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REORIENTING BUDGETARY SUPPORT TO AGRICULTURE FOR CLIMATE CHANGE MITIGATION

A MODELLING ANALYSIS

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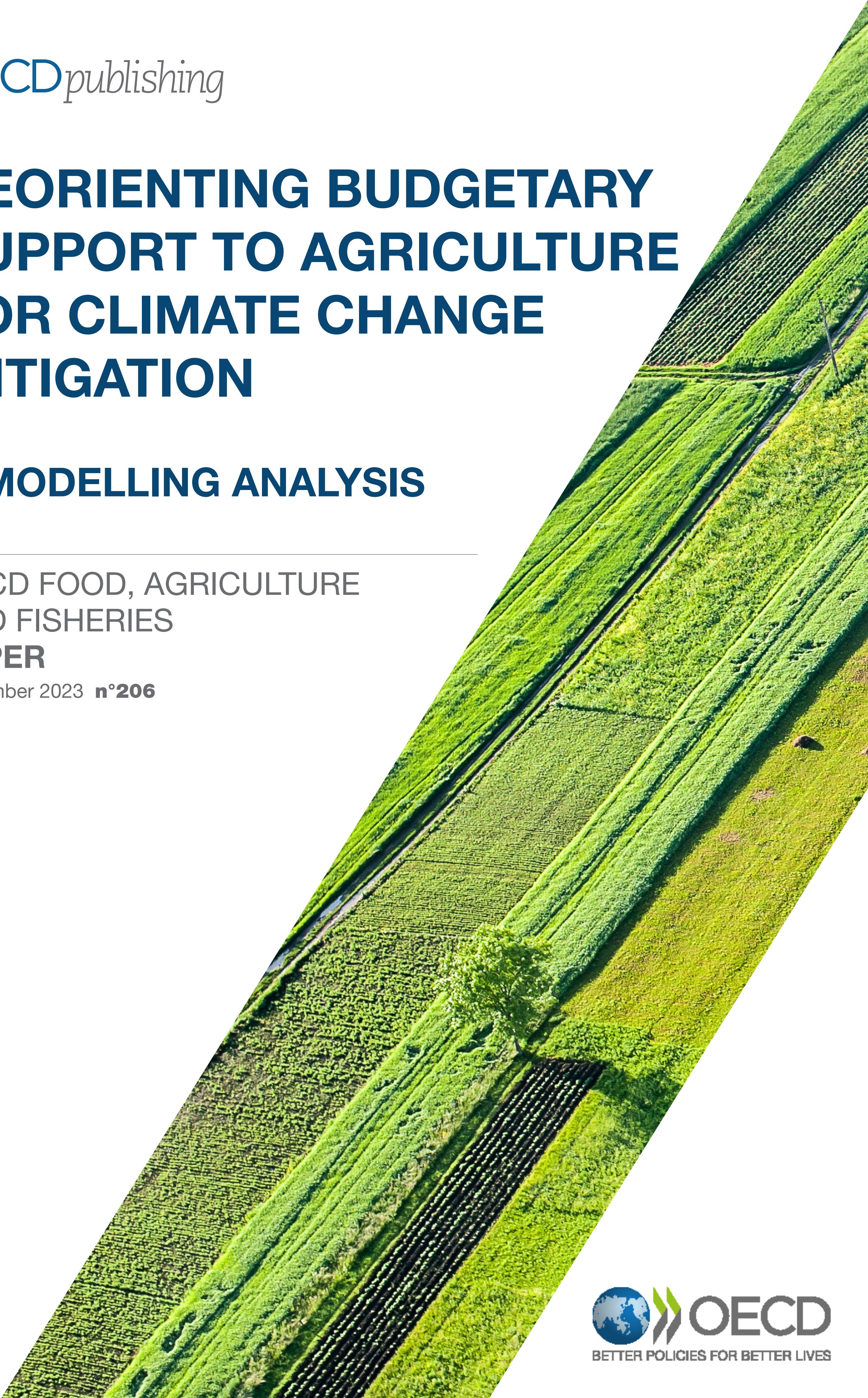

BETTER POLICIES FOR BETTER LIVES

OECD TRADE AND AGRICULTURE DIRECTORATE

Reorienting Budgetary Support to Agriculture for Climate Change Mitigation: A Modelling Analysis

Hugo Valin, Ben Henderson, and Jussi Lankoski

Reforming agricultural support is increasingly considered a viable means to enhance agriculture's contribution to climate change mitigation, while fulfilling broader food systems policy objectives related to food security and livelihoods. This study uses a new computable general equilibrium model to investigate a set of global policy reform scenarios that reorientate governments' budgetary transfers to agriculture to reduce greenhouse gas emissions. The results suggest that removing budgetary support globally would reduce agricultural emissions by 2.1% with potential negative effects on food supply. Reorienting existing support, instead, could have significantly stronger effects: decoupling payments from production and tying these to suitable agri-environmental practices could raise emission reduction to over 4% without harming food supply. Targeted investments in productivity and abatement technologies could bring additional emission savings in the long term with co-benefits for food security. Overall, combining green decoupling and investment policies in OECD countries would reduce global agricultural emissions by 5% – or by 11% if extended to other regions – while balancing outcomes across the three dimensions of the food systems' triple challenge.

Key words Agricultural policy, computable general equilibrium, domestic support, greenhouse gas emissions, total factor productivity, marginal abatement cost, land use change

JEL codes C68, Q11, Q18, Q54

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Key messages

- Reforming agricultural policies by reorienting agricultural support is increasingly considered to be a viable means to enhance agriculture's contribution to climate change mitigation, while fulfilling broader food systems policy objectives related to food security and livelihoods. However, the potential effects of such policy reforms are likely to be complex.
- This study explores these issues and contributes to this agenda by simulating a set of global policy reform scenarios that reorientate governments' budgetary transfers to agriculture with a view to helping the sector in its transition to a lower emission future. It relies on a combination of OECD data on budgetary support to producers and a newly expanded version of the computable general equilibrium model METRO, tailored for agricultural and environmental comparative static analyses, and applied here for the first time.
- The simulations suggest, first, that simply removing all budgetary support to farmers would moderately reduce GHG emissions by 2.1%, but slightly decrease food supply and farm income. A more targeted removal of the potentially most climate-harmful payments to farmers – composed of the most market distorting payments (output-based, variable input-based), as well as livestock headage payments – would achieve two-thirds of the climate benefits from a full removal of budgetary support and reduce payments by just one fourth, thereby limiting farm income losses.
- Phasing out potentially most climate-harmful payments and decoupling other factor-based payments could further reconcile GHG abatement and livelihood protection objectives, while also mitigating food supply losses. GHG abatement could reach −4.1% if decoupled producer payments were combined with suitable agri-environmental practices, such as reduced tillage or reduced livestock stocking rates, provided these do not lead to agricultural land expansion.
- Targeted investments appear to be particularly effective at reducing GHG emissions without negatively impacting food provision and farm production. Investing in R&D to spur productivity growth could substantially lower emissions in the long term at less than USD 20 per tCO_2-eq, and be scaled up over time, with additional co-benefits from land savings, especially if focused on livestock. Programmes financing adoption of abatement technologies and practices could help to immediately decrease emissions by 5.1% for less than USD 50 per tCO_2-eq.
- Combining long-term investment programmes with the above agricultural support reforms appears to be the most promising and cost-effective approach to deliver the transformations required in long run. Blending decoupling of the potentially most climate-harmful payments, environmental measures and targeted investments in productivity and abatement technologies in the OECD would reduce global agricultural emissions by 5% – or by 11% if extended to other regions – while balancing outcomes across the three dimensions of the food systems' triple challenge.

Executive Summary

Agriculture faces a unique challenge in relation to climate change. It is among the sectors most exposed to climate change; it generates a significant proportion of greenhouse gas (GHG) emissions, but it can also contribute to lowering these emissions, including by sequestering carbon. At the same time, the sector is expected to deliver on three key objectives – food security, livelihoods and wider environmental sustainability.

Agriculture is also the beneficiary of significant public support, receiving USD 817 billion of transfers annually across the OECD and major emerging economies in 2019-2021. Of this total, USD 500 billion is composed of budgetary support disbursed by governments, USD 293 billion of which goes to individual producers and shapes their production decisions. Ensuring that resources transferred to producers help the sector transition to a more sustainable future is an important objective for policy makers, producers and society as a whole, and one increasingly discussed in policy fora.[1] That said, information on the impacts of reforms remains rather general and stylised.

This study aims to add clarity to this debate by assessing the implications of various policy reforms for agriculture, using a computable general equilibrium model and detailed policy data. It finds that the targeted restructuring of financial support can help the sector mitigate its emissions, although such a transition will also require new investments in productivity growth and abatement technologies to achieve its food security and other objectives.

The reform options investigated in this report focus on government expenditures in the 54 countries monitored by the OECD, while non-budgetary instruments, such as market price support (MPS), are kept unchanged.[2] The scenarios are organised into four groups of policy simulations: 1) budgetary support removals, 2) greater and greener decoupling of producer payments, 3) investments towards productivity growth and targeted mitigation technologies, 4) a combination of those options. The simulations provide useful insights about the advantages and drawbacks of the different reform options:

- Removing all budgetary support to farmers would reduce agricultural emissions – including direct non-CO_2 emissions and CO_2 emissions from agricultural soils – by 2.1% (−133 $MtCO_2$-eq/yr) but would also decrease calorie supply (−0.7%), farm receipts (−2.4%) and real (price-deflated) value added of the sector (−0.3%).
- Alternatively, removing only the most climate-harmful payments – defined as output-based, part of input-based, and livestock headage payments[3] – would deliver 65% of these emission savings (−1.4%, or −87 $MtCO_2$-eq/yr), for a 24% reduction in producer payments (USD 56 billion). Food supply losses would be partly mitigated (−0.4%) with limited impacts on farm receipts and real value added.
- Decoupling producer payments from production without changing the volume of support transferred achieves 84% of the emissions savings obtained in the payments removal scenario (−1.7%, or −112 $MtCO_2$-eq/yr). Calorie losses would be less (−0.2%), receipts slightly higher (+0.2%) and sectoral real value added would increase (+0.4%), as land payments are shifted to labour and capital.
- Decoupling producer payments with additional environmental cross-compliance measures reduces notably more emissions, by −4.1% (−266 $MtCO_2$-eq/yr). This result, driven by the soil carbon

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[1] This has been dubbed the “repurposing” agenda in international policy fora.

[2] In 2019-2021, MPS accounted for an annual positive transfer of USD 317 billion (and a USD −117 billion negative transfer in emerging countries). It represents one of the potentially most production- and trade-distorting forms of support, with potential to also increase pressures on natural resources and to raise national greenhouse gas emissions. Due to market leakages, however, the net global GHG emission effect of removing market price support remains uncertain (OECD, 2022[2], p.25).

[3] Input-based payments considered here (USD 41 billion) mostly correspond to variable input payments (see details in Annex G). Animal payments are considered potentially most climate-harmful if paid on headage basis, even if environmental provisions may exist in some cases.

sequestration under reduced tillage, and lower animal production from less intensive grazing, remains conditional on the mitigation of indirect land use change emission risks. Food supply is also reduced and real value added benefits are lowered compared to the sole support decoupling.

- Investing in agricultural productivity growth would both increase calorie availability and reduce GHG emissions at less than USD 20 per tCO_2-eq. Investments in agriculture as a whole raises food supply (+1.0%) by more than when the livestock sector is targeted alone (+0.6%). However, livestock-related R&D investments notably boost the emission savings (−2.0% or −126 $MtCO_2$-eq/yr) compared to untargeted investments (−1.3% or −81 $MtCO_2$-eq/yr). Gross farm receipts and employment drop with lower prices and more efficient production, but farm production and real sectoral value added increase in both scenarios.
- Investing in emissions abatement technologies is the most effective scenario for mitigation, with −5.1% achieved globally (−327 $MtCO_2$-eq/yr) at USD 50 per tCO_2-eq. Targeting such technologies would only generate a slight production rebound (+0.1%) and agricultural land expansion (+0.2%) at this price.

These results remain subject to modelling uncertainties and the newly developed model could be further enhanced with refined assumptions on payment modalities and technologies, and consideration of the role of MPS and the dynamic effects for productivity and land use. Nonetheless, they highlight how targeted investments can be the single most effective approach to reduce GHG emissions among considered scenarios. Investing directly in abatement technologies achieves the highest emission savings, with limited impacts on production, incomes and market prices. Agricultural productivity investments deliver more marked positive outcomes along all food systems dimensions and are particularly efficient for climate change mitigation when they target high emitting sectors. While improved productivity growth takes time to materialise, it would also generate further emission reductions and environmental co-benefits through land use savings.

More immediate incentives through payment reforms would also achieve emission reductions, although these would be only one-off benefits and not possible to scale up. Decoupling producer payments could be a practical alternative to full budgetary support removal in terms of climate mitigation, by dampening potential economic and food security losses of the reforms, while improving the income transfer efficiency of the support. Adding cross-compliance measures could also boost the climate benefits of the reforms, provided that it does not generate indirect land use change due to land productivity losses.

In view of the advantages and limitations above, a combination of options appears the best way to maximise climate and other sustainability benefits, while reconciling short-term and long-term objectives. Mixing decoupling of potentially most climate-harmful payments, environmental measures and targeted investments in productivity and abatement technologies would reduce emissions by 10.6% globally when implemented in all regions covered, and 5.1% when implemented in the OECD only, with a balanced outcome across the three dimensions of the food systems' triple challenge. The most desirable portfolio of reforms and investments may differ country by country, depending on the current level and structure of support, the agriculture sector profile and other societal policy needs.

1. Introduction

Agriculture is increasingly expected to contribute to mitigating climate change, as other sectors ramp up their efforts and agriculture's share of economy-wide greenhouse gas (GHG) emissions grows. Meanwhile, the sector still faces a formidable triple challenge with the need to provide food security and nutrition to a growing population, generate viable livelihoods for more than 500 million farmers worldwide, and to do so while using natural resources in an environmentally sustainable way (OECD, 2021[1]). Yet, current agricultural policies are not well-adapted to address these challenges. Only a small share of the USD 817 billion of estimated support for agriculture in 2019-21 across OECD countries and major emerging economies addresses these priorities in a coherent and efficient way (OECD, 2022[2]).

In 2019-21, a total USD 611 billion of consumer and taxpayer support was transferred to individual producers, with the remainder of the USD 817 billion comprising general service payments and taxpayer support to consumers. Of this USD 611 billion, a majority share was delivered in the form of production and trade distorting support measures, including USD 317 billion of positive market price support (MPS) and USD 74 billion in payments linked to output or unconstrained use of variable input. A further USD 220 billion was provided as a mixture of coupled and uncoupled producer payments targeting other assets, but only a relatively small amount (USD 1.7 billion) was clearly dedicated to delivering public goods.

Meanwhile, over the past two decades, the share of support devoted to general services to the sector declined from 16% (in 2000-2002) to 13%. The total budget devoted to general services accounted for USD 100 billion in 2019-2021, but only a quarter of it (USD 26 billion) was dedicated to R&D, a category with a strong potential to raise productivity while lowering the emissions intensity of production.

This current structure of support is not well-suited to meeting the climate challenge. Production and trade distorting support measures not only inflate prices for consumers, but also encourage marginal increases of production, which in turn can have negative environmental impacts triggered by more intensive use of GHG-emitting inputs (e.g. fertilisers), or by land-use change or increased energy use emissions as more resources are allocated to agriculture (OECD, 2022[2]; Henderson and Lankoski, 2020[3]). Further reforms to decouple support from production could deliver important market and environmental benefits. Moreover, budgetary resources liberated by subsidy reforms could also be used to directly tackle environmental externalities and generate more significant sustainability outcomes. Recently, there have been increased calls for "repurposing" agricultural support towards addressing environmental externalities and public goods. as well as supporting innovation to enhance the sustainable productivity of the sector (FAO, UNDP and UNEP, 2021[4]; Gautam et al., 2022[5]). In November 2022, OECD Agriculture Ministers also committed to "intensify efforts as appropriate to reform or reorient agricultural policy, and in particular to address those support measures that are harmful to the environment, to move towards sustainable agriculture and food systems" (OECD, 2022[6]). However, additional work is needed to improve upon the first early assessments and produce further relevant guidance for agricultural policy reforms.

The present study investigates the extent to which the restructuring of domestic support could help to improve the environmental performance of agriculture while still delivering along the other dimensions of the food systems' triple challenge – food security and livelihoods. Within the large set of important environmental challenges related to air, water, soil, or biodiversity, the analysis focuses primarily on GHG emissions, considering the importance of agriculture in contributing to climate change mitigation efforts in the context of the Paris Agreement.[4] The emphasis is put on the role that reforms in government budget expenditures can play; the role of MPS policies is not investigated here, as their phasing down does not release additional budgetary resources, and their consistent representation requires specific modelling enhancements that could be conducted in another analysis.

The added value of this work, compared to previous literature, is twofold. First, a new CGE modelling framework, METRO-PEM, is developed with a full coupling to the OECD PSE database, allowing for a high level of granularity in policy description. This new model allows for more precise characterisation of the role of different payments (production factors affected, coupling and decoupling) compared to existing

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[4] This does not preclude future extension of such analysis to other environmental domains, such as undertaken in other recent OECD analyses (Guerrero et al., 2022[48]).

studies. Second, this study examines a broad set of measures, all of which are consistently implemented in the same modelling tool – PSE payment adjustments, agricultural practices related to environmental cross-compliance, productivity investments and emission abatement subsidies for climate policies. The use of a global CGE model for this type of agri-environmental modelling allows in particular easier comparison and connections with work conducted in other policy domains requiring a full economic market representation (e.g. agricultural trade, food, resource policies).

The report is structured as follows. Section 2 examines the findings from the past literature on this question. Section 3 introduces the modelling framework used for the analysis, METRO-PEM, with a particular emphasis on the representation of PSE data, and the model enhancement conducted for this analysis. The different scenarios explored for this analysis are also introduced. Section 4 presents the results obtained for the different scenarios. Section 5 discusses the findings, current limitations and plans for next steps of the analysis.

2. Literature background

A large number of past studies have looked at the impact of reforms in agricultural support and their potential environmental benefits. This has particularly been the case for the European Union (EU), where successive Common Agricultural Policy (CAP) reforms have been scrutinised from an environmental perspective, including the introduction of payment decoupling (2003), "Greening" payments (2013) and, more recently, the Farm to Fork Strategy. These analyses were often based on partial equilibrium and farm-level linear programming models (Schmid, Sinabell and Hofreither, 2007[7]; Acs et al., 2010[8]; Barreiro Hurle et al., 2021[9]), computable general equilibrium (CGE) analyses (Gohin, 2006[10]; Helming and Tabeau, 2017[11]) or agent-based models (Brady et al., 2009[12]; Hristov et al., 2020[13]). They usually confirm the benefits of removing the most environmentally harmful subsidies but find more mixed environmental outcomes when analysing the effects of simpler decoupling or greening payments.

OECD studies have tried to characterise more precisely the environmental impacts of specific forms of agricultural support (Henderson and Lankoski, 2019[14]; Henderson and Lankoski, 2020[3]; Lankoski and Thiem, 2020[15]; DeBoe, 2020[16]). These analyses have used a categorisation of agricultural support policies based on the OECD Producer Support Estimate (PSE) classification to analyse the impacts of specific support policy instruments. They find that different types of support measures have different environmental impacts. The most market distorting support measures tend also to be the most environmentally harmful, as they encourage further production or input use without providing incentives to improve management practices. This is generally true for output payments, but input payments can be even more harmful, by encouraging more intensive use of, and pressure on, resources. In contrast, fully decoupled payments based on non-current crop area are the least environmentally harmful form of producer support, while well-designed agri-environmental payments can be beneficial for the environment (Guerrero, 2021[17]; OECD, 2010[18]; DeBoe, 2020[16]).

The environmental impacts of agricultural policies have received renewed attention with the pressing needs of climate change action. Recent analyses have examined greenhouse gas emissions as a global externality, taking into account the international responses to domestic policy changes. For instance, Laborde et al. (2021[19]) analyse the impacts of reforming current agricultural support globally (coupled support measures and border protection) on GHG emissions from agriculture using IFPRI's CGE model MIRAGRODEP. They find that the worldwide removal of coupled producer payments could lower global farm output by 0.9%, with smaller reductions for the most emission-intensive commodities (beef −0.7% and dairy −0.6%). Global GHG emissions from agriculture would decrease by 0.6%, which is less than the fall in output, because of the lower decline in emission-intensive products and to some relocation of production to regions with higher emissions intensities. In contrast to coupled producer payments, removing current border measures was found to have a near-zero impact on global agricultural output, decreasing it by 0.1%.

FAO, UNDP and UNEP (2021[4]) applied the MIRAGRODEP framework to a broader set of scenarios, distinguishing different types of subsidies and including low-income countries. They find that removing domestic support would reduce agricultural emissions by 0.3%, with the largest contribution from factor-based subsidies (−0.24%), followed by input subsidies (−0.16%), whereas the removal of output subsidies would slightly increase emissions (0.09%). They also estimate separately impacts on land use change (which would fall by 0.18%) and energy use emissions (−0.87%). That approach has been revisited and further extended in Gautam et al. (2022[5]) using the same model, with additional scenarios and indicators. These authors find that the removal of coupled producer payments would have a relatively larger impact on global production and GHG emissions (lowering emissions by −1.48%, of which −0.59% is from direct emissions from production and the rest from land use change). They then examine the impact of adding environmental cross-compliance to support (reflecting the adoption of organic agricultural practices), which delivers more substantial mitigation outcomes, lowering GHG emission by 15%. They finally investigate the effects of repurposing a share of the current budgetary support towards emissions-reducing and productivity-enhancing innovations, which was found to improve economic welfare while significantly reducing global GHG emissions (by 40.5%).

