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Desktop analysis of agricultural subsidies and environmental impacts

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Institute for International Trade: Desktop Analysis of Agricultural Subsidies and Environmental Impacts

Desktop analysis of agricultural subsidies and environmental impacts

A review of the literature on the relationship between trade and production distorting agricultural subsidies and adverse environmental impacts, with a particular focus on greenhouse gas emissions.

Final Version: 7 September 2022

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Executive summary

Based on the available literature, this report explores the impacts of production and trade-distorting domestic support in agriculture on climate (i.e., greenhouse gas emissions) and the environment (i.e., water, biodiversity, and land degradation).

The World Trade Organization (WTO) and the Organisation for Economic Cooperation and Development (OECD) already provide a great deal of valuable information on domestic support in agriculture, though for different purposes and using different methodologies. Yet the essential story that emerges is the same. In nominal terms, domestic support for agriculture is high, is increasing, is highly concentrated in just a handful of countries, and is further concentrated on relatively few commodities. Moreover, much of this support relies on policy instruments that distort production and trade and are environmentally harmful. Today, there is little constraint on governments providing trade-distorting and environmentally harmful support to agriculture. Without changes to multilateral rules, there will be even less constraint in the future.

The available literature also provides a great deal of information on the impacts of agricultural support on production, trade, and, more recently, the environment. The conceptual pathways through which subsidies can impact the environment are well established. Negative impacts of production and trade-distorting support result from induced increases in the use of inputs and stocking rates (the intensive margin), changes in land use across different farming activities (the extensive margin), and changes in the land brought into or taken out of production (the entry-exit margin). Positive impacts from targeted support policies can result from increases in environmental goods, such as carbon storage, resilience to natural disasters, and preservation of rural landscapes. Actual impacts vary for several reasons, highlighting the importance of empirical analysis.

Empirical research on agriculture and climate linkages has increased since the Paris Agreement was signed in 2016. Two major recent studies estimated the effects of reduced agricultural support on greenhouse gas (GHG) emissions, amongst other impacts. The global results were unambiguously positive for GHG emission reductions, but with significant variation across countries. The latest of these studies also constructed an illustrative scenario whereby savings from support reductions were repurposed to innovation measures that enable substantial GHG emission reductions.

Research on other environmental impacts (water, biodiversity, land degradation) of subsidy reform has focused on the magnitude of environmentally harmful subsidies (EHS), the costs of inaction, and strategies for reform. There is broad agreement that much of the support provided to agriculture today is environmentally harmful, with USD estimates ranging from 345 billion to 520 billion per year. It was beyond the scope of this report to examine the many sub-national studies that explore the relationship between agriculture, domestic support, water, biodiversity, and land degradation.

Finally, this report concludes that an innovative approach to addressing the domestic support pillar at the WTO is within reach and would encompass two elements:

1. improving awareness and understanding of available information and analysis while filling strategically important knowledge gaps; and
2. building a coalition of stakeholders in support of an evidence-based discourse and a modern package of agriculture policies that would work better for people and the planet.

There is arguably more information already available on agricultural support and its production, trade, climate, and other environmental impacts than for any other sector. Successful policy reform in a sector as sensitive as agriculture requires more than just good data; it requires coalition building. A sustained evidence-based networking initiative that incorporates active public engagement and global coalition building should be developed on a priority basis.

Introduction

This report synthesises the available literature examining the impacts of production and trade-distorting agricultural support on GHG emissions and on water, biodiversity, and land degradation. The list of references is provided at the end of this report.

This report begins with an overview of agricultural support, drawing on WTO and OECD data.

The WTO data are available from information notified by its 164 members, organised according to the definitions of domestic support agreed in the Uruguay Round Agreement on Agriculture (URAA, 1994). The OECD data cover 54 countries representing three-quarters of global agriculture value-added, organised according to an economic framework agreed by OECD members. The primary purpose of the WTO data is to monitor country compliance with agreed multilateral commitments, while the primary purpose of the OECD data is to enable an analysis of the incidence and likely impact of applied policies.

The main section of this report provides an overview of the pathways between agricultural support and environmental impacts, followed by a summary of the available studies specifically examining the impact of agricultural support on GHG emissions and on water, biodiversity, and land degradation. Further details are provided in a Technical Annex. The literature on GHG emissions is more extensive than the literature addressing the impact of agricultural support on these other environmental dimensions. This is due to the global nature of GHG emissions, which lends itself to global modelling and analysis, in contrast to the much more local nature of impacts on water, biodiversity, and land degradation. Finally, information obtained from officials in selected international organisations on related analysis currently underway or planned is briefly described.

The concluding section highlights additional research and analysis that would further clarify the relationships between agricultural subsidies and environmental impacts, focusing on activities that could help inform an innovative approach to reform WTO rules on 'domestic support' (agricultural subsidies).

Overview of agricultural subsidies (domestic support)

WTO domestic support data

The URAA reflected the wide array of agriculture policies in place during the mid-1980s through the early-1990s, which in many countries provided high levels of often production and trade-distorting support. Agreed disciplines sought to distinguish trade-distorting support from the support that is minimally trade distorting via differentiated commitment categories or Boxes[1].

The Amber Box includes domestic support measures that clearly distort production and trade, notably subsidies directly linked to input use and production quantities and measures that support domestic prices at levels higher than international prices. The former encompasses various forms of budgetary payments, while the latter is estimated as the gap between administered prices on the domestic market and international reference prices that are fixed as the average of the 1986-88 period. These fixed external reference prices have remained unchanged since.

The permissible limit to Amber Box support has two components: "*de minimis*" support, equivalent to 5% of the value of agricultural production for developed countries and 10% for developing countries (for product-specific as well as for non-product specific support, i.e., a total of 10% and 20%, respectively); and a final bound total aggregate measurement of support (FBTAMS) only available to those thirty-two WTO members that had higher support than de minimis levels at the time the URAA was concluded. Because they are expressed as a percentage of the value of production, *de minimus* support limits increase over time.

There is also a Blue Box, wherein direct payments to farmers under production limiting programmes are permissible without limits. Such payments are generally viewed as less trade distorting than Amber Box support as they are based on fixed area, yield, or animal numbers (i.e., not based on current input use or output).

The Development Box provides all developing countries with wide scope to encourage agricultural and rural development, including input subsidies for resource-poor farmers, subsidies for new investments, and support for diversification away from illicit narcotic crops. Support under the Development Box is available without limit.

[1] WTO Fact Sheet, *Domestic Support in Agriculture*, https://www.wto.org/english/tratop_e/agric_e/agboxes_e.htm

Finally, there is a Green Box for support that is minimally or non-trade distorting and available to all WTO members without limit.

Annex Figures 1 and 2 summarise recent and forecast domestic support entitlements under the Amber Box, while Annex Figures 3 through 7 highlight the evolution over time of domestic support provided, as notified by WTO members within each of the Boxes. Annex Figure 8 shows both the support entitlements and support provided, in nominal terms, for selected countries during the most recent year when complete data are available (i.e., 2016), while Annex Figure 9 presents support provided by the same countries as a percentage of the value of national production in 2016.

The *de minimis* component of the limit on Amber Box support across the WTO membership has grown over the past two decades to about 1 trillion USD today and is expected to double to 2 trillion USD within a decade[2]. Most of the permissible support is available to relatively few WTO members; five large economies (China, EU, India, US, and Japan) accounted for two-thirds of support entitlements in 2016. By 2030, it is expected that just five WTO members (China, India, Indonesia, EU, and Brazil) will account for three-quarters of support entitlements.

Actual support provided by WTO members is much lower than these support entitlements. For example, support notified under the Amber Box totalled about USD 80 billion in 2016, a significant decrease from levels of support above USD 100 billion for the years immediately prior. Support provided is also highly concentrated, with just five countries accounting for 80% of the total in 2016 (China, the US, EU, Japan, and India).

The EU had been by far the primary user of the Blue Box for several years, even as its expenditures thereunder were reduced significantly over time. Blue Box support notified in 2016 was USD 12 billion, with China providing slightly more support than the EU. Together they provided 90% of this category of support. Just two other countries notified Blue Box support in 2016 (Japan and Norway).

Support notified under the Development Box increased significantly between the early 2000s and 2008 but has since stabilised at just under USD 30 billion. India alone provided 74% of this support in 2016.

Minimally or non-trade distorting support provided under the Green Box has increased significantly over the past 15 years, reaching almost USD 440 billion in 2016; 85% of this support was provided by three countries (China, US, EU).

Support expressed as a percentage of the value of production (VoP) can facilitate international comparisons of support provided by also reflecting the size of the agriculture economy in WTO member states. The highest relative level of Amber Box support in 2016 was provided by Japan (about 9% of the VoP), followed by the US and Russia (under 5% of the VoP), and lower levels in the EU, India, China, and Brazil. Blue box support was highest in the EU (around 2% of the VoP), with lower relative levels in Japan and China. India remained by far the highest user of Development Box support (over 6% of the VoP). Most countries relied more on minimally-trade distorting Green Box support, with the highest relative levels in the US (34%[3] of the VoP), followed by Japan, the EU and China (around 20%, 17%, and 13%, respectively).

OECD estimates of support for agriculture

A brief comparison of OECD and WTO methodologies for measuring support[4]

The OECD developed a methodological framework to measure and evaluate the impact of support to agriculture in response to its 1982 Ministerial Trade Mandate. Both the framework and the support estimates that it provided subsequently served as an important reference for international negotiations that culminated with agriculture being brought into the multilateral rules-based trading system with the 1994 URAA.

Since then, the OECD methodology has been regularly reviewed and improved; its estimates of support to agriculture are updated annually (most recent to 2020) for 37 OECD member countries, five non-OECD EU member states, and 12 emerging economies with which the OECD collaborates on agricultural policy. The OECD data group all policy support that affects agriculture into four main categories: the Producer Support Estimate (PSE), the General Services Support Estimate (GSSE), the Consumer Support Estimate (CSE), and the Total Support Estimate (TSE)[5].

There are important and deliberate differences in the WTO and OECD methodologies for monitoring and evaluating support for agriculture, particularly regarding the OECD PSE and the WTO AMS.

The PSE reflects the value of all government transfers to agricultural producers. There are two main types of transfers: various forms of budgetary payments, funded by taxpayers, and market price support (MPS) which derives from policies that support domestic prices at levels higher than international prices and, as such, are funded by consumers. The PSE includes all agricultural policies, regardless of their nature, objective, and impact.

The AMS also includes budgetary payments and MPS; however, it is a narrower concept covering only domestic support considered to be trade distorting and excludes explicit trade policies, such as import restrictions and export measures. At the WTO, explicit trade policies are covered separately under the current negotiating framework's market access and export competition pillars. In addition, other measures are also excluded from the AMS and included in other WTO support categories, such as payments under production-limiting programmes (Blue Box) and some income support schemes (Green Box).

MPS is a significant component of both the PSE and the AMS, but there are two hugely important differences in the methodologies applied. The PSE considers actual domestic and current international prices to estimate the 'price gap', which is then applied to all domestic production to calculate total MPS. The AMS estimates the 'price gap' using current domestic

2 Australia and New Zealand, JOB/AG/171 https://docs.wto.org/dol2fe/Pages/SS/directdoc.aspx?filename=q:/Jobs/AG/171.pdf&Open=True

3 Note that the largest share of which is domestic food aid

4 OECD (2001), *The Uruguay Agreement on Agriculture*, OECD Publishing, Paris; also see Brink (2018) and Effland (2011)

5 See definitions in the Annex

administered prices and a fixed external reference price; the average price observed over 1986-88 (this 35-year-old external reference price is still used today). In addition, the AMS only calculates market price support when domestic administered prices exist. In effect, any market price support that derives from border measures alone but where there is no explicit domestic administered price would not be included.

The OECD GSSE is made up of transfers that support agriculture as a whole, such as food inspection services, research and development, education and training, and infrastructure. The WTO Green Box represents a broader category of non-trade distorting support as it also includes measures that might have a more direct impact on production and trade, such as some income support schemes.

In brief, none of this suggests that one methodology is better or worse than the other – they are deliberately different because they serve different purposes. The WTO data are aligned with the definitions of domestic support commitments negotiated and agreed upon in the URAA and allow those commitments to be monitored. The OECD data are aligned with an economic framework agreed by OECD members and enable an analysis of the incidence and impact of current and alternative policy instruments.

OECD agriculture support data[6]

OECD data cover 54 countries that together account for about three-quarters of global agriculture value-added. As detailed in Annex Table 1, OECD estimates that during the 2018-20 period, agricultural policies transferred almost USD 720 billion per year to the sector. Over the same period, agricultural policies in a few countries also transferred USD 104 billion per year out of the sector. As a result, net annual support totalled USD 615 billion (equivalent to 0.8% of GDP across the 54 countries).

Of the total support transferred, USD 540 billion per year was provided to individual producers. Over 60% of this amount was delivered via highly production and trade-distorting policies, i.e., USD 272 billion in MPS and USD 66 billion in payments directly tied to output quantities or input use. The remaining USD 202 billion was provided through various forms of payments that are more decoupled from farm production decisions and subsequently less trade distorting. These more decoupled payments also tend to have less impact on GHG emissions and on land, water, and biodiversity resources. Payments for long-term resource retirement (which can include fragile land) and for providing environmental public goods represented just USD 4.8 billion and USD 1.5 billion per year, respectively. Negative MPS totalled USD 104 billion as a few countries applied policies that effectively 'taxed' producers favouring domestic consumers. The net PSE, USD 436 billion, represented an average of just over 11% of gross farm receipts across all countries.

Spending on various general services for the sector totalled USD 102 billion per year, most of which (i.e., USD 86 billion) was spent on infrastructure, innovation, and stockholding. Consumer subsidies via various food assistance programmes averaged USD 78 billion per year.

These aggregate data mask a wide variation in the level and nature of support in individual countries. In nominal terms, the highest levels of support during 2018-20 were provided by China, the EU, Japan, and the US. Both China and Japan rely relatively more on MPS, while the EU and US rely primarily on direct payments. The highest levels of direct payments were provided by the EU, China, India, and the US. The EU relies on payments that do not require production; China relies relatively little on payments based on output; India relies almost exclusively on payments based on input use; and the US relies primarily on payments requiring production (see also OECD, 2021: Tables 8.1, 11.1, 13.1, 16.1, and 29.1).

While support for agriculture has continued to increase in nominal terms, overall producer support as a share of gross farm receipts (%PSE) has declined from 18% two decades ago to 11% today. The %PSE is arguably a more informative basis for cross country comparisons and reveals a somewhat different picture (Annex Figures 10 and 11). The %PSE declined in virtually all countries over the past two decades but increased in a few (Indonesia, China, and the Philippines); a small level of positive support in Vietnam became a low level of negative support, while the amount of negative support in Argentina and India increased.

Across the 54 countries, support ranged from less than 5% (New Zealand, Brazil, Ukraine, Australia, and Chile) to more than 40% (Japan, Korea, Switzerland, Norway, and Iceland). Producer support was negative in three countries (Argentina, Vietnam, and India). Highly trade-distorting MPS continued to be prevalent apart from a few countries that provided overall low levels of support (New Zealand, Brazil, Ukraine, Australia, Chile) and two countries that relied primarily on direct payments (US and EU).

The Nominal Protection Coefficient (NPC) compares prices received by producers with world market prices. It is a useful indicator of how agricultural support contributes to any misalignment between the prices received domestically and those available on world markets (Annex Figure 12). While prices are almost perfectly aligned in a few countries (Australia, Chile, Brazil, and New Zealand), the gaps between producer prices and international market prices range widely, with domestic prices 60% above world prices in some countries (Iceland, Norway, Korea, and Japan) and more than 10% below world prices in others (India and Argentina).

Despite the significant methodological differences, the essential story emerging from available data is the same. In nominal terms, domestic support for agriculture is high and continues to increase, is highly concentrated in just a handful of countries, and is further concentrated on relatively few commodities. Moreover, much of the domestic support provided relies on policy instruments that distort production and trade and are environmentally harmful. Today, there is little constraint on governments providing trade-distorting and environmentally harmful support to agriculture. Without changes to multilateral rules, there will be even less constraint in the future.

[6] OECD (2021), *Agricultural Policy Monitoring and Evaluation*, OECD Publishing, Paris, https://doi.org/10.1787/22217371

[7] The report also presented results from three scenarios that targeted emission-intensive production inputs and consumer products, such as a consumer-level GHG tax on ruminant meat and dairy products consumed within OECD countries and a GHG-based tax on emission-intensive agricultural inputs, including ruminant animals and fertiliser, at both global and OECD levels. These scenarios are not reviewed here.

Linkages between agricultural support and environmental impacts

Environmental pathways

This section aims to lay out the pathways by which agricultural support policies impact the environment. The section synthesises the findings from the available literature, focusing on the key environmental channels through which the impacts are observed, namely through impacts on greenhouse gas emissions, water, biodiversity, and land degradation.

The linkages between agricultural support and environmental impacts are determined by a range of factors stemming from the prevailing market and regulatory conditions and the level of compliance with policies and regulations. Such support changes the economic incentives facing participants in the agricultural sector and influences environmental outcomes through:

- the number of agricultural goods produced
- the mix of agricultural goods produced
- where the agricultural goods are produced in terms of local, regional and international spatial scales; and
- how the agricultural goods are produced in terms of the technologies employed (Mamum et al., 2019).

More specifically, the literature highlights several pathways at both the farm level and at more aggregated spatial scales, focusing on the increased use of inputs and changes in stocking rates (referred to as the intensive margin), the induced changes in the allocation of land between different agricultural activities (known as the extensive margin), and the amount of land entering or leaving agricultural production (known as the entry-exit margin), (e.g. OECD, 2004; OECD, 2005; OECD, 2010; OECD, 2013; Mayrand et al., 2003; Henderson and Lankoski, 2019; DeBoe, 2020).

The environmental outcomes associated with these pathways can be extensive and are well documented. For example:

- Increased input use intensity, particularly synthetic pesticides, herbicides and fertilisers, can lead to an increased toxic chemical, nutrient and greenhouse emissions per unit of output.
- Increasing livestock numbers or stocking rates can increase environmental degradation associated with livestock, including ruminant GHG emissions, soil erosion, the spread of invasive species in grazing lands, nutrient emissions from manure and urine patches, etc.
- Increased water use, especially for irrigated agriculture, can result in various environmental impacts, including salinity, surface and groundwater depletion, and biodiversity loss due to the loss of freshwater habitats.
- The conversion of land from fallow or low-intensity agricultural uses towards more intensive agricultural uses or bringing more agricultural land into the sector can cause severe environmental harm by destroying habitats and causing significant biodiversity loss, decreasing carbon sinks, increasing erosion, etc.
- At the same time, the abandonment of agricultural land due to changes in agricultural support has also been identified as having negative environmental impacts, including negative impacts of invasive species, increased risk of wildfire, and erosion (if abandoned land lacks adequate soil cover).

The literature highlights that agricultural policies can also produce positive environmental impacts (DeBoe 2020a, 2020b; OECD 2021). Pathways for positive impacts focus on creating incentives to reduce the negative impacts of agriculture, as outlined above. Agricultural activity can also produce valuable environmental goods such as carbon storage, preservation of rural landscapes, resilience to natural disasters (such as flooding, landslides, fire and snow damage), pollination, soil functionality, habitat provision and control of invasive species. (OECD, 2018; OECD, 2011; DeBoe, 2020). Adding to the mix, the use of agri-environmental policies (i.e. environmental policies that are specifically targeted to the agriculture sector) encompass a wide range of mechanisms, including regulatory instruments (such as standards on inputs, technologies, and performance), environmental cross-compliance requirements, payments for ecosystem services, environmental taxes (e.g. on fertilisers and pesticides), tradeable allowances (such as for water), environmental subsidies, and publicly-funded investments in research and development. (DeBoe, 2020).

