2	102
BRA	125	31	0	0	4	27	187
CAN	4	-38	-1	0	7	-9	-37
CHN	-3	-25	11	14	-12	5	-9
CIS	-26	74	2	3	-23	-117	-88
EUR	-159	236	-2	-3	28	25	126
IND	4	55	2	4	17	0	83
JPN	-1	-70	4	0	-10	5	-72
NZL	13	99	0	4	-1	0	115
RAS	-1	51	4	1	2	24	83
RLA	40	18	-1	-2	-12	4	47
KPA	2	2	14	0	28	16	62
USA	0	-242	3	0	2	112	-125
No Coupled Payments	**-54**	**-75**	**-122**	**-8**	**-73**	**-91**	**-423**
AFR	0	-7	-3	0	2	-7	-15
AUS	1	0	0	0	0	-1	1
BRA	11	0	-3	0	-5	1	4
CAN	-1	-1	0	0	-2	0	-4
CHN	0	9	-82	-1	-48	-10	-132
CIS	-5	-16	0	-2	-2	6	-18
EUR	-55	-71	0	-9	2	0	-132
IND	1	10	-17	1	0	0	-5
JPN	-2	-3	0	0	0	-2	-7
NZL	0	-1	0	2	0	0	1
RAS	-2	-6	-6	1	-1	-16	-31
RLA	-2	2	-2	0	1	-6	-7
KPA	0	-1	0	0	-1	0	-2
USA	-2	9	-9	-1	-18	-57	-77
Full Reform	**-89**	**78**	**-29**	**5**	**8**	**9**	**-18**
AFR	-38	-80	-7	2	11	-19	-132
AUS	30	74	0	-2	0	0	101
BRA	118	32	-3	0	-1	27	173
CAN	3	-37	-1	0	5	-11	-41
CHN	-2	-21	-34	14	-5	9	-41
CIS	-11	29	2	1	-23	-112	-115
EUR	-237	148	-3	-15	32	21	-54
IND	4	51	2	1	14	0	72
JPN	-4	-70	4	0	-12	5	-76
NZL	13	101	0	5	-1	0	118
RAS	-1	51	4	1	-4	25	76
RLA	33	28	-1	0	-17	-5	38
KPA	3	0	14	0	27	16	59
USA	1	-228	-6	0	-17	54	-196

Note: Colour shading indicates results magnitude (green = positive, red = negative). BEF=Beef, DRY=Milk and dairy products, EGG=Eggs, LMB=Lamb, PRK=Pig meat, PTM=Poultry meat. AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA= Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments.

Table A D.7. Policy reform impacts on regional AFOLU GHG emissions (Mt CO_2eq)

	BEF	DRY	EGG	LMB	PRK	PTM	Total
No Border Measures	**-13**	**189**	**30**	**21**	**43**	**79**	**347**
AFR	-39	-79	-7	2	14	-16	-125
AUS	28	75	0	-3	-1	2	102
BRA	125	31	0	0	4	27	187
CAN	4	-38	-1	0	7	-9	-37
CHN	-3	-25	11	14	-12	5	-9
CIS	-26	74	2	3	-23	-117	-88
EUR	-159	236	-2	-3	28	25	126
IND	4	55	2	4	17	0	83
JPN	-1	-70	4	0	-10	5	-72
NZL	13	99	0	4	-1	0	115
RAS	-1	51	4	1	2	24	83
RLA	40	18	-1	-2	-12	4	47
KPA	2	2	14	0	28	16	62
USA	0	-242	3	0	2	112	-125
No Coupled Payments	**-54**	**-75**	**-122**	**-8**	**-73**	**-91**	**-423**
AFR	0	-7	-3	0	2	-7	-15
AUS	1	0	0	0	0	-1	1
BRA	11	0	-3	0	-5	1	4
CAN	-1	-1	0	0	-2	0	-4
CHN	0	9	-82	-1	-48	-10	-132
CIS	-5	-16	0	-2	-2	6	-18
EUR	-55	-71	0	-9	2	0	-132
IND	1	10	-17	1	0	0	-5
JPN	-2	-3	0	0	0	-2	-7
NZL	0	-1	0	2	0	0	1
RAS	-2	-6	-6	1	-1	-16	-31
RLA	-2	2	-2	0	1	-6	-7
KPA	0	-1	0	0	-1	0	-2
USA	-2	9	-9	-1	-18	-57	-77
Full Reform	**-89**	**78**	**-29**	**5**	**8**	**9**	**-18**
AFR	-38	-80	-7	2	11	-19	-132
AUS	30	74	0	-2	0	0	101
BRA	118	32	-3	0	-1	27	173
CAN	3	-37	-1	0	5	-11	-41
CHN	-2	-21	-34	14	-5	9	-41
CIS	-11	29	2	1	-23	-112	-115
EUR	-237	148	-3	-15	32	21	-54
IND	4	51	2	1	14	0	72
JPN	-4	-70	4	0	-12	5	-76
NZL	13	101	0	5	-1	0	118
RAS	-1	51	4	1	-4	25	76
RLA	33	28	-1	0	-17	-5	38
KPA	3	0	14	0	27	16	59
USA	1	-228	-6	0	-17	54	-196