The implications of removing and repurposing agricultural support have not only been investigated from a climate change perspective. Some of the above studies (FAO, UNDP and UNEP, 2021[4]; Gautam et al., 2022[5]) also integrated other environmental (land use change), economic (farm income, food prices) and social (employment, poverty, and nutritional status) variables. Analysis using the GTEM CGE finds that removing budgetary support would be effective in reducing GHG emissions (−1.6%) but comes at the expense of food security, unless accompanied by a trade policy reform (Fell et al., 2022[20]; Cao, Burns and Greenville, 2023[21]). Springmann and Freund (2022[22]), using a broader framework combining the MAGNET CGE and a global risk-disease model, estimate the impacts of repurposing of agricultural budgetary support on dietary changes and on disease mortality. Their results indicate that removing producer payments provides economic and environmental benefits, although it could adversely affect population health. The re-direction of producer payments towards environmentally friendly and healthy food products (including fruits, vegetables, and other horticultural products) could help to improve population health and reduce GHG emissions (by −1.7% and −0.2% in supported OECD and non-OECD countries, respectively, partially offset by a 0.5% increase in unsupported countries). They also consider reallocation of producer payments between countries as a repurposing option to improve environmental and health outcomes at a global level.

All the above studies indicate that global reforms of agricultural support have different impacts depending on the instruments being changed. They also find that the potential for delivering environmental benefits from removing support alone is limited. Since reforming budgetary support only slightly lowers global agricultural production, it tends to generate similarly small environmental impacts. The exact extent of the impacts, however, varies depending on the scenario considered, the sources of GHG emissions, the model used, and more importantly, on the sources of support data (IO consortium or OECD PSE data, with different treatments in the model databases). Closer scrutiny and consistency are needed to better understand how support, as assessed through the OECD PSE analysis, impacts climate change, as well as other environmental and economic outcomes.

At the same time, Gautam et al. (2022[5]) and Springmann and Freund (2022[22]) clearly stress that the budgetary resources liberated by the removal of payments coupled to production could generate substantial environmental benefits if used to directly tackle environmental externalities from agricultural production. In terms of climate change mitigation objectives, only Gautam et al. (2022[5]) consider the targeted use of payments to support mitigation technologies, but in highly stylised scenarios, with a flat 30% of emissions reduction assumed, without explicit link to specific technologies or evaluation of the costs involved. Abatement costs for the agricultural sector are, however, more precisely known (Ragnauth et al., 2015[23]) and have already been used in other forms of analysis focusing on the impact of carbon pricing (Golub et al., 2012[24]; Frank et al., 2018[25]). Linking financial transfers with abatement costs is a critical step needed to provide deeper insights for policy makers about the potential benefits of reallocating agricultural budgetary support within the sector.

Finally, some analyses have looked at the role of R&D investment for climate change mitigation. Fuglie et al. (2022[26]) find that global investments in agriculture productivity growth could help reduce greenhouse gas emissions, but not as effectively as targeted environmental policies. They highlight however the synergies that can be found between the two forms of interventions, as productivity growth can lower the implementation costs of environmental policies. They find for their different policy scenarios a range of marginal cost for emission reduction of USD 14-22 per tonne CO_2-eq, taking into account both farm and land use emissions savings. Their results confirm the strong potential associated with productivity growth investments, as also highlighted in previous literature (Burney, Davis and Lobell, 2010[27]; Valin et al., 2013[28])

3. Methods

3.1. Modelling framework

This study relies upon the METRO-PEM CGE model to investigate a range of agricultural policy reform options for climate change mitigation. This model combines the features from two pre-existing OECD tools, the METRO and PEM models. It also relies on an extended data infrastructure, including the full OECD PSE database, as well as detailed GHG emission accounts and sustainability indicators.

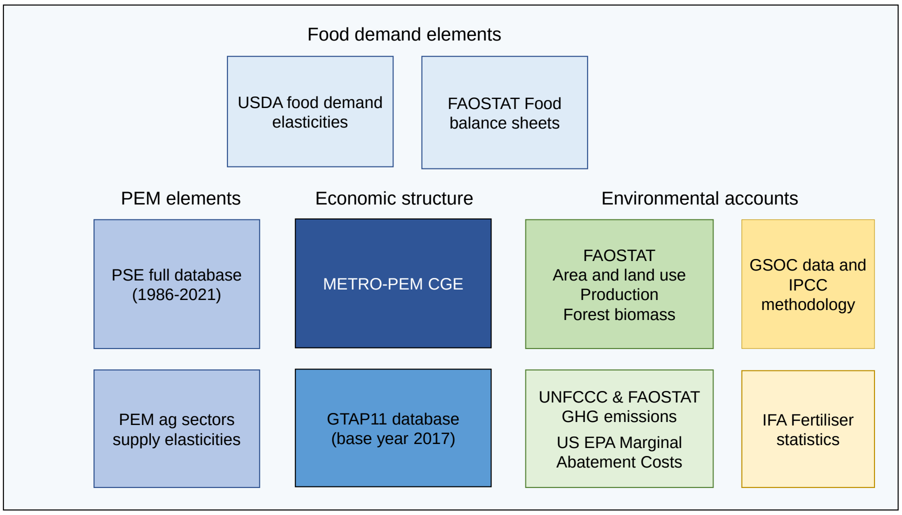
3.1.1. METRO-PEM main features

METRO-PEM is based on the METRO computable general equilibrium (CGE) model, designed for the analysis of macroeconomic and trade policies. It is structured around the full economy Social Accounting Matrices (SAMs) from the GTAP database, which covers 141 regions and 65 economic sectors, and was here applied at a detailed sectoral level for crops (separating rice, wheat, other coarse grains, sugar crops, oilseeds, vegetables and fruits, fibre crops, other crops) and livestock (cattle meat, dairy, other animal products). The agri-food sectors are also disaggregated to properly describe some key supply chains (See Annex A for the sectoral resolution).

In addition to having more detailed sectoral resolution for agriculture than in the METRO model, METRO-PEM incorporates certain features of the PEM model, in particular its representation of land use and supply, along with some of its factor mobility assumptions. The similarities with the PEM framework also include the direct integration of the PSE database within METRO-PEM, which allows for a more refined assessment of the impacts of reforms to agricultural support. For the purposes of this study, detailed GHG emission accounts are also incorporated into METRO-PEM, as a complement to the usual economic data in this class of models, as well as additional environmental indicators.

To provide results more representative of today's economy, METRO-PEM has been developed based on the most recent version of the GTAP database (GTAP 11, pre-released version 2), which takes 2017 as a base year. The model has been linked to the most up-to-date version of the PSE database, providing policy information from the years 1986 to 2021. It has also been complemented by other datasets as to supply and demand elasticities, as well as environmental accounts, as illustrated in Figure 3.1 below. More information on the different sources used as well as the model parameterisation can be found in Annex B.

Figure 3.1. Data environment of the METRO-PEM modelling framework



Note: FAOSTAT = Food and Agriculture Organization Corporate Statistical Database, USDA = United States Department of Agriculture, PSE = OECD's Producer Support Estimate, PEM = OECD's Policy Evaluation Model, GSOC = Global Soil Organic Carbon, IPCC = Intergovernmental Panel on Climate Change, GTAP = Global Trade Analysis Project, UNFCCC = United Nations Framework Convention on Climate Change, IFA = International Fertilizer Industry Association.

A number of modifications were made to the initial METRO model structure and parameterisation to adapt the model to agricultural policy issues and embed PEM features. Among the main new features are:

- A more disaggregated sectoral representation (eight crop sectors, three livestock sectors, forestry, fisheries, seven food processing sectors and the chemical sector as separate inputs –Annex A).
- Restructured and re-parameterised agriculture production functions to better capture factor and inputs substitution behaviour, calibrated using PEM elasticities. Animal capital and general capital were in particular distinguished to capture the specific effects of livestock headage payments on GHG emissions.
- A new land factor mobility module replicating the land conversion structure from PEM, and expanded with an additional land supply function to represent entry and exit of land for all sectors.
- Segmented factor markets for capital and labour to reflect the imperfect mobility of these factors between agriculture and other sectors of the economy.

More information on the METRO-PEM model assumptions and parameterisation are provided in Annex B.

3.1.2. Greenhouse gas emission modelling

Considering the climate mitigation focus of this analysis, particular attention has been paid to the representation of GHG emissions associated with changes in production patterns in METRO-PEM. A complete emission inventory was rebuilt using the FAOSTAT detailed data for agriculture emissions, as well as UNFCCC accounts for Annex I countries. This approach allows all the relevant accounts for agriculture non-CO_2 emissions across eight sources (enteric fermentation, manure management, manure left on pasture, manure applied to cropland, synthetic fertiliser, crop residues, burning of crop residues, rice cultivation), representing 96% coverage of the IPCC agriculture sources, to be distinguished.[5] To ensure consistency of emissions with UNFCCC accounts, all emission factors obtained from FAOSTAT were also rescaled to match UNFCCC totals by source in each Annex I country. This adjustment leads to slightly higher world emissions (6 432 $MtCO_2$-eq/yr for direct agriculture emissions and organic soils drainage), compared to when FAOSTAT data alone are used (6 349 $MtCO_2$-eq/yr). In the case of fertilisers, the International Fertiliser Association 2018 data on nitrogen application by sector and region were also used (Ludemann et al., 2022[29]) to better allocate fertiliser emissions across sectors. A detailed presentation of the emissions accounts represented in the model, and their mapping to the production function Inputs and factors is provided in Annex C.

For the non-CO_2 direct agricultural emissions above, marginal abatement cost curves were introduced in the model, based on data from US EPA (2019[30]). Three groups of sources are covered: livestock, cropland and rice cultivation. Abatement possibilities are represented in the model by an additional layer of substitution in the production function, where latent technologies with a marginal share in the production and lower emission intensities can replace the default technologies. When incentivised through a subsidy, the share of these technologies can therefore increase in the production function, which leads to a reduction of emission intensity of agricultural products (see more details in Annex D).

Some LULUCF accounts relevant for agriculture were also used for the analysis. FAOSTAT data was used for the integration of CO_2 and N_2O emissions for organic soils drainage, particularly relevant in some regions such as Southeast Asia or the European Union. Soil organic carbon was also included through a dedicated bookkeeping module using SOC reference data and the IPCC 2019 revised guidelines and covering a total stock of 454 Gt of carbon stored in cropland, grassland and forest soils. SOC stocks are considered to be stable at the base year, but change when the area of crops varies, depending on their tillage practice. Once SOC stock variation are computed in METRO-PEM, related annual GHG emissions can be calculated by dividing the stock difference by a reference period of 20 years, in line with IPCC Tier 1

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[5] One missing account in the current model is savannah burning for which more data on cultivation practices are needed to perform a sectoral attribution. Other minor sources of emissions under the IPCC agriculture account (3.G-3.J) are currently not accounted for by FAOSTAT, and therefore not included in METRO-PEM, but these represent less than 1% of non-CO_2 emissions from agriculture.

recommendations.[6] More complete information on the modelling of SOC in the model is provided in Annex E.

Finally, an important component of LULUCF emissions is related to land use change. Because METRO-PEM is static, land use change emissions cannot be calculated in the base year with the model. However, a dedicated module was also designed to estimate these emissions in the case of a policy shock, by comparing land use change between the scenario and the counterfactual base year. The methodologies used for these calculations are presented in Annex F, covering deforestation and foregone sequestration. Due to the technical and policy-related uncertainties underlying these estimates, estimates for these accounts are presented separately in the analysis and only used to discuss how the land use change could affect the initial assessment of policy impact on emissions.

3.1.3. Representation of PSE data in METRO-PEM

For this analysis, primary data on budgetary support from the OECD PSE database are directly used and integrated in the model as explained below, in place of the initial data on PSE contained in the GTAP database.[7] Several reasons motivate this approach. First, when allocated to monetary flows in the SAMs, agricultural policy payments can be mixed in the GTAP database with other transfers (e.g. labour tax) which means the part of transfers associated with agricultural policies can only be partly traced back. In addition, payments are represented as a share of production or production factor values, which means that different production of factor use levels leads to deviation from the initial statistics. Last, relying on the initial dataset allows direct use of the detailed information at policy line level.

Table 3.1 presents the allocation of the PSE categories across the different production factors of METRO-PEM, following their direct integration from the OECD database. Category A2 (Payments based on output) is allocated to output values. For categories C (Payments based on current area/animals/receipts/income), D (Payments based on non-current area/animals/labour, with production required), and E (Payments based on non-current area/animals/labour, without production required), the PSE database contains information on the administration criteria, which is used for the initial allocation: Land, if payments are per cultivated area; Animal capital, when these are per animal head; and Labour, for payments based on receipts or income. Category B (Payments based on inputs) is more complex. It is composed of different sub-categories B1 (Payments based on variable inputs), B2 (Payments based on fixed capital formation) and B3 (Payments based on on-farm services) which all contain a large range of specific policies targeting well-defined factors (or all of them in some cases). In the GTAP database, these payments are broadly distributed across all inputs (B1 and B3) or attributed to capital. To take better account of the policy specificities, payments were attributed in METRO-PEM based on a detailed analysis of the PSE database at the policy line, to precisely allocate each payment to the impacted input or production factor. This approach differs slightly from that used for the PSE classification, which is focused on the implementation criteria of the policy, independently of its effects. More details on the treatment applied to Category B payments in METRO-PEM are presented in Annex G.

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[6] This means that the time horizon for the policy simulation is considered to be up to 20 years. This assumption appears reasonable but should be kept in mind. Beyond that time horizon, SOC related emission flows would be stopped according to the simplified IPCC Tier 1 model, and emissions would then need to be annualised differently.

[7] This PSE data implementation into GTAP only covers the PSE budgetary transfer information, as market price support (MPS) instruments are captured in GTAP through different data sources. Tariffs in GTAP are based on applied tariff data and represented for each bilateral trade relation, using information from the MAcMap database. This means protection estimates may differ from those in the PSE database, which compares domestic prices to a reference price. The OECD data on General Services Support Estimates (GSSE) and Consumer Support Estimates (CSE) are also not integrated in the GTAP database. In this paper, neither MPS, CSE or GSSE are considered to change in policy scenarios.

Table 3.1. PSE transfers allocation in METRO-PEM based on GTAP data

	Allocation in METRO-PEM	Comments and differences with GTAP initial allocation
A1. Market price support (MPS)	*Not allocated, remains based on the default GTAP tariff information*	Similar to GTAP, where MPS is only represented in the global dataset through tariffs
A2. Payments based on output	Production output	Similar to GTAP
B1. Payments based on variable inputs	Specific intermediate inputs or factor, as per design of each policy	Applied proportionally in GTAP to all intermediate inputs, irrespective of the policy design
B2. Payments based on fixed capital formation	Specific intermediate inputs or factor, as per design of each policy	Applied in GTAP to capital (animal and general capital undifferentiated)
B3. Payments based on on-farm services	Specific intermediate inputs or factor, as per design of each policy	Applied proportionally in GTAP to all intermediate inputs, irrespective of the policy design
C. Payments based on current A/An/IR/I*, production required	Land (A), Animal capital** (An), or Labour (R/I), based on information contained in the PSE database	Similar to GTAP
D. Payments based on non-current A/An/IR/I*, production required	Land (A), Animal capital** (An) or Labour (R/I), based on information contained in the PSE database	Similar to GTAP
E. Payments based on current A/An/IR/I*, production not required	Land (A), Labour (R/I), based on information contained in the PSE database (no animal payments)	In GTAP, category E is allocated proportionally across all production factors, except for the EU pillar 1 where it is allocated entirely to land.
F. Payments based on non-commodity criteria	*Currently not allocated*	Similar to GTAP. These payments may be added in the future as subsidy for non-production
G. Miscellaneous payments	*Not allocated*	

Notes: *A/An/R/I: A = Area, An = animal number, R = receipts, I = income.
** Animal capital and General capital are distinguished in METRO-PEM, in contrast to GTAP.
GTAP allocation information sourced from GTAP 10 documentation (Aguiar et al., 2019[31]).

Besides the question of production input and factor attribution, payments within categories A, B, C and D may also target specific commodities (or sectors). Allocation of payments directed to one sector (Single Commodity Transfers, or SCT) are allocated to the one corresponding GTAP sector. Transfers targeting all commodity (All Commodity Transfers, ACT) and other transfers to producers (OTP) are distributed proportionally across all commodities, which means that their relative contributions to production costs are the same for all sectors. The treatment of Group Commodity Transfers (GCT) is more delicate because a very large set of commodity groups exist in the PSE database (66 groups), with a number of them specific to one or several countries. The allocation of these payments in METRO is performed through a detailed mapping table used to distribute the payments across the GTAP sectors, proportionally to the production value of each PSE product. This allocation differs substantially from the approach used in GTAP, where the mapping is only performed at the GTAP sector level. The GCT distribution is then different between METRO-PEM and GTAP data for GCT categories including specific products in each GTAP sector.[8]

The payments in category E are considered decoupled from current production and are therefore allocated proportionally across all products and factors following the methodology of OTP payments. The initial allocation of payment E in the data, based on the PSE dataset information, is considered for 82% as land-based and 18% as labour-based. The impact of category E payments is disputed in the literature (Bhaskar and Beghin, 2009[32]; Moro and Sckokai, 2013[33]). Although decoupled by design, these payments are, however, observed in practice to maintain a production incentive, therefore remaining partly coupled.

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[8] For instance, if a payment is allocated to maize and rapeseed, the METRO-PEM method distributes the payment between the “Other grains” and “Oilseeds” sectors proportionally to the production value of maize and rapeseed, whereas the GTAP approach will split the payment proportionally to the production value of “Other grains” and “Oilseeds”, independently from the production volume of other products that could be present in these sectors.

Category F payments (based on non-commodity criteria) are currently not allocated in METRO-PEM, as is also the case in GTAP.[9]

Although METRO-PEM is interfaced through this approach with PSE dataset for the full period 1986-2021, only the year 2017 is used in this analysis to be consistent with the base year of the GTAP database. Table 3.2 presents the resulting allocation of budgetary transfers across METRO-PEM production factors for that year. In 2017, OECD countries accounted for the largest share of these payments (USD 124 billion), with the European Union (EU27)[10] covering more than half of payments.

Following the allocation approach above, the first factor to which PSE payments are allocated is the land (51%). Payments to land include both coupled and decoupled payments; in the case of the European Union, all decoupled payments are, for instance, allocated to this factor. Capital and labour also receive sizable allocations, 13% each. Input and output subsidies, which are considered to be more distorting forms of budgetary support, represent 20% and 4% of the total allocation, respectively. Irrigation-related subsidies (including water preferential pricing, lower electricity rates for pumping and direct support to infrastructure) represent alone 6% of the budgetary support, and fertiliser subsidies 5% (a large share of these in India). The allocation of payments across sectors can also be observed in Table 3.2 illustrating the different sectors specificities.

The methodology applied here allows most of the budgetary support initially inventoried in the PSE database (97%) to be precisely captured in METRO-PEM, with the exception of Categories F and G payments. Simulations based on these data allow up to USD 232 billion of payments in the model to be removed or reallocated across categories A2 to E. Because this information is mixed with other payments in the GTAP database, it is difficult to simulate precisely the removal or reallocation of the same amount of budgetary support as in the PSE database. When using GTAP11 with its own embedded subsidy rates, the total amount of positive transfers to production factors and output in the agricultural sector only amounts to USD 156 billion in the base year 2017, which means one third of the budgetary support cannot be traced back.

Finally, it should be noted that, similar to the GTAP database, METRO-PEM data currently do not cover the full extent of MPS (Category A1) – only the tariff part is present in the dataset – nor does it cover the Consumer Support Estimate (CSE) or the General Services Support Estimate (GSSE), which are all part of the OECD data. MPS would be relevant to add but would require careful preliminary analysis of the underlying components (tariffs, non-tariff measures, domestic instruments) to make a relevant allocation of the transfer in the model. For that reason, no scenario on MPS is considered in this paper. CSE information could also be of interest in future METRO-PEM analyses, as CGEs represent the consumer side of the market in detail and could therefore capture the macroeconomic effect of adjustments in CSE. In the case of GSSE, even if these estimates are not directly relevant for market distortions and not explicitly modelled for this project, they are critical in the productivity improvements discussion, as it will be highlighted further below.

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[9] Although not integrated here, Category F payments integration could be relevant to implement in future analysis. Indeed, these payments, that contain payments for long-term resource retirement (F1), production of specific non-commodity products (F2), and other non-commodity criteria (F3), include a set of measures that encourage environmental outcomes, and often explicitly or implicitly incentivise a decrease of production (e.g. payments for land set-aside, hedges, extensive grassland, afforestation etc.). Currently, the PSE database identifies USD 6.9 billion per year in Category F payments in 2019-2021, not accounted for in the modelling. Such payments could play an important role in restoration of ecosystems services.

[10] Although the United Kingdom was part of the European Union in 2017, for more relevance in this analysis, the European Union (EU27) data are separated here from the United Kingdom (accounted for as part of the “Rest of Western Europe” region in METRO-PEM).