There are, of course, also broader environmental policy instruments that are not targeted at the agricultural sector but that will still have an impact on the environmental and economic performance

Market price support and coupled subsidies are among the potentially most environmentally harmful support policies

of the sector. These include policies such as carbon taxes, reforms of fossil fuel subsidies, biofuel mandates, forestry and native vegetation policies, etc.

The literature emphasises that the environmental impacts of agricultural policies are mediated by several factors, underscoring the complexity of causal pathways and the need to assess impacts empirically, taking into account specific policy and physical contexts (OECD, 2010; Lingard, 2002; Just and Antle, 1990). For example, behavioural responses from individuals and firms in the sector to the economic incentives created by agricultural policies will vary, with implications for the resulting scale, scope and severity of environmental impacts. The environmental impacts of individual decisions will vary due to a wide range of location-specific physical factors, including landscape characteristics (soil type, slope, aspect, proximity to water bodies or aquifers, precipitation, attenuation capacity of land and receiving water bodies, etc.) (Bärlund, Lehtonen and Tattari, 2003; Lingard, 2002).

While these pathways layout the general links between agricultural support and environmental impacts, the types of agricultural support will also have important implications for their environmental outcomes. The literature focuses on three broad policy channels: market price support, coupled support, and decoupled support (Mamun et al., 2019). DeBoe (2020) further breaks down the types of policy instruments using the OECD's PSE categories. However, in broad terms of identifying the environmental impacts of types of instruments, the simpler three-category framework is sufficient.

Market price support consists of barriers to trade such as tariffs, licences and quotas that raise or lower the domestic price relative to world prices. Coupled subsidies include measures such as payments based on commodity output and payments based on unconstrained variable input use. Market price support and coupled subsidies are among the potentially most environmentally harmful support policies (Henderson and Lankoski, 2019; Henderson and Lankoski, 2020; OECD, 2020; DeBoe, 2020). Such policies are coupled with farmers' production decisions. They cannot be easily targeted, thus providing incentives for the intensification of input use, the allocation of land for supported crops, and the entry of land into the agricultural sector. Studies have shown their negative impacts on water quality and direct agricultural GHG emissions, and they may negatively influence biodiversity by promoting less diverse agricultural systems (DeBoe, 2020; Lankoski and Thiem, 2020).

Payments based on variable inputs without appropriate constraints can encourage the excessive use of fertilisers, herbicides and pesticides. Such coupled payments generally have negative impacts on water quality and greenhouse gas emissions; authors attribute this to coupled payments incentivising intensification. They may have negative or positive impacts on biodiversity depending on whether they promote crop diversity versus monoculture. Over-application of fertilisers and animal manure leads to substantial nutrient surpluses and nitrogen and phosphorus run-off. Nitrogen pollution causes severe damage to freshwater ecosystems, harming invertebrates and fish, causing acidification and eutrophication, stimulating the growth of toxic algae and lowering oxygen levels in water (hypoxia). Excessive or inadequate pesticide use has been associated with declines in populations of birds, insects, amphibians and aquatic and soil communities, as well as negative impacts on human health (Guerrero, 2018; Sud, 2020).

Decoupled subsidies refer to payments unrelated to the area and production levels of specific commodities, livestock numbers, and input use. Such schemes can be either fully or partially decoupled. Partial decoupling (i.e. introducing a policy mix that entails both coupled and decoupled support elements) tends to have a neutral or negative impact on biodiversity indicators. This is due to incentives to homogenise agricultural production and, in some cases, replacing coupled payments with decoupled payments encourages land abandonment. Effective design of cross-compliance requirements or agri-environmental schemes could mitigate or reverse these negative impacts, indicating that it is important to assess the policy mix as a whole and assess the effects of policy reform dynamically. Full decoupling (i.e. removing all market price supports and coupled payments, both with and without mandatory environmental conditions) reduces nutrient balances at the country level by removing intensification incentives. Full decoupling without mandatory conditions (and in the absence of effective agri-environmental schemes) tends to increase agricultural land abandonment.

Quantitative studies on GHG emissions impacts from agricultural subsidy reform

The agricultural sector has a long history of studies that seek to quantify the impact of various economic policies, technological developments, demographic trends, and exogenous shocks on agricultural production, markets, trade, incomes and prices. These studies generally focused on the implications of agricultural policy reform packages for the sector and were used to help guide policymakers in designing policy packages and interventions. The modelling tools have evolved considerably over the years in line with advances in computing power and modelling techniques and in response to policymakers' demands for broader and deeper information and analysis.

In recent years, the policy and analytical focus on the linkages between climate change and the agricultural sector have increased dramatically. This has largely been spurred by the signing of the Paris Agreement, the ensuing demands of designing and implementing the Nationally Determined Contributions by countries, and the production of landmark reports such as the IPCC Special Report on climate change and land (IPCC 2020). The analysis has largely focused on the demand and supply-side mitigation options for agricultural GHG emissions. This has centred around two broad aspects. One stream of analytical work has addressed the impact of climate change on the agricultural sector and the agriculture-related risks of climate change (e.g. Rosenzweig et al., 2014; Blanco et al., 2017; Tanure et al., 2020). A complimentary stream of work has focused on the mitigation potential of the agricultural sector to contribute to the global mitigation goals under the Paris Agreement (e.g. Wollenberg et al., 2016; Frank et al., 2018).

There have been very few quantitative studies assessing the climate impacts of the reform of agricultural support. The focus of quantitative studies to date has primarily been on the implications of carbon taxes and consumption taxes on GHG emissions from agriculture, both at the global and regional levels (e.g., Jensen et al., 2019; Fellman et al., 2019; Meijl et al., 2018; Himics et al., 2018). Other studies have focused on farm-level assessments of the environmental impacts of agricultural reform (e.g., Henderson and Lankoski, 2019).

In the last few years, there has been an increased focus on a broader range of policy objectives within agriculture and food systems. This is consistent with the broader push towards green growth and greening the economy and has particularly been high on the agenda in the recovery from the COVID pandemic. Recognition that climate and environmental sustainability must go hand-in-hand with objectives related to food security, poverty reduction in the agricultural sector, food affordability, and healthy diets has led to an increased emphasis on analysis of multiple objectives to support decision making. This has, in turn, led to a focus on repurposing existing agricultural support towards programmes and objectives that will increase overall social well-being.

In this section, three major studies on the effects of agricultural support reform on GHG emissions are reviewed, together with seven additional studies that use a range of models to assess other types of policy interventions designed to reduce agricultural GHG emissions, primarily carbon taxes, emission abatement subsidies and various EU policy initiatives.

A more detailed overview of the ten studies reviewed is provided in the Technical Annex. The remainder of this section provides an overview of the results of the studies with particular emphasis on the drivers underpinning the results and the key issues that they reveal when undertaking quantitative analysis of agricultural subsidy reform in the context of climate and environmental goals.

Repurposing agricultural support

Two major reports focused on the theme of repurposing agricultural policies were released in 2021 and 2022. The reports by FAO, UNDP and UNEP, "A Multi-Billion-Dollar Opportunity: Repurposing agricultural support to transform food systems", and by World Bank and IFPRI, "Repurposing Agricultural Policies and Support: Options to Transform Agriculture and Food Systems to Better Serve the Health of People, Economies, and the Planet" (FAO, UNDP and UNEP 2021; Gautam et al. 2022) were both based on simulations undertaken with IFPRI's global computable general equilibrium model. The first of these reports was released in the lead-up to COP26 in Glasgow (FAO, UNDP and UNEP 2021). It has a very broad focus and presents a quantitative analysis of the economic, environmental and health impacts of the removal of border measures and fiscal subsidies in the agricultural sector. The report covers indicators on agricultural production, farm income and employment, nature (primarily land use but also including chemical inputs and a broad measure of biodiversity), GHG emissions, food consumption and affordability, healthy diets, and equity.

The section on the impacts on climate presents projected changes in GHG emissions in 2030 due to the removal of various agricultural support measures (FAO, UNDP and UNEP 2021, pp. 61-64). It focuses on changes in GHG emissions stemming from changes in crop and livestock production (primarily affecting nitrous oxide and methane emissions), changes in energy use associated with crop and livestock production, and land-use change effects such as deforestation or the conversion of pastureland to cropland.

The report presents results for the world, developed countries, BRIC countries, and non-BRIC countries. It breaks down GHG emissions into emissions from agricultural production, emissions from energy use in agriculture, and emissions from land-use changes. The removal of domestic fiscal support and border measures is projected to reduce GHG emissions at the global level, with significant different impacts on developed, BRIC and non-BRIC countries. Emission reductions in non-BRIC countries are a key driver of the overall results, largely due to shifts away from emission-intensive livestock production to crop production in these countries. This goes hand in hand with a decrease in forest land being converted to agricultural use in non-BRIC countries. The removal of border support is also a key factor dominating the results, accounting for around 71% of the total projected reductions in GHG emissions (mostly from non-BRIC countries).

The second report, this one from the World Bank and IFPRI, continues the focus on the theme of repurposing agricultural policies and support, with a time horizon of 2040. Once again, it simulates the projected impacts of removing all agricultural subsidies and border support on a range of indicators covering national real income, farm output, prices and employment, farm poverty, nutrition and diets, GHG emissions, and changes in agricultural land use (broadly defined as "nature"). The report also incorporates a series of scenarios where savings from abolishing agricultural subsidies are directed to several alternative fiscal purposes.

Consistent with the results in FAO, UNDP and UNEP (2021), the removal of domestic support is unambiguously positive for GHG emission reductions, although the magnitudes of the changes are slightly lower. This reduction is unevenly spread between developed and developing countries, with the percentage reductions being larger in developed countries. The removal of agricultural trade barriers reduces the percentage changes in GHG emission reductions; however, the removal of border support does not play as big a role in driving the overall results in this analysis compared to the 2021 report. It is argued in the report that this is the result of complex dynamics in the model between the tax on consumers imposed by market price support, the presence of substantial negative market price support in a few major producing and consuming countries, and shifts in the location and composition of emission-intensive production.

Another major difference between the two reports lies in the source of the GHG emission reductions. The 2021 report projects that the reduction in GHG emissions will primarily come from the non-BRIC developing countries, while emissions from developed and BRIC countries are projected to actually increase by 2030 relative to the baseline (see Table 2). This is in contrast to the 2022 study where both developed and developing countries are projected to reduce GHG emissions by 2040 relative to the baseline. It is impossible to determine what is driving this difference without further details on the technical parametrisation of the model. But it does highlight the sensitivity of modelling results to the input data, parameters and assumptions employed.

The repurposing scenarios are the major innovative and novel feature of the Gautam et al. (2022) report. The scenarios represent a series of hypothetical thought experiments on the possible outcomes of different fiscal strategies for redistributing the funds currently directed towards domestic agricultural support. Table 3 presents the projected impacts on the key climate indicators by 2040 under the repurposing scenarios. Each scenario projects a reduction in GHG emissions, except for the scenario under which uniform support is provided to non-CO2 intensive products only. It is particularly noteworthy that the scenarios whereby the support is redirected towards green innovation result in very high GHG emission reductions (up to a 40% reduction in GHG emissions by 2040). This results from efficiency gains leading to significantly reduced input use and the move of agricultural land back to its natural uses. To a large extent, these results are driven by the assumptions of an exogenous 30% reduction in emission intensity and a 30% increase in productivity. Nevertheless, the report notes that investing in research and development to enhance productivity and reduce emission intensity has potentially significant payoffs.

The two reports identify several areas for further analysis in enhancing the analytical toolbox to support increased agricultural productivity and reduced GHG emissions from agriculture, including:

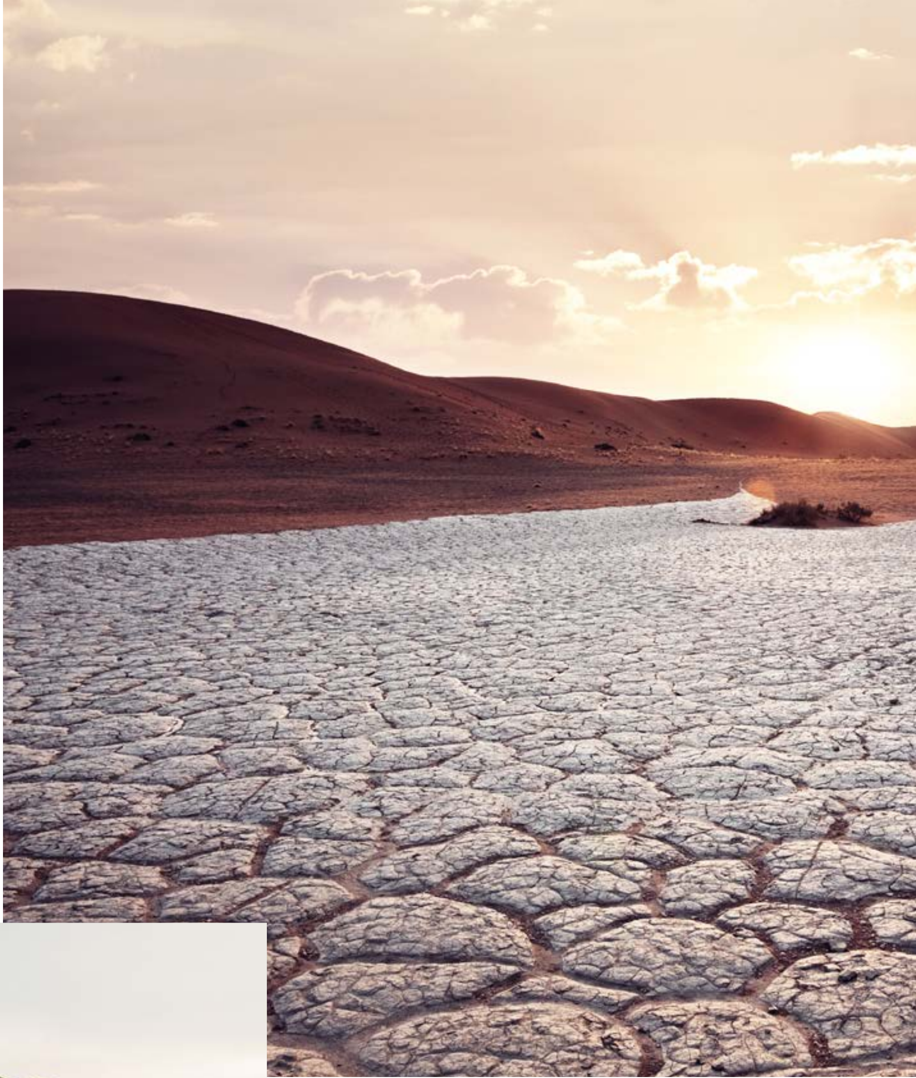
- the role of public research
- the implications of higher agricultural productivity for farm labour
- the use of carbon taxes and conditionality in terms of the impacts on production costs and incentives for producers
- incentives for dietary change and the links to the food system
- specific policy needs at the country level.

An earlier study by IFPRI employing the MIRAGRODEP model highlights the importance of including as full a range of impacts as possible. Laborde et al. (2020, 2021) is a forerunner of the analysis in FAO, UNDP and UNEP (2021) and Gautam et al. (2022). It undertakes a quantitative analysis of the impacts of incentives on agricultural outputs and emissions and addresses impacts on overall output, differences in incentives across countries, differences in incentives across commodities, and differences in the technology used for production. Crucially, however, the analysis does not include the impacts of land-use changes on emissions. Ignoring the role of land-use changes alters the magnitude and direction of projected impacts of GHG emissions from agricultural support reform (see Table 4). This is hardly surprising as land-use and land-use changes accounted for around 43% of global GHG emissions from agriculture and land use in 2018 (FAO 2020). This also underscores the importance of fully accounting for the range of environmental channels through which the impacts are manifested. Searchinger et al. (2020) show that those impacts may be even more consequential if the indirect land-use change (ILUC) caused by changes in policies results in deforestation or conversion of pastureland to cropland.

Carbon taxes, abatement subsidies and other policy instruments

As noted above, the paucity of quantitative studies directly addressing the climate implications of agricultural subsidies and subsidy reform reflects the relatively recent policy focus on how to address the multiple objectives in the food system around climate, environment, health, poverty, and livelihoods. In addition, the push to redirect or repurpose agricultural support has grown significantly in recent years, although there has been a call for "green" agricultural subsidies for some time. Indeed, several important policy changes in how support is provided in the sector, for example, decoupled payments and conditional payments and payments for ecosystem services, reflect this history.

Projected climate and production impacts are crucially influenced by the emission intensities assumed for different products in different countries, the type, pace and uptake of mitigation technologies, and the depiction of land use changes.



However, for the sake of comparison and to illustrate the ways in which agro-economic models can address a range of policy questions around climate change, a selection of recent studies are reviewed below. In contrast to the three studies reviewed above, these studies differ significantly in their methodology, scope, policy focus and time horizon. As a result, they provide useful insights into the key drivers that need to be born in mind when considering the results of quantitative analyses in this area. These include:

- The location and relocation of production are crucially influenced by the emission intensities assumed for different products in different countries. While most studies tend to use a very similar set of emission intensities, it is important to be aware of their role in driving projections of GHG emission reductions through the reallocation of agricultural production as a result of policy shocks.
- The role of technical change and assumptions about climate mitigation technologies' type, pace, and uptake

is crucial. This can drive the impacts of policy simulations, particularly in partial equilibrium models where shifts in the marginal abatement curves for agricultural production can significantly influence the climate pathways.

- As noted above, the inclusion of land use and land-use changes, and how it is modelled, is particularly important. This is especially the case when the models are being called upon to do multiple services in addressing issues around biodiversity, deforestation, and so on.
- Questions about the leakage of GHG emissions tend to be particularly relevant to analysis undertaken using partial equilibrium models as they are less able to address the dynamic issues around the relocation of agricultural emissions. Nevertheless, from both a political perspective and in terms of overall climate goals, the issue of leakage needs to be addressed carefully in modelling studies. The issue of carbon leakage seems to be particularly high profile for the EU and will likely become more so if there is a push towards initiatives such as climate clubs.
- The fiscal dimensions of agricultural support reform and undertaking climate action are largely unaddressed in the current models. For example, assumptions about the recycling of tax revenues can be significant in assessing the macroeconomic and sectoral outcomes of modelling analyses. This is an area worthy of future research.
- Differential treatment of GHG gases is highlighted as an area where there is a need to go beyond a focus on CO2 and address the warming potential and short and long-term effects of different climate pollutants (especially methane and nitrous oxide).

A recent OECD study by Henderson et al. (2021) examines the impact of carbon taxes and emission abatement subsidies in identifying how much the agriculture, forestry, and other land use (AFOLU) sector could limit long-term global warming temperature increases to 1.5°C and 2°C. The key messages from the analysis highlight the complexity of instrument choices and interactions:

- A comprehensive policy strategy comprising agriculture and land-use emission taxes and subsidies for carbon sequestration, at a carbon price consistent with a 20C (1.50C) objective, could reduce global AFOLU emissions by 8 GtCO2 eq/year (12 GtCO2 eq/year) in 2050. This represents an 89% (129%) reduction in net AFOLU emission.
- 63% of the net emission reductions with the comprehensive policy package relate to land-use and land-use change and forestry (mainly avoided deforestation) emissions, 28% to agriculture emissions and 9% to soil carbon sequestration.
- The policy choices invoke different trade-offs: while a global carbon tax on AFOLU is twice as effective in lowering emissions as an equivalently priced emission abatement subsidy. The use of emission taxes lowers agricultural production by 3-8% and per capita consumption by 2-4%, which emission abatement subsidies avoid. Taxes also raise revenues, while subsidies require government expenditures.
- A shift to lower emission diets by consumers is assessed to have a much smaller impact on reducing agricultural emissions than any policy packages that tax these emissions.