Note: Colour shading indicates results magnitude (green = positive, red = negative). CRP=emissions from crop production, LSP= emissions from livestock production, LUCF= land use change emissions from forests, LUCG= land use change emissions from grasslands, LUCN= land use change emissions from other natural areas, ORS=Organic soils emissions, SOC= soil organic carbon. AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments.

Table A D.8. Policy reform impacts on land use (1000 ha)

	CRP	GRS	FOR	ONV
No Border measures	**828**	**252**	**-2895**	**1816**
AFR	-707	-3374	809	3271
AUS	41	-41	0	0
BRA	854	4158	-2665	-2347
CAN	-37	55	0	-17
CHN	176	-411	0	239
CIS	-678	318	0	360
EUR	-169	-1189	0	1358
IND	-563	244	0	319
JPN	-1324	-213	0	1537
NZL	-6	721	0	-715
RAS	794	-357	-42	-400
RLA	2832	473	-978	-2328
KPA	-461	-21	-19	502
USA	75	-112	0	37
No Coupled Payments	**-584**	**-1027**	**-864**	**2472**
AFR	7	90	-26	-71
AUS	27	-27	0	0
BRA	465	343	-353	-455
CAN	-10	-23	0	33
CHN	-1610	178	0	1409
CIS	55	-394	0	339
EUR	129	-1175	0	1046
IND	164	177	0	-341
JPN	-10	-31	0	41
NZL	0	54	0	-54
RAS	-117	192	-116	63
RLA	919	127	-368	-678
KPA	-44	0	0	43
USA	-559	-537	0	1096
Full Reform	**-133**	**1244**	**-3879**	**2768**
AFR	-787	-3402	720	3470
AUS	-11	11	0	0
BRA	1044	3944	-2665	-2323
CAN	-59	35	0	24
CHN	-1058	210	0	860
CIS	-655	38	0	617
EUR	31	-1964	0	1933
IND	-346	253	0	93
JPN	-1324	-247	0	1571
NZL	-7	726	0	-720
RAS	635	-92	-134	-422
RLA	3584	2178	-1781	-3982
KPA	-512	-21	-19	552
USA	-670	-424	0	1094

Note: Colour shading indicates results magnitude (green = positive, red = negative). CRP=Cropland, GRS=Grassland, FOR=Forest, ONV=Other natural vegetation areas. AFR=Africa, Turkey and the Middle East, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, CIS= Commonwealth of Independent States (CIS) and Rest of Eastern Europe, EUR=EU and EFTA, IND=India, JPN=Japan, NZL=New Zealand, RAS= Rest of Asia, RLA=Rest of Latin America, KPA=Korea and Pacific Islands, USA=United States. No Border Measures: No Tariff + Reduced NTMs + No Export Tax scenarios. No Coupled Payments: 100% removal of specific commodity transfers other than market price support. Full Reform: No Trade Restrictions + No Coupled Payments.

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This report was declassified by the Joint Working Party on Agriculture and the Environment in June 2022 and was prepared for publication by the OECD Secretariat.

Comments are welcome and can be sent to tad.contact@oecd.org.