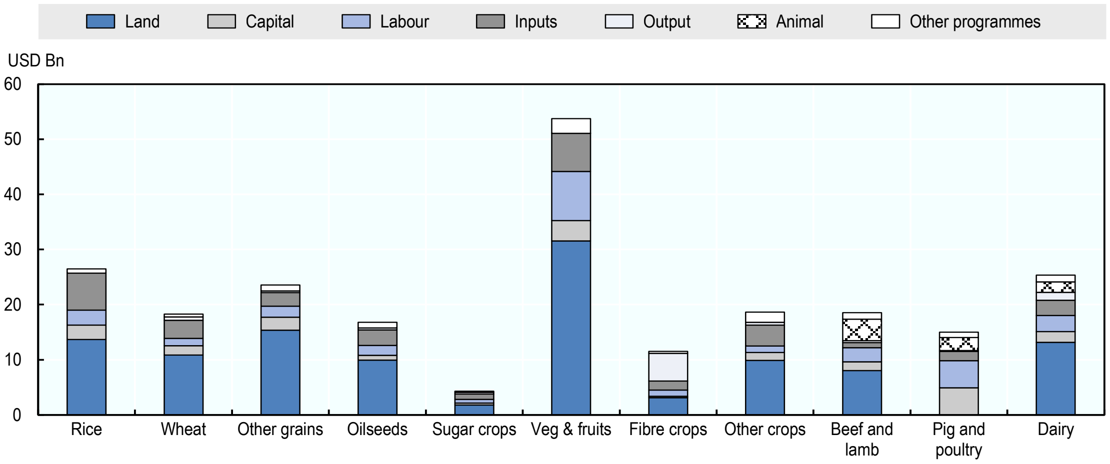
Table 3.2. PSE payments data allocation by factor in METRO-PEM, by category

Million USD, year 2017

Category	A2*	B**				C			D			E		Total***
Factor	Output	Input	Land	Cap.	Lab.	Land	Cap.	Lab.	Land	Cap.	Lab.	Land	Lab.	
OECD[1]	3 841	12 101	1 446	7 843	4 670	34 037	5 632	3 389	1 551	263	166	48 348	667	123 954
Australia		351	0	192	96			77				4	529	1 249
Canada		277	0	91	23	484	56	510						1 441
European Union[2]	504	4 075	1 071	5 407	712	20 363	4 759	255	4			38 084	8	75 240
Japan	1 476	253	332	102	251	2 318		119				2 795		7 645
Korea		227	0	177	104	1 531		64				774		2 877
Mexico	47	839	43	1 153	67	266			433	136				2 985
New Zealand			0	18	3			3						25
Rest Western Europe[3]	623	897	0	241	21	1 478	781	88	1 114	127	166	3 588	131	9 255
Türkiye	1 098	526	0	291	1	796	32	234						2 978
United States	93	4 657	0	169	3 392	6 801	4	2 038				3 103		20 257
Argentina	106	71	0	221	29	10								437
Brazil	174	732	341	1 590	462			115						3 413
China	4 511	4 327	5 815	10 177	2 017	23 518	177	2 051					9 642	62 236
India		24 416	1 461	355	6 293									32 525
Russia	380	390	0	2 206	82	592	22	43						4 421
Rest of Asia		2 813	50	438	7	93		18						3 419
Rest of Lat. Am.	22	422	21	255	138	35								894
Rest of World[4]	74	603	21	533	98	16	12	233		37			8	931
Total	9 109	45 877	9 155	23 617	13 797	58 301	5 844	5 848	1 551	301	166	48 348	10 317	232 230

Note: Cap. = Capital, Lab. = Labour. *Payments A1 correspond to market price support (non-budgetary payments) and are therefore not explicitly included here, and solely remain based on the default GTAP data on tariffs. ** See detail for allocation of policy programmes in Category B across production factors in Annex G. *** The total does not include USD 5.9 billion for category F and USD 1.1 billion for category G, which are not implemented in the model as not tied to production.
Country notes: [1]OECD total in this aggregation does not include Chile, Costa Rica and Colombia, as these countries are merged with others in the Rest of Latin America (Lat. Am.) aggregate, neither Iceland, because the region is not singled out in the GTAP data. [2] European Union in METRO-PEM corresponds to EU27. The United Kingdom is accounted for separately. [3] Rest West. Eur. corresponds to "Rest of Western Europe". It includes the United Kingdom, Norway and Switzerland. [4] Rest of the World data include Iceland.
Source: METRO-PEM database, based on OECD PSE data (OECD, 2022[2]).

Figure 3.2. PSE payments data allocation in METRO-PEM, by sector and factor



Note: total amount allocated in the figure: USD 232.2 billion. "Other programmes" correspond to payments that are not assumed to affect farm gate prices in METRO-PEM and are not allocated to a production factor.
Source: METRO-PEM database, based on OECD PSE data (OECD, 2022[2]).

3.2. Scenario design

To study the impact of agricultural support reforms on GHG emissions and sustainability indicators, different options for restructuring support are investigated. All these options are compared against a counterfactual reflecting a current policy status quo, in the base year 2017. The different policy options analysed are summarised in Table 3.3 and explained in more detail below. They are structured in three different scenario groups: budgetary support removal, budgetary support decoupling, and targeted investments.

Table 3.3. Scenario set-up for reform options

#	Scenario name	Description
0	Baseline	Current 2017 policies. Used as counterfactual for analysis of all scenarios
1)	**Removal of budgetary producer support**	
1-a	No budgetary support	Removal of all forms of budgetary support to producers in 2017
1-b	No potentially most climate-harmful payments	Removal of output-based, variable input-based, and livestock headage 2017 payments*
2)	**Decoupling of budgetary producer support**	
2-a	Simple decoupling	Transfer of cat. A, B, C and D of budgetary support to category E.
2-b	Green decoupling	Simple decoupling + tillage reduction + pasture grazing intensity reduction
3)	**Targeted investments**	
3-a	Agricultural productivity	Increase by 3% in crop and livestock total factor productivity in targeted regions
3-b	Livestock productivity	Increase by 6% only for livestock total factor productivity in targeted regions
3-c	Mitigation technology	Abatement technologies and practices deployed for a 50 USD per tCO_2e subsidy
4)	**Policy combination**	
4-a	Policy mix – all regions	Combination of Green decoupling (2-c) + Livestock productivity investment (3-b) + Mitigation technology (3-c) in all regions covered
4-b	Policy mix – OECD	Combination of Green decoupling (2-c) + Livestock productivity investment (3-b) + Mitigation technology (3-c) in main OECD regions

Note: * For more details on payments considered, see Annex G

3.2.1. Removal of budgetary producer support

1-a) No budgetary support to producers. This scenario corresponds to a counterfactual case where all budgetary support to agricultural producers would be removed and can be used to assess the model performance and compare the results with similar studies examining this type of scenario. Here, producer payments are removed for all regions covered by the OECD PSE database (i.e. the OECD countries, EU27 non-member countries, and 11 emerging economies covering most of the key players of agricultural markets). Categories of payments removed are A2, B, C, D and E. This corresponds to a decrease by USD 232 billion in producer support to the sector.[11] Market price support, which amounted to an extra USD 226 billion in 2017 and which in METRO-PEM is solely represented through the tariff information contained in GTAP, is kept unchanged in this analysis, as well as GSSE and CSE.

1-b) No potentially most climate-harmful payments. This second option targets specific forms of payments that directly affect production level, and therefore greenhouse gas emissions. These payments include the most distortive forms of support, i.e. output-based and variable input-

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[11] Note that, within these USD 232 billion of payments, USD 6.5 billion of input-based payments correspond to costs associated with some environmental programmes under Category B. It is assumed that removing these payments has no impact on production as these extra costs covered would not occur if those programmes were not in place. This also applies to decoupling and combined scenarios, and these programmes are not targeted by the removal of potentially most climate-harmful payments (scenario 1-b). For more detail on Category B treatment in METRO-PEM, see Annex G.

based payments, that are considered as potentially most environmentally harmful.[12] To these, also livestock support allocated on animal head basis (headage payments) are considered as part of potentially most harmful payments for climate, considering the high-emission intensity of livestock products, and that animals are the source of these emissions.[13] The policy shock in this scenario is applied to the same regions as those targeted by scenario 1-a. The total amount removed is USD 56 billion, i.e. 24% of the amount removed in scenario 1-a, and is composed of USD 41 billion of variable input payments, USD 9 billion of output-based payments, and USD 6 billion of livestock headage payments. It is noteworthy that 68% of these payments are provided in non-OECD countries, and 43% in India in the form of input-based payments.[14]

3.2.2. Decoupling of budgetary producer support

The options considering reforms to budgetary support are more precisely designed through scenarios of reallocation of payments to farmers to less coupled forms of support, which can also be complemented by some environmental conditionality clauses to strengthen environmental outcomes. The following scenarios are analysed:

2-a) Simple decoupling. In this scenario, budgetary support that is coupled to production (output, input and factor payments with production requirement) is reallocated as payments that are less distortive for production (land payments without production requirement, payments to general capital or farmer income). Specifically, this is performed by removing payments classified in categories A2, B, C and D of the producer support, and reallocating these to category E as follows: 50% to labour income, considered here as a proxy for a direct payment to farmer income, and 50% to land and (non-animal) capital based on their initial shares.[15] As a result, a total of USD 167 billion of payment is reallocated across sectors and payment categories in the model.[16] The impact of the scenario on payments to output, inputs and the different production factors is illustrated in Figure 3.3.

Overall, the decoupling leads to the removal of the potentially most climate-harmful payments (USD 9 billion of output-based payments, USD 41 billion of input-based payments, and USD 6 billion of livestock headage payments). Land, capital and labour payments also undergo significant restructuring, both across sectors and categories. A total of USD 69 billion of land

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[12] This includes all variable input payments without constraints leading to increased use of intermediate good consumption, as well as fixed capital and on-farm services support oriented towards higher input use (e.g. new greenhouses investments). In the approach taken for this study, variable input payments associated with environmental measures (USD 6.5 billion) are not removed, as well as crop insurance payments (USD 6 billion), which are allocated to land factors, like some other insurance programmes classified in Category C. See Annex G for details.

[13] Headage payments are considered here potentially more climate-harmful than land-based or capital-based payments to the livestock sector, because the unit of payment is directly tied to the GHG emission source. Annex I provides an illustration of how standard headage payments impact production and GHG emission response in the model. That said, this assumption does not take into account the fact that headage payments can be accompanied in some cases by environmental provisions. More research would be needed to identify and further differentiate among these payments.

[14] The total amount of variable input payments in India in 2017 is estimated at USD 32 billion, of which USD 24 billion are considered potentially most climate-harmful. This latter group is mostly composed of irrigation subsidies (48%, both through pumping electricity subsidy and investment support), and fertiliser subsidies (42%). Variable input payments not included in the climate-harmful category for India are notably financial relief against disasters (USD 6.3 billion) and crop insurance subsidies (USD 1.5 billion). In China, all payments classified as variable input-based in 2017 (USD 4 billion) correspond to crop and livestock insurance subsidies, and only the latter group (livestock insurance subsidies, USD 2 billion) is considered potentially most climate-harmful, assuming insurance indemnities are proportional to animal numbers or to output in the case of livestock production losses.

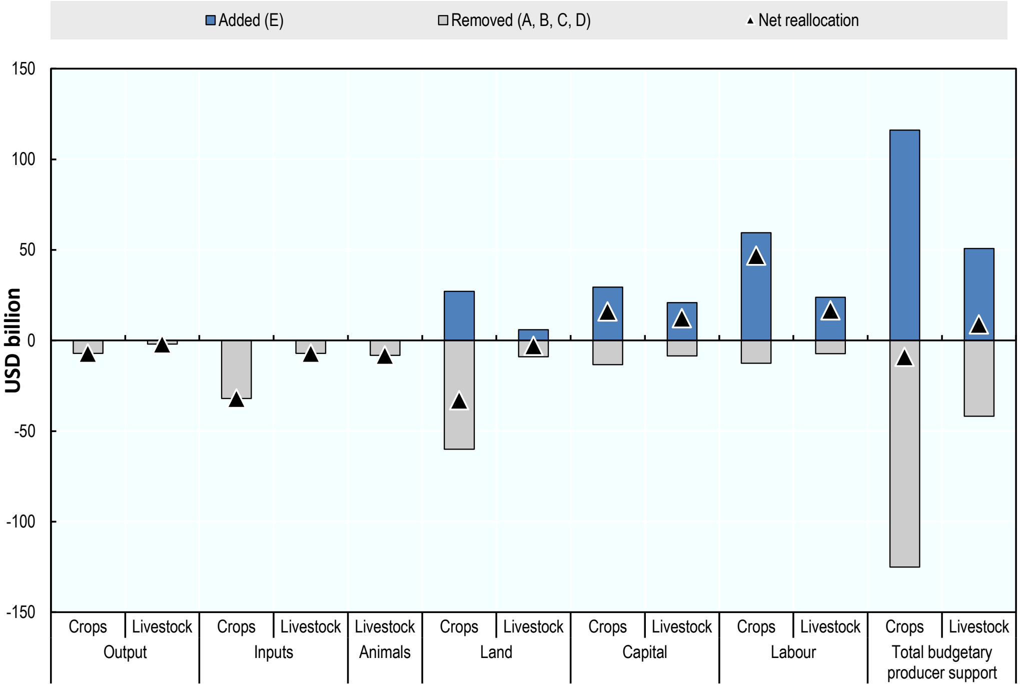
[15] This distribution of payments only applies to transfers that are reallocated, whereas initial transfers under category E are left unchanged. Allocating decoupled payments to these factors still implies a partial coupling to production, but one that is less tied to land than assumed in the initial data. The labour factor currently accounts both for farm-owned labour and hired labour. Additional data would be required to distinguish the two factors in the production function.

[16] This amount does not include input payments for environmental services, amounting to USD 6.5 billion in Category B, which are kept unchanged.

payments is reclassified as payment on historical basis, without production requirement. As only a part of this total is reallocated to land under category E (within the 50% allocated to non-labour factors), this leads to a net decrease of land payments by USD 36 billion. In parallel, capital payments (excluding payments to animal) increase by USD 29 billion, whereas payments to labour, representing half of the new allocation (USD 83 billion), increase by a net USD 64 billion.

Examining the support reallocated as a share of gross farm receipts reveals that some regions are more affected than some others in relative terms, such as Rest of Western Europe, Japan, Korea, Mexico, or Türkiye. These regions however do not rank highly in absolute terms, due to the moderate size of their agricultural sector. Globally, four other regions account for the largest share (80%) of the support restructuring. These are the People's Republic of China (hereafter "China") (USD 53 billion), the European Union (USD 37 billion), India (USD 33 billion) and the United States (USD 17 billion). See supplementary figures in Annex H.

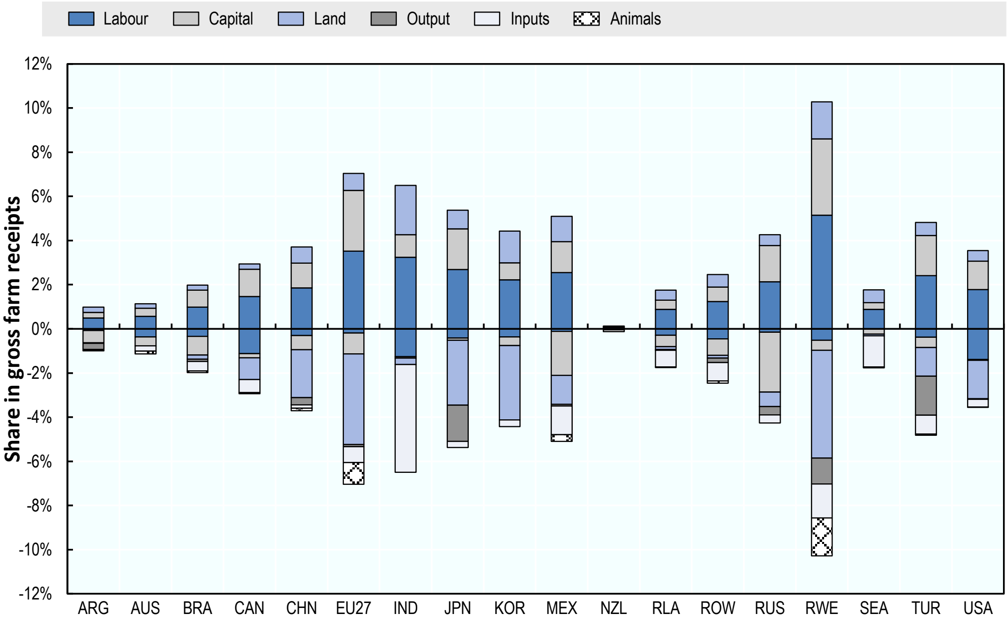
Figure 3.3. Total transfers across output, input and factors payments in the decoupling scenarios



Note: Land, capital and labour both experience some decreases and increases, because these factors are used both in categories A, B, C and D (removed) and in categories E (where the payments are added).
Source: METRO-PEM simulations, based on PSE database and scenario assumptions.

Figure 3.4. Relative transfers by payment forms and regions in the decoupling scenarios

Transfers in budgetary payments as share of the gross farm receipts



Notes: ARG=Argentina, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, EU27=European Union (without United Kingdom), IND=India, JPN=Japan, KOR=Korea, MEX=Mexico, NZL=New Zealand, RLA=Rest of Latin America, ROW=Rest of the World, RUS=Russia, RWE=Rest of Western Europe, SEA=Southeast Asia, TUR=Türkiye, USA=United States, WLD=World.
Source: METRO-PEM simulations, based on PSE database and scenario assumptions.

2-b) Green decoupling. In this scenario, the reallocation of budgetary support is conducted as for the simple decoupling, except that all producers receiving the payments are assumed to adopt the environmentally friendly management practices required for eligibility for the payments. Two changes of practices are considered: improved tillage practices for main annual crops cultivation, and reduced grazing intensity for ruminants.

On the crop side, reduced or minimum tillage is applied as a conservation practice for all cereals (except rice), annually grown oilseeds, sugar beet and fibre crops (see Annex E for soil organic carbon modelling). The change of practice is implemented in all regions except Rest of the World, based on practices already observed. In regions where conservation tillage is used by an important share of farmers (North and South America, Oceania), all producers are assumed to adopt no till practices for these crops. For other regions, producers adopt reduced tillage if they were still relying on conventional tillage practices. It is important to note that no specific costs are considered here in the modelling for the adoption of reduced or no tillage management compared to conventional tillage, nor are any yield benefit. In general, reduced tillage is part of a wider range of practices that, according to available literature, could allow farmers to improve sequestration in their soil at very low cost (Pellerin et al., 2017[34]; Fuss et al., 2018[35]), with 80% of soil sequestration potential estimated to be below USD 20 per tonne CO_2 (Smith et al., 2007[36]).

On the livestock side, a reduction of stocking density of animals on pasture is assumed, as part of a pasture conservation cross-compliance measure. Grazing pressure is decreased by 10% per unit of land in all regions where payments are transferred. This assumption is implemented in the model by reducing productivity of pastureland for ruminants, in all regions except Rest of the World. No direct cost is associated to this measure, but it does generate market price responses, which means that the benefits from local changes in production practices can be jeopardised by indirect land use adjustments if that risk is not mitigated (Box 1). Although grassland SOC can also be strongly influenced by land management and grazing intensity, no change of SOC is modelled in grassland under this scenario.

3.2.3. Targeted investments

In these scenarios, a part of the budgetary support is redirected towards innovation and investments targeting emission abatement technologies. This set of scenarios includes in particular:

3-a) Agricultural productivity investment. Under this scenario, new public investments are directed to research and development (R&D) for crop and livestock production technologies (e.g. improved seeds and breeds) to increase total factor productivity for these sectors by 3%. The amount of investment needed is estimated based on recent analysis from Baldos et al. (2018[37]), revisiting the work on long term returns to R&D expenditures from Alton et al. (2011[38]). Looking at long time series for the US, these authors find that long-term elasticity of TFP to R&D capital stock amount to 0.27−0.43 with a linear model, and 0.08−0.51 with a log model. Based on these estimates, the assumption taken here is an elasticity of 0.3 between TFP growth and R&D capital investment. Such elasticity would also be suitable for developing economies, based on a literature review by Fuglie (2017[39]), except for the sub-Saharan Africa region, where estimates are found to be lower. A TFP improvement of 3% in the long term, which corresponds to about +0.1% increment in TFP growth rate over a period of 30 years, would require a 10% increase in R&D expenditures. Considering public expenditures in agricultural knowledge generation amounted in 2017 to USD 15.5 billion (OECD, 2022[2]) for the countries covered by this analysis, an increased public expenditure of USD 1.5 billion per year would be required to achieve a 3% increase in TFP, which represents only 1.5% of the budgetary support to general services.[17] For the scenario considered here, the same TFP increase is applied to all regions targeted by the previous reform scenarios, assuming a coordinated research agenda is undertaken, involving also knowledge transfer. This effect of this additional expenditure is introduced in the model without impacting other categories of budgetary support.

3-b) Livestock productivity investment. Under this scenario, a same amount of R&D investment is assumed as for the scenario 3-a, but the research efforts are now devoted entirely to the livestock sector TFP. The same elasticity of TFP response to R&D capital stock is applied as for general agriculture, with a value of 0.3. Transferring crop TFP investments to livestock is assumed to double the benefits for that sector and the TFP is increased by 6% instead of 3%. Factors include here all usual production factors and inputs, including feed, which means the TFP increase is in particular associated with increase in feed conversion efficiency improvement. On the crop side, TFP in that scenario is kept unchanged.

3-c) Abatement technology investment. In this scenario, investments are oriented towards abatement technologies specific to each sector, based on information from emission abatement potentials and their cost. There is a large span of estimates on the extent to which agricultural emissions could be reduced through new technology deployment. Here, the analysis relies on abatement levels estimated by the US Environmental Protection Agency (US EPA, 2019[30]) for cropland soil emissions, livestock and rice cultivation. It assumes that at a cost of 50 USD per tCO_2-eq, about 400 $MtCO_2$-eq can be abated per year globally, which is close to the 600 $MtCO_2$-eq (range 300-1300) estimated by the IPCC at a cost lower than USD 100 per tCO_2-eq (OECD, 2022[2]). In this scenario, abatement costs are supported through the public budget with a subsidy amounting to 50 USD per tCO_2-eq avoided. This approach is therefore different from an emission taxation approach, usually applied in other sectors and often taken as base assumption in the literature (Frank et al., 2018[40]). The scenario also considers that costs are not borne by producers but fully covered by the public budget, which also implies that farmers

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[17] If investments efforts were similarly applied to agriculture knowledge transfer, an additional investment of USD 1.1 billion would be needed. These estimates are based on the OECD (2022[2]) estimates of USD 26.7 billion (in current dollar), over 54 countries in 2017 for total agriculture knowledge and innovation system (knowledge generation + transfer). Other sources find higher estimates of world public R&D expenditures at the beginning of that decade, e.g. USD 38.1 billion in 2010 (in 2009 USD PPP) (Pardey et al., 2016[79]) or 42.3 billion in 2011 (in 2010 USD PPP) (Fuglie, 2017[39]). Differences can be attributed to the various data sources used, the set of regions considered, and the accounting metric applied. That said, adopting the highest estimate would not significantly affect the observation that investment requirements under this scenario remain relatively low compared to total expenditures or changes in budgetary transfers considered in the other scenarios. Gautam et al. (2022[5]) assume on their side that a 30% increase of TFP could be achieved by investing 1% of agricultural output value in public R&D.

mitigate their emissions at no cost, or can benefit from a surplus if some technologies are available at lower cost than the marginal cost of USD 50 per tCO_2-eq.[18] Like in other scenarios, the policy is implemented in all the regions with policy information (including those where only a few countries are covered), and no reform is considered for the Rest of the World. More details on the marginal abatement cost curves used and their implementation in METRO-PEM can be found in Annex D.