A recent paper from the EU's Joint Research Centre by Barreiro-Hurle et al. (2021) assessed the economic, environmental and climate impacts of three major recent EU initiatives: the Post-2020 CAP legal proposals; the Farm-to-Fork Strategy; and the Biodiversity Strategy. The time horizon for the simulations was 2030, with the base year of 2018. In each of the scenarios, the policy packages lead to changes in land allocation, animal numbers, production, and the trading position of the EU compared to the baseline. But in each scenario, there is considerable leakage of non-CO2 agricultural emissions outside the EU due to emission increases in non-EU regions under the assumption that there is no additional mitigation action taken in the rest of the world. This is a similar finding observed in the study by Jansson et al. (2021) and is a feature of the partial equilibrium modelling framework used.

A paper by Perez-Domingo et al. (2021) focuses on the potential implications for the agricultural sector of mitigation options for methane emissions from the sector. The policy scenarios focus on the imposition of a global carbon tax on non-CO2 agricultural emissions (methane and nitrous oxide), reaching values of USD 150 per tonne and USD 500 per tonne and on a shift toward a low-animal-protein diet. However, there is a novel additional focus in analysing the warming potential of different climate pollutants. The implied warming effect of methane emissions is much stronger in the short term and a smaller effect in the long term than CO2 emissions.

The study's results highlight significant potential reductions in non-CO2 emissions under all scenarios. For example, the imposition of carbon pricing could reduce agricultural non-CO2 emissions by up to 58% compared to the baseline in 2070. However, the assumed carbon prices are very high compared to current carbon pricing levels. Carbon pricing has, in general, the largest effect on emissions. Still, with increasing carbon price levels, the negative economic impacts on the agricultural sector in terms of lower production continue to increase, while further emission reductions are relatively small. This reflects a situation where the technical abatement options are fully applied relatively early in the period, and further reduction comes from price-induced reductions in consumption.

The study's results also highlighted the importance of taking the characteristics of methane as a short-term pollutant more explicitly into account. They underscored the importance, but also the complexity, of taking a multi-gas approach to mitigation options. For example, promoting low-meat diets is more effective at reducing greenhouse gas emissions than carbon pricing when mitigation policies are based on metrics that reflect methane's short- and long-term behaviour.

A study by Janson et al. (2021) uses the agricultural sector model CAPRI to simulate the impact of removing the voluntary coupled support for ruminants that are permitted under the EU Common Agricultural Policy. The results are broad as expected, with the policy change leading to a reduction in GHG emissions in the EU of 2 354 kt CO_2eq and emissions in the rest of the world increasing by 1 738 kt CO_2eq. This emissions leakage results in a net global decrease of 616 kt CO_2eq from the policy change, or around a quarter of the emissions decrease in the EU.

OECD (2019) aims to assess the potential of different policies and options, primarily carbon taxes and emission abatement subsidies, to reduce agricultural GHG emissions. Global GHG taxes appear to be the most effective mitigation policy, with and without a food subsidy. Still, they impose the highest economic costs on agricultural producers, particularly in the emission-intensive ruminant sectors of many developing countries. While a GHG tax and abatement payments provide the same marginal mitigation incentives, a GHG tax causes an increase in the cost and price of agriculture output; hence causing a reduction in the aggregate supply and demand for agricultural products, particularly in the more emission-intensive activities. The role of land-use change is important in driving the results as there is a global shift in land cover from pasture to forest and shrubland as the ruminant grazing footprint contracts. The report also notes that the OECD GHG tax scenario leads to the leakage of emissions from OECD to non-OECD countries.

The report highlights several observations that underscore the interconnectedness of the emission/food security nexus:

- Influencing consumer preferences to obtain more calories from non-ruminant animal sources has the highest benefits among the analysed scenarios.
- Consumption taxes are the least effective measure to reduce greenhouse gases, especially when these are decoupled from the actual carbon produced, owing to the inelasticity of demand for broad food groups.
- Consumption taxes would also raise food prices, potentially leading to food security risks for low-income consumers.
- Reducing food waste can be a strategy to mitigate climate change, but it is important to consider the high costs of reducing waste could raise food prices and potentially lead to food security concerns.
- Supply-side mitigation via carbon taxes has a high potential to reduce emissions from agriculture with limited risks in terms of food security.
- Increasing productivity in agricultural production systems could potentially reduce emissions and increase food availability and improve access via lower prices.

Van Meijl et al. (2018) undertake a systematic inter-comparison of five global climate and agro-economic models to assess the range of potential impacts of climate change on the agricultural sector by 2050. By applying a set of scenarios and harmonized assumptions on basic model drivers to the five models, the analysis aims to narrow the discrepancies between the models on the potential impacts of climate change on agricultural production by 2050 and the economic consequences of stringent global emission mitigation efforts.

The results of the scenarios indicate that mitigation measures strongly reduce agricultural non-CO_2 emissions by about 40-45%, with methane and nitrous oxide being reduced by 50% and 30%, respectively. The modelled GHG emission mitigation measures have a negative impact on primary agricultural production. The impacts of mitigation policies in reducing global agricultural production are larger than the negative impacts due to climate change effects in 2050. However, this is partially due to the limited impact of the climate change scenarios by 2050. Similarly, by 2050 climate impacts affect global agricultural prices less strongly than ambitious mitigation policies across the models in this study. The price impact is higher in the livestock sector because livestock production is more emission-intensive, and higher emission taxes directly increase livestock production costs. The magnitude of the producer price changes is very different between the models, mainly due to differences in the general model set-up (especially the treatment of technological change and price responsiveness of demand) and assumptions on mitigation measures (e.g. carbon pricing).

Finally, a study by Himics et al. (2018) investigates the linkages between trade liberalisation and climate in the agricultural sector with a focus on the free trade agenda of the EU. It also replicates the impacts of a carbon tax on non-CO_2 emissions and combines the carbon tax and trade liberalisation scenarios to assess the effectiveness of the policies individually and collectively for the agricultural sector. Scenario results indicate that the simulated trade liberalisation has only modest effects on agricultural GHG emissions by 2030. A reallocation effect drives the results as domestic EU agricultural production shifts to non-EU producers. Much of the change is caused by changes in crop production.

In contrast, pricing agricultural non-CO_2 emissions in the EU triggers the adoption of mitigation technologies, contributing significantly to the projected emission reductions. The carbon tax also has a greater impact on the emission-intensive livestock sector. Emission leakage, however, partially offsets the EU emission savings as production increases in less emission-efficient regions in the world, and in the case of the trade liberalisation scenario, actually increases global GHG emissions.

Quantitative studies on water, biodiversity, and land degradation impacts from agricultural subsidy reform

The literature on quantitative assessments of the linkages between agricultural subsidies and non-climate environmental outcomes falls into two distinct categories. Studies at the global level have generally focused on bolstering the economic and business case for reform of environmentally harmful subsidies (EHS), while those at the national level have largely addressed the specific policy reform challenges at the local, regional and national scale. This section provides a review of the range of the key insights from studies at both global and national levels.

Insights at the global level

At the global level, the literature has centred on defining, identifying and quantifying agricultural subsidies that are harmful to the environment. In this literature, agricultural subsidies have largely been brought under the umbrella of EHS, which has focused on estimating the magnitude of EHS, assessing the costs of inaction, and identifying potential reform strategies. In contrast with the studies reviewed on the linkages between agricultural support and climate change, there have been few major studies using global models trying to estimate the economic, (non-climate) environmental, and social impacts of EHS reform. There are two major reasons for this. First, the data, metrics and indicators around water, biodiversity, deforestation, land degradation and so on are not, at this stage, amenable to such large-scale global modelling. However, two recent studies have taken a tentative first step in this direction (discussed below). Second, the complexity of the dynamic interactions between policies, ecological processes and economic, environmental, and social outcomes is best contextualised and modelled at the local scale due to the very site-specific nature of these interactions.

The early literature on the linkages between subsidies, including agricultural subsidies, and the environment focused on defining what constituted environmentally harmful subsidies and identifying the pathways between the subsidies and environmental impacts (OECD 1998, 2000, 2001, 2003; van Beers and de Moor 2021). However, securing an agreed definition of EHS proved elusive and subject to considerable debate and analysis, with several frameworks and checklists being proposed (OECD 2005, 2006, 2007). Over the last decade, there has been an increasing focus on estimating the magnitude of EHS and on laying out the political economy issues involved in reforming EHS. This has been primarily directed at making the economic and business case for reform of EHS at a global, regional and national level in an effort to strengthen support for EHS reform, including agricultural subsidies reform (OECD 2017a).

In terms of quantifying agricultural EHS, OECD (2020) estimates that more than half the support to agricultural producers in 54 OECD and emerging countries covered by the OECD agricultural policy monitoring report, totalling USD 345 billion, is provided in ways that are potentially most harmful to the sector's sustainability, while most of the rest does little to help. In OECD countries alone, support deemed potentially most harmful to the environment averaged USD 112 billion from 2017 to 2019. FAO, UNDP and UNEP (2021) estimate that USD 470 billion of agricultural subsidies are "price distorting or harmful to nature and health", amounting to 87% of all agricultural subsidies. In a recent report, the value of EHS in agriculture was estimated to be USD 520 billion a year (Koplow and Steenblik 2022).

In terms of water-related EHS in agriculture, according to OECD (2020) data, total public agriculture-related support for water in these 54 countries increased from USD 25.9 billion in 2000 to USD 54.2 billion in 2011 before declining to USD 41.6 billion in 2019 (Ashley and Gruere 2021). Most of that support (70%) focused on irrigation (from irrigation development to support for water in irrigation), and 18% was dedicated to agriculture-related hydrological infrastructure (comprising all basin and sub-basin infrastructure work that may be related to agricultural water management). The remaining amount was split between conservation-related and water risk-related management expenditures.

Close to three-quarters of water-related EHS was provided in emerging countries, especially India and China (58%), where a large amount of support was provided to irrigation (around USD 15.4 billion in 2019) via irrigation-related water or electricity subsidies. In OECD countries, total water-related agriculture support declined progressively from USD 18.7 billion at the peak of the series in 1995 to USD 6.8 billion in 2019 (Ashley and Gruere 2021), in part due to a reduction in irrigation-related support for agriculture. 86% of water-related EHS is dedicated to investment enabling the functioning of the sector, with only 24% of total water-related support linked to agricultural production.

Analysis and data on the costs of land degradation are less advanced than that for agriculture and water. For example, Nkonya et al. (2015) estimate the costs of land degradation at around USD 231 billion a year. Local tangible losses (mainly provisioning services) account for 46% of this cost, the rest being due to the loss of ecosystem services. However, the literature on the linkages between land degradation and agricultural support is less well-developed (DeBoe, 2020).

Studies from major global initiatives such as The Economics of Ecosystems and Biodiversity (TEEB) and the Intergovernmental Science-policy Platform for Biodiversity and Ecosystem Services (IPBES) have focused increasing attention on both quantification and analysis of subsidies harmful to biodiversity and on identifying reform strategies (see, for example, TEEB 2010, 2018a, 2018b; IPBES 2016, 2018). Recognition that EHS have an impact on ecological systems has also been increasing with studies such as UNEP (2021) and Dasgupta (2021) focusing on nature as a whole and developing a systems perspective on the policy issues and challenges.

The reform of EHS has also found its way into global processes such as the G7, G20 and discussions around the post-2020 framework for the Convention on Biological Diversity (CBD). In the G7, the Italian, French and UK Presidencies in 2017, 2019 and 2021, respectively, placed increasing attention on the issue of EHS reform (see OECD 2012, 2017c, 2019, 2021). The linkages between EHS reform and a range of adverse environmental impacts from climate oceans through to biodiversity and pollution have been a feature of these global efforts. The G20 has echoed calls to reform EHS, particularly in relation to water (Gruere et al., 2020). Similarly, the draft post-2020 framework for the CBD calls on countries to "redirect, repurpose, reform or eliminate incentives harmful for biodiversity, including [X] reduction in the most harmful subsidies, ensuring that incentives, including public and private economic and regulatory incentives, are either positive or neutral for biodiversity" by 2030 (CBD 2030).

As noted above, few quantitative studies at the global level focused on the non-climate environmental impacts of agricultural subsidy reform. However, two recent studies reviewed above made a first step in incorporating biodiversity and land use impacts into global assessments of agricultural subsidy reform. FAO, UNDP and UNEP (2021) incorporated "Impacts on nature" in their multi-objective analysis of agricultural support. The report focused on changes in land use, chemicals use, and a biodiversity index as a result of removing agricultural subsidies and border measures (FAO, UNDP and UNEP 2021, pp. 56-61). Removing all agricultural support (border measures and fiscal subsidies) is projected to result in a decline in agricultural land of 0.15% in 2030 relative to the baseline. Cropland and pastureland are projected to decline by 0.05% and 0.20%, respectively, while forest and other land habitats are projected to increase by 0.08% and 0.17%, respectively. Again, however, the impacts vary across countries, with agricultural land projected to increase and forest habitat to decrease in BRIC countries as livestock production shifts marginally away from non-BRIC developing countries to developed countries and BRIC countries.

The study also projected a reduction in the use of chemical inputs (pesticides and fertiliser) amounting to 0.22% in 2030 relative to the baseline. Removing border support alone is projected to increase chemical input use due to large exporting countries increasing crop production because of improved market access. However, this would be more than offset by a reduction in chemical input use resulting from the removal of fiscal subsidies.

The impacts on biodiversity were assessed via a biodiversity index that was constructed based on land-use changes. The study projected an increase in the biodiversity index of 0.10% globally in 2030 relative to the baseline, with biodiversity increasing in developed and non-BRIC developing countries and marginally declining in BRIC countries. However, it should be emphasised that this index is a very rough approximation of biodiversity and is formed by very strong assumptions about the relationship between land use, chemical use and biodiversity. It underscores the methodological challenge in selecting an appropriate and robust biodiversity index at a global scale, comparable across countries and amenable to aggregation into country groupings.

In the study emanating from the World Bank and IFPRI, Gautum et al. (2022) used a similar multi-objective approach to assess the impact of agricultural support removal and repurposing on a range of indicators, including "nature", which is defined as changes in agricultural land created by changes in agricultural incentives. The elimination of domestic support and trade barriers were projected to have only minimal impacts on agricultural land (-0.02% in 2040 relative to the baseline) (Gautum et al. 2022, Table D.1). The repurposing scenarios revealed mixed outcomes for changes in agricultural land, with small increases under the uniform support and increased conditionality scenarios (0.02% and 0.62%, respectively) and a significant decline of -2.15% under the green investment scenario (Table D.3).

These two studies represent an initial foray into using global CGE models for analysing the economic and environmental outcomes for non-climate environmental indicators. The ability to push further into this area is, at this stage, severely constrained by the availability of appropriate data and metrics that reflect the myriad complexities of ecological and economic interactions. Nevertheless, several organisations such as IIASA and OECD focused on linking up suites of global economic and biological models to address questions of the impacts of reform on nature, writ large. This is becoming more feasible as computing power increases to enable the models to be linked at fine geographical scales. Global data on environmental variables at a fine scale become more available through, for example, the increased use of satellites to remotely gather data.

In summary, several insights can be drawn from the foregoing review:

- The economic and business case for action in reforming agriculturally related EHS has been strengthened over time, and interest at a global level is now moving into strategies and frameworks for government and business action (e.g. OECD 2017a, 2017c; Koplow and Steenblik 2022). The establishment of the Taskforce on Nature-related Financial Disclosures is further evidence of this progress (see https://tnfd.global).
- While precise definitions of agricultural EHS vary at the margin (for example, are uninternalized externalities included in the definition), there is broad agreement on the magnitude of EHS in agriculture.
- The increasing policy interest in EHS at a global level is generating demands for integrated systems analysis to support discussions around agricultural subsidy reform. Continued efforts to link agro-economic and biophysical models at scale can provide considerable payoffs in terms of better understanding the complex dynamics at play.

Insights at the national level

At the national level, there are two broad streams of relevant literature. First, and mirroring the global level efforts, work is increasing pace to estimate EHS, including agriculture-related EHS. This focus on increased transparency around public support sheds light on the linkages between EHS and economic, environmental and social indicators at a finer and more local geographical scale than is evident at the global level. For example, several countries are undertaking national-level assessments to systematically identify their public subsidies that are harmful to biodiversity or the environment more generally. France, Germany and Italy are examples of G7 countries that have done this (OECD 2021).

To further increase transparency, the evolving use of green budgeting is a step toward helping countries examine and improve the alignment of government spending and fiscal policy with environmental objectives. This implies understanding both the positive and negative impacts of budgetary and fiscal decisions on the environment. However, most of the green budgeting exercises are climate-focused and tend to address only positive support for the environment.

With its "Green Budget for 2021", France is the only country that has completed a comprehensive assessment of its budget to identify all positive and negative environmentally-related expenditures (OECD 2021). Ireland undertook a National Biodiversity Expenditure Review in 2018, while the EU has developed a climate and biodiversity tagging methodology to track progress in its budget under its 2014-2020 EU Multi-annual Financial Framework, building on the OECD Rio markers methodology.

Much of the work on identifying and assessing agricultural support at the national level is increasingly driven by the need to finance environmental investments. For example, there is a strong push toward identifying the investment gaps and financing needs in the water sector in general and in the agricultural water in particular (e.g. Ashley and Gruere 2021).

Second, there is a myriad of national and sub-national modelling studies aimed at strengthening the understanding of the linkages between agricultural policy instruments, including subsidies, and their environmental impacts. These studies are largely based on biophysical models, sometimes coupled with partial equilibrium economic models or regional input-output models, and seek to examine a range of issues at the nexus between agricultural support and the environment. The finer scale allows the models to reflect site-specific characteristics more accurately and usefully. They tend to focus on farm-level technical efficiency around the use of fertiliser, pesticides and water as inputs to agricultural production (see, for example, Laukkanen and Nauges, 2014; Minviel and Truffe, 2017; Graham et al., 2021; Biffi et al., 2021; OECD 2017b). Studies have also focused on the biodiversity and water impacts of land use and land-use changes in the agricultural sector due to agricultural support and reform.

While it is beyond the scope of this paper to review the significant number of modelling studies at the local and national levels across countries, several insights are important to highlight:

- There is increasing transparency around agricultural EHS and their impacts at the national and sub-national levels; However, more needs to be done to strengthen the information and evidence base for reform.
- Green budgeting initiatives can foster and support such transparency and can help to harness the political impetus being provided at the G7 and G20 alongside the outcomes of high-profile global reviews such as the Dasgupta Report.
- The focus on farm-level, local, and regional impacts facilitates the technical discussions on the feasibility of alternative policy options to meet multiple objectives around production, poverty, sustainability, healthy diets, etc. However, there is an ongoing need to develop better and more integrated data on biodiversity, land degradation and water impacts to support these efforts and provide a more holistic analysis.
- Investment in information tools and techniques to strengthen the systems approach to integrated biodiversity data is key to enhancing the modelling ability to take an integrated approach that links the various environmental agendas (e.g., climate, biodiversity, water) and the economic and social goals.

Information available on analysis underway and planned

Meetings were organised virtually to complement this desktop review from late January through mid-February 2022 with senior officials in selected international organisations (IOs) on a confidential and without attribution basis. Each meeting explored work that was underway or planned to analyse agricultural (and wider) subsidy reform options and the related environmental and climate impacts and views on key information gaps that constrain progress on agricultural subsidy reforms that would deliver better environmental and climate outcomes.