3.2.4. Combined policies

To complement the different policies tested in each scenario group, and assess their performance when implemented jointly, two combined scenarios are finally added:

4-a) Policy mix – all regions. This scenario combines the scenarios delivering the largest benefits on climate change mitigation. These are the Green decoupling scenario (2-b), the Livestock productivity scenario (3-b) and the Abatement technology investments (3-c). All measures from these scenarios are simultaneously applied in all regions, except the Rest of the World.

4-b) Policy mix – OECD. This scenario is similar to the previous one, but measures are here only applied in main OECD regions, explicitly represented in the model: Australia, Canada, the European Union, Korea, Japan, Mexico, New Zealand, Rest of Western Europe, Türkiye and the United States.[19]

4. Results

In this section, the results are first presented in a first overview section featuring key indicator results across all scenarios, and the main associated insights. More detailed results by sectors and regions are presented in the following subsections to better understand the drivers of these results.

4.1. Climate benefits of the reform options

The performance of the different scenarios is first assessed on their potential to mitigate GHG emissions (Figure 4.1). First, changes in direct emissions on the farm – non-CO_2 emissions, as well as drainage and soil organic carbon are presented. The impact of indirect land use change emissions is discussed further below in a separate section.

Overall, all the policy scenarios analysed lower emissions, but their range of impact varies greatly, from −81 $MtCO_2$-eq/yr (−1.3%) for the Agriculture productivity scenario up to −327 $MtCO_2$-eq/yr (−5.1%) in the case of the Abatement technology scenario.

The scenario 1-a, where all budgetary support is removed, reduces emissions by −133 $MtCO_2$-eq/yr (−2.1%). This is driven by the strong decrease of production in supported regions, which is only partly compensated by increased production in other regions. Removing only the potentially most climate-harmful support (1-b), i.e. a subset of 24% of the payments, already achieves 65% of the reduction in 1-a, with −87 $MtCO_2$-eq/yr (−1.4%).

Indeed, by targeting output, input and livestock headage payments, scenario 1-b reduces emissions from most prominent direct sources, such as livestock and fertiliser non-CO_2 emissions, instead of affecting the utilisation of all production factors without distinction. This scenario is therefore more efficient in terms of emission abatement per unit of support removed. The additional emissions reduction observed in scenario 1-a, where all budgetary support is removed, comes from land-based sources, such as rice cultivation,

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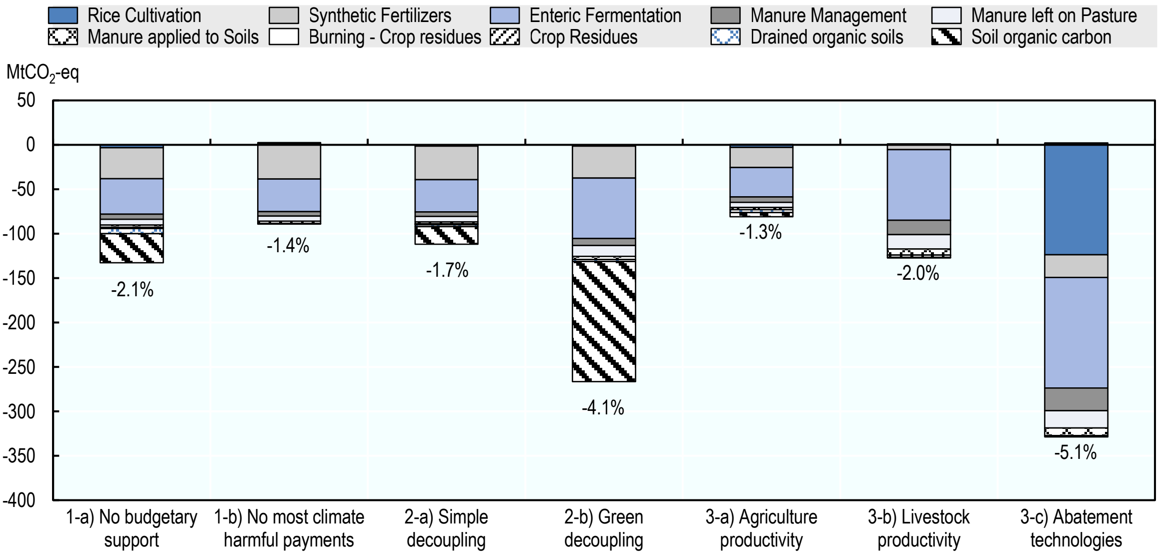
[18] This assumption is made for sake of simplification. It is likely that, in practice, even in the case where a subsidy programme would support farmers' investments in adopting new technologies, such adoption would still involve additional costs (operation time, maintenance, etc.) that could be hard for producers to recover.

[19] The five following OECD countries are therefore not covered by the scenario, as currently merged with larger regional aggregates: Chile, Colombia, Costa-Rica, Iceland, and Israel.

drained organic soils and organic carbon sequestration in agricultural soils, only partly targeted by the remaining producer payments.

The decoupling scenarios (2-a and 2-b) achieve comparable or even greater emissions reductions than scenario 1-a/1-b, without reduction in farming activities in supported regions. Under these scenarios, where transfers to producers are held constant, the benefits of phasing out all potentially most climate-harmful payments are maintained, and an important share of land-based payments is reallocated to labour and capital, which also reduces land use and leads to carbon sequestration in freed agricultural land. As a result, the emission reduction achieved under scenario 2-a exceeds that of 1-b and achieves 84% of the reduction of scenario 1-a without payments, at −112 MtCO$_2$-eq/yr (−1.7%). This mitigation potential can be substantially enhanced by adding environmental cross-compliance measures, as is done in scenario 2-b.[20] The improved tillage assumption considered for crops leads to significant soil organic sequestration, while livestock emissions are further decreased following the reduction in grazing intensity. As a result, the Green decoupling scenario mitigates −266 MtCO$_2$-eq/yr, more than twice the reduction level of any other scenario of support restructuring. With −4.1% reduction, this remains however a relatively modest abatement in relative terms. This good performance also does not take into account the potential risk of indirect land use change emissions in response to the lower productivity of grassland. If this risk is not mitigated, the emissions savings from this scenario can be substantially offset (Box 1).

Figure 4.1. Global GHG emission changes for all scenarios



Note: All calculations based on the GWP$_{100}$ from AR6.
Source: METRO-PEM simulations.

The efficiency of more targeted instruments illustrated above is echoed by the findings in the third scenario which considers productivity investments to stimulate TFP growth. The 10% increase in R&D expenditures, which is assumed to increase TFP by 3% delivers emission savings of −81 MtCO$_2$-eq/yr (−1.3%). If R&D investments only target livestock, 0% TFP growth for crops and 6% for livestock, the emission savings are significantly boosted, with −126 MtCO$_2$-eq/yr (−2.0%) saved for the same investment cost. This is explained by the high emission intensity of the livestock sector, but also because TFP growth in the livestock sector decreases the demand for feed crops, as it improves the feed conversion efficiency of livestock (through breed improvements, better herd management and prevention of diseases). Conversely, TFP growth for crops tends to provide lower cost feed to the livestock sector which stimulates livestock production to increase, offsetting some of the direct mitigation savings in the crop sector. Importantly, these

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[20] The scenario set does not contain a case where scenario 1-a) would be combined with the green practices measures from scenario 2-b), i.e. where the cross-compliance of the payments would be replaced by a command-and-control approach to have farmers adopt the environmental practices. Such scenario would likely increase even further the emission reduction but involve the same types of trade-offs on farm revenue as discussed further below.

productivity investments can be scaled up over time, unlike the policy reforms considered in scenario groups 1 and 2 that can only be achieved once.

The abatement technology scenario performs the best in terms of emission savings, with −327 MtCO$_2$-eq/yr (−5.1%). The high effectiveness of this scenario is driven by the direct targeting of emissions and the deployment of dedicated technical solutions targeting crops and livestock sources. This scenario is the only one to substantially decrease rice emissions, which accounts for 38% of the total abatement. These reductions are typically obtained through better seasonal management of rice flooding, alternative wetting and drying techniques and switches to dryland production. Enteric fermentation is the other large source of abatement, also contributing 38%, mostly using antimethanogens, propionate precursors, as well as the deployment of methane digesters. Compared to other scenarios, fertiliser emission reductions and soil organic sequestration are much lower.

The GHG emission results give a good indication of the relative performance of the scenarios. However, it should be noted that emissions from potential indirect land use changes are not represented, as only emissions tied to agricultural practices are accounted for. The potential implication of adding land use change emissions on the scenario results are discussed in Box 1, and provide insights about the land use dynamics triggered by the scenarios. However, it should be kept in mind that these are quite speculative compared to other emission responses estimated above and are derived without specific consideration of land use regulations.

Box 1. Exploring how emissions from land use change could affect the results

In the main set of results, LULUCF emissions are only included for the soil pool, as these directly depend on agricultural activity variables. Emissions from land use change associated with the natural vegetation pool are more challenging to quantify in this analysis, due to the coarse spatial resolution of the model, and the uncertainties associated with land use change dynamics. Therefore, these emissions are approached here through an exploratory analysis, subject to a number of simplifying assumptions.

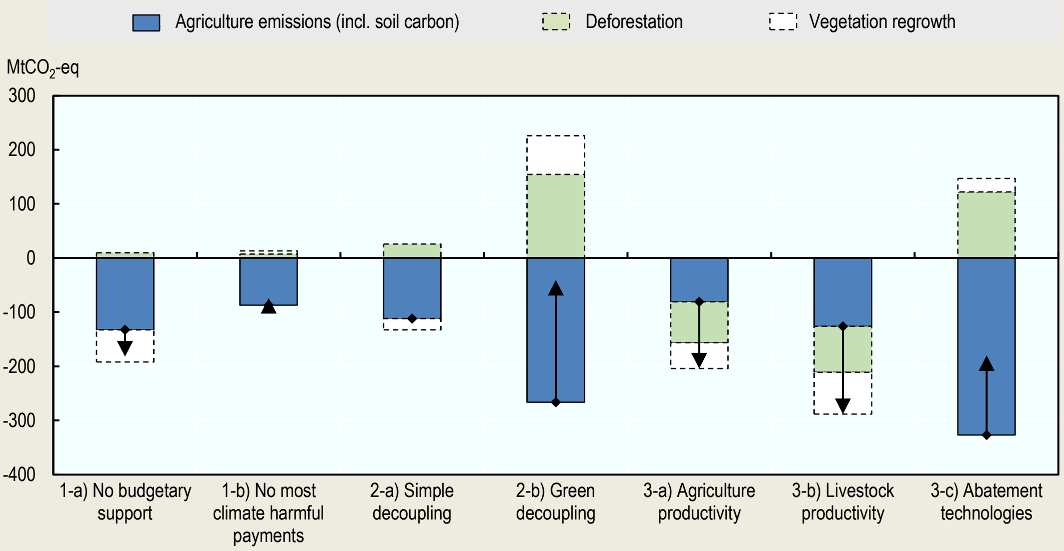
Two main sources are tentatively covered: i) deforestation emissions, associated with biomass clearing when agricultural land expands into forest; ii) foregone carbon sequestration associated with use of land for agriculture, compared to a counterfactual where land would be left to natural vegetation regrowth. Several assumptions are needed to derive land use change emissions for these sources. In the case of deforestation, a statistical method is used on national level time series to estimate the share of agricultural land expanding into forest for the three main tropical deforestation basins, covering the following model regions: Brazil, Rest of Latin America, Southeast Asia and Rest of the World, whereas deforestation is not assumed to be tied to agricultural activities for other regions anymore. Regional emission factors are then applied, based on FAO Forest Resource Assessment data on carbon in forests. As METRO-PEM is static, an amortisation period also needs to be chosen to derive annual emissions, set arbitrarily at ten years considering the medium-term horizon used for the analysis. In the case of foregone sequestration, land not used for agriculture is assumed to become a carbon sink, and the associated carbon accumulation rate is derived using IPCC estimates for natural forest regrowth. Expanding agricultural land into non-forested areas is then assumed to reduce this carbon sink, or conversely, land returned to nature from agriculture is considered to sequester carbon. Due to the various possible fates of abandoned land, also subject to land sealing, disturbances, or degradation, half of the land returned to nature is assumed to recover with the natural forest regrowing rate. More details on the methodology applied to living biomass land use change emissions, and comparison with some other modelling assumptions in the literature, can be found in Annex F.

The potential implications of adding land use emissions to the scenario results are presented below (Figure 4.2). Agriculture and soil carbon emissions, covered by the main model accounts, are featured in blue, whereas amortised deforestation emissions and foregone carbon sequestration from vegetation regrowth are in green and white, respectively. The impact of adding these sources to the emission base is illustrated by the black arrows. The direction and magnitude of the arrows provide the most interesting insights rather than their end points. In the case of full budgetary support removal and simple decoupling, emission reductions are boosted, and further enhanced as land payments are reduced and agricultural land is returned to nature (scenario 1-a). However, in the case of the green decoupling (2-

b), the increase in grassland observed above can come at a high price in terms of deforestation emissions and foregone carbon sequestration, which could almost offset their emission savings. A similar effect is observed for scenario (3-c) due to the rebound of the livestock sector in some tropical regions, in response to technology investments. In contrast, the land savings effects from the productivity scenario can more than double the benefits already observed for agricultural and soil emissions.

As highlighted above, all these estimates are subject to a number of assumptions and should be rather highlighted for their qualitative insights. They illustrate the potential reinforcing or countervailing nature of the land use change emissions in these scenarios, when no land regulation policies are considered. This shows the importance of these regulations to guarantee the positive outcomes of some of the scenarios considered.

Figure 4.2. Absolute change in GHG emissions, by scenario with land use change sources, in the absence of land use regulations globally



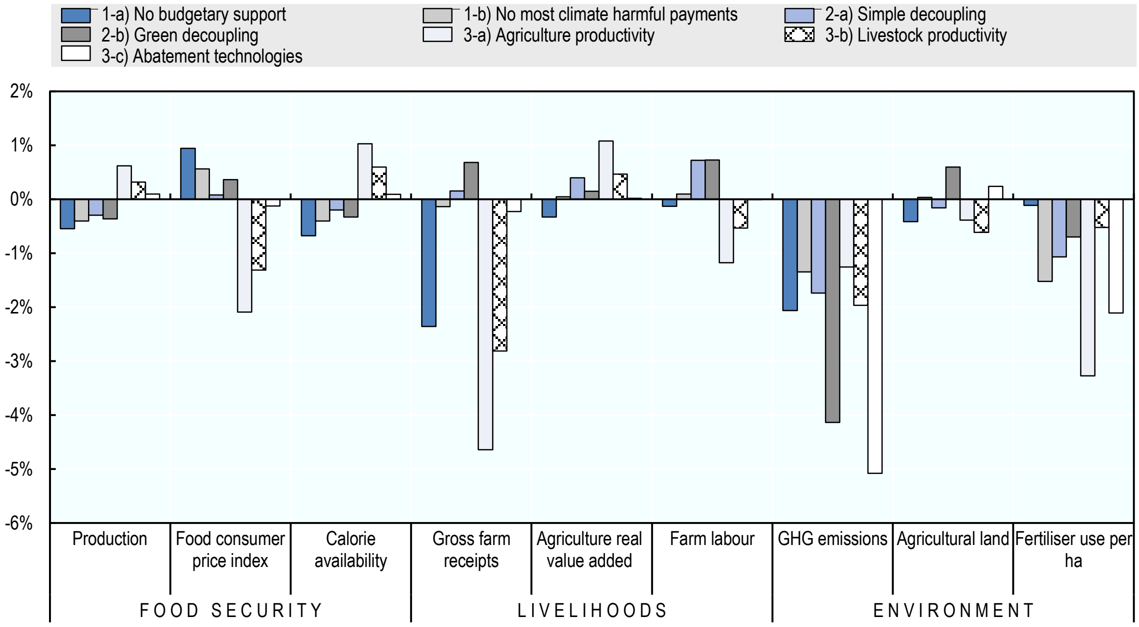
Note: black arrows indicate the potential overall displacement of net emission changes if deforestation and vegetation regrowth are added to agricultural and soil carbon emissions.

4.2. Scenario performance on the food systems' triple challenge

For a more complete evaluation of the different scenarios, the GHG abatement performance needs to be considered alongside other environmental sustainability metrics and indicators representing the two other facets of food systems' triple challenge: food security and livelihoods. For this purpose, various indicators pertaining to this challenge are presented side by side in Figure 4.3.

While all of the scenarios improve *environmental sustainability* by reducing GHG emissions, some scenarios may create negative environmental impacts associated with land use expansion or fertiliser application. Removing the potentially most climate-harmful payments decreases subsidies for fertiliser, which lowers crop yields and offsets the reduction of agricultural land observed in scenarios 1-a. Agricultural land increases more substantially in the case of the green decoupling scenario (+0.6%), as the decrease in grazing intensity linked to this reform triggers an expansion of pastureland. This suggests a need to accompany such policies with measures to lower demand for ruminant products and better control unintended consequences of indirect land use effects. This land expansion effect can potentially offset some of the emission savings achieved with these scenarios due to biomass clearing from land use change (Box 1). The productivity scenarios (3-a/3-b) are also land saving, but the subsidising of abatement technologies (3-c) generates a rebound effect through lower farm gate prices, which in turn lead to an expansion of agricultural land (+0.2%).

Figure 4.3. Relative change in key global sustainability indicators across all scenarios



Note: Relative change for production is calculated on value basis at constant price, agricultural land on area basis, and fertiliser in total fertiliser value purchased per hectare, at constant price.
Source: METRO-PEM simulations.

In addition to land use effects, all policies analysed lead to a decrease in fertiliser use intensity (on an area basis). The largest savings are obtained when agricultural productivity is enhanced as a whole (scenario 3-a), and when targeted abatement options are financed, which include optimised fertiliser application approaches. Targeting potentially most climate-harmful payments – that include fertiliser subsidies – also reduces fertiliser application under scenario 1-b, whereas decoupling and subsidy removal lead to lower reductions in remaining scenarios, due to the large volumes of land payments removed (USD 117 billion in 1-a and USD 36 billion in 2-a/2-b). Indeed, the higher cost of land creates incentives for farmers to intensify their production and apply more fertilisers, which partly offsets the effect of removing some of the fertiliser subsidies.

The *food security* outcomes of the different scenarios are only captured here through a subset of indicators (availability, food consumer prices),[21] but these stand already in stark contrast with those concerning environmental sustainability. Production decreases for all the scenarios reforming the budgetary support (groups 1 and 2), which increases food prices, and decreases food calorie availability. This does not come as a surprise considering that all these scenarios remove or decouple producer payments from production. This clearly highlights, however, the trade-offs between food security and environmental sustainability that the policy reforms bring about.

Only the targeted investment scenarios appear to circumvent that dilemma. The agricultural productivity scenario 3-a performs the best in terms of raising production, decreasing food prices, and boosting calorie availability, the latter increasing by +1.0%. By comparison, the livestock productivity scenario does not stimulate aggregate agricultural output (shown here in tonnes), because less crops are needed for feeding animals, and it also delivers less food price and availability benefits (+0.6% increase on calorie basis). Overall, with a total food supply benefit of +1% for a 3% agricultural TFP increase in scenario 3-a, one third of the productivity improvement appears to benefit food consumption, against two third in savings of resources. This contrasts with the last scenario on abatement technologies that only marginally benefits

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[21] It is acknowledged that the measurement of food availability through an estimation of total calorie supply remains a simplified metric, not reflecting the importance of food composition in various macro- and micro-nutrients also fundamental to good nutrition and health.

production (+0.1% for calorie availability), as the subsidies are invested in additional expenditures to reduce emissions, without any modelled productivity co-benefit.

Livelihood indicators also provide useful additional insights. Gross farm receipts decrease for scenarios removing payments (Group 1) as they lose the budgetary support. But receipts increase when payments are restructured, as farmers benefit from higher market prices than in the baseline, without any loss of revenue from government expenditures. In contrast, farm gate prices are significantly reduced by the increase in TFP, due to the additional supply of products to the market, which also substantially decreases gross farm receipts.

Another relevant metric for assessing the performance of the farm sector is the value added of the sector. Real value added variation is represented here, to better show the effect on agents' asset volume, independently from market price responses, and to better reflect the impacts on the productivity of the sector.[22] Removing the budgetary support unambiguously decreases the real value added for the sector, due to its effect on lowering production. However, under scenario 1-b when only the potentially most climate-harmful payments are removed, real value added increases, notably because the abandonment of input subsidies leads to an expansion in land use, bringing in new production factors that were previously unused in the economy. In the decoupling scenarios, and more importantly in the Green decoupling case, revenue also increases as farm-owned factors are favoured over purchased inputs. However, the green decoupling scenario also sees a pasture productivity decrease, which limits its real value added benefits compared to the simple decoupling case. In contrast, real value added is mechanically increased in the productivity scenarios due to the total factor productivity increase, and unchanged under scenario 3-c.