Much of the work currently underway in IOs on agricultural support and the environment appears to be a direct follow-on from earlier initiatives that explored "repurposing" agricultural support to address objectives linked to "greening". That focus was largely motivated by the 2021 UN Food Systems Summit and by COP26. Some of this interest in "repurposing" at a global level is now beginning to look beyond "greening" to focus instead on how policies can contribute to the full range of Sustainable Development Goals (in particular, healthy diets, global food security and nutrition, and poverty reduction). However, at a regional and national level, there is continued strong interest in country-specific analysis to explore "repurposing" agriculture support towards better environmental and climate outcomes. In some cases, a more integrated economy-wide approach to "greening" is emerging, aiming to focus limited public funds on the highest economic, environmental, and social priorities.

The WTO Trade and Environmental Sustainability Structured Discussions is a noteworthy recent initiative, with 71 WTO members indicating Ministerial level "Support (for) continued discussions on the environmental effects and trade impacts of relevant subsidies and the role of the WTO in addressing these." This initiative is also based on a holistic approach looking across trade, subsidies, and the environment, but already some members are advocating for a particular focus on agriculture subsidies and their impacts.

There is a great deal of long-standing work at the OECD on subsidy measurement and analysis across several sectors that address not just the economic but also the environment and climate impacts. This work majorly contributes to improving the transparency of government support and enables other researchers to draw on OECD-generated data to undertake a wide range of analyses. Across the OECD, interest in addressing environmentally harmful subsidies based on robust policy data, analysis, and dialogue appears to be increasing.

A joint IO report (IMF, OECD, WBG, and WTO) on subsidy reform is nearing completion and is expected to have comprehensive coverage of subsidies' nature, scale, and impacts. It should contribute to raising international awareness further, not just of the prevalence of subsidies but of the urgency to introduce reforms so that competitive suppliers everywhere can access a global level playing field.

Overall, while there is widespread awareness that environmental considerations strengthen the economic case for moving away from production and trade-distorting agricultural support, few specific new initiatives are underway, and few planned.

Directions for future work

Both the WTO and the OECD already provide a great deal of valuable information on domestic support in agriculture.

However, the methodologies used to estimate support levels are different, are not always well understood and correctly interpreted, and, generally, are under-utilised.

A great deal of information is available on the impacts of agriculture subsidies on production, trade, and, more recently, the environment. The conceptual pathways through which subsidies can impact the environment are well established and encompass both the unintended negative impacts of production and trade-distorting support and the positive impacts of targeted support policies that aim to increase a range of environmental goods.

The available literature emphasises the need to assess impacts empirically. Actual impacts can be expected to vary considering various factors, such as the nature and scale of support provided, location-specific physical conditions, and the risk preferences and related behaviour of farmers.

Much of the empirical research to date has focused on the impacts of policy reform on agricultural production, trade, prices, and incomes. More recently, it has addressed climate linkages—however, few quantitative studies assess the climate impacts of reduced agriculture support per se. The results are highly sensitive to the assumptions employed, the data input, and the model parameters. These aspects warrant more attention. A useful innovation of the most recent studies that could be further developed at the country and global level extends the analysis of likely impacts by 'repurposing' savings from support reductions to new policy measures that target improved innovation and environmental outcomes. Other areas warranting further consideration include the treatment of methane and nitrous oxide, C02 emissions, leakage of GHG emission reductions, and land-use change.

In terms of non-climate environmental impacts, there is broad (though not universal) agreement on the magnitude of EHS in agriculture and a growing interest in integrated agro-economic and biophysical models to clarify the complex dynamics at play. Clarifying impacts on water, biodiversity, and land degradation, however, warrant much more granular attention at national and local levels.

An essential conclusion of this report is that an innovative approach to addressing the domestic support pillar at the WTO would encompass two elements:

1. **improving awareness and understanding of available information and analysis while filling strategically important knowledge gaps**
2. **building a coalition of stakeholders in support of an evidence-based discourse and a modern package of agriculture policies that would work better for people and planet.**

Information, analysis and communication

Multilateral negotiations to agree to new disciplines on agricultural subsidies depend partly on improving the availability, timeliness, and shared understanding of WTO data on the nature, level, and sources of agricultural support. There are various options available to improve policy transparency at the WTO, from renewed member commitments to notify (and penalties for not doing so) to counter-notifications by other members to mandating experts within IO Secretariats (or in academic or private research bodies) to provide domestic support estimates periodically based on an agreed methodology. Consideration should also be given to increasing the capacity of the WTO Secretariat to make policy data and related analysis available in an easily accessible form to all members and various publics. Options should be explored and then acted upon as a priority.

While recognising the clear preference that WTO negotiators have for data submitted by members in-line with agreed commitments, much greater use should be made of existing OECD data and analysis. A more widely shared understanding of the prevalence and likely impacts of current domestic support on production, trade, and the environment would facilitate effective national reforms and internationally agreed disciplines. This work could be undertaken within the OECD or via increased analytical collaboration between OECD and WTO. Another option could build on the existing consortium of IOs (OECD, FAO, IFPRI, WBG, WTO, IADB) that is already working to improve agricultural policy monitoring and analysis and extend these efforts to encompass climate and environment as well as production and trade impacts.

Specific areas of further research include:

- distinguishing better, a priori, between good subsidies (NTDS) and bad subsidies (TDDS): this would aim to ensure that countries do not simply shift from current support measures to alternative measures that might have different but still negative effects on production, trade, and the environment
- examining in-depth the prevalence and likely impacts of commodity-specific support, which for some commodities is at very high levels and which would be expected to have larger negative impacts on agriculture production, trade, and the environment
- analysing the broad category of input subsidies with a view to 'unpacking' the various components and isolating those measures that have the most negative production, trade and environmental impacts
- analysing the specific needs, interests, and policy options available to less developed countries, many of which have no or very low domestic support and whose interests could best be served by increasing NTDS to the sector.

Public engagement, networking and coalition building

There is arguably more information already available on agricultural support and its production, trade, climate, and other environmental impacts than for any other sector, yet addressing domestic support at the WTO remains elusive. Successful policy reform in sensitive sectors where member positions are diverse requires more than just good data and information available; it requires coalition building. A dedicated and sustained networking initiative that brings information in a highly accessible form together with active public engagement and coalition-building should be developed on a priority basis and launched, if feasible, immediately following MC12.

The first step in building a robust coalition should be to undertake a detailed stakeholder analysis to identify the key environment, agriculture, trade, and other interest groups and to determine their aims and expectations (looking across governments, IOs, the private sector, academic bodies, think tanks, NGOs, and civil society). At the same time, an initial stocktaking brief outlining available information, analysis, and advice should be developed on the basis of this report.

Specific areas of possible activities include:

- identifying opportunities to contribute an evidence-based subsidy reform narrative to targeted international meetings: G7, G20, APEC, WTO, and OECD; this would include considering alternative policy approaches to achieve stated goals without negative economic and environmental impacts
- working with official events aligned to multilateral structures such as the Think 20, Think 7, Global Solutions Summit, and the WTO's Annual Public Forum
- exploring opportunities to engage directly with and contribute information and analysis to the WTO Trade and Environmental Sustainability Structured Discussions
- exploring opportunities for comprehensive subsidy reform, of which agriculture would be but one element; providing subsequent insights to WTO members with shared interests in ambitious plurilateral negotiations on comprehensive subsidy reform
- cooperating with private sector representatives, identify public, private, and public-private measures that would improve the performance of global food systems (i.e., to increase productivity, sustainability, and resilience); including establishing markets for sustainably storing carbon, enabling digital applications for all, increasing access to innovation and reducing the productivity gap, and so on.

"An innovative approach to addressing domestic support at the WTO would encompass...building a coalition of stakeholders in support of an evidence-based discourse and a modern package of agriculture policies that would work better for people and planet."

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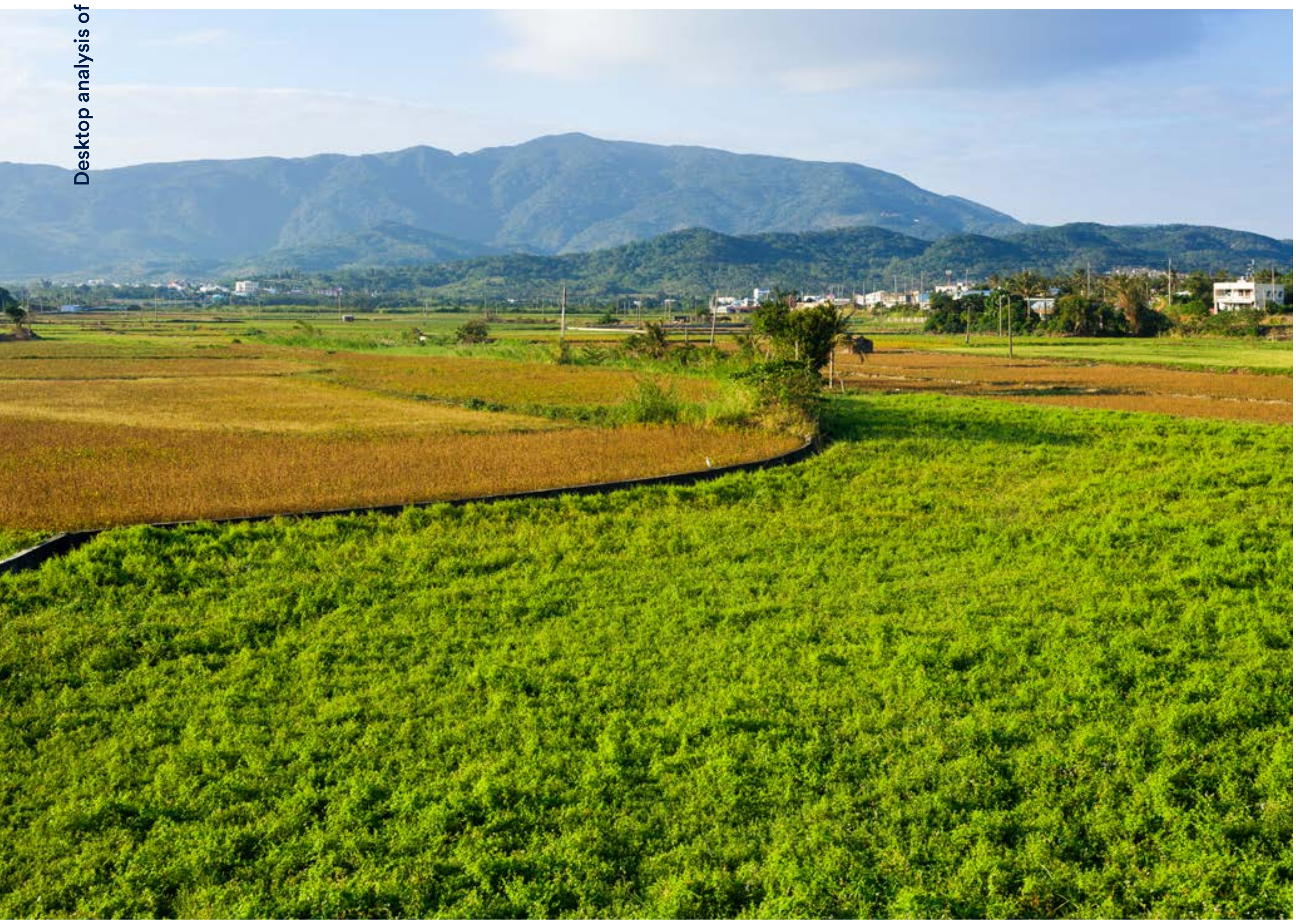

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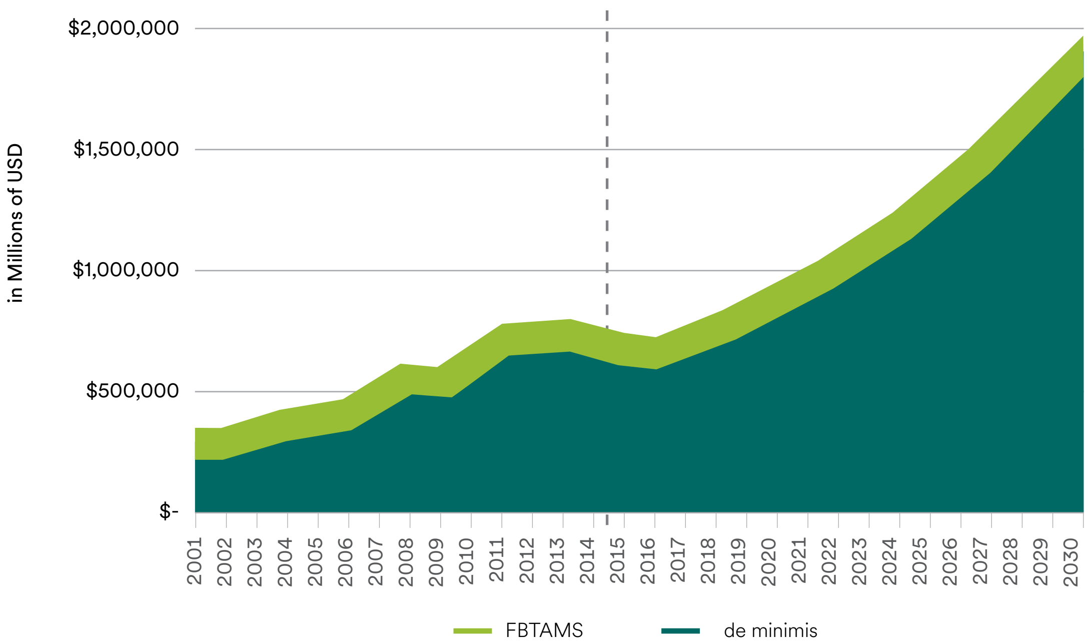
Appendices

Appendix I: Tables & figures

Appendix II: technical annex: summary of studies reviewed

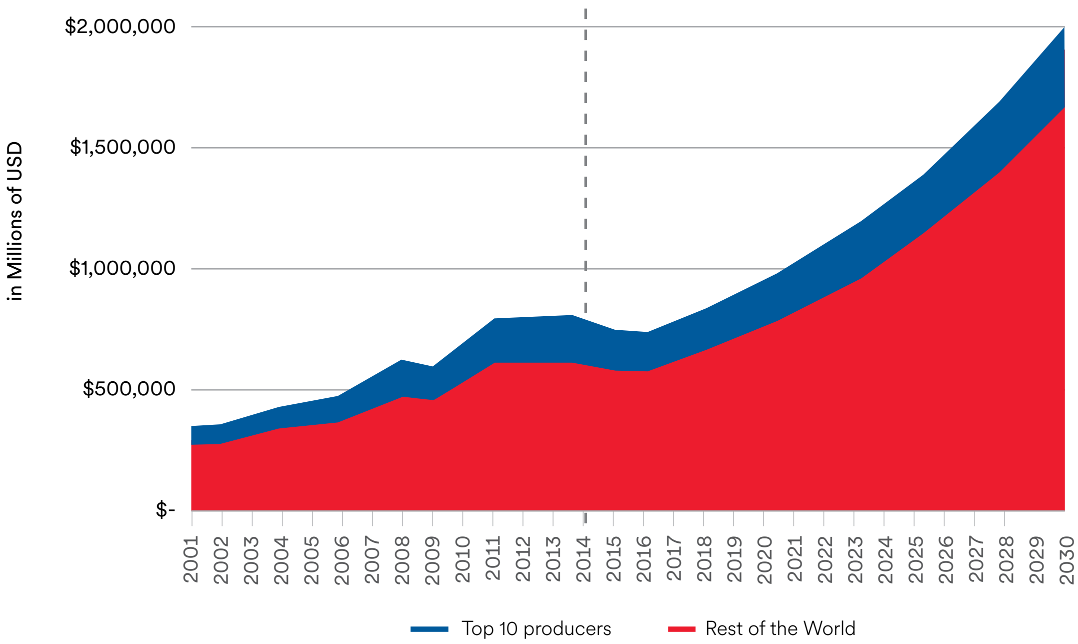
Appendix I
Tables & figures

Figure 1: Growth in entitlements of Amber Box support, all WTO members



Source: Australia and New Zealand, JOB/AG/171

Figure 2: Growth in entitlements of Amber Box support, the top 10 countries and ROW



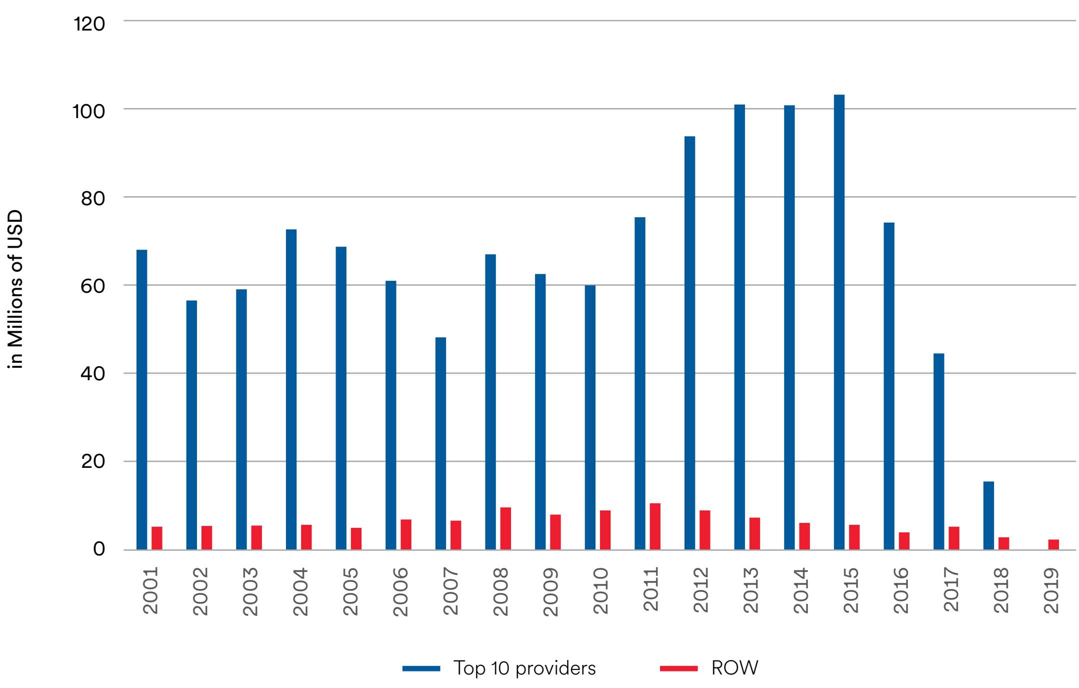
Source: Australia and New Zealand, JOB/AG/171

Growth of entitlements of Amber Box support, top 10 countries in 2016 and in 2030

Rank	Top 10 in 2016	Share
1	China	28.07%
2	European Union	15.66%
3	India	9.62%
4	United States	6.96%
5	Japan	6.03%
6	Brazil	4.58%
7	Indonesia	3.69%
8	Turkey	1.79%
9	Russia	1.54%
10	Mexico	1.39%