Last but not least, farm labour response to the scenarios is also contrasted across scenario groups. It is only slightly impacted in the support removal scenarios (±0.1%), mostly due to slight reallocation effects of production, but it is strongly boosted in the decoupling scenarios (+0.7% in 2-a/b) due to the increased transfer efficiency of the payments, more directly targeting labour. However, when total factor productivity is increased, demand for labour also decreases, which leads to a decrease in farm labour, in particular in the crop TFP scenario (−1.2%), while the livestock TFP scenario impacts are relatively less severe (−0.5%), and the abatement technologies are neutral. The whole economy implications of labour decreases in scenario Group 3 are nevertheless not necessarily negative, as the freed labour force can potentially be used in other sectors with a higher productivity, but the overall outcome ultimately depends on the labour market situation (alternative activities in rural areas, urban-rural mobility, full employment or not).

4.3. Sectoral and regional impacts

In this section, a brief snapshot of the main sectoral and regional level results is provided to better understand the main dynamics at play in the model. More complete tables of results at regional level are available in Annex H.

The decomposition of the production impacts by sector provides some more insights on the differentiated role played by agricultural activities (Figure 4.4). Among all scenarios analysed, the scenario of full budgetary support removal (1-a) is the one having the largest impact on overall crop production, except other grains and other crops. For many crop sectors, moving from 1-a to 1-b, where only potentially most climate-harmful payments are removed, creates similar production impacts, due to the strong production coupling from inputs, in particular due to the effect of removing fertilisers subsidies. When decoupling the payments, the same transfer as in 1-b are phased out, and land payments are also decreased, which explains the relative decrease in production of most crop sectors in the simple decoupling scenario 2-a, relative to 1-b. The livestock sector, in comparison, shows more differentiated results between the simple decoupling and the removal of payments. This is because the sector is a net beneficiary of payments in the simple decoupling scenario, as some crop payments are reallocated to livestock (Figure 3.3). In

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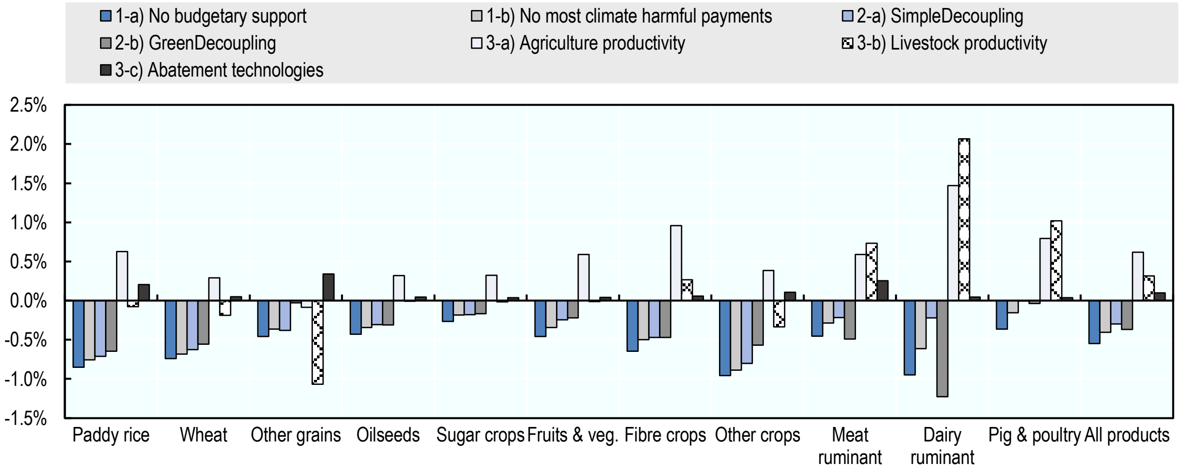
[22] Value added is here meant as value added at producer prices (and not at factor costs), which does not include public support to the sector, to the difference of the gross farm receipts indicator that includes it. Furthermore, value added variation is measured here in real terms, i.e. in volume, which means that both output and input prices are kept constant, to measure the effective value creation. Value added in nominal terms (in value) would be different, considering that all countries are here shocked simultaneously, which affects global prices and farm revenues, as can be seen for instance when comparing with gross farm receipts in the scenario groups 2 and 3.

contrast, the livestock sector is the most negatively affected by scenario 2-b, when payments decoupling is linked to a decrease in grazing intensity, except for pigs and poultry that do not depend on pasture land.

The sectoral results from the scenario 3-a and 3-b, with investment-led TFP increases, show opposite patterns for most sectors, compared to the group 1 and group 2 scenarios, as already noted above. In scenario 3-a, when TFP is increased for all sectors, production expands for all activities except other grains, due to the decreased demand for feed products by the livestock sector, which consumes a large share of other grains such as maize. Livestock has the largest production response (up to +1.5% in 3-a) among all sectors, as they benefit from both their own TFP improvement, but also from the lower feed prices driven by TFP growth for crop production. When investment in TFP is focused on livestock, the effect on crop production is reversed, and a decrease is observed for all crops, most notably other grains, wheat and other crops, all of which used as feed. The livestock sectors benefiting the most from the TFP growth are first the dairy sector, and then pig and poultry, due to the larger share of feed costs in their production structure. Production in the abatement technology scenario is less affected than in other scenarios, because payments are targeted towards additional investment costs in these technologies, and do not affect other production factors. The change in transfers between governments and farms is also relatively low in this scenario (USD 23 billion), compared to Group 1 scenarios, or the volumes reallocated in Group 2. Producer prices are therefore less affected and the rebound of production, visible in most emission intensive sectors (rice, ruminant meat) and for feed crops (other grains), remains relatively limited.

Figure 4.4. Relative change in world production volume, by sector and scenario

Based on variation in output volume in USD at fixed price



Note: Fruits & veg. = Fruits and vegetables.
Source: METRO-PEM simulations.

To better understand how the different regions contribute to the results, the GHG emission distribution across regions is presented in Figure 4.5, through eight large regional groups, aggregated from the 18 model regions.

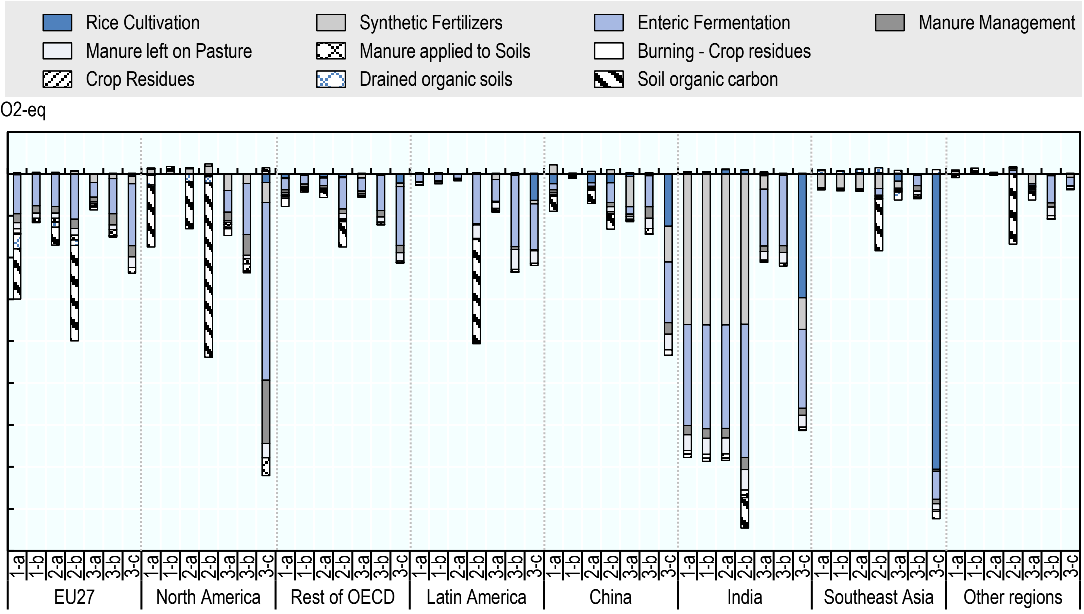
The results immediately highlight that some specific regions substantially contribute to the results. The largest decrease in scenarios of groups 1 and 2 are observed in India, which is consistent with the observation of the large volume of potentially most climate-harmful payments are located in that region, in particular input-based payments (Figure A.H.1). India is, in addition, a high-emitting region, in part due to inefficient production systems, which leads to higher GHG emissions response for a given change in production (in absolute terms). Emission variations in India are strongly driven by livestock sources, notably enteric fermentation, but fertiliser emissions decrease, as expected, in direct response to input payment removals.

The European Union is the second most strongly impacted region for scenario groups 1 and 2. It is characterised by a decrease in livestock emissions, but also responds to agricultural land reductions with an increase SOC stocks. With reductions in agricultural land area, drainage emissions from wetlands are also reduced.

Other regions react less strongly to the removal or decoupling of producer payments. In scenario 2-b, the agri-environmental measures still trigger some visible impacts in all regions, particularly through increased SOC sequestration (United States, Rest of OECD, Southeast Asia, other regions) and through reduced livestock emissions (Latin America, China). Peatland drainage also increases in Southeast Asia under green decoupling, due to expansion of pasture land. TFP scenarios 3-a and 3-b, in comparison, have more evenly distributed impacts across regions. The main sources of emissions reduced in these scenarios are from livestock, as no targeted agri-environmental measures are considered.

The strongest regional variations in emissions are observed for scenario 3-c that reflect the range of emission reductions along the marginal abatement cost curves. At USD 50 per tCO_2-eq, North America, India and Southeast Asia are the regions showing the largest decrease in GHG emissions. For the India and Southeast Asia, this is mostly explained by the abatement in the rice sector that also greatly contributes to mitigation in China. For North America, the large reduction in emissions can be related to the US EPA abatement cost curve results for the livestock sector, where the United States is able to abate more emissions (-20%) at a cost of USD 50 per tCO_2-eq, compared to the rest of the world (-5%). More detailed results on GHG emissions can be found in Annex H, decomposed across the 18 model regions.

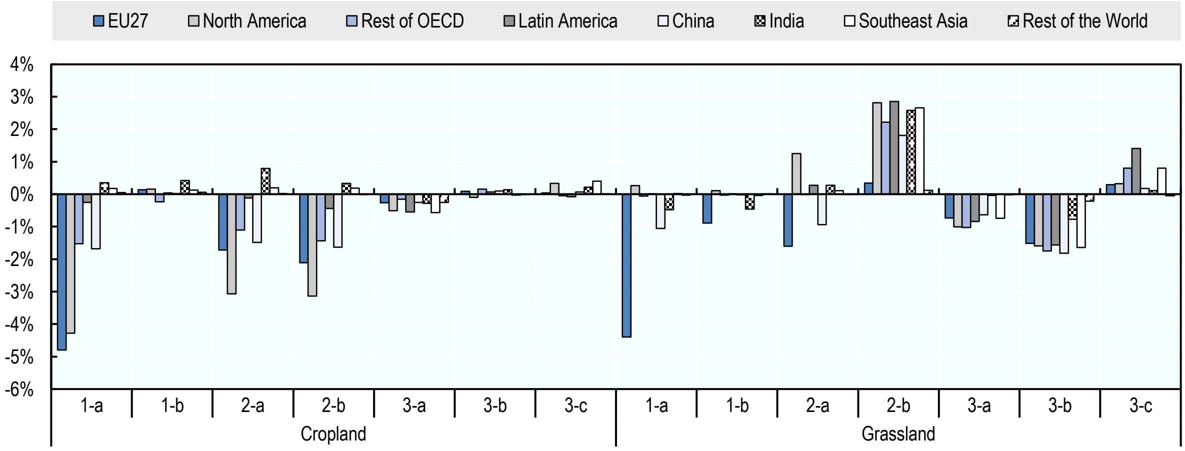
Figure 4.5. Relative change in GHG emissions, by region, scenario, and source



Note: Scenarios: 1-a = No budgetary support, 1-b = No potentially most climate-harmful payments, 2-a = Simple decoupling, 2-b = Green decoupling, 3-a = Agriculture productivity, 3-b = Livestock productivity, 3-c = Abatement technologies.
The eight regions presented here are aggregates from the 18 modelled regions. “Rest of OECD” includes model regions: Australia, Canada, Japan, Korea, Mexico, New Zealand, Rest of Western Europe, Türkiye. “Latin America” includes: Argentina, Brazil and Rest of Latin America. “Other regions” includes: Russia and Rest of the World.
Source: METRO-PEM.

The scenarios also impact land use differently in the various regions, which can drive some additional emissions, not included here, as part of the main sources (Box 1), as well as some other environmental impacts, for instance on biodiversity. Figure 4.6 shows the relative change in cropland and grassland observed in the different scenarios, by main region. In scenarios where land payments are reduced (1-a, 2-a and 2-b), cropland area decreases notably in the supported regions. This impact is, however, more differentiated by region in the case of grassland, because land payments play a larger role for the livestock sector for example, in the case of the European Union. In the case of scenario 2-b, grassland also strongly reacts to the decrease in grazing intensity, with an expansion of 2-3% in many regions in response to the modelled grassland productivity decline of 10%. In contrast, scenario 1-b, by targeting potentially most climate-harmful payments, has less impact on land use, except in the case of India, where removing input payments leads to a substitution between fertiliser and land, causing an expansion of cropland at the expense of grassland and other land uses. Productivity scenarios show the anticipated patterns, with a decrease of land use as TFP is increased. For scenario 3-a where all agriculture benefits from productivity gains, land use savings are observed both for cropland and grassland. For scenario 3-b, land savings are focused on grassland as expected, with a slight expansion of cropland and crop production in response to the livestock production rebound. The abatement technology scenario 3-c has less impact on cropland area, but the impact of the subsidy on grassland is more marked, due to the economic surplus for producers accessing technologies at lower costs than the payment of USD 50 per tCO_2-eq, which triggers a rebound of up to 1% in some regions like Rest of OECD or Latin America.

Figure 4.6. Relative change in land use, by region, scenario, and land type



Note: Scenarios: 1-a = No budgetary support, 1-b = No potentially most climate-harmful payments, 2-a = Simple decoupling, 2-b = Green decoupling, 3-a = Agriculture productivity, 3-b = Livestock productivity, 3-c = Abatement technologies.
The eight regions presented here are aggregates from the 18 modelled regions. “Rest of OECD” includes model regions: Australia, Canada, Japan, Korea, Mexico, New Zealand, Rest of Western Europe, Türkiye. “Latin America” includes: Argentina, Brazil and Rest of Latin America. “Other regions” includes: Russia and Rest of the World.
Source: METRO-PEM.

4.4. Overall outcome and policy mix

Overall, none of the scenarios appear to deliver evenly across all dimensions of the food systems’ triple challenge simultaneously, although the effectiveness of some options is clear at global level, with respect to GHG abatement, even when more uncertain land use change emissions are factored in. The budgetary support removal scenarios perform well on climate, but less so on food security and livelihoods. Removing potentially most climate-harmful payments achieves 66% of the emissions savings of scenario 1-a, while only reducing 24% of the full budgetary expenditures on producer payments, which illustrates the potential efficiency gains from more targeted removals of these payments. A full decoupling could, however, achieve more emissions savings by returning land to nature in supported regions.

The decoupling scenarios score well on climate and can deliver higher benefits when associated with relevant environmental cross-compliance measures, while limiting harmful impacts on livelihoods in supported regions. These promising results can be explained by the phasing out of budgetary support that encourages emissions in the model, such as livestock headage, output-based and input-based payments, and their replacement by potentially less climate-harmful payments to labour, capital and land. The abatement of emissions is obtained without the loss of gross farm revenues, and farm labour is also increased due to improved income transfer efficiency. SOC sequestration also plays a substantial role in boosting climate benefits under this scenario. In addition, reduced cattle grazing could generate additional emissions savings from a decrease in herd size, although international displacement and land use change could jeopardise these benefits due to deforestation and foregone sequestration. Improved practices are indeed considered here with zero or negative productivity effect, and these scenarios in particular fail to maintain food security, as food production declines and prices increase.

Only scenarios with targeted investments appear to deliver benefits across the food security, economic and climate dimensions. In the case of the productivity scenarios, climate effectiveness, however, depends on the sector targeted by productivity investment, and is slow to obtain, as returns on investments may take decades to materialise. This option therefore brings more uncertainty than the others that can be more immediately deployed. When realised, TFP gains for livestock deliver the most substantial climate benefits, whereas a more widespread investment also embracing crops leads to larger food security benefits in the long term. Land use savings effects would potentially boost these benefits, provided rebound effects remain limited. Farm receipts and agricultural labour remain the sole indicators of concern in the TFP scenarios, as the increased productivity lowers prices for consumers but also for producers, and less resources are needed for production. These structural changes generate overall macroeconomic benefits but the outcome for farmers depends on policies that can go beyond the agricultural sector, including labour market conditions, their mobility to more productive activities and the redistributive effect of policies accompanying the transitions. In the case of the abatement technology scenarios, impacts along the food security and livelihood dimensions are also positive, albeit limited, and agricultural land use increases, which increases land use emissions and may bring negative side-effects that need to be mitigated.

All these scenarios can also be analysed under a mitigation cost-efficiency lens with respect to the use of public budget funds. Table 4.1 shows how funds recovered or disbursed by governments compare with the emission savings achieved.

- In the case of group 1 scenarios, it appears that divesting from current agricultural support policies, effective in reducing emissions, would not be the most cost-effective option from a climate policy perspective, as abatement would remain relatively low compared to the funds recovered. The prime motivation for reducing payments to producers should therefore remain based on other policy objectives, as well as the opportunity costs of the funds, rather than a climate policy target. This also appears to be the case for scenario 1-b targeting potentially most climate-harmful payments.
- For the decoupling scenarios, which keep the budget constant, GHG emission savings appear to come at no cost for the government, including in the Green decoupling scenario relying rather on regulation measures. Abatement could, however, bring extra costs for farmers in these scenarios, and the maximum associated costs are also calculated for the case where the government would cover those.[23] Costs of mitigation for SOC sequestration are assumed to be USD 20 per tCO_2-eq maximum, based on the literature (Pellerin et al., 2017[34]; Fuss et al., 2018[35]), which, combined with other emissions reductions observed in that policy, leads to an overall abatement cost of USD 8.6 per tCO_2-eq abated under the Green decoupling. This is also the range of values obtained for the productivity scenarios, with the livestock productivity scenario showing a cost of only USD 12 per tCO_2-eq abated, which is consistent with, but at the low end of, the literature examining such strategies (Fuglie et al., 2022[26]).
- Last, the abatement technology scenarios appear slightly more expensive, but this can be explained by the larger emissions reduction targeted. Effective costs would also depend on the strategy taken. If farmers' abatements are all paid at USD 50 per tCO_2-eq on the basis of emissions realised, public cost expenditures would be USD 16.3 billion. However, subsidising adoption of emissions saving technologies could also lead to production rebound effects, offsetting a part of the mitigation gains, and leading to an effective higher abatement cost-efficiency at USD 69 per tCO_2-eq and a public fund disbursement of USD 22.6 billion. Conversely, if payments subsidise only technologies bringing positive costs for the farmer, and win-win technological investments are not subsidised, the costs go down to USD 10.1 billion for the government and the average abatement cost is USD 31 per tCO_2-eq. These results indicate that the cost range to achieve mitigation through abatement technologies would remain overall higher than typical costs through SOC improvement measures or productivity growth investments – although these latter are less well known and require more time to deliver mitigation benefits.

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[23] Note that this scenario is not modelled, and costs for the government could be slightly different, due to possible rebound effects associated with credit, as observed in scenario 3-c explicitly using abatement cost curves.

The above results suggest that an efficient mix of policies for GHG mitigation, based on the set of policy reforms considered, could involve a combination of Group 2 and Group 3 scenarios. This would allow reaching the full extent of climate benefits observed across sources, keeping the income transfer efficiencies associated with the decoupling scenarios, while benefiting from the food security and other livelihoods benefits from TFP growth, that latter being amenable to further scaling up with appropriate investments.

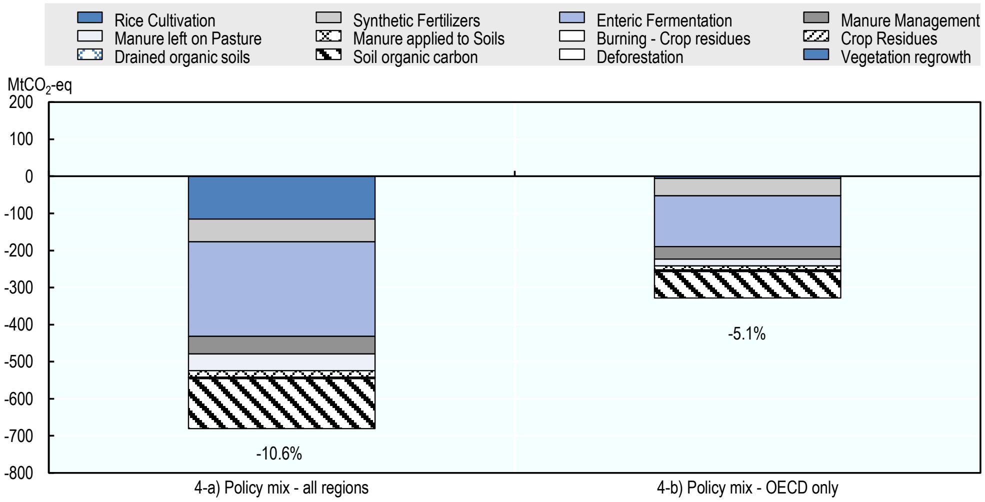
Table 4.1. Emissions abatement cost-efficiency of public budget expenditure, by scenario

Scenario	GHG emissions abatement (MtCO$_2$-eq/year)	Public budgets change (Bn USD)	Abatement per public budget expenditure (kgCO$_2$-eq/USD)	Average abatement cost (USD per tCO$_2$-eq)
	(1)	(2)	(3)	(4)
Budgetary support removal				
1-a) No budgetary support	-132.7	-232.2	-0.6	< 0
1-b) No potentially most climate-harmful payments	-86.9	-56.5	-1.5	< 0
Decoupling				
2-a) Simple decoupling	-112.0	0.0	∞	0.0
2-b) Green decoupling				
- Environmental regulations only	-266.3	0.0	∞	0.0
- SOC costs on government (upper bound)	-266.3	2.3	115.8	8.6
Targeted investments				
3-a) Agriculture productivity	-80.9	1.5	53.9	18.5
3-b) Livestock productivity	-126.5	1.5	84.3	11.9
3-c) Abatement technologies				
- at 50 USD per tonne CO$_2$-eq	-326.7	16.3	20.0	50.0
- with producer response to subsidy	-326.7	22.6	14.5	69.2
- discounting negative cost technologies	-326.7	10.1*	32.4	30.9
Policy mix				
4-a) Policy mix - all regions	-680.8	21.5	31.7	31.6
4-b) Policy mix – OECD	-328.4	6.7	49.0	20.4

Note: Columns (3) and (4) are calculated as follows: (3) = − (1) / (2) and (4) = − (2) / (1) *1000. For budgetary support removal scenarios, average abatement costs are not a relevant notion (as there is no investment incurred) and therefore only the sign of the relation is indicated.
* for 3-c) with negative cost technologies discounting, the value of the 125 MtCO$_2$-eq of abatement available at negative cost is excluded from the public cost in (2). The producer response is also not accounted here.
Source: METRO-PEM.

A new Policy mix scenario (4-a) is therefore introduced, combining scenarios 2-b, 3-b, and 3-c for all regions targeted for the reforms. An alternative scenario Policy mix – OECD (4-b) is also considered, where only main OECD regions apply the reform. GHG emissions results obtained for these two scenarios are presented in figure 4.7. Emissions savings obtained for scenario 4-a amount to −10.6% compared to no reform, which is the double of the gains obtained for the most efficient scenario considered so far (3-c). The average abatement cost under this mix of measures is estimated at USD 32 per tCO$_2$-eq, assuming that the green decoupling component is only handled through regulations. If only main OECD regions are implementing the reform (scenario 4-b), gains fall at −5.1% of global emissions, which remain substantial, as these countries account for a smaller share of global emissions. The average abatement cost under this new scenario drops to USD 20.4 per tCO_2-eq, mostly due to the larger abatement possibilities assumed for livestock in North America embodied in the marginal abatement cost curves.[24]

Figure 4.7. Absolute change in GHG emissions by source for policy mix scenarios



Source: METRO-PEM.

Figure 4.8 also examines the performance of these new policy mix scenarios against the other food systems metrics previously used, and also side by side with the targeted scenarios comprising the mix. Regarding food security, the two policy mix scenarios lead to consumer price reductions and positive or nil changes in calorie availability, offsetting the negative impacts of the green decoupling scenario. On the livelihoods front, although transfers to farms remain negative due to the contribution of productivity growth, real value added increases, and farm labour does not fall as previously observed in 3-b. Last, considering environmental dimensions in addition to the emissions saving benefits, the two scenarios also lead to reductions in fertiliser emissions and generate only marginal or no agricultural land expansion. The policy mix scenarios therefore appear to perform better than their different individual components across the various domains.

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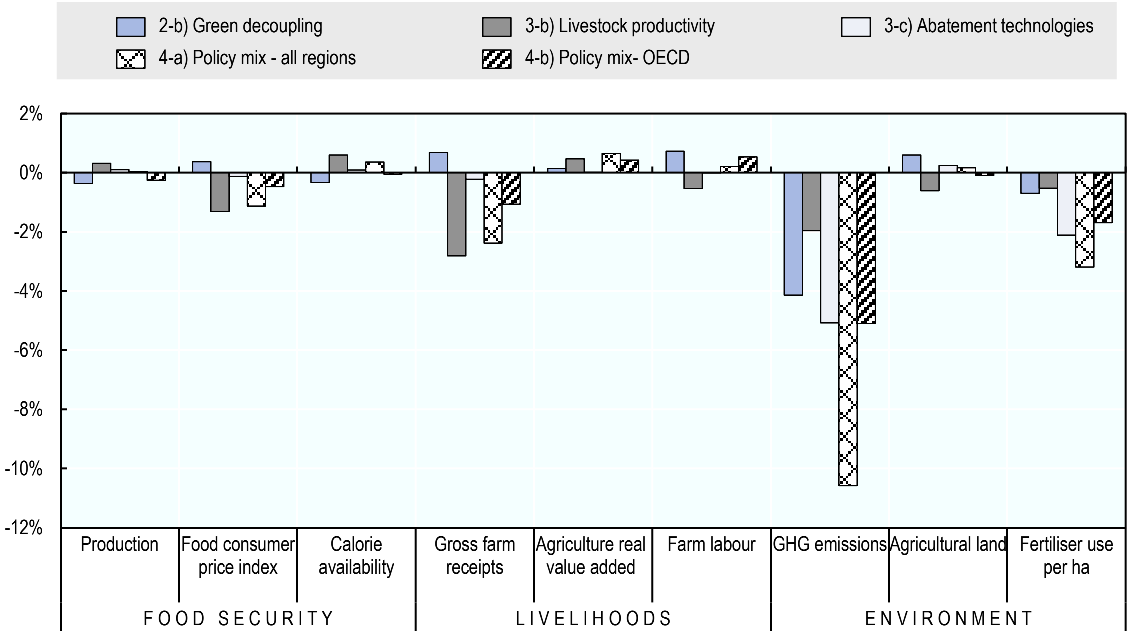
[24] It should be noted that when deriving additional land use emissions for these two scenarios along the method introduced in Box 1, these do not appear to significantly affect this outcome. For scenario 4-a, these additional emissions could offset about 20% of the observed savings, much less than for other scenarios, due to the contribution of the productivity improvement assumed here. For scenario 4-b, land use effects would be marginal, because no deforestation is assumed in the targeted regions.

Figure 4.8. Relative change in key global food systems indicators for policy mix scenarios, compared to other selected scenarios



Note: scenarios 4-a is defined as the combination of 2-b, 3-b and 3-c scenarios. Scenario 4-b follows the same assumption but is only applied to main OECD regions (see Table 3.4).

5. Discussion

The analysis and benchmarking of policy scenarios offered in this report reveal the potential GHG emission reductions that policy makers could expect from reforming budgetary support and targeting productivity growth and technological investments. Policy reform options can be compared from a total abatement perspective, but also based on their relative cost-efficiencies, as well as the trade-offs that these reforms can induce for other food systems' objectives.

The combination of the newly developed METRO-PEM framework with the OECD PSE database, which is rich in policy detail, permits a much finer assessment of costs and benefits attached to these options than has previously been possible with more aggregated global models. Furthermore, expanding the set of GHG emissions for agriculture to include soil carbon stocks, and exploring the link to deforestation and other land use changes provides additional insights into the role played by the land use interface for these policy reforms.

As highlighted by the previous section, different policy options appear to play useful roles within a larger policy package, but none are revealed as a solution on its own. Removing budgetary support (Scenario Group 1) reduces emissions but negatively impacts food security and livelihoods. Decoupling (Scenario Group 2) reduces the impact on livelihoods and can potentially boost environmental benefits locally with enhanced land management practices, provided that risks of indirect land use change emissions are mitigated. Conversely, productivity growth R&D investments (Scenarios 3-a/3-b) support food security and farm real value added but reduce farm receipts and employment. They have the advantage of scalability, but can also take decades to deliver, in contrast to the previous one-off budgetary measures that can be directly implemented. Investments in abatement technologies can also be used to boost emission savings but may generate some slight production rebounds. For these reasons, the combination of policies – including environmental measures, productivity investments and abatement technology deployment – is the best way to balance the different benefits and substantially abate emissions, while keeping abatement costs low, and performing well across the food security and livelihood dimensions.

The findings above are based on observations from a set of deterministic simulations, grounded in the initial model calibration. In order to test the robustness of these results, a sensitivity analysis was conducted, targeting specific model parameters (land supply elasticity, factor supply elasticity, intensification elasticity, etc.). Results, presented in Annex I, show that the choice of these parameters influence the magnitude of the results, but rather moderately. More importantly, the hierarchy of the scenarios is not affected, and therefore the conclusions above, appear to be robust to parametric uncertainty.

The current analysis remains, however, subject to other forms of limitations that are useful to note here. First, assumptions on abatement potentials and costs are based on simplified assumptions or a limited set of studies.

- In the case of soils, only a scenario of change in tillage is considered, but other practices (cover crops, better residues management) could also be considered, which could further improve the return of organic carbon to the soils. According to a comprehensive analysis by FAO (2022[41]), a 5% increase of carbon input to the soil could sequester around 200 $MtCO_2$/year in cropland (Sustainable Soil Management scenario 1, SSM1) versus 113 $MtCO_2$/year in this analysis in the region considered. This potential could be increased to 500 $MtCO_2$/year at global scale if grassland, paddy fields and shrubland were also included, and even higher potentials would be reached for more ambitious scenarios (1-2 $GtCO_2$ removed per year for 10%-20% carbon input increase, according to the SSM2 and SSM3 scenarios). This means green decoupling measures could be much more ambitious than assumed in the scenarios considered here.
- Similarly, for scenario 3-c, abatement costs are all based on a single study (US EPA, 2019[30]) that assumes relatively conservative mitigation potentials, in particular for other regions than the United States. The calibration is based on a total abatement of 0.4 $GtCO_2$-eq, which is on the low end of the IPCC range (0.3-1.3 $GtCO_2$-eq), and some other modelling studies assume much higher abatement estimates at USD 50 per tCO_2-eq, in the range 0.5-1 $GtCO_2$-eq (Frank et al., 2018[40]).
- Finally, abatement potentials in this study are modelled at regional level and only partly take into account the heterogeneity of farms, with their diversity of practices and emission factors. This is for instance the case for scenario 2-b); whereas for scenario 3-c), the marginal abatement cost curves from US EPA (2019[30]) capture some elements of heterogeneity (spatial heterogeneity of fertiliser application, farm size for investment costs in livestock), but other sources of variability could also result in lower abatement costs for subsets of producers.

Although uncertainty will remain on these potentials and costs, the current model calibration could be revised in the future as more technologies and emission factor data become accessible. Considering the three previous remarks, the abatement volumes associated with the scenarios 2-b and 3-c should certainly be seen as low-end estimates for the mitigation potentials. Conversely, the static nature of the model does not allow to differentiate the lagged effects from productivity investments in scenario 3-a and 3-b, from other forms of interventions. The literature assumes long time horizons – typically 35 to 50 years – to see the full extent of such benefits materialise (Fuglie et al., 2022[26]). This means the results associated to these scenarios could be overestimated if shorter timeframes are considered. The rather general nature of the empirical relationship estimated between R&D investments and productivity growth also means results from these two scenarios remain rather stylised and the nature of investments would need to be specified to reduce these uncertainties.

Another important area of uncertainty concerns the role of land use change. An attempt was made to derive deforestation and foregone carbon sequestration estimates to enrich the analysis, but such calculations are difficult due to the data uncertainties (Pendrill et al., 2022[42]), as well as limits imposed by the current level of resolution of the model, which only tracks land use change at the national level. The static nature of the model is also a challenge for the analysis of land use change, as deforestation trends do not only depend on current pressure from agriculture, but also on the pace of crop yield growth. Furthermore, the policy landscape is evolving fast, and actions taken on the ground in response to increased awareness of the urgency to combat deforestation could already have impacts not visible in the statistics (Austin et al., 2021[43]). Some more advanced modelling features could be used in the future to refine the land use responses, building on experience from other models more focused on land use (see last section of Annex F). For instance, decomposing land use at the subnational level could also help to better capture land heterogeneity (e.g. by AEZ zones (Baldos and Corong, 2020[44])), and could be undertaken once these data are available for the latest version of the GTAP database. Such refinements are key to be able, in the future, to extent the set of indicators covered in this type of analysis to other environmental sustainability dimensions, such as biodiversity and land degradation.

The integration of the PSE data at a more granular level into METRO-PEM is an important improvement of the present analysis. A much more precise representation of the input-based payments was introduced, allowing their role in the production functions to be better captured. The current model version remains, however, rather aggregated sector-wise, and more work will be needed to ensure that the GTAP representation of agricultural sectors in each country accurately depicts the production volumes and cost structures reported by more specialised datasets. The analysis focused on budgetary support to producers and to public R&D, and other forms of support remain to be explored, notably market price support. In terms of sectoral resolution of producer payments, even though fertilisers were explicitly represented here, the role of other critical inputs like fossil fuels, water or electricity, for which payment data was introduced, has not been distinguished as yet. It is also noteworthy that an important volume of payments are sourced from a small number of regions, in particular for the potentially most climate-harmful payments. For instance, fertiliser subsidies are mostly observed in 2017 in India and Indonesia, and more tailored representation of the dynamics observed in all regions – and notably, a distinction between conjunctural payments and more structural (permanent) ones – would improve the analysis of mitigation potentials, as well as of the potential trade-offs, particularly in terms of food security. It is particularly important not to overshadow, through the climate focus of this analysis, the many functions of agricultural policies both for livelihoods and for the consumers. These dimensions are only schematically covered here, and further exploration of these dimensions could bring more nuance to the current evaluation of the scenarios, or inspire some new policy designs, for instance for livelihoods, equitable trade or provision of nutritious and healthy food.

Nonetheless, even if improvements can be made to the analysis, the present modelling brings new findings on the effectiveness and efficiency of different options for climate change mitigation. The pros and cons of different policy approaches clearly emerge, and the set of policies could be further broadened to include scenarios of emissions taxation (OECD, 2019[45]; Henderson et al., 2021[46]) and more diverse sets of policies (Henderson, Frezal and Flynn, 2020[47]). More realistic prospective scenarios, looking at planned and anticipated policies for agriculture and forestry, could be envisaged in the future, as well as analysis on the role of market price support, which could also play an important role in the climate-related reform agenda for agricultural policy (Laborde et al., 2021[19]; Guerrero et al., 2022[48]). Further work to represent policies at a finer policy scale, using PSE information, as well as their linkages to a broader set of environmental variables, would enrich the analysis and further enhance its utility for policy makers.

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Annex A. List of model sectors and regions

METRO-PEM structure is based on GTAP database (Aguiar et al., 2019[31]). The current model version (this study) is using the version 11 of the database, in its 2nd pre-released version (v11p2), with statistics reconciled for the year 2017. Correspondence between GTAP and METRO-PEM sectors is provided below in Table A A.1. The list of regions and mapping to the more detailed METRO database, also based on GTAP and combined with the input-output tables to represent embedded value added in trade, is presented in Table A A.2.

Table A A.1. METRO-PEM sectoral aggregation

Sector group	Model code	Sector name	GTAP sector code
Primary agriculture	apdr	Paddy rice	pdr
	awht	Wheat	wht
	agro	Other coarse grains	gro
	av_f	Vegetable and fruits	v_f
	aosd	Oilseeds	osd
	ac_b	Sugar crops	c_b
	apfb	Fibre crops	pfb
	aocr	Other crops	ocr
	actl	Cattle, sheep and goats	ctl
	aoap	Monogastrics, other animals	oap, wol
	armk	Dairy cattle	rmk
Other primary resources	afrs	Forestry	frs
	afsh	Fisheries	fsh
	aextr	Natural resources	coa, oil, gas, oxt
Processed agriculture products	acmt	Ruminant meat	cmt
	aomt	Pig and poultry meat and eggs	omt
	avol	Vegetable oils and cakes	vol
	amil	Dairy products	mil
	apcr	Processed rice	pcr
	asgr	Sugar	sgr
	aofb	Other food, beverages and tobacco	ofd, b_t
Industry	aman	Manufacturing	tex, wap, lea, lum, ppp, p_c, bph, rpp, nmm, i_s, nfm, fmp, ele, eeq, ome, mvh, otn, omf
	achm	Chemical products (crp)	chm
Services	aotp	Transport services	atp, wtp, otp
	aser	Other services	ely, gdt, wtr, cns, trd, afs, whs, cmn, ofi, ins, rsa, obs, ros, osg, edu, hht, dwe

Source: METRO-PEM, February 2023 version.

Table A A.2. METRO-PEM regional aggregation

METRO-PEM code	METRO-PEM Region name	METRO database code
AUS	Australia	aus
CAN	Canada	can
EUR	European Union (27 Members states)	aut, bel, cyp, cze, dnk, est, fin, fra, deu, grc, hun, irl, ita, lva, ltu, lux, mlt, nld, pol, prt, svk, svn, esp, swe, bgr, hrv, rou
JPN	Japan	jpn
KOR	Korea	kor
MEX	Mexico	mex
NZL	New Zealand	nzl
RWE	Rest of Western Europe (United Kingdom, Norway, Switzerland)	gbr, che, nor
TUR	Türkiye	tur
USA	United States	usa
ARG	Argentina	arg
BRA	Brazil	bra
CHN	China	chn, hkg
IND	India	ind
RUS	Russia	rus
RAS	Rest of Asia (partial coverage)	brn, khm, idn, lao, mys, phl, sgp, twn, tha, vnm
RLA	Rest of Latin America (partial coverage)	chl, col, per, cri
ROW	Rest of World (incl. Middle East, Africa)	isr, sau, mar, tun, zaf, row

Note: regional codes refer to the METRO-TiVa database, itself based on the GTAP database. Regional codes are the same between METRO-TiVa and GTAP, except for 'row' that contains other GTAP countries currently not disaggregated in the METRO-TiVa input data.
Source: METRO-PEM, February 2023 version.

Annex B. METRO-PEM technical description[25]

Background

METRO-PEM is a new modelling tool developed at the OECD Trade and Agriculture Directorate (TAD) to analyse the impact of agricultural policy reforms as well as various scenarios related to agricultural and food markets in a computable general equilibrium (CGE) framework. It builds on the combination of two other models, with a long history within the work of the directorate: the METRO CGE model, which offers the overall structure for METRO-PEM and. the Policy Evaluation Model (PEM), a partial equilibrium model used for analysis of agricultural policy changes in specified OECD countries.

METRO (ModElling TRade at the OECD) is a CGE model developed and maintained at TAD for trade policy analysis (OECD, 2020[49]).[26] CGEs are fully-fledged market equilibrium models integrating all agents, sectors and factors of the economy into a single framework solved at once. This characteristic has placed these models among the core tools for applied analysis of macroeconomic issues, such as fiscal distribution or trade policies (Shoven and Whalley, 1984[50]; Hertel, 1997[51]). The comprehensiveness of the sectoral coverage however often comes to the detriment of sectoral details. Most standard global frameworks, such as the Global Trade Analysis Project (GTAP) model, rely on canonical representations of production functions calibrated with generic elasticities for broad group of sectors (Aguiar et al., 2019[31]). The OECD METRO model is by default calibrated on the GTAP database and its initial structure follows many of the GTAP model features. Refinements have been included in METRO to better represent trade policy features, in particular tariffs and non-tariff measures, as well as trade in value added (TiVA module). The representation of the agricultural sector remains rather standard, however, which limits the capacity of the model to assess the impacts of agricultural policy reforms.

The Policy Evaluation Model (PEM) is a partial equilibrium (PE) model, focused on the agricultural sector, that has been applied since 2000 at TAD in the context of agricultural policy evaluation (OECD, 2001[52]; OECD, 2005[53]). The model benefits from a more detailed representation of agricultural production, with disaggregated sectors and factors, and more specific elasticities used for calibration. However, the number of countries covered by PEM is limited and trade representation is simplified (no bilateral relations), whereas upstream and downstream activities within the food supply chain are only partly represented (food transformation, energy, fertiliser, irrigation, etc.).

METRO-PEM aims to bridge the gap between these two models to improve the modelling of agricultural policy, by incorporating some of the detailed partial equilibrium features from PEM into the METRO CGE framework. Some first steps along this approach were successfully tested in the past using the GTAP model, with the development of GTAPEM (OECD, 2006[54]). This workstream has been rebooted with METRO-PEM, using the METRO model as a main development platform (OECD, 2020[55]). Further developments led to a full revision of agricultural production functions in METRO, with more tailored representation of intermediate products (feed, fertilisers), and segmentation of factor markets. A dedicated module was also designed to calibrate the new supply functions based on PEM land and production price elasticities.

Model general features

A CGE structure

METRO-PEM is structurally built as an extension of the METRO model and therefore reproduces a number of its structural CGE features. It is designed as a comparative static framework built on a series of regional Social Accounting Matrices (SAMs), linked together by trade relationships. The underlying data, sourced from the GTAP database, distinguishes different types of agents – households, firms, government – and describes all the monetary flows circulating in the economy. Agents' production and consumption choices in response to change in prices are then determined in the model through utility-maximising functions,

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[25] This technical description documents the METRO-PEM model for its January 2023 version.

[26] For more information, see www.oecd.org/trade/topics/metro-trade-model/.

consistent with the microeconomic theory. In METRO, household consumption is for instance described through a Linear Expenditure System (also known as Stone-Geary utility function), which allows to represent subsistence consumption expenditures. Whereas firms optimise their consumption through nested Constant Elasticity of Substitution (CES) functions, aimed at describing the degree of substitution between different factors and inputs, or for some more detailed group of inputs, through Leontief functions (fixed basket of goods).

Compared to other standard CGEs, METRO presents also a few specificities particularly tailored for trade policy analysis. Production and trade of goods are distinguished by consumption use – intermediate, household, government or capital good, which allows a more precise description of global value chains (GVC) and ability to implement more targeted scenarios. The model is also extended for more advanced trade analysis. For example, ad valorem equivalents (AVE) of non-trade measures (NTMs) have been estimate for the METRO database (Benz and Jaax, 2020[56]; Cadot, Gourdon and van Tongeren, 2018[57]) and changes to the estimates can be applied in the model as a simulation using an iceberg cost approach (OECD, 2017[58]). In addition, the METRO ICIO-TiVA module allows for post-simulation calculation of ICIO tables and standard Trade in Value added (TiVA) indicators to allow for more detailed analysis of GVCs.