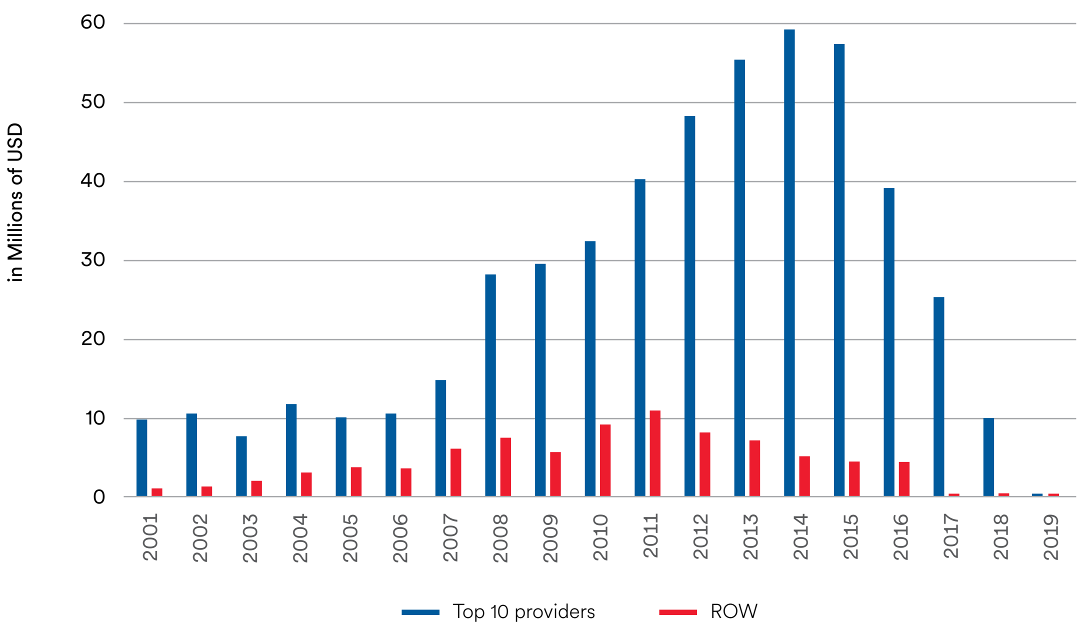
Rank	Top 10 in 2030	Share
1	China	42.27%
2	India	11.51%
3	Indonesia	8.09%
4	European Union	6.56%
5	Brazil	6.09%
6	United States	3.86%
7	Japan	2.30%
8	Turkey	1.85%
9	Russia	1.05%
10	Mexico	0.73%

Figure 3: Amber Box support, top 10 providers and ROW



Source: Authors' calculation based on WTO notifications

Figure 4: De minimus support, top 10 providers and RoW



Source: Authors' calculation based on WTO notifications

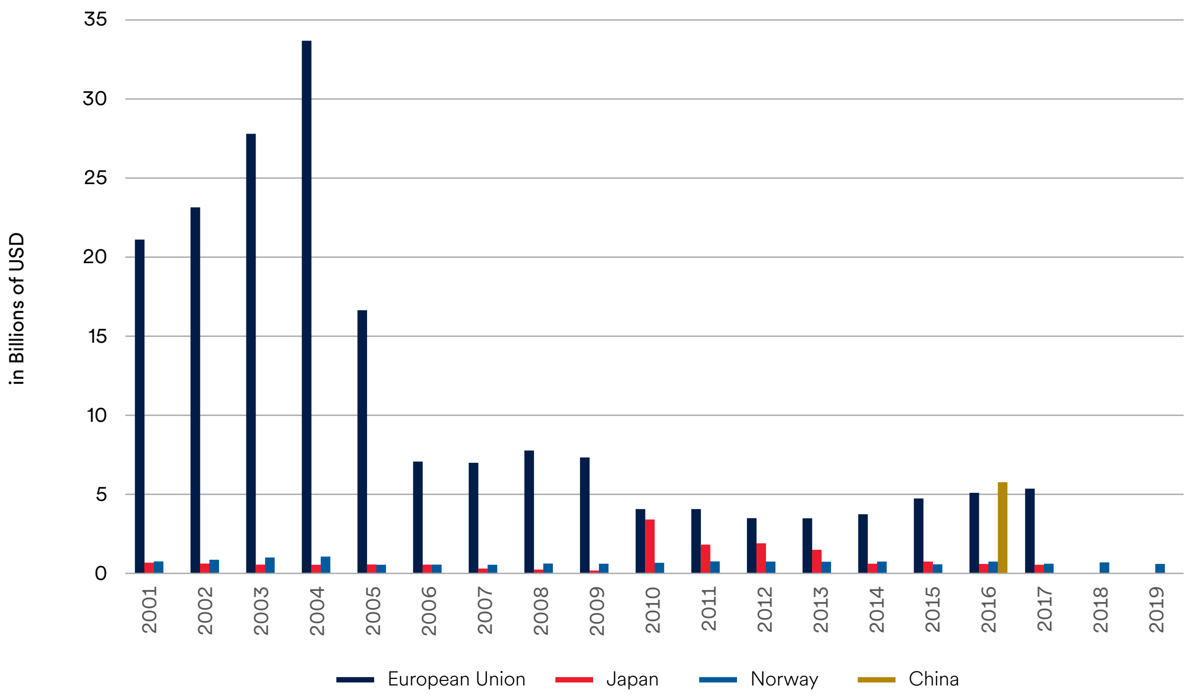
Amber Box support, top 10 providers in 2016

Rank	WTO Member Name	Share
1	China	29.74%
2	United States	20.48%
3	European Union	13.30%
4	Japan	10.14%
5	India	7.15%
6	Russian Federation	3.85%
7	Canada	2.79%
8	Brazil	2.73%
9	Turkey	2.57%
10	Switzerland	1.77%

De minimus support, top 10 providers in 2016

Rank	WTO Member Name	Share
1	United States	27.76%
2	China	25.12%
3	India	12.73%
4	Russian Federation	6.74%
5	European Union	6.22%
6	Brazil	4.86%
7	Japan	4.78%
8	Turkey	4.53%
9	Canada	3.90%
10	Mexico	1.03%

Figure 5: Blue Box support notified



Source: Authors' calculation based on WTO notifications

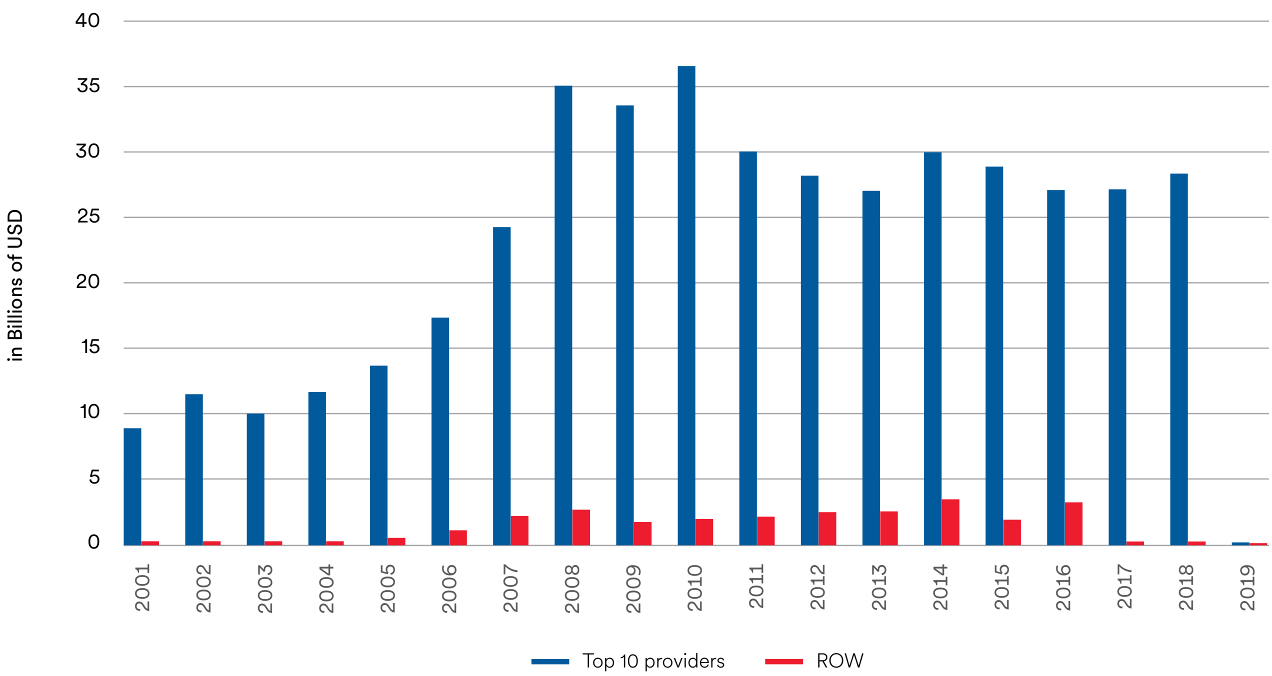
Blue Box support, all users in 2016

Rank	WTO Member	Share
1	China	47.19%
2	European Union	41.24%
3	Japan	6.34%
4	Norway	5.23%

Development Box support, top 10 providers in 2016

Rank	WTO Member	Share
1	India	73.89%
2	Indonesia	8.89%
3	Thailand	5.93%
4	Turkey	2.68%
5	Brazil	2.37%
6	Mexico	2.05%
7	Colombia	1.06%
8	Philippines	0.96%
9	Sri Lanka	0.72%
10	Peru	0.36%

Figure 6: Development Box support, top 10 providers and RoW

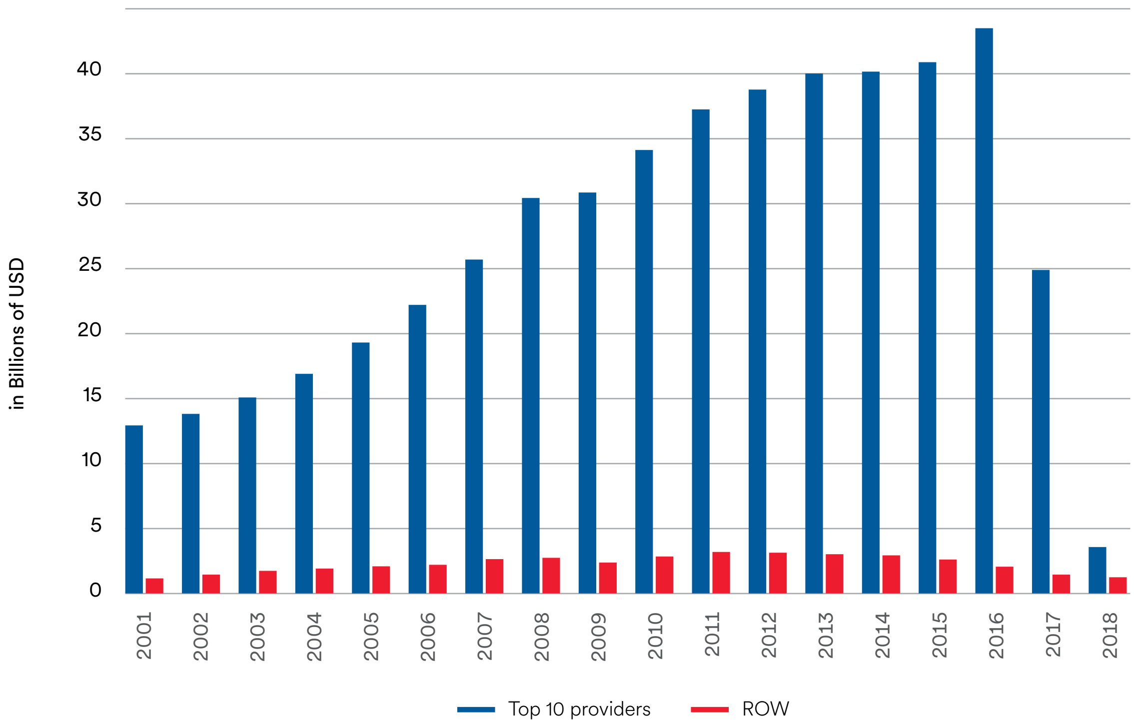


Source: Authors' calculation based on WTO notifications

Green Box support, top 10 providers in 2016

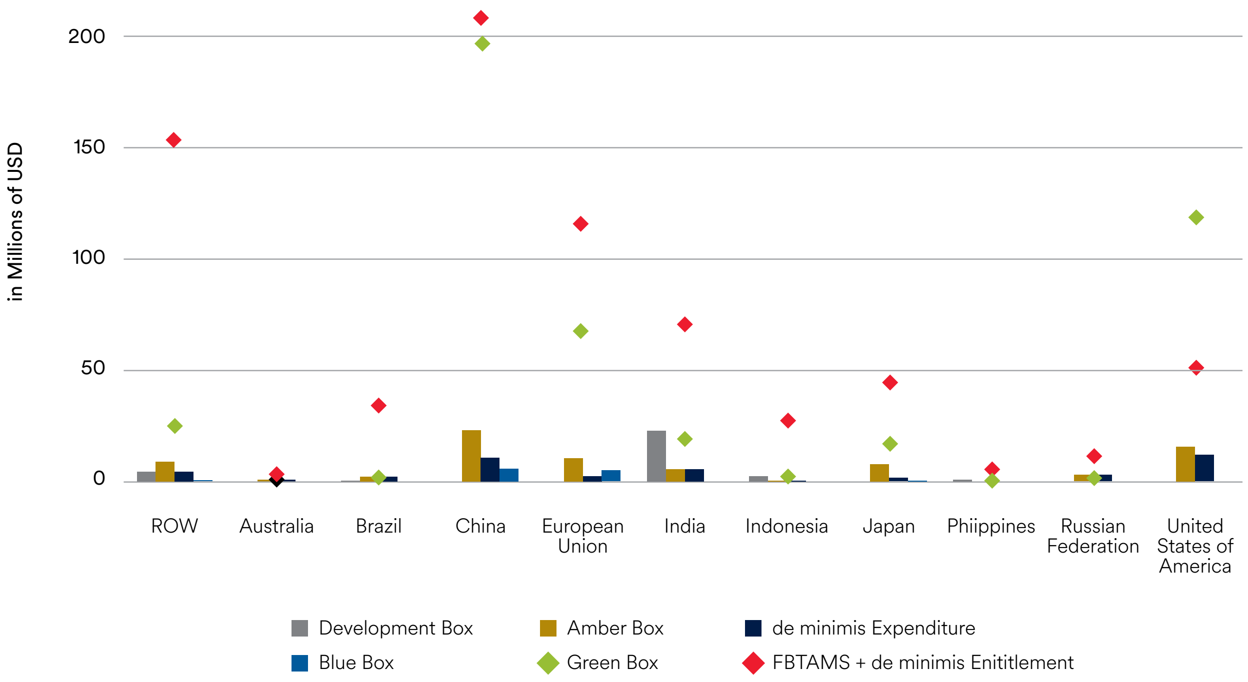
Rank	WTO Member	Share
1	China	43.37%
2	United States	26.23%
3	European Union	14.98%
4	India	4.19%
5	Japan	3.84%
6	Cuba	1.34%
7	Mexico	0.91%
8	Switzerland	0.60%
9	Thailand	0.53%
10	Indonesia	0.47%

Figure 7: Green Box support, top 10 providers and RoW



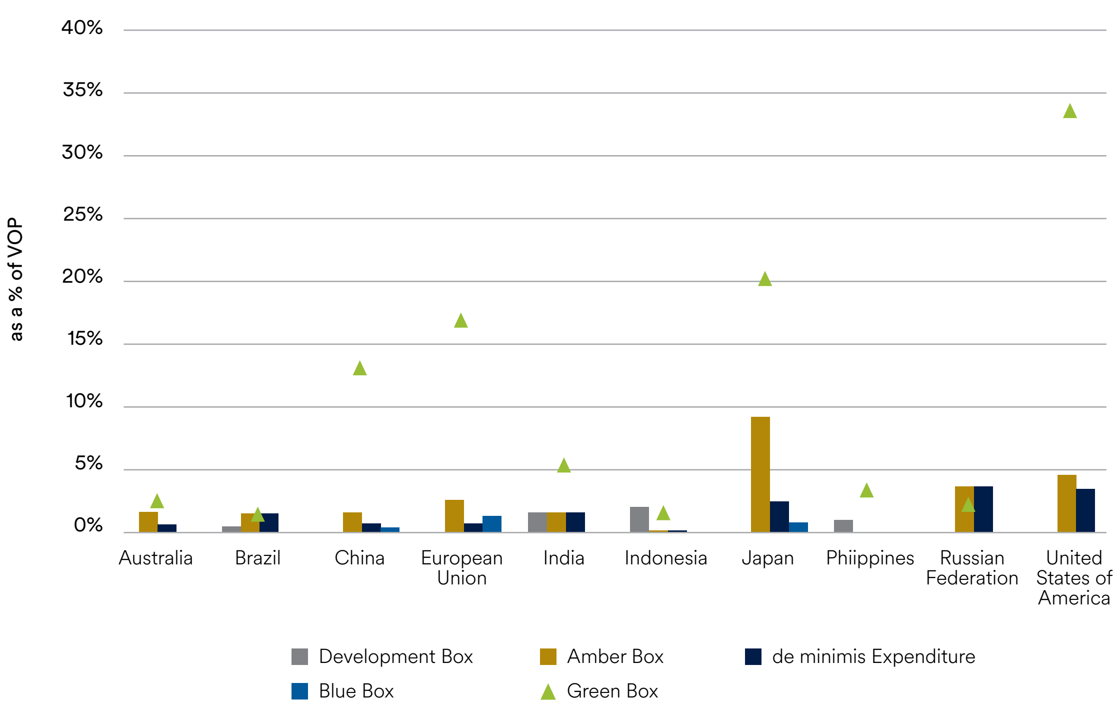
Source: Authors' calculation based on WTO notifications

Figure 8: Notified agricultural domestic support expenditures and FBTAMS + de minimus entitlements (2016)



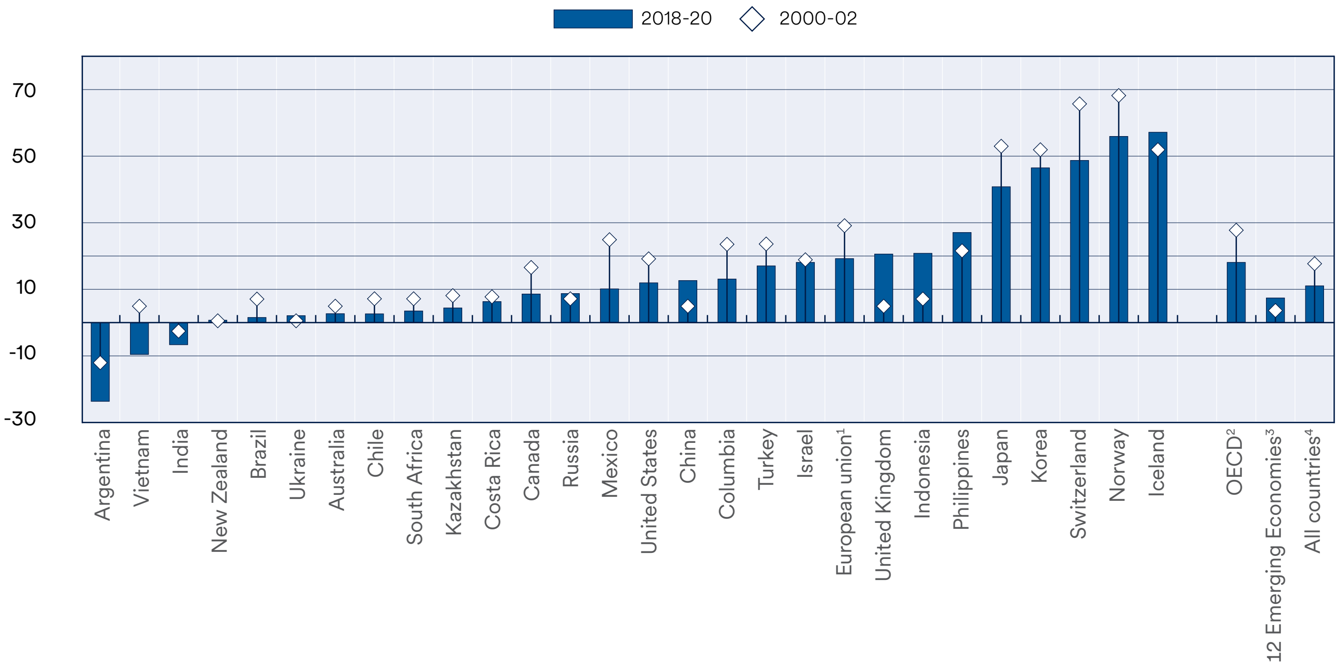
Source: Authors' calculation based on WTO notifications

Figure 9: Notified agricultural domestic support expenditures as a % of VoP, selected countries, 2016



Source: Authors' calculation based on WTO notifications

Figure 10: OECD Producer Support Estimate by country, 2000-02 and 2018-20: percentage of gross farm receipts



Source: OECD (2021), "Producer and Consumer Support Estimates", OECD Agriculture statistics (database), http://dx.doi.org/10.1787/agr-pcse-data-en.

Notes: Countries are ranked according to the 2018-20 levels.

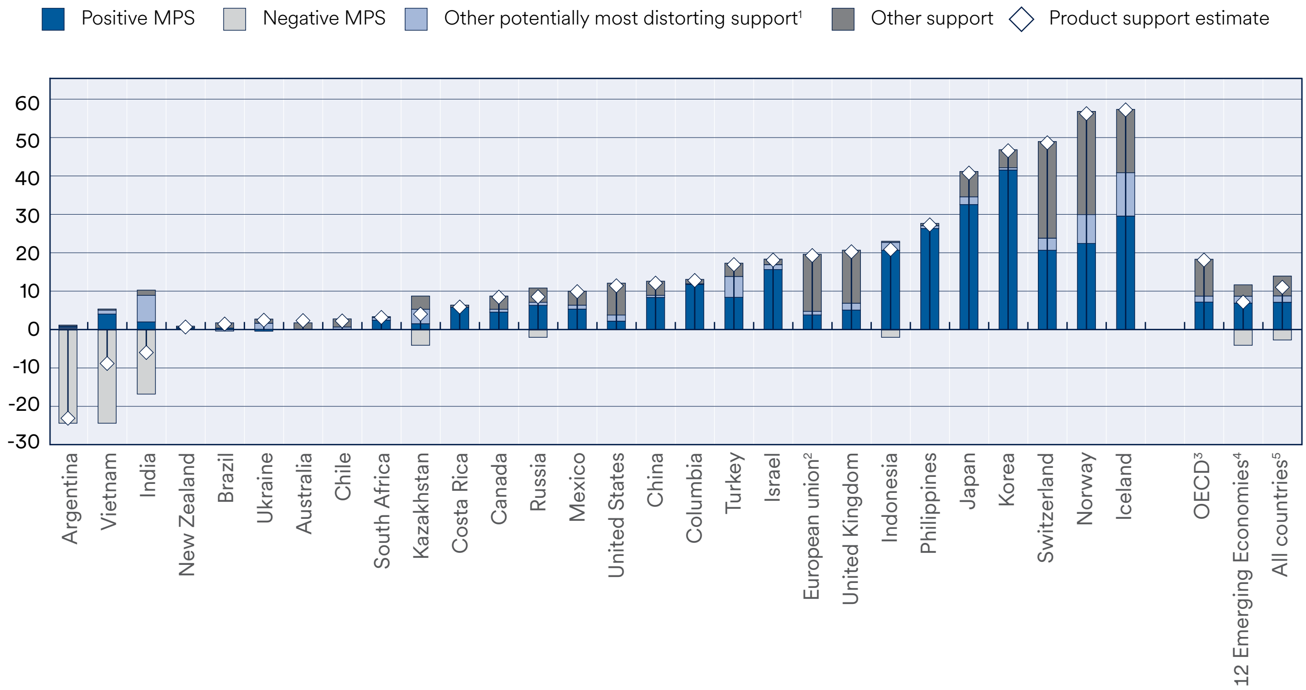
1. EU15 for 2000-02, EU28 for 2018-19 and EU27 plus UK for 2020.

2. The OECD total does not include the non-OECD EU Member States. Latvia and Lithuania are included only for 2018-20. Costa Rica became the 38th member of the OECD in May 2021. In the data aggregates used in this report, however, it is included as one of the 12 Emerging Economies.

3. The 12 Emerging Economies include Argentina, Brazil, China, Costa Rica, India, Indonesia, Kazakhstan, the Philippines, Russian Federation, South Africa, Ukraine and Viet Nam.

4. All countries total includes all OECD countries, non-OECD EU Member States, and the Emerging Economies. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Figure 11: Potentially most distorting transfers and other support by country, 2018-20: percentage of gross farm receipts



Source: OECD (2021), "Producer and Consumer Support Estimates", OECD Agriculture statistics (database), http://dx.doi.org/10.1787/agr-pcse-data-en

Notes: Countries are ranked according to the %PSE levels.

1. Support based on output payments and on the unconstrained use of variable inputs.

2. EU28 for 2018-19, EU27 plus UK for 2020.

3. The OECD total does not include the non-OECD EU Member States. Costa Rica became the 38th member of the OECD in May 2021. In the data aggregates used in this report, however, it is included as one of the 12 Emerging Economies.

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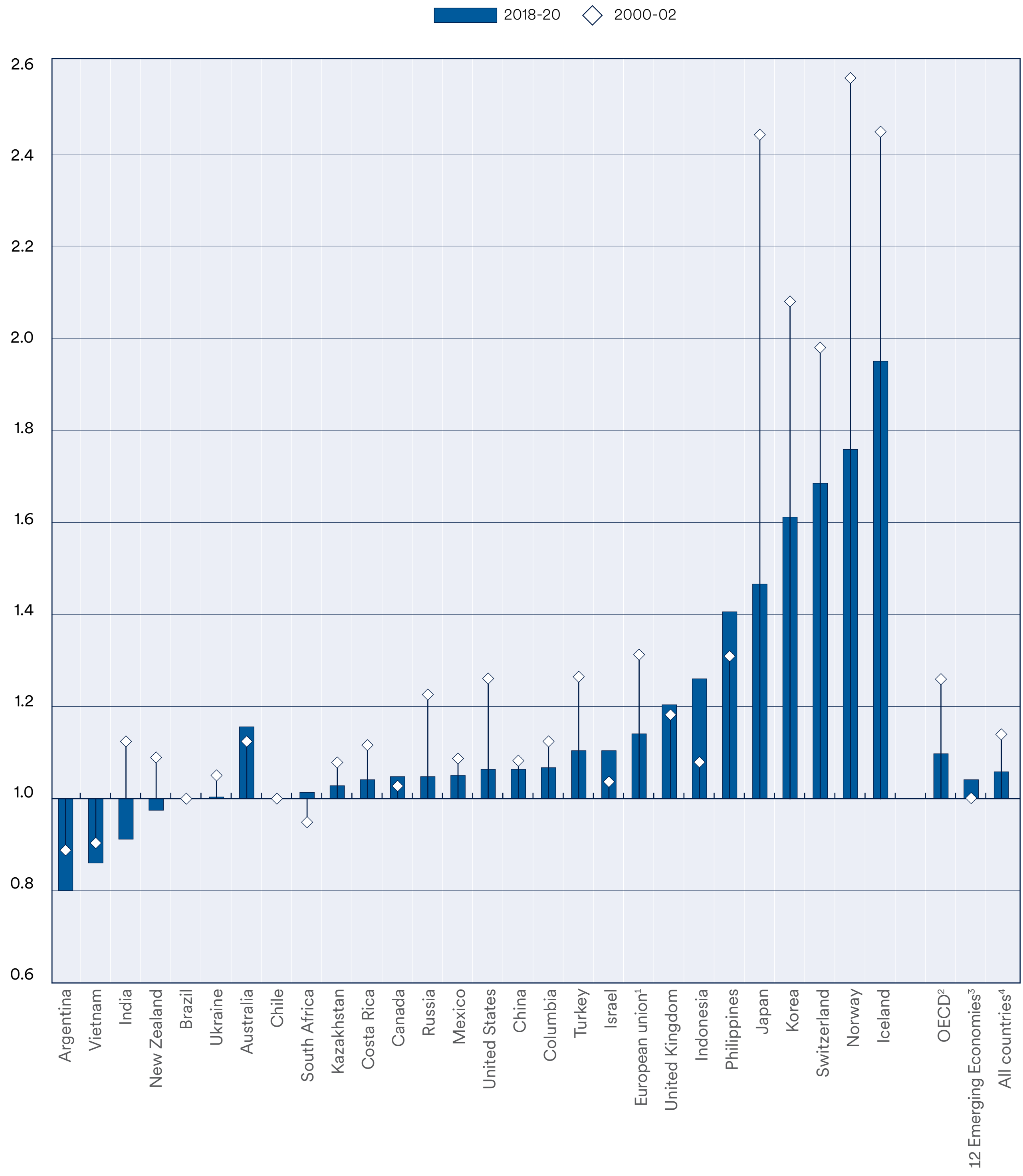
Figure 12: Producer Nominal Protection Coefficient by country, 2000-02 and 2018-20



Source: OECD (2021), "Producer and Consumer Support Estimates", OECD Agriculture statistics (database), http://dx.doi.org/10.1787/agr-pcse-data-en.

Notes: Countries are ranked according to the 2018-20 levels.

1. EU15 for 2000-02, EU28 for 2018-19 and EU27 plus UK for 2020.

2. The OECD total does not include the non-OECD EU Member States. Latvia and Lithuania are included only for 2018-20. Costa Rica became the 38th member of the OECD in May 2021. In the data aggregates used in this report, however, it is included as one of the 12 Emerging Economies.

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Table 1: All countries, OECD Estimates of Support to Agriculture

	2000-02	2018-20	2018	2019	2020p
Total value of production (at farm gate)	**1 195 819**	**3 638 643**	**3 572 201**	**3 581 869**	**3 761 858**
of which: share of MPS commodities (%)	72.4	76.4	74.9	76.4	77.8
Total value of consumption (at farm gate)	**1 181 908**	**3 495 771**	**3 355 887**	**3 475 764**	**3 655 662**
Producer Support Estimate (PSE)	**237 753**	**435 565**	**427 680**	**437 727**	**441 287**
Support based on commodity output	140 753	180 512	189 789	176 910	174 838
Market price support[1]	125 385	167 956	172 960	169 624	161 285
Positive Market price Support	149 601	272 438	272 142	271 504	273 668
Negative Market price Support	-24 217	-104 482	-99 182	-101 880	-112 384
Payments based on output	15 369	12 556	16 829	7 286	13 553
Payments based on input use	36 844	95 950	93 628	91 967	102 254
Based on variable input use	19 491	55 312	51 477	52 353	62 107
with input constraints	342	1 861	1 647	1 880	2 057
Based on fixed capital formation	9 545	29 194	31 379	28 425	27 778
with input constraints	630	3 514	4 194	3 374	2 974
Based on on-farm services	7 808	11 444	10 772	11 190	12 370
with input constraints	967	1 611	1 575	1 533	1 723
Payments based on current A/An/R/I, production required	42 194	79 505	72 787	86 667	79 062
Based on Receipts / Income	3 986	6 734	6 607	6 548	7 046
Based on Area planted / Animal numbers	38 209	72 772	66 180	80 119	72 016
with input constraints	16 898	39 658	33 179	46 551	39 245
Payments based on non-current A/An/R/I, production required	71	2 197	2 235	2 373	1 985
Payments based on non-current A/An/R/I, production not required	14 091	68 864	61 592	71 519	73 482
With variable payment rates	4 318	5 023	3 021	6 391	5 659
with commodity exceptions	4 079	4 880	2 864	6 254	5 521
With fixed payment rates	9 773	63 841	58 571	65 128	67 823
with commodity exceptions	6 081	2 565	2 510	2 515	2 669
Payments based on non-commodity criteria	3 664	6 421	5 415	6 595	7 253
Based on long-term resource retirement	3 358	4 820	3 875	5 041	5 545
Based on a specific non-commodity output	237	1 502	1 462	1 489	1 555
Based on other non-commodity criteria	69	99	78	65	153
Miscellaneous payments	136	2 115	2 235	1 697	2 412
Percentage PSE (%)	**18.2**	**11.2**	**11.2**	**11.4**	**10.9**
Producer NPC (coeff.)	**1.13**	**1.06**	**1.06**	**1.06**	**1.05**
Producer NAC (coeff.)	**1.22**	**1.13**	**1.13**	**1.13**	**1.12**
General Services Support Estimate (GSSE)	**55 289**	**101 670**	**105 413**	**99 616**	**99 983**
Agricultural knowledge and innovation system	10 996	26 362	26 805	25 978	26 304
Inspection and control	2 718	8 238	7 947	8 477	8 289
Development and maintenance of infrastructure	23 354	41 501	43 918	40 178	40 408
Marketing and promotion	5 602	5 845	5 387	5 799	6 349
Cost of public stockholding	10 144	17 751	19 497	17 131	16 624
Miscellaneous	2 475	1 973	1 859	2 053	2 008
Percentage GSSE (% of TSE)	**17.2**	**16.5**	**17.6**	**16.6**	**15.4**

	2000-02	2018-20	2018	2019	2020p
Consumer Support Estimate (CSE)	**-118 283**	**-152 228**	**-156 394**	**-170 858**	**-129 433**
Transfers to producers from consumers	-125 857	-182 574	-185 556	-185 099	-177 068
Other transfers from consumers	-22 410	-57 761	-47 623	-57 622	-68 038
Transfers to consumers from taxpayers	28 315	77 881	66 334	61 192	106 117
Excess feed cost	1 669	10 226	10 450	10 671	9 557
Percentage CSE (%)	**-10.3**	**-4.5**	**-4.8**	**-5.0**	**-3.6**
Consumer NPC (coeff.)	**1.14**	**1.07**	**1.07**	**1.08**	**1.07**
Consumer NAC (coeff.)	**1.11**	**1.05**	**1.05**	**1.05**	**1.04**
Total Support Estimate (TSE)	**321 358**	**615 116**	**599 427**	**598 535**	**647 386**
Transfers from consumers	148 267	240 335	233 179	242 721	245 107
Transfers from taxpayers	195 501	432 542	413 871	413 436	470 318
Budget revenues	-22 410	-57 761	-47 623	-57 622	-68 038
Percentage TSE (% of GDP)	**1.0**	**0.8**	**0.8**	**0.8**	**0.9**
Total Budgetary Support Estimate (TBSE)	**195 973**	**447 160**	**426 467**	**428 911**	**486 101**
Percentage TBSE (% of GDP)	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**

Note: p: provisional. NPC: Nominal Protection Coefficient. NAC: Nominal Assistance Coefficient.
A/An/R/I: Area planted/Animal numbers/Receipts/Income.
The All countries total includes all OECD countries, non-OECD EU Member States, and the Emerging Economies: Argentina, Brazil, China, Costa Rica, India, Indonesia, Kazakhstan, the Philippines, Russian Federation, South Africa, Ukraine and Viet Nam. The All countries total for 2000-02 includes data for all countries except Latvia and Lithuania, for which data are not available.
1. Market Price Support (MPS) is net of producer levies and excess feed cost. MPS commodities: see notes to individual country tables.
Source: OECD (2021), "Producer and Consumer Support Estimates", OECD Agriculture statistics (database), http://dx.doi.org/10.1787/agr-pcse-data-en.

WTO boxes: domestic support in agriculture

In WTO terminology, agriculture subsidies in , are identified by "boxes".

Amber box: Nearly all domestic support measures considered to distort production and trade fall into the amber box, which is defined in Article 6 of the Agriculture Agreement as to all domestic supports except those in the blue and green boxes. These include measures to support prices or subsidies directly related to production quantities.

These supports are subject to limits. "De minimis" minimal supports for both product-specific and non-product-specific support are allowed, defined as a share of the value of agricultural production. This threshold is generally 5% of the value of agricultural production for developed countries and 10% for most developing countries — although some WTO members agreed to a different level when they negotiated to join the WTO. Furthermore, 32 WTO members with larger subsidies than the de minimis levels at the beginning of the post-Uruguay Round reform period committed to reducing these support levels.

Blue box: This is the "amber box with conditions" — conditions designed to reduce distortion. Any support that would normally be in the amber box is placed in the blue box if the support also requires farmers to limit production (details set out in Paragraph 5 of Article 6 of the Agriculture Agreement). There are no limits on spending on blue box subsidies.

Development Box: Article 6.2 of the Agriculture Agreement allows developing countries additional flexibilities in providing domestic support. The type of support that fits into the developmental category are measures of assistance, whether direct or indirect, designed to encourage agricultural and rural development and that are an integral part of the development programmes of developing countries. They include investment subsidies which are generally available to agriculture in developing country members, agricultural input subsidies generally available to low-income or resource-poor producers in developing country members, and domestic support to producers in developing country members to encourage diversification from growing illicit narcotic crops.

Green Box: The green box is defined in Annex 2 of the Agriculture Agreement. In order to qualify, green box subsidies must not distort trade or at most cause minimal distortion (paragraph 1). They have to be government-funded (not by charging consumers higher prices) and must not involve price support. They tend to be programmes that are not targeted at particular products and include direct income supports for farmers that are not related to (are "decoupled" from) current production levels or prices. They also include environmental protection and regional development programmes. Green box subsidies are therefore allowed without limits, provided they comply with the policy-specific criteria set out in Annex 2.

Source: WTO Fact Sheet, Domestic Support in Agriculture

OECD estimates of support to agriculture: selected definitions

Producer Support Estimate (PSE): The annual monetary value of gross transfers from consumers and taxpayers to agricultural producers, measured at the farm gate level, arising from policy measures that support agriculture, regardless of their nature, objectives or impacts on farm production or income. It includes market price support, budgetary payments and budget revenue foregone, i.e. gross transfers from consumers and taxpayers to agricultural producers arising from policy measures based on: current output, input use, the area planted/animal numbers/receipts/incomes (current, non-current), and non-commodity criteria.

Market Price Support (MPS): The annual monetary value of gross transfers from consumers and taxpayers to agricultural producers arising from policy measures that create a gap between domestic market prices and border prices of a specific agricultural commodity, measured at the farm gate level. MPS is available by commodity, and sums of negative and positive components are reported separately where relevant along with the total MPS.

Consumer Support Estimate (CSE): The annual monetary value of gross transfers from (to) consumers of agricultural commodities, measured at the farm gate level, arising from policy measures that support agriculture, regardless of their nature, objectives or impacts on consumption of farm products. If negative, the CSE measures the burden (implicit tax) on consumers through market price support (higher prices), which offsets consumer subsidies that lower prices for consumers.

General Services Support Estimate (GSSE): The annual monetary value of gross transfers arising from policy measures that create enabling conditions for the primary agricultural sector through the development of private or public services, institutions and infrastructure, regardless of their objectives and impacts on-farm production and income, or consumption of farm products. The GSSE includes policies where primary agriculture is the main beneficiary but does not include any payments to individual producers. Therefore, GSSE transfers do not directly alter producer receipts or costs or consumption expenditures.

Total Support Estimate (TSE): The annual monetary value of all gross transfers from taxpayers and consumers arising from policy measures that support agriculture, net of the associated budgetary receipts, regardless of their objectives and impacts on-farm production and income or consumption of farm products.