Because of its structure based on METRO, the METRO-PEM model keeps all the characteristics of METRO and is maintained to keep consistency with the source model. All the METRO-PEM extensions are built in the GAMS language in a modular way and can be activated or not as part of the METRO model. The two models however differ in their sectoral resolution and parameterisation. Data adjustments on production structure are also performed in METRO-PEM that are not included in METRO. The METRO-PEM model is also currently not accessible through the METRO graphical user interface.

Sectoral and regional data

Like METRO, the METRO-PEM structure is grounded in the economic data from the GTAP database (Aguiar et al., 2019[31]). The current model version is using the version 11 of the database, in its 2nd pre-released version (v11p2), with statistics reconciled for the year 2017.[27] The GTAP v11 version covers 151 regions and 65 economic sectors, which are usually used in a more aggregated form for simulations, to enable faster resolution and higher model stability. The agricultural sector is represented in GTAP through 12 primary crop and livestock sectors and complemented with 8 agri-food transformation sectors, plus fisheries and forestry activities. METRO-PEM replicates the sectoral information for its agricultural sector definition – with all crop sectors disaggregated (rice, wheat, other coarse grains, sugar crops, oilseeds, vegetables and fruits, fibre crops, other crops) and three livestock sectors (ruminant meat, dairy, other animal products).[28] The agri-food sectors are also disaggregated to properly describe some key supply chains (see Annex A).GTAP data provide all fundamental economic information for production and consumption, input and outputs, as well as trade flows for METRO-PEM sectors. The database also contains a series of elasticity values, including substitution elasticities, and trade (Armington) elasticities. These are usually used for industry and services sector parameterisation in METRO-PEM, whereas different sources are used for agriculture, in particular sourced from the PEM model (see further below). This is the case, for instance, of substitution elasticities in production functions or land transformation elasticities. In addition, although GTAP initially uses the OECD PSE data to construct its tax rate information for agricultural sectors, this data is substituted with a direct link to the in-house OECD PSE database maintained at TAD to ensure a full consistency and granularity of policy information in METRO-PEM scenarios, with data accessible from 1986 to the most recent years. Additional datasets from USDA are also used to replace GTAP demand elasticities.

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[27] The dataset is a pre-released version (v2) shared only with GTAP board members (including the OECD) and is still to be released to the public.

[28] The ‘wool, silk-worm cocoons’ sector from GTAP (‘wol’) is currently aggregated with the ‘ruminant meat’ sector (‘aop’) in METRO-PEM, due to its small size in many regions. This assumption will be reconsidered as the model further develops.

One of the strengths of METRO-PEM is its broad regional coverage, thanks to the large number of countries and regions represented in the GTAP database (151 for GTAP 11).[29] The GTAP regions can be aggregated in a flexible manner in METRO-PEM, like in METRO.[30] Currently, the METRO-PEM model has been aggregated around 18 regions – 8 OECD countries, plus two high income country blocks (EU and Rest of Western Europe), 5 emerging economies, and 3 rest of world regional aggregates (see Annex A). This list will be further expanded as the model develops to single out a larger number of OECD regions and major players on world agricultural markets.

Data satellite accounts

In order to apply METRO-PEM to a broader set of questions, the economic data from the model have also been complemented by other socioeconomic and environmental datasets, as illustrated in Figure 3.1 (main text). Currently, the METRO-PEM data ecosystem includes a diverse range of databases, offering more precise policy parameters or finer indicators, while the GTAP economic information is not directly modified.[31] The main datasets included are the following:

- The OECD PSE dataset: this dataset provides detailed information on agricultural support for 54 countries for the period 1986-2021, and its use is at the core of the simulation presented in this paper. More information on how the data were used is presented in Section 3.1.2 and Annex G.
- The PEM model factor substitution elasticities and supply elasticities: these come directly from the PEM parameterisation used at the OECD to represent the impact of policy changes on the agricultural sector. PEM elasticities are used to parameterise METRO-PEM agricultural production functions (see next Section).
- USDA food demand elasticities: the food own-price and income elasticities estimations by Muhammad et al. (2011[59]) from USDA ERS, performed for 144 countries and a broad range of food and other products are used as an input for the demand system calibration of METRO-PEM.
- FAOSTAT Food Balance Sheets: information on food availability for consumers in tonnes of products and in kilocalories was sourced from FAOSTAT and used in METRO-PEM to obtain a representation of diet composition, as a function of household consumption of different food products.
- FAOSTAT Production, land use and forests living biomass carbon stocks: production and land use information was sourced from FAOSTAT to construct a satellite account to the model calculating variation in production output in tonne-equivalent, to derive land use changes in physical units, and to assess carbon stock variations associated with deforestation, based on data collected through the Forest Resource Assessment.
- GSOC maps and IPCC parameters for Soil organic carbon (SOC): soil distribution information and IPCC information on ecoregions, soil organic carbon reference levels and Tier 1 emission factors were used to construct a simplified bookkeeping module for soil organic carbon accounting (see Annex E).
- GHG accounts from UNFCCC and FAOSTAT: non-CO_2 emissions accounts were based on UNFCCC data for Annex I countries by source (rice cultivation, enteric fermentation, etc.) and

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[29] The GTAP 11 regions include the 141 regions – 121 countries and 20 regional aggregates – already available in GTAP 10, plus the ten following countries: Chad, Comoros, Congo, Gabon, Iraq, Lebanon, Syrian Arab Republic, Serbia, Sudan and Palestine. For the full list of the GTAP 10 regions, see https://www.gtap.agecon.purdue.edu/databases/regions.aspx?version=10.211

[30] In METRO, one potential restriction on aggregation possibilities comes from the use of the OECD ICIO database to split services trade by use categories, which is only available for 64 regions. Therefore, the standard METRO database includes 64 individual regions with OECD ICIO information plus rest of world. The regions without OECD ICIO information are aggregated into rest of world.

[31] Future adjustments to GTAP database to better reconcile the economic information with other statistical accounts are not excluded. The only modifications to the GTAP database currently made in METRO-PEM are the reclassification of land endowment from non-ruminant animals as capital, and the forest natural resources endowment as land.

distributed across agricultural products within each source based on emissions information from FAOSTAT. For non-Annex I countries, CH_4 and N_2O emissions were based on FAOSTAT Tier 1 accounts. For all regions, CO_2 emissions from organic soil drainage were also added using FAOSTAT (Section 3.1.3).

- Synthetic fertiliser application data from International Fertilizer Association were also integrated into the model, to better estimate level of mineral fertiliser input by crop and precisely distribute synthetic fertiliser emissions across the different crop sectors.

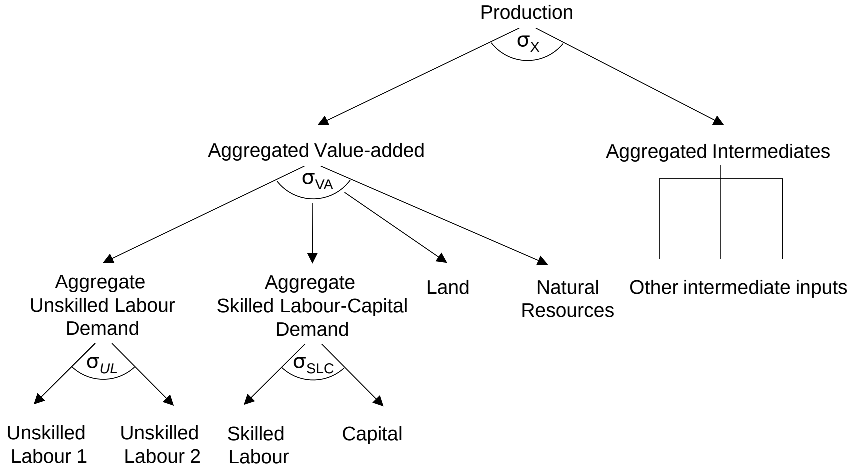
Agricultural sector representation

The agricultural sector received particular attention in the construction of METRO-PEM and has been modified from its initial structure inherited from METRO. Production functions have been adapted to better represent specificities of factor and inputs in agricultural sectors, and the parameterisation was revisited based on information from the PEM model.

Production functions

The most generic production functions in METRO-PEM are based on the initial representation in METRO. Their design is close to the GTAP nested Constant Elasticity of Substitution (CES) structure, with only one additional level of substitution for production factors (Figure A B.1). Production (top-level) and intermediates are obtained through CES or Leontief functions depending on the METRO set-up, whereas factors are structured around separate CES bundles for unskilled labour and for skilled labour and capital. Factors can therefore be highly substitutable within these bundles, whereas the substitution between factor aggregates and land or natural resources is considered more sluggish. This production function is kept in METRO-PEM for all non-agricultural sectors (including forestry, fisheries, and agri-food industry).

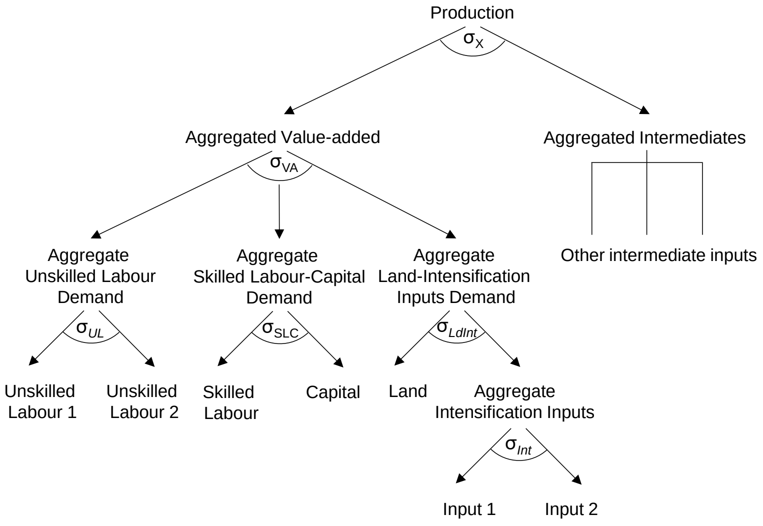
Figure A B.1. Standard production function in METRO-PEM (non-agricultural sectors)



Source: Adapted from OECD (2020[49]).

In the case of the agricultural sectors, new structures of production functions were implemented to better reflect inputs and factor specificities. Figure A B.2 gives a visual representation of the new production function for crop sectors. In this new structure, some intermediate inputs are directly introduced as a substitute of land in a new bundle representing possibilities of intensification for land through chemical inputs. These purchased inputs are no longer part of the intermediates branch of the production function (right-hand side of the figure). In this new representation, inputs on the value-added side are in addition substitutable within an extra CES level. Other intermediates remain perfect complement, but they can still substitute with the aggregated value added through the top CES production level. This new representation allows more flexibility in the production function, and calibration of supply elasticities to match with those from the PEM framework (see further below).

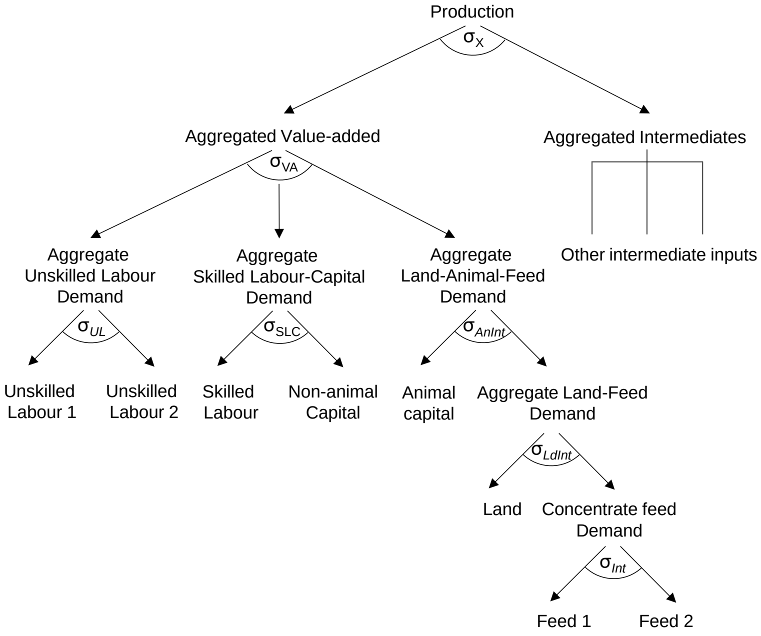
Figure A B.2. Crop sectors production function in METRO-PEM



Source: Modified figure adapted from OECD (2020[49]).

In the case of the livestock sectors, the same representation of land intensification possibilities is adopted, with concentrate feed inputs used as substitute with land (Figure A B.3). This applies to the ruminant sectors in particular – for the “other animal products” sector, all the factor payments to land are reclassified in METRO-PEM as payment to capital, considering grassland is not used. An additional important specificity introduced in the livestock sector function of METRO-PEM is the distinction of animal capital from other non-animal capital. Animal capital is placed in a separate bundle from skilled labour and non-animal capital, and put in substitution with the Land-Feed aggregate bundle within the value added CES. This provides two extra features: first, it is possible to represent explicitly the livestock feed efficiency and, if relevant, to allow for an endogenous response of this efficiency to prices (disactivated by default); second, it allows to create indicators associated to animal population (such as manure production or enteric fermentation emissions) and perform scenarios considering alternative technologies on these.

Figure A B.3. Livestock sectors production function in METRO-PEM



Source: Modified figure adapted from OECD (2020[49]).

Land factor market representation

The initial structure of METRO assumes perfect mobility of land. To improve this representation, a structure of nested Constant Elasticity of Transformation (CET) functions was introduced to differentiate land conversion patterns by sector following a similar approach as in the GTAPEM model (Huang et al., 2004[60]), that already implemented a CET structure based on the PEM structure (OECD, 2005[53]).[32]

The functional forms structure for land markets in METRO-PEM is organised around four-levels of CET nesting (OECD, 2020[55]). The lowest level of the nested structure corresponds to the total land supply, across all sectors, in each region. The highest level of the nest directly links to the land demand of each agricultural sector in the model (as well as the forestry sector). The structure in-between can be designed depending on the calibration preference. In the current version of METRO-PEM, the CET nesting structure is fully developed across the four transformation tiers and follows the specification illustrated in Figure A B.4. By default, the same structure is applied to all regions in the model, but transformation elasticities are region specific (see further below).

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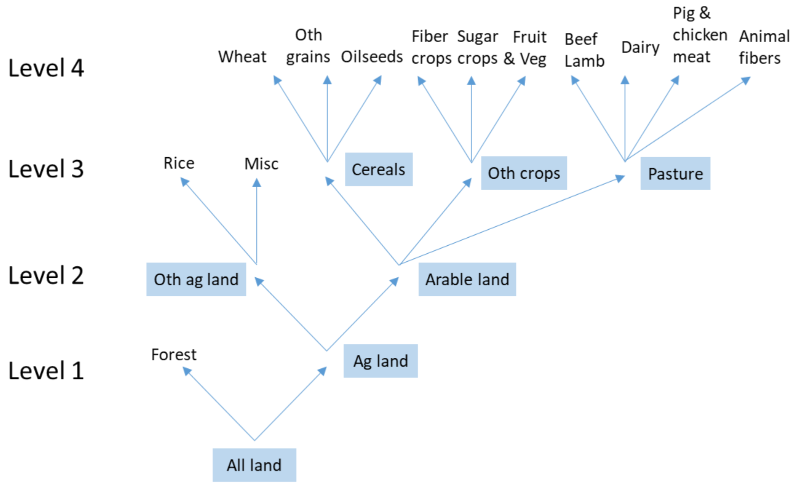
[32] The land CET nested structure can also be activated in METRO without using the other features from METRO-PEM.

Figure A B.4. Default nesting structure for the METRO-PEM land allocation with full sectoral disaggregation

Blue labels correspond to nodes (CET aggregates) whereas other labels indicate METRO-PEM sectors



Note: The animal fibre sector (wool, silk) is represented here as a separate sector but is currently merged with the beef and lamb sector due to its small size. In addition, for the pig and poultry sector, the land endowments were reclassified as non-animal capital, considering that these sectors do not play an important role in land use dynamics, and GTAP allocation to the land factor for that sector may not be well justified
Source: OECD (2020[55]).

In addition to the four levels of nested CET functions, a land reserve is also represented with a land supply elasticity attached to the land aggregate at the lowest level of the nest. This specification differs from standard CGE models assuming a fixed land pool, but follows more advanced practices used in models applied to agriculture and land use issues that aim at representing the possibilities of land expansion at the margin of agriculture and managed forest, into natural forest, savannah or idle land (Schmitz et al., 2013[61]). Overall land supply is specified as:

$$Land_{Total} = Land_{Total,0}\left(\frac{W_{Land}}{W_{Land,0}}\right)^{\sigma_{\mathrm{Land}}}$$

where $Land_{Total}$ corresponds to the total land used by economic activities,

W_{Land} is the rental price of total land in production

σ_{Land} is the elasticity of land supply

and the subscript 0 refers to the initial value of these variables.

The land supply curve is currently calibrated with the same elasticity value as for the transformation elasticity at the lowest level of the CET nest – 0.05 or 0.1. This assumption will be revisited in the future as more details on land use change get incorporated.

Other factor market closures

The closure of capital and labour markets have also been modified in METRO-PEM, in order to better calibrate the agricultural sector production functions and replicate the behaviour of the PEM model. The specificities of each factor market closure are detailed below:

- *Capital*: Non-animal capital is considered imperfectly mobile in METRO-PEM, with segmented markets between agricultural and non-agricultural sectors, implemented through a CET, to the difference of the METRO model where it is perfectly mobile (or immobile) across all sectors. One exception is the case of annual field crops, for which capital is kept perfectly mobile, to reflect the assumption of perfect mobility in PEM for machinery and equipment across crop sectors. For the livestock sector, beside the immobile general capital, animal capital is also represented and treated differently. As the model is calibrated for a long-term equilibrium, animal number is considered a fixed price illimited supply resource, which means it is assumed farmers adjust their herd size to the final market conditions.[33] Expansion constraints, however, arise from other factors availability, such as land, non-animal capital, labour, as well as feed crops.

- *Labour:* Like for capital, a segmented market representation is introduced for the labour market in METRO-PEM, between agriculture and non-agriculture markets, but also between agricultural sectors. The imperfect mobility of labour reflects the sluggishness of factor supply and the degree of specialisation of farms. It follows here again the PEM model assumption of limited mobility across sectors for non-land factors. It is to note that METRO also allows for more sophisticated representation of labour markets, including an unemployment module, but that one is not used by default in METRO-PEM.
- *Natural resources*: For all sectors depending on specific natural resource pools (fisheries, and other natural resources – oil, gas, coal and others), natural resources are assumed immobile. The only exception is the forestry sector, as its natural resource endowment is reclassified in METRO-PEM as a land endowment and introduced in the nested-CET structure of the land market.
- *Input*: The input factors part of the value-added branch in the production function of agricultural sectors are directly supplied by the other sectors outputs in METRO-PEM without any mobility constraint. This means that feed crops and chemicals can be freely reallocated across agricultural sectors based on its respective sector needs.

The different market closure applied in METRO-PEM are summarised in Table A B.1.

Table A B.1 Overview of factor market closure assumptions in METRO-PEM

Factor	Crop sectors	Livestock sectors	Other sectors
Land	Imperfect mobility across land-based sectors (four tier nested CETs). Land supply curve for total land.	Imperfect mobility across land-based sectors (four tier nested CETs). Land supply curve for total land	Imperfect mobility across land-based sectors (four tier nested CETs). Land supply curve for total land.
Non-animal capital	Perfectly mobile between annual field crops, imperfectly mobile (CET) between annual field crops, and other crop and livestock sectors	Imperfectly mobile (CET) among livestock sectors, with crops and with non-agricultural sectors	Perfectly mobile among non-agricultural sectors. Imperfectly mobile (CET) with agriculture
Animal capital	--	Fixed price unlimited supply	--
Labour	Imperfectly mobile (CET) among crops and with livestock sectors	Imperfectly mobile (CET) among livestock sectors and with crops	Perfectly mobile among non-agricultural sectors. Imperfectly mobile (CET) with agriculture
Natural resources	--	--	Fixed supply
Intensification inputs	Perfectly substitutable across all sectors	Perfectly substitutable across all sectors	Perfectly substitutable across all sectors

Source: METRO-PEM.

Parameterisation and calibration

The parameterisation and calibration of METRO-PEM follows very closely the approach from METRO, except in the case of the agricultural sector. Thanks to the more detailed production structure of crops and livestock sectors in METRO-PEM, it is indeed possible to perform a detailed calibration of the model directly using parameters from PEM, and to test the calibration performance to assess the extent to which the model reflects the production behaviour of the PEM model (or any other source taken as a reference).

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[33] This assumption may be revised in the case of ruminant herds for shorter-time horizon simulations.

Agricultural production parameters set-up

The PEM documentation provides, for each region in the model, four different elasticities of substitution across agricultural production factors, and also specific supply elasticities for factors, such as labour, capital or feed concentrate. The set of elasticity values used for the different substitution relations in PEM is presented in Table A B.2. The elasticities in METRO-PEM production functions, described in earlier sections (Figures A B.2 and A B.3), are determined through the following mapping:

- *Value added vs. intermediate CES (Level 1 – σ_X)*: PEM elasticities of substitution between purchased and farm-owned factors are used.
- *Unskilled vs. Skilled-Capital vs Land-Inputs CES (Level 2 – σ_{VA})*: PEM elasticities of substitution between land and other farm-owned factors are used.
- *Non-land factors bundles (Level 3 – σ_{UL}/σ_{SLC})*: the elasticities of substitution between detailed unskilled labour categories, or between skilled labour categories and capital are not used in PEM. The usual value used in METRO is an elasticity of 3. To better align with PEM factor suppl
- *Animal vs Land-Feed in value added (Livestock level 3 – σ_{AnInt})*: this elasticity value is not used in PEM and is therefore currently set to zero in METRO-PEM.
- *Land vs. inputs in value added (Crops level 3/Livestock level 4 - σ_{LdInt})*: For crop sectors, PEM elasticities of substitution between land and purchased factors are used. For livestock sectors, elasticities of substitution between land and feed are used.
- *Inputs in value added (Crops level 4/Livestock level 5 – σ_{Int})*: PEM elasticities of substitution among purchased inputs are used, with their crops and livestock values, respectively.