Percentage PSE (%PSE): PSE transfers as a share of gross farm receipts (including support in the denominator).

Percentage TSE (%TSE): TSE transfers as a percentage of GDP. Producer Nominal Protection Coefficient (producer NPC): The ratio between the average price received by producers (at the farm gate), including payments per tonne of current output, and the border price (measured at the farm gate). The Producer NPC is also available by commodity.

Source: OECD (2021)

Appendix II Technical annex: summary of studies reviewed

The purpose of this Appendix is to summarise the ten studies discussed in the main body of the report (see Table 1 for an overview of the models). Further details can be found in the studies, but the aim is to summarise the model characteristics, scenarios and key results. Before delving into the studies, a brief overview of the types of agro-economic models used in studies is provided to illustrate the relative strengths of the different modelling approaches used in the studies.

Overview of model types

The reviewed models vary significantly and include partial equilibrium models, computable general equilibrium models, and integrated assessment models. The models differ in model specification, parameterisation, scenario assumptions and data sources. Their characterisation of the agricultural sector is quite different, reflecting each model's history and original purpose. They also differ considerably in terms of the purposes to which they are intended and used for policy analysis.

The most comprehensive type of the models reviewed is the set of **computable general equilibrium (CGE)** models. This class of model is well suited to address many of the policy questions required to quantitatively assess the economic, competitiveness, and food security consequences of ambitious GHG mitigation targets for agriculture. A key strength of the CGE framework is its capacity to capture inter-sectoral relationships within agriculture and between agriculture and other sectors, including other land-use sectors. Other identified strengths include its ability to track trade relationships that influence competitiveness and leakage outcomes of mitigation policies and the flow of costs and benefits to different sectors of the economy, including government, consumers and producers. The MIRAGRODEP and MAGNET models are CGE models reviewed in this paper.

Partial equilibrium (PE) models of markets, or systems of related markets, determine prices, profits, production, and the other variables of interest under the assumption that there are no feedback effects on the underlying demand or supply curves that are specified in advance. This implies that the analysis only considers the effects of given policy action in the market(s) that are directly affected and does not account for the economic interactions between the various markets in a given economy. This is in contrast to CGE models, where all markets are simultaneously modelled and interact with each other. One drawback of the PE model is applying a comparative static modelling framework to a dynamic decision problem. CAPRI, Aglink-Cosimo, and GLOBIOM are examples of PE models reviewed in this paper.

Integrated Assessment Models (IAMs) are used to evaluate the technological and economic feasibility of climate goals, such as the Paris Agreement's long-term temperature goal to hold global warming well below 2°C and pursue efforts to limit this warming to 1.5°C above pre-industrial levels. They coupled detailed models of energy system technologies with simplified economic and climate science models to evaluate different population, economic and technological pathways, allowing an assessment of the feasibility of achieving specific climate change mitigation goals. The results of these models play a central role in the IPCC process. In this paper, IMAGE is an IAM.

While the models have steadily grown in sophistication in many of these areas, it has to be kept in mind that they are simplifications of reality and designed to illustrate complex processes. There is an inherent tension between the complexity of modelling ecological processes, which often have a strong spatial nature and where local context matters, and the demands of policy modelling for clarity and parsimony in the representations of broader economic perspectives.

Studies focused on repurposing agricultural support

Two major reports focused on the theme of repurposing agricultural policies were released in 2021 and 2022. The first of these was jointly prepared by the FAO, UNDP and UNEP, A Multi-Billion-Dollar Opportunity: Repurposing agricultural support to transform food systems and was released in the lead-up to COP26 in Glasgow (FAO, UNDP and UNEP 2021). It has a broad focus and presents a quantitative analysis of the economic, environmental, and health impacts of removing border measures and fiscal subsidies in the agricultural sector. The report covers indicators on agricultural production, farm income and employment, nature (primarily land use but also including chemical inputs and biodiversity), GHG emissions, food consumption and affordability, healthy diets, and equity.

The section on the impacts on climate presents projected changes in GHG emissions in 2030 due to the removal of various agricultural support measures (FAO, UNDP and UNEP 2021, pp. 61-4). It focuses on changes in GHG emissions stemming from changes in crop and livestock production (primarily affecting nitrous oxide and methane emissions), changes in energy use associated with crop and livestock production, and land-use change effects such as deforestation or the conversion of pastureland to cropland. The modelling analysis is based on IFPRI's global computable general equilibrium model, MIRAGRODEP.

Table 2 presents the results of the simulations from FAO, UNDP and UNEP (2021). The report presents results for the World, Developed Countries, BRIC Countries, and Non-BRIC Countries. It breaks down GHG emissions into emissions from agricultural production, energy use in agriculture, and land-use changes. The removal of domestic fiscal support and border measures is projected to reduce GHG emissions at the global level, with significant different impacts on developed, BRIC and non-BRIC countries. Emission reductions in non-BRIC countries are a key driver of the overall results, largely due to shifts away from emission-intensive livestock production to crop production in these countries. This goes hand in hand with a decrease in forest land being converted to agricultural use in non-BRIC countries. The removal of border support is also a key factor dominating the results, accounting for around 71% of the total projected reductions in GHG emissions (mostly from non-BRIC countries).

A second report using the MIRAGRODEP model was jointly published by the World Bank and IFPRI in early 2022, entitled Repurposing Agricultural Policies and Support: Options to Transform Agriculture and Food Systems to Better Serve the Health of People, Economies, and the Planet (Gautam et al. 2022). It focuses on the theme of repurposing agricultural policies and support, this time with a time horizon of 2040. Once again, it simulates the projected impacts of removing all agricultural subsidies and border support on a range of indicators covering national real income, farm output, prices and employment, farm poverty, nutrition and diets, GHG emissions, and changes in agricultural land use (broadly defined as "nature"). The report also incorporates a series of scenarios in which the savings from abolishing agricultural subsidies are directed to several alternative fiscal purposes. The scenarios include:

- **restructuring domestic support** achieved by redistributing the current subsidy budget uniformly across all agricultural products. This keeps the average support rate unchanged from the level of support in 2020 and is similar to decoupled transfers. In addition, a second scenario is developed whereby the existing support is redistributed in a uniform subsidy rate on non-CO2-intensive activities (which are not explicitly defined in the report).
- **conditionality** where the availability of domestic support is conditional on producers switching to products or production processes that are less environmentally harmful (for example, less GHG-intensive), using currently available technologies. The scenario assumes a reduction in agricultural productivity and emission intensities of 10 per cent over the period to 2040. While recognising that such an assumption is inherently arbitrary, the rationale underpinning these assumptions is that cross-compliance conditions can increase costs and reduce productivity if farmers are required to use technologies and farming approaches that they might not otherwise have done.
- **repurposing green innovation** by directing a part of the existing domestic support to target innovation that reduces emissions and increases productivity (for example, through investment in climate-smart agriculture). The balance of the domestic support goes back to the taxpayers. The scenario assumes a 30 per cent reduction in emissions per unit of output and a 30 per cent increase in productivity. Several subsidiary simulations are presented with differing assumptions on the funding source for the research and development: exogenous and cost less to taxpayers; publicly funded green innovation driven by an additional 1% of agricultural output being spent on research and development across the world; and where this additional public funding is spent in either developed countries only or in developing countries only.

The key results for the climate indicators under these scenarios are summarised in Table 3. Consistent with the results in FAO, UNDP and UNEP (2021), the removal of domestic support is unambiguously positive for GHG emission reductions, although the magnitudes of the changes are slightly lower. This reduction is unevenly spread between developed and developing countries, with the percentage reductions being larger in developed countries. Adding in the removal of agricultural trade barriers reduces the percentage changes in GHG emission reductions. However, the removal of border support does not play as big a role in driving the overall results in this analysis compared to the 2021 report. It is argued in the report that this is the result of complex dynamics in the model between the tax on consumers imposed by market price support, the presence of substantial negative market price support in a few major producing and consuming countries, and shifts in the location and composition of emission-intensive production.

Another major difference between the two reports lies in the source of the GHG emission reductions. The 2021 report projects that the reduction in GHG emissions will primarily come from the non-BRIC developing countries, while emissions from developed and BRIC countries are projected to increase by 2030 relative to the baseline (see Table 2). This is in contrast to the 2022 study where both developed and developing countries are projected to reduce GHG emissions by 2040 relative to the baseline. It impossible to determine what is driving this difference without further details on the technical parametrisation of the model. Nevertheless, it does highlight the sensitivity of modelling results to the input data, parameters and assumptions employed.

The repurposing scenarios are the major innovative and novel feature of the Gautam et al. (2022) study. The scenarios represent a series of hypothetical thought experiments on the possible outcomes of different fiscal strategies for redistributing the funds currently directed towards domestic agricultural support. Table 3 presents the projected impacts on the key climate indicators by 2040 under the repurposing scenarios. Each scenario projects a reduction in GHG emissions, except the scenario under which uniform support is provided to non-CO2 intensive products only. It is particularly noteworthy that the scenarios whereby the support is redirected towards green innovation result in very high GHG emission reductions (up to a 40% reduction in GHG emissions by 2040). This results from efficiency gains leading to significantly reduced input use and the move of agricultural land back to its natural uses. To a large extent, these results are driven by the assumptions of an exogenous 30% reduction in emission intensity and a 30% increase in productivity. Nevertheless, the report notes that investing in research and development to enhance productivity and reduce emission intensity has potentially significant payoffs.

The two reports identify several areas for further analysis in enhancing the analytical toolbox to support increased agricultural productivity and reduced GHG emissions from agriculture, including:

- the role of public research
- the implications of higher agricultural productivity for farm labour
- the use of carbon taxes and conditionality in terms of the impacts on production costs and incentives for producers
- incentives for dietary change and the links to the food system
- specific policy needs at country level.

An earlier study by IFPRI employing the MIRAGRODEP model highlights the importance of including as full a range of impacts as possible. Laborde et al. (2020, 2021) is a forerunner of the analysis in FAO, UNDP and UNEP (2021) and Gautam et al. (2022). It undertakes a quantitative analysis of the impacts of incentives on agricultural outputs and emissions and addresses impacts on overall output, differences in incentives across countries, differences in incentives across commodities, and differences in the technology used for production. Crucially, however, the analysis does not include the impacts of land-use changes on emissions. Significantly, ignoring the role of land-use changes alters the magnitude and direction of projected impacts of GHG emissions from agricultural support reform (see Table 4). This is hardly surprising as land use and land-use changes accounted for around 43% of global GHG emissions from agriculture and land use in 2018 (FAO 2020). This also underscores the importance of fully accounting for the range of environmental channels through which the impacts are manifested. Furthermore, Searchinger et al. (2020) show that those impacts may be even more consequential if the indirect land-use change (ILUC) caused by changes in policies results in deforestation or conversion of pastureland to cropland.

Studies focused on carbon taxes, abatement subsidies and other policy instruments

Henderson et al. (2021)

This study takes a broad perspective of the agriculture, forestry, and other land use (AFOLU) sectors to identify how much the sector could limit long-term global temperature increases to 1.5°C and 2°C. It uses the Global Biosphere Management Model (GLOBIOM) to assess several policy packages that apply a combination of taxes and subsidies (set at the same carbon price) to AFOLU emissions and abatement sources. The taxes cover non-CO2 emissions from agriculture (principally methane and nitrous oxide emissions from animals and crops) and CO2 emissions from Land Use, Land-Use Change and Forestry (LULUCF), mainly from deforestation. On the other hand, subsidies reward carbon sequestration in forest biomass (e.g. through afforestation) and agricultural soils (from improved cropland and grazing land management) and the uptake of non-CO2 abatement technologies in agriculture.

GLOBIOM is a global partial equilibrium model that includes both the agricultural and forestry sectors, including the bioenergy sector. In addition to modelling production, markets, trade, prices and land use, the model covers major GHG emissions, including CO2 from above and below-ground biomass changes and methane and nitrous oxide emissions. It also includes a set of technical non-CO2 mitigation options for the agricultural sector and marginal abatement costs for soil organic carbon sequestration.

A large number of mitigation scenarios out to 2050 were modelled, and a baseline scenario. These scenarios aim to calculate the net GHG emission reductions possible in AFOLU that are consistent with the 1.5oC and 2oC targets and that carbon taxes and abatement subsidies to varying sectors and GHG emission reduction targets. One of the purposes of this approach was to assess how applying different policies to different combinations of emission sources and sinks within AFOLU might affect the mitigation potential of the sector as a whole. For example, non-Co2 emissions and soil carbon sequestration in agriculture and CO2 emissions and carbon sequestration in non-agricultural LULUCF. This gives insights into the types of policy trade-offs that might need to be made in developing mitigation options.

It is beyond the scope of this report to go into the detailed results of these scenarios. These are well-detailed in Henderson et al. (2021). However, the key messages from the analysis are worth highlighting here:

- "Modelling results suggest that a comprehensive policy strategy, comprising of agriculture and land use emission taxes and subsidies for carbon sequestration, at a carbon price consistent with a 20C (1.50C) objective could reduce global AFOLU emissions by 8 GtCO2 eq/year (12 GtCO2 eq/year) in 2050. This represents an 89% (129%) reduction in net AFOLU emission.
- 63% of the net emission reductions with the comprehensive policy package relate to land use and land use change and forestry (mainly avoided deforestation) emissions, 28% to agriculture emissions and 9% to soil carbon sequestration.
- The policy choices invoke different trade-offs: while a global carbon tax on AFOLU is found to be twice as effective in lowering emissions as an equivalently priced emission abatement subsidy, the use of emission taxes lowers agricultural production by 3-8% and per capital consumption by 2-4%, which emission abatement subsidies avoid. Taxes also raise revenues, while subsidies require government expenditures.

- A shift to lower emission diets by consumers is assessed to have a much smaller impact on reducing agricultural emissions than any of the policy packages that tax these emissions." Henderson et al. (2021, p. 5).

Barreiro-Hurle et al. (2021)

A recent paper from the EU's Joint Research Centre by Barreiro-Hurle et al. (2021) used the CAPRI model to assess the economic, environmental and climate impacts from three major recent EU initiatives: the Post-2020 CAP legal proposals; the Farm-to-Fork Strategy; and the Biodiversity Strategy. The time horizon for the simulations was 2030, with the base year of 2018. The scenarios modelled were relatively complex given the wide range of measures included in the three broad initiatives. For example, the CAP legal proposal includes assumptions around direct payments (coupled and decoupled), Green Payments, capping of budgets, convergence across the EU, agri-environmental schemes, sugar and dairy quotas, and tariffs and tariff-rate quotas. In addition, the CAP legal proposal was also modelled with additional assumptions around enhanced environmental and climate ambition, under which conditionality is tightened, eco-schemes are extended along with agri-environmental schemes, greater endogenous technical change and reductions in fertiliser and pesticide use.

While the Farm-to-Fork Strategy and the Biodiversity Strategy have many policy elements, the scenarios in the analysis focus on targets related to pesticides, nitrates, landscape elements and organic farming; this scenario is modelled with both the basic CAP legal proposal and the CAP legal proposal with enhancing ambition. In addition, funding from the EU Next Generation package is included in a further simulation, assuming that an additional budget would be provided to make mitigation technologies more accessible.

The results of the simulations for GHG emission reductions are summarised in Table 5. In each of the scenarios, the policy packages lead to changes in land allocation, animal numbers, production, and the trading position of the EU compared to the baseline. However, there is considerable leakage in non-CO2 agricultural emissions outside the EU in each scenario due to emission increases in non-EU regions under the assumption that there is no additional mitigation action taken in the rest of the world. This is a similar finding as observed in the study by Jansson et al. (2021) and is a feature of the partial equilibrium modelling framework used by CAPRI.

The report highlights several limitations and areas for improvement in the CAPRI modelling tool to better represent the new environmental and climate targets that the agricultural sector is expected to meet. While it is clear that no model can perfectly capture the complexities of policy packages such as the CAP or the Farm-to-Fork and Biodiversity Strategies, there are some areas where further work on limitations might be useful. These include data issues such as regional pesticide use by pesticide category, model specifications such as the distinction between organic and conventional farming, targets around reducing food waste, the move towards different diets, and the demand side promotion of organic and sustainably produced food. In addition, the CAPRI model is not comprehensive in the representation of emission mitigation technologies and the adoption of technologies and farm practices. Nevertheless, the model and the simulation results provide a useful first exploration of the potential impacts of environmental and climate policies in the EU, focusing on potential interactions between targets and eliciting indicative insights into production and market impacts.

Perez-Domingo et al. (2021)

This study focuses on the potential implications for the agricultural sector of mitigation options for methane emissions. The policy scenarios focus on the imposition of a global carbon tax on non-CO2 agricultural emissions (methane and nitrous oxide), reaching values of USD 150 per tonne and USD 500 per tonne and on a shift toward a low-animal-protein diet. However, there is a novel additional focus in analysing the warming potential of different climate pollutants. The implied warming effect of methane emissions is much stronger in the short term and a smaller effect in the long term than CO2 emissions. The technical underpinnings of this addition are very complex and depend on the potential implications of different methane valuations in the scenarios and their links to warming potential. However, the policy message that emerges clearly from the analysis is that multi-gas mitigation policies are expected to be more cost-effective than CO2-only approaches, particularly with respect to the distribution of costs across different sectors.

Three agro-economic models (CAPRI, GLOBIOM and MAGNET) were used to provide detailed representations of the agricultural sector, cross-sectoral linkages through factor markets, substitution effects, and GHG emissions by agricultural production activity. Such a multi-model approach provides good coverage of the range of variables of interest. Moreover, it is becoming more feasible with the increased computing power available and enhanced ability to link the models in a meaningful way.

The scenario results highlight significant reductions in non-CO2 emissions relative to the baseline under all scenarios. For example, the imposition of carbon pricing could reduce agricultural non-CO2 emissions by up to 58% compared to the baseline in 2070. However, the assumed carbon process is very high compared to current carbon pricing levels. In general, carbon pricing has the largest effect on emissions. However, with increasing carbon price levels, the negative economic impacts on the agricultural sector in terms of lower production continue to increase, while further emission reductions are relatively small. This reflects a situation where the technical abatement options are fully applied relatively early in the period, and further reduction comes from price-induced reductions in consumption.

A key insight is that choosing a particular metric for methane's warming potential is key to determining optimal mitigation options, with metrics based on shorter-term impacts leading to greater overall emission reduction. Also, promoting low-meat diets is more effective at reducing greenhouse gas emissions compared to carbon pricing when mitigation policies are based on metrics that reflect methane's long-term behaviour. A combination of stringent mitigation measures and dietary changes could achieve substantial emission reduction levels, helping reverse the contribution of agriculture to global warming.

Jansson et al. (2021)

A recent paper by Janson et al. (2021) uses the agricultural sector model CAPRI to simulate the impact of removing the voluntary coupled support for ruminants that are permitted under the EU Common Agricultural Policy. The CAPRI model is a global, comparative static, partial equilibrium model covering the agricultural sector with a detailed country-level representation of the EU agricultural sector and CAP and more simplified representations for countries outside the EU. The analysis is focused on the likely impact until 2030 on global GHG emissions resulting from the removal of voluntary coupled support in the EU and on the potential leakage effects from such a reform. In addition to a central policy scenario, several scenarios are presented that provide some sensitivity analysis as key parameters are varied (e.g. supply and demand elasticities, import-substitution elasticities, emission intensities for non-EU regions).

The results are broad as expected, with the policy change leading to a reduction in GHG emissions in the EU of 2 354 kt CO2eq and emissions in the rest of the world increasing by 1 738 kt CO2eq. This emissions leakage results in a net global decrease of 616 kt CO2eq from the policy change, or around a quarter of the emissions decrease in the EU. These results were very sensitive to the parameters in the model, with the results for the change in global emissions ranging from -2 956 to +1 465 kt CO2eq. The results are also sensitive to variations in the elasticities and emission intensities, although they tend to scale the results rather than reverse the direction.

The results are largely driven by inelastic demand for agricultural products and opportunities to trade resulting in a shift in production from the EU to other countries, hence the higher emissions outside the EU. The authors note that this illustrates one of the problems of a unilateral reform policy and points to the need for a policy package that encompasses a range of productivity-enhancing measures and GHG reduction measures applied on a global scale.

OECD (2019)

The OECD report on Enhancing Climate Change Mitigation through Agriculture (OECD 2019) presents the results of several simulations designed to assess the potential of different policies and options to reduce agricultural GHG emissions. The report uses two global and one farm-scale models to perform the assessments. The findings are discussed within the context of the existing literature on the global mitigation potential of the agricultural sector. While the report did not cover the issue of the reform of domestic support and border measures, it is nonetheless important to review the analysis to identify several key features relevant to the broader issue of the quantitative assessment of the links between agricultural policies and GHG emission abatement. Two sets of the analysis presented in the report are reviewed below.

The first set of simulations used the Modular Applied GeNeral Equilibrium Tool (MAGNET), a dynamic multi-sector, multi-region CGE model covering the global economy. It includes extensive modelling of land markets and agricultural policies, biofuel policies, and the socio-economic and environmental impacts of environmental policies. The time horizon for the simulations was 2050. The analysis focused on GHG mitigation policies that applied only to non-CO2 emissions in the agricultural sector and not GHG emissions in other sectors of the economy. It excludes methane and nitrous oxide emissions from biomass burning and fuel and energy use and CO2 emissions from fuel and energy use in the sector.

The analysis assesses several scenarios using carbon taxes and abatement payments that directly target emissions, including:

- a global tax on agricultural GHG emissions
- the OECD tax on agricultural GHG emissions
- a global tax on agricultural GHG emissions combined with a food consumption subsidy
- a global abatement payment for agricultural GHG emission reductions
- the OECD abatement payment for agricultural GHG emission reductions.

The first three of these scenarios assume a steadily increasing carbon tax over the simulation period, reaching USD 100/tCO2eq for the period 2041-2050. The other two scenarios provide an abatement payment to cover the mitigation costs of agricultural producers, based on the same carbon price path as for the first three scenarios.

The key results for GHG emission reductions under the five scenarios are presented in Table 6. Global GHG taxes appear to be the most effective mitigation policy, with and without a food subsidy. However, they impose the highest economic costs on agricultural producers, particularly in the emission-intensive ruminant sectors of many developing countries. While a GHG tax and abatement payments provide the same marginal mitigation incentives, a GHG tax causes an increase in the cost and price of agriculture output; hence causing a reduction in the aggregate supply and demand for agricultural products, particularly in the more emission-intensive activities. In addition, the role of land-use change is important in driving the results as there is a global shift in land cover from pasture to forest and shrubland as the ruminant grazing footprint contracts. The report also notes that the OECD GHG tax scenario leads to the leakage of emissions from OECD to non-OECD countries.

The second set of model simulations presented in OECD (2019) uses a partial equilibrium model of global agricultural markets to assess the food security and emission implications from several demand-side and supply-side mitigation options. The Aglink-Cosimo model has a high level of detail on agricultural commodity markets and can capture interactions with market policies (see OECD and FAO (2015) for model documentation). In addition, recent developments in incorporating GHG emission intensities per commodity produced and regional marginal abatement cost curves allow reporting on direct agricultural emissions. However, as the type of model implies, the results are inherently partial. They do not consider the linkages and interactions with the broader economic system as is done under the CGE modelling exercises. This reduces the ability to model the effects of land-use changes or technical and structural change, amongst other variables.

Six policy interventions were developed to mitigate emissions and were compared to the baseline scenario with a time horizon of 2030. The scenarios addressed several global food security indicators (consumer food price index, agricultural income index, calorie availability index) and emission changes. They focused around reducing the share of food consumed by ruminants, reducing food waste, imposing carbon taxes and improving productivity on the production side:

1. A preference shift towards 10% less consumption of ruminant products.
2. A consumer demand tax USD 60 per ton of CO2eq emitted by each product, applied globally.
3. Reduction in food waste with no assumptions about the cost of reducing waste.
4. Reduction in food waste with exponentially increasing costs of waste reduction.
5. A carbon tax on agricultural supply activities of USD 60 per ton of CO2eq emitted.
6. A productivity improvement of 10% for all agricultural products, increasing linearly from 2018.

The results for the GHG emissions under each scenario are summarised in Table 7. While all scenarios project reduced GHG emissions in 2030, the results need to be considered together with the impact on food security as captured by the indicators on food availability, food prices and farm incomes. The report highlights several observations that underscore the interconnectedness of the emission/food security nexus:

- "Influencing consumer preferences so that more calories are obtained from non-ruminant animal sources has the highest benefits among the analysed scenarios. However, the mechanism by which such a change could be achieved is not specified.
- Consumption taxes are the least effective measure to reduce greenhouse gases, especially when these are decoupled from the actual carbon produced, owing to the inelasticity of demand for broad food groups, and would raise food prices, potentially leading to food security risks for low income consumers.
- Reducing food waste can be a strategy to mitigate climate change, but it is important to take into consideration that the potentially high costs to reduce waste could raise food prices, and potentially lead to food security concerns.
- Supply side mitigation via carbon taxes has a high potential to reduce emissions from agriculture with limited risks in terms of food security.

- Increasing productivity in agricultural production systems could potentially reduce emissions and increase food availability, in addition to improving access via lower prices." OECD (2019, p. 97)

van Meijl et al. (2018)

This study undertakes a systematic inter-comparison of five global climate and agro-economic models to assess the range of potential impacts of climate change on the agricultural sector by 2050. By applying a set of scenarios and harmonised assumptions on basic model drivers to the five models, the analysis aims to narrow the discrepancies between the models on the potential impacts of climate change on agricultural production by 2050 and the economic consequences of relentless global emission mitigation efforts. The models cover integrated assessment (through the IMAGE model), partial equilibrium models (with CAPRI, GLOBIOM and MAgPIE) and a computable general equilibrium model (MAGNET). Each of these models except for MAgPIE has been described elsewhere in this review; MAgPIE is a partial equilibrium model covering the agricultural sector along with bioenergy and water (see Lotze-Campen et al. 2008).

The approach recognises the fact that agro-economic models can present quite different results when analysing the economic and related impacts of climate change on agriculture. It is often unclear what drives these differences, whether they are due to model specification, model parametrisation, scenario assumptions, or data sources. The primary interest in the study is not only the scenario results but also the comparison of what is driving model results after the harmonisation of key model inputs. The study reflects the aims of the long-standing Agricultural Model Intercomparison and Improvement Project (see https://agmip.org/).

The baseline draws on several Shared Socioeconomic Pathways (SSPs) to map out future trends in population, incomes, trade liberalisation, the environmental impact of food consumption, and environmental protection, coupled with assumptions about climate change-related crop yield impacts and mitigation measures in the agricultural sector. These are combined with two selected Representative Concentration Pathway scenarios to depict climate impacts. The agricultural GHG mitigation scenarios are constructed around a carbon price being imposed on direct non-CO2 emissions from the agricultural sector, CO2 emissions from land use and land-use change, and fossil fuel-related CO2 emissions in the sector.

The results of the scenarios indicate that mitigation measures strongly reduce agricultural non-CO2 emissions by about 40-45%, with methane and nitrous oxide being reduced by 50% and 30%, respectively. This is consistent across the different SSPs. The modelled GHG emission mitigation measures have a negative impact on primary agricultural production for all SSPs across all models. In terms of reduced global agricultural production, the impacts of mitigation policies are larger than the negative impacts due to climate change effects in 2050. However, this is partially due to the limited impact of the climate change scenarios by 2050.

Similarly, by 2050 climate impacts affect global agricultural prices less strongly than ambitious mitigation policies across the models in this study. The price impact is higher in the livestock sector because livestock production is more emission-intensive, and higher emission taxes directly increase livestock production costs. The magnitude of the producer price changes is very different between the models, mainly due to differences in the general model set-up (especially the treatment of technological change and price responsiveness of demand) and assumptions on mitigation measures (e.g. carbon pricing).

Himics et al. (2018)

This study investigates the linkages between trade liberalisation and climate in the agricultural sector with a focus on the free trade agenda of the EU. It also simulates the impacts of a carbon tax on non-CO2 emissions and combines the carbon tax and trade liberalisation scenarios to assess the effectiveness of the policies individually and collectively for the agricultural sector. The study uses the CAPRI model, a global partial equilibrium model for agriculture. It assesses impacts against a baseline reference scenario that assumes status quo policies and employs exogenous assumptions about macroeconomic developments drawn from the annual OECD-FAO agricultural market outlook horizon of 2030. The trade liberalisation scenario assumes full elimination of tariffs for most agricultural commodities and a 50% tariff cut for other products for countries that were negotiating Free Trade Agreements with the EU at the time of the study (Canada, Vietnam, US, Mercosur countries, Japan, Thailand, the Philippines, Indonesia, Australia, and New Zealand). The carbon tax scenario employs a EUR 50 tax per ton of CO2eq on methane and nitrous oxide emissions on EU agricultural activities.

Scenario results indicate that the simulated trade liberalisation by itself has only modest effects on agricultural GHG emissions by 2030 (Table 8). The results are driven by a reallocation effect as domestic EU agricultural production shifts to non-EU producers. Much of the change is driven by changes in crop production. In contrast, pricing agricultural non-CO2 emissions in the EU triggers the adoption of mitigation technologies, which contributes significantly to the projected emission reductions. The carbon tax also has a greater impact on the emission-intensive livestock sector. Emission leakage, however, partially offsets the EU emission savings as production increases in less emission-efficient regions in the world, and in the case of the trade liberalisation scenario, actually increases global GHG emissions.

The results hinge on the key assumptions that future trade agreements between non-EU countries are not considered and that the climate actions are limited to the EU only. This is to be expected as the underlying model is partial equilibrium and does not account for dynamic responses to changing parameters or assumptions.

Table 1: Overview of quantitative studies reviewed

Study	Type of model[a]	Model(s) used[b]	Time horizon	Policy focus
Gautam et al. (2022)	CGE	MIRAGRODEP	2040	Agricultural support reform impacts on GHG emissions and repurposing agricultural support
FAO, UNDP, UNEP (2021)	CGE	MIRAGRODEP	2030	Agricultural support reform impacts on GHG emissions and repurposing agricultural support
Labourde, et al. (2020)	CGE	MIRAGRODEP	2030	Agricultural support reform impacts on GHG emissions
Henderson et al. (2021)	PE	GLOBIOM	2050	Carbon taxes and emission abatement subsidies
Barreiro-Hurle et al. (2021)	PE	CAPRI	2030	Implementation of EU CAP policies, Farm-to-Fork Strategy, and Biodiversity Strategy
Perez-Domingo, et al. (2021)	CGE and PE	CAPRI, GLOBIOM, MAGNET	2070	Carbon price on methane
Jansson et al (2021)	PE	CAPRI	2030	Removal of EU voluntary coupled support
OECD (2019)	CGE and PE	MAGNET and Aglink-Cosimo	2050 (CGE), 2030 (PE)	Carbon taxes and emission abatement subsidies
Meijl et al. (2018)	CGE, PE and IAM	CAPRI, MAGNET, IMAGE, GLOBIOM, MAgPIE	2050	Carbon tax on agricultural products
Himics, et al. (2017)	PE	CAPRI	2030	EU trade liberalisation and EU carbon tax

a. PE = partial equilibrium model; CGE = computable general equilibrium model; IAM = integrated assessment model.

b. MAGNET = Modular Applied GeNeral Equilibrium Tool; GLOBIOM = Global Biosphere Management Model;

MAgPIE = Model of Agricultural Production and its Impact on the Environment; CAPRI = Common Agricultural Policy; Regionalised Impact Modelling System; IMAGE = Integrated Model to Assess the Global Environment; MIRAGRODEP = Modelling International Relations under Applied General Equilibrium + African Growth and Development Policy Modeling Consortium.

Table 2: Summary of impacts of removing agricultural support on climate indicators (from FAO, UNDP and UNEP (2021))

Indicator	Border measures	Fiscal Subsidies				All Support
		Total	Output subsidies	Input subsidies	Factors of Production	
Percent change from 2030 levels						
GHG emissions from agricultural production	-0.22	-0.30	0.09	-0.16	-0.24	-0.60
Developed countries	1.41	-0.82	0.57	-0.33	-1.11	0.01
BRIC countries	0.49	0.07	-0.03	-0.02	0.13	0.59
Non-BRIC developing countries	-2.03	-0.33	-0.10	-0.19	-0.05	-2.24
GHG emissions from energy use in agriculture	0.16	-0.87	-0.18	-0.26	-0.43	-0.65
Developed countries	0.46	-1.47	-0.23	-0.26	-1.00	-0.90
BRIC countries	-0.08	-0.54	-0.15	-0.30	-0.10	-0.59
Non-BRIC developing countries	0.16	-0.47	-0.19	-0.14	-0.14	-0.27
GHG emissions from land-use change	-3.38	-0.18	-0.45	-0.60	0.28	-3.89
Developed countries	2.79	0.68	-0.94	0.02	0.84	1.80
BRIC countries	28.45	-1.55	0.67	-4.09	-2.59	27.33
Non-BRIC developing countries	-8.10	-0.41	-0.34	-0.62	0.24	-8.39
Change from 2030 levels in thousand tonnes of CO2e						
Total GHG emissions	-55 651	-11 342	1 487	-15 769	-2 724	-78 383
Developed countries	31 415	-11 651	6 638	-5 836	-16 427	3 876
BRIC countries	26 080	6 424	-1 456	-1 432	8 001	32 951
Non-BRIC developing countries	-113 146	-6 115	-4 695	-8 500	5 703	-115 209

Source: FAO, UNDP and UNEP (2021), Table 7

Table 3: Projected impacts of removing agricultural support and repurposing scenarios on climate indicators (from Gautum, et al. (2022))

	GHG emissions from agricultural production	GHG emissions from land-use change	Total GHG emissions
	% change by 2040 with respect to baseline		
Support removal scenarios			
Removal of domestic support	-0.59	-0.89	-1.48
• Developed countries	-1.52	-4.52	-6.04
• Developing countries	-0.38	-0.07	-0.44
Removal of trade barriers and domestic support	-0.20	-0.35	-0.55
Repurposing scenarios			
Uniform support – All products	0.49	-1.14	-0.65
Uniform support - Non-CO2-intensive products only	-0.05	0.31	0.26
Conditionality	-19.17	4.59	-14.58
• Conditionality – for developed countries only	-3.42	1.42	-1.99
• Conditionality – for developing countries only	-15.49	3.11	-12.38
Repurposing for green innovation	-24.14	-16.31	-40.45
• Exogenous funding for innovation	-23.48	-15.09	-38.57
• Publicly funded	-23.55	-15.22	-38.77
• Publicly funded in developed countries only	-6.72	-4.79	-11.50
• Publicly funded in developing countries only	-17.41	-10.47	-27.88

Source: Gautam, et al. (2022), Tables D.1 and D.2.

Table 4: Summary of scenario results of impacts on GHG emissions of removing agricultural support (from Laborde et al. (2020, 2021))

	Total	Crop residues	Enteric fermentation	Manure	Rice	Synthetic fertiliser	Energy and other[a]
			% change by 2040 with respect to baseline				
Removing coupled subsidies							
World	-34420	-2915	-6016	-3871	-1041	-10138	-10439
Developed economies	-18116	-1079	-4017	-2987	-206	-4942	-4795
Developing economies	-16304	-1836	-1909	-884	-834	-5197	-5644
Removing border measures							
World	127635	4129	91043	39624	-1193	1203	-7171
Developed economies	25597	3115	11644	9139	201	3042	-1544
Developing economies	102037	1013	79399	30486	-1394	-1839	-5628
Removing all support							
World	102071	1257	88780	37691	-2331	-7511	-15815
Developed economies	7590	1728	7529	6086	-33	-1811	-5909
Developing economies	94481	-471	81251	31605	-2298	-5700	-9906
Maintaining income support							
World	56232	1642	47711	19126	-2267	-5965	-4015
Developed economies	10968	2664	2530	3671	-14	-512	-2629
Developing economies	45264	-1022	45181	15455	-2252	-5453	-6645

Source: Gautam, et al. (2022), Tables D.1 and D.2.

Table 5: Summary of EU agricultural GHG emission reductions in 2030 under the CAPRI partial equilibrium model (from Barreiro-Hurle et al. (2021))

Scenario	Non-CO_2 agricultural emissions	CO_2 and non-CO_2 agricultural emissions	Leaked reduction in non-CO_2 agricultural emissions
	Percentage change relative to the baseline, 2030		**%**
Farm-to-Fork Strategy + Biodiversity Strategy + CAP legal proposal	-14.8	-20.1	66
Farm-to-Fork Strategy + Biodiversity Strategy + CAP legal proposal with enhanced ambition	-17.4	-28.0	51
Farm-to-Fork Strategy + Biodiversity Strategy + CAP legal proposal with enhanced ambition and Next Generation EU package	-19.0	-28.9	47

Source: Barreiro-Hurle et al. (2021)

Table 6: Summary of annual agricultural non-CO2 emission reductions policies in 2050 under the MAGNET CGE model (MtCO2eq) (from OECD (2019))

Scenario	OECD	Non-OECD	Global
Global GHG tax	143 (8%)	4 299 (39%)	4 442 (35%)
Global GHG abatement payment	194 (12%)	926 (8%)	1 120 (9%)
OECD GHG tax	477 (29%)	-192 (-2%)	284 (2%)
OECD GHG abatement payment	217 (13%)	-19 (0%)	197 (2%)
Global GHG tax and food subsidy	144 (9%)	3 861 (35%)	4 005 (32%)

Source: OECD (2019), Table 2.1.

Table 7: Summary of global agricultural GHG emission reductions in 2030 under the Aglink-Cosimo partial equilibrium model (from OECD (2019))

Scenario	Global
1. Reducing consumption of ruminant products by 10%	-15%
2. Consumption tax on agricultural products	-5%
3. Reduction in food waste at no cost	-8%
4. Reduction in food waste with exponentially rising costs	-13%
5. Carbon tax on agricultural supply activities	-15%
6. Increase in productivity of 10%	-6%

Source: OECD (2019), p. 92.

Table 8: Summary of EU agricultural GHG emission reductions in 2030 under the Aglink-Cosimo partial equilibrium model (from Himics et al. (2018))

Scenario	Non-CO_2 agricultural EU emissions	Change in GHG emissions due to production effects	Leaked reduction in non-CO_2 agricultural emissions
	Percentage change relative to the baseline, 2030	% of total change in GHG emissions	%
Free Trade Agreement (FTA) trade liberalisation	-1.6	83	151
Carbon tax	-9.5	-28.0	21
Combined FTA and carbon tax	-10.7	-28.9	50

Source: Himics et al. (2018)

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Kaurna acknowledgement
We acknowledge and pay our respects to the Kaurna people, the original custodians of the Adelaide Plains and the land on which the University of Adelaide's campuses at North Terrace, Waite, and Roseworthy are built. We acknowledge the deep feelings of attachment and relationship of the Kaurna people to country and we respect and value their past, present and ongoing connection to the land and cultural beliefs. The University continues to develop respectful and reciprocal relationships with all Indigenous peoples in Australia, and with other Indigenous peoples throughout the world.