Table A B.2 PEM model production function elasticities

Example of the European Union

		Among purchased inputs	Between land and other farm-owned factors	Between land and purchased inputs	Between purchased and other farm-owned	Between land and feed
Crops	Base	0.5	0.4	0.5	0.9	-
	Min	0.0	0.0	0.0	0.0	-
	Max	1.0	0.8	1.0	1.8	-
Milk & beef	Base	0.15	0.15	0.15	0.15	0.5
	Min	0.075	0.075	0.075	0.075	0.25
	Max	0.3	0.3	0.3	0.3	1.0

Source: PEM documentation (OECD, 2005[53]).

Each region in the PEM model has been assigned a specific set of elasticities as presented in Table A B.2, which is preserved to the best extent in METRO-PEM, as these were based on a literature review conducted for PEM calibration – documented in OECD (2001[52]) – and reviewed by country experts over the years in the context of country-level studies at the OECD.

Factor mobility parameterisation

As per the assumptions presented above, factor markets mobility in METRO-PEM relies on CET functions that require also parameterisation. For a number of cases, elasticity values were aligned on PEM assumptions as follows:

- *For labour mobility*: In PEM, farm-owned factors other than land are sector-specific and supplied to each of them with an elasticity of 0.5. To best match this assumption, an elasticity of transformation of -0.5 is applied in METRO-PEM a large number of countries present in PEM, which defines the degree of imperfect mobility of labour across crops and livestock sectors. For the case of middle-income countries and developing regions, the CET elasticity considered is however set higher (-0.8) to reflect the higher migration flows existing within rural areas and between rural and urban areas.

For all regions, the same elasticity also applies to the mobility to non-agricultural sectors. Mobility between non-agricultural sectors is considered perfect in METRO-PEM.

- *For capital mobility***:** the same elasticity of transformation of -0.5 is applied to non-animal capital, to also align with the assumption in PEM. Considering that PEM considers perfect mobility for machinery and equipment capital between crop sectors, an exception is also made in METRO-PEM for capital mobility between annual fields crops (which excludes fruits and vegetables and other crops), which is considered without constraint (perfect mobility). For the livestock sector, non-animal capital is also imperfect mobile across sectors, with -0.5 as a transformation elasticity value. Animal capital, on its side, is not set as a constraining factor, and is modelled in unlimited supply at a fixed price for each livestock sector.
- *For land mobility*: land transformation elasticities from PEM are implemented as described in Table A B.3 below, based on the PEM documentation and in-code adjustments in more recent versions of the model. The set of land elasticities in OECD (2006[54]) was indeed simplified over time, with only two values distinguished for the highest mobility tier (Level 4) in the most recent PEM versions. For specific sectors in a few regions (European Union, Japan, Korea), some further adjustments were made on these values, to better reflect experienced gained with PEM on some country studies.

Table A B.3. Default PEM elasticities currently used for METRO-PEM land allocation module

Region	Level 1/Level 2	Level 3	Level 4
PEM regions			
Canada	0.05	0.14	0.55
China*	0.05	0.18	0.33
European Union	0.05	0.15	0.33
Japan	0.05	0.11	0.33
Korea*	0.10	0.11	0.33
Mexico	0.10	0.11	0.55
United States	0.10	0.15	0.55
Rest of Western Europe (based on EU)	0.05	0.15	0.33
Non PEM regions			
Australia (PEM default values)	0.05	0.15	0.33
New Zealand (PEM default values)	0.05	0.15	0.33
Türkiye (PEM default values)	0.05	0.15	0.33
Other regions low LUC (India, Russia, Rest of World)	0.05	0.15	0.33
Other regions high LUC (Brazil, Argentina, Rest of Latin America, Southeast Asia)	0.10	0.21	0.55

Source: Based on OECD (2006[54]) and recent PEM version updates. For levels 1 and 2 in METRO-PEM, only one level exists in PEM and the same value is then applied. Regions with (*) were added in recent versions of PEM. LUC = land use change.

Demand and trade

As indicated earlier, METRO-PEM demand system follows a LES specification structured around the Stone-Geary utility function where utility U is of the form:

$$U = \prod_i (q_i - c_i)^{\beta_i}$$

with q_i the quantity consumed, c_i the minimum consumption, and β_i the marginal utility of good *i.* Maximising the utility under budget constraint imposes that the parameters β_i, be proportional to budget shares, which means that the function only allows $n+1$ degrees of freedom – the minimum consumption shares for c_i and the Frisch parameter defining the overall marginal utility of income. To calibrate this demand system, it is therefore only possible to target demand income elasticities or demand price elasticities, but not the two at the same time.

For the METRO-PEM demand calibration, the income elasticities from the USDA ERS database (Muhammad et al., 2011[59]) are used to estimate all minimum consumption shares in the LES demand system of each region. The last degree of freedom is determined by the Frisch parameter. Income elasticities fit for the demand function are displayed in Table A B.4. It is then possible to derive the price elasticities corresponding to this parameterisation. Table A B.5 shows the uncompensated own-price demand elasticities obtained for the demand system after such calibration. Cross-price elasticities are not shown here, but are close to zero for all primary and processed agricultural goods, due to the small share occupied in the household budgetary expenditure. A better characterisation of cross-price elasticities within food categories – e.g. substitution between cereals or meat types – will be performed in the future, but requires a modification of the demand system with the addition of a level of CES bundles to group the food products.

Table A B.4 Demand income elasticities used for METRO-PEM demand system calibration

	EU27	USA	CAN	MEX	CHN	JPN	KOR	IND	SEA	RWE	AUS	NZL	TUR	RUS	BRA	ARG	RLA	ROW
pdr	0.06	0.03	0.04	0.09	0.27	0.04	0.06	0.27	0.24	0.07	0.02	0.03	0.17	0.06	0.18	0.12	0.19	0.20
wht	0.06	0.03	0.04	0.09	0.27	0.04	0.06	0.27	0.16	0.08	0.02	0.03	0.17	0.06	0.18	0.12	0.18	0.20
gro	0.08	0.03	0.04	0.09	0.27	0.04	0.06	0.27	0.23	0.07	0.02	0.03	0.17	0.06	0.18	0.12	0.18	0.20
v_f	0.16	0.04	0.12	0.25	0.32	0.12	0.09	0.32	0.24	0.13	0.13	0.17	0.26	0.13	0.27	0.22	0.11	0.17
osd	0.09	0.03	0.07	0.12	0.27	0.07	0.07	0.28	0.23	0.03	0.06	0.06	0.19	0.08	0.20	0.15	0.20	0.21
c_b	0.19	0.06	0.15	0.31	0.39	0.16	0.12	0.39	0.04	0.17	0.16	0.21	0.32	0.16	0.33	0.27	0.28	0.20
pfb	0.94	0.96	0.96	0.97	0.94	0.96	0.48	0.97	0.93	0.96	0.96	0.96	0.97	0.48	0.97	0.97	0.96	0.82
ocr	0.26	0.07	0.19	0.40	0.55	0.19	0.14	0.55	0.43	0.20	0.19	0.26	0.41	0.22	0.44	0.34	0.44	0.33
ctl	0.27	0.17	0.24	0.32	0.38	0.24	0.15	0.39	0.38	0.23	0.25	0.26	0.34	0.17	0.35	0.33	0.35	0.32
oap	0.26	0.17	0.24	0.32	0.37	0.24	0.14	0.33	0.37	0.21	0.25	0.26	0.34	0.17	0.35	0.33	0.35	0.31
rmk	0.55	0.35	0.49	0.66	0.80	0.50	0.31	0.80	0.80	0.48	0.51	0.54	0.71	0.34	0.72	0.69	0.70	0.66
frs	0.52	0.52	0.52	0.52	0.53	0.52	0.26	0.53	0.52	0.52	0.52	0.52	0.53	0.26	0.53	0.53	0.52	0.45
fsh	0.41	0.26	0.37	0.51	0.65	0.38	0.24	0.66	0.58	0.36	0.38	0.41	0.56	0.27	0.57	0.53	0.58	0.53
cmt	0.25	0.17	0.24	0.32	0.38	0.24	0.15	0.39	0.36	0.23	0.25	0.26	0.34	0.17	0.35	0.33	0.33	0.32
omt	0.27	0.17	0.24	0.32	0.38	0.24	0.15	0.39	0.32	0.23	0.25	0.26	0.34	0.17	0.35	0.33	0.33	0.32
vol	0.10	0.03	0.07	0.12	0.27	0.07	0.07	0.28	0.22	0.05	0.06	0.06	0.19	0.08	0.20	0.15	0.19	0.20
mil	0.54	0.35	0.49	0.66	0.78	0.50	0.31	0.80	0.72	0.48	0.51	0.54	0.71	0.34	0.72	0.69	0.68	0.66
pcr	0.05	0.03	0.04	0.09	0.26	0.04	0.06	0.27	0.22	0.08	0.02	0.03	0.17	0.06	0.18	0.12	0.18	0.20
sgr	0.22	0.06	0.15	0.31	0.39	0.16	0.12	0.39	0.36	0.17	0.16	0.21	0.32	0.16	0.33	0.27	0.22	0.21
ofb	0.24	0.07	0.19	0.40	0.55	0.19	0.14	0.55	0.39	0.20	0.19	0.26	0.41	0.22	0.44	0.34	0.26	0.29
extr	0.53	0.53	0.53	0.53	0.53	0.53	0.27	0.54	0.52	0.53	0.53	0.53	0.53	0.27	0.53	0.53	0.50	0.47
man	1.22	1.19	1.23	1.27	1.36	1.23	0.61	1.30	0.93	1.22	1.24	1.22	1.17	0.65	1.25	1.18	0.93	0.77
chm	1.24	1.22	1.24	1.32	1.48	1.24	0.63	1.54	1.18	1.24	1.24	1.25	1.33	0.67	1.34	1.28	0.55	0.74
otp	1.13	1.13	1.13	1.15	1.14	1.13	0.57	1.20	1.00	1.13	1.13	1.14	1.16	0.58	1.16	1.16	1.11	1.04
ser	0.92	0.87	0.88	0.94	1.01	0.92	0.47	1.05	0.69	0.90	0.87	0.92	0.97	0.54	0.94	0.93	0.65	0.74

Note: See Annex A for sector and region codes.
Source: METRO-PEM, aggregated from Muhammad et al. (2011[59]).

Table A B.5. Uncompensated own-price elasticities for final demand in METRO-PEM

	EU27	USA	CAN	MEX	CHN	JPN	KOR	IND	SEA	RWE		AUS	NZL	TUR	RUS	BRA	ARG	RLA	ROW
pdr	-0.05	-0.02	-0.03	-0.07	-0.18	-0.03	-0.10	-0.17	-0.20	-0.06		-0.02	-0.02	-0.12	-0.09	-0.13	-0.09	-0.17	-0.18
wht	-0.05	-0.02	-0.03	-0.07	-0.18	-0.03	-0.10	-0.17	-0.13	-0.06		-0.02	-0.02	-0.12	-0.09	-0.13	-0.09	-0.16	-0.18
gro	-0.06	-0.02	-0.03	-0.07	-0.18	-0.03	-0.10	-0.17	-0.19	-0.06		-0.02	-0.02	-0.12	-0.09	-0.13	-0.09	-0.16	-0.18
v_f	-0.13	-0.03	-0.10	-0.18	-0.22	-0.10	-0.15	-0.21	-0.20	-0.11		-0.10	-0.12	-0.19	-0.19	-0.19	-0.16	-0.10	-0.16
osd	-0.07	-0.02	-0.05	-0.09	-0.18	-0.05	-0.11	-0.17	-0.19	-0.03		-0.04	-0.05	-0.13	-0.11	-0.14	-0.11	-0.18	-0.19
c_b	-0.15	-0.04	-0.12	-0.23	-0.26	-0.12	-0.18	-0.24	-0.03	-0.13		-0.12	-0.16	-0.23	-0.24	-0.23	-0.20	-0.25	-0.18
pfb	-0.75	-0.74	-0.77	-0.69	-0.62	-0.78	-0.74	-0.60	-0.76	-0.76		-0.74	-0.72	-0.70	-0.70	-0.69	-0.72	-0.86	-0.76
ocr	-0.21	-0.05	-0.15	-0.29	-0.36	-0.16	-0.22	-0.34	-0.35	-0.16		-0.15	-0.20	-0.30	-0.32	-0.31	-0.25	-0.39	-0.30
ctl	-0.21	-0.13	-0.19	-0.23	-0.25	-0.20	-0.23	-0.24	-0.31	-0.18		-0.19	-0.20	-0.25	-0.24	-0.25	-0.25	-0.31	-0.30
oap	-0.21	-0.13	-0.19	-0.23	-0.25	-0.20	-0.22	-0.20	-0.30	-0.17		-0.19	-0.20	-0.25	-0.24	-0.25	-0.25	-0.32	-0.29
rmk	-0.44	-0.27	-0.39	-0.47	-0.53	-0.41	-0.47	-0.52	-0.65	-0.38		-0.39	-0.41	-0.51	-0.50	-0.51	-0.51	-0.62	-0.61
frs	-0.42	-0.40	-0.42	-0.38	-0.35	-0.42	-0.40	-0.33	-0.43	-0.41		-0.40	-0.39	-0.38	-0.38	-0.37	-0.39	-0.46	-0.42
fsh	-0.33	-0.20	-0.30	-0.36	-0.44	-0.31	-0.37	-0.42	-0.48	-0.28		-0.29	-0.30	-0.40	-0.39	-0.41	-0.39	-0.52	-0.50
cmt	-0.20	-0.13	-0.19	-0.23	-0.26	-0.20	-0.23	-0.24	-0.30	-0.18		-0.19	-0.20	-0.25	-0.25	-0.25	-0.25	-0.30	-0.30
omt	-0.21	-0.13	-0.19	-0.24	-0.26	-0.20	-0.23	-0.24	-0.27	-0.18		-0.19	-0.20	-0.25	-0.24	-0.25	-0.25	-0.30	-0.30
vol	-0.08	-0.02	-0.05	-0.09	-0.18	-0.05	-0.11	-0.18	-0.18	-0.04		-0.04	-0.05	-0.14	-0.11	-0.14	-0.11	-0.17	-0.19
mil	-0.43	-0.27	-0.39	-0.48	-0.52	-0.41	-0.47	-0.51	-0.60	-0.38		-0.39	-0.41	-0.52	-0.51	-0.52	-0.52	-0.62	-0.61
pcr	-0.04	-0.02	-0.03	-0.07	-0.18	-0.03	-0.10	-0.17	-0.18	-0.06		-0.02	-0.02	-0.12	-0.09	-0.13	-0.09	-0.16	-0.18
sgr	-0.17	-0.04	-0.12	-0.23	-0.26	-0.12	-0.18	-0.25	-0.29	-0.14		-0.12	-0.16	-0.23	-0.24	-0.24	-0.20	-0.20	-0.20
ofb	-0.21	-0.05	-0.16	-0.31	-0.41	-0.17	-0.23	-0.37	-0.36	-0.17		-0.16	-0.21	-0.32	-0.34	-0.33	-0.27	-0.26	-0.29
extr	-0.42	-0.41	-0.43	-0.38	-0.35	-0.43	-0.41	-0.33	-0.43	-0.42		-0.41	-0.40	-0.39	-0.39	-0.38	-0.40	-0.45	-0.43
man	-0.98	-0.92	-0.99	-0.93	-0.93	-1.00	-0.95	-0.85	-0.81	-0.97		-0.96	-0.92	-0.88	-0.96	-0.91	-0.90	-0.88	-0.77
chm	-0.99	-0.94	-0.99	-0.95	-0.98	-1.00	-0.97	-0.96	-0.97	-0.98		-0.95	-0.94	-0.96	-0.97	-0.95	-0.95	-0.50	-0.69
otp	-0.91	-0.87	-0.91	-0.85	-0.77	-0.92	-0.89	-0.78	-0.83	-0.90		-0.87	-0.86	-0.86	-0.85	-0.84	-0.87	-0.99	-0.96
ser	-0.91	-0.93	-0.91	-0.85	-0.85	-0.94	-0.91	-0.83	-0.81	-0.93		-0.93	-0.92	-0.87	-0.91	-0.86	-0.91	-0.80	-0.85

Note: See Annex A for sector and region codes.
Source: METRO-PEM model results.

For trade, Armington elasticities in METRO-PEM are based on the GTAP database. For substitution between imports of different origin, estimates are sourced from Hertel et al. (2007[62]), as reported in Table A B.6. The substitution elasticities between domestic consumption and imports are set at half the value of substitution across imports, following the rule of thumb usually applied in the trade modelling literature.

Table A B.6. Armington import substitution elasticities

Sector	Substitution elasticity	Sector	Substitution elasticity	Sector	Substitution elasticity
pdr	10.1	oap	5.2	sgr	5.4
wht	8.9	rmk	7.3	ofb	3.6
gro	2.6	frs	5	extr	14.1
v_f	3.7	fsh	2.5	man	7.2
osd	4.9	cmt	7.7	chm	6.6
c_b	5.4	omt	8.8	otp	3.8
pfb	5	vol	6.6	ser	3.9
ocr	6.5	mil	7.3		
ctl	4	pcr	5.2		

Note: See Annex A for sector and region codes.
Source: METRO-PEM, aggregated from Hertel et al. (2007[62]).

Annex C. GHG emissions accounts in METRO-PEM

Extensive GHG emission accounts were integrated to METRO-PEM for this analysis. For this purpose, additional datasets from different sources have been integrated in the modelling framework. Usually, CGE models relying on the GTAP database rely on the precompiled accounts distributed by the GTAP Centre, and based on FAOSTAT data (Chepeliev, 2020[63]). These data cover all non-CO_2 emission sources, allocated to different factor or input uses in the GTAP database. This approach has however several limitations. First, the data lack granularity on sources of GHG emissions (for instance, enteric fermentation and manure management emissions are not distinguished), and relies on mapping distribution based on economic value accounts, for instance for fertiliser emission distribution by crop. Second, it does not take into account data from the more detailed reporting by countries under the UNFCCC, in particular for Annex I countries. Last, at the time when the current study was conducted, the GTAP 10 non-CO_2 accounts were the most recent dataset available from the GTAP centre, whereas METRO-PEM is using GTAP 11 with a more recent base year.

In order to address these limitations, a complete emission inventory was rebuilt for METRO-PEM directly using the FAOSTAT detailed data for agriculture emissions, as well as UNFCCC accounts. This approach allows to distinguish all the relevant accounts for non-CO_2 emissions. The overall emissions accounted for in METRO-PEM are presented below in Table A C.1. All main emission accounts are included in the case of agriculture (96% coverage), one missing account in the current model being savannah burning, for which more data on cultivation practices are needed to perform a sectoral attribution. Other minor sources of emissions under the IPCC agriculture account (3.G-3.J) are currently not accounted for by FAOSTAT, and therefore not included in METRO-PEM, but these represent less than 1% of non-CO_2 emissions from agriculture. To ensure consistency of emissions with UNFCCC accounts, all emission factors obtained based on FAOSTAT were rescaled to match UNFCCC totals by source in each Annex I country. This adjustment leads to slightly higher world emissions (6 432 MtCO_2-eq/yr for direct agriculture emissions and organic soils drainage), compared to when FAOSTAT data alone are used (6 349 MtCO_2-eq/yr).

Emissions in METRO-PEM are then allocated to sector output or production factors as indicated in Table A C.1. Livestock emissions are typically tied to animal capital, whereas rice emissions and organic soil drainage are related to area of land cultivated. Fertiliser emissions are directly tied to the use of fertiliser input in the production function. To accurately allocate these emissions across sectors, the International Fertiliser Association 2018 data on nitrogen application by sector and region were used (Ludemann et al., 2022[29]).[34] Last, crop residue emissions are allocated proportionally to the sector output of the corresponding crop sector.

The use of FAOSTAT accounts also allows for the integration of some CO_2 emission data corresponding to drainage of organic soils (classified in the LULUCF category in IPCC accounts). This source has a particular weight in some regions, such as Southeast Asia, but also the European Union. These accounts were not adjusted to UNFCCC reported values for that specific source, because of incomplete reporting.

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[34] Fertiliser emissions are more specifically driven by nitrogen-based fertiliser application, but the model does not distinguish the fertiliser chemical composition. The FAOSTAT data used takes, however, in consideration the variation in fertiliser applied by region.

Table A C.1. Agricultural GHG emissions coverage in METRO-PEM by category

IPCC code	Category description	GHGs	Allocation in the model	METRO-PEM 2017 emissions	Share 2017 non-CO_2 emissions
3.	**Agriculture**			($MtCO_2$-eq)	
3.A	Enteric fermentation	CH_4	Animal capital	2 723	45%
3.B	Manure management	N_2O, CH_4	Animal capital	413	7%
3.C	Rice cultivation	CH_4	Land (rice)	671	11%
3.D	Agricultural soils	N_2O		1 879	32%
3.D.1	Direct N_2O emissions from managed soils	N_2O	as detailed further below:		24%
3.D.1.a	Synthetic fertilisers	N_2O	Chemical products input to crop sector	471	8%
3.D.1.b	Manure applied to soils	N_2O	Animal capital	132	2%
3.D.1.c	Manure left on pastures	N_2O	Animal capital	533	10%
3.D.1.d	Crop residues	N_2O	Output	202	3%
3.D.1.f	Cultivation of organic soils	N_2O	Land	80	2%
3.D.2	Indirect N_2O emissions from managed soils	N_2O	as per categories in 3.D.1	461	8%
3.E	Burning savanna	N_2O, CH_4	Land	NA	4%
3.F	Field burning of crop residues	N_2O, CH_4	Output	30	1%
3.G	Liming	CO_2	*not covered*	NA	1%*
3.H	Urea application	CO_2	*not covered*	NA	0%*
3.I	Other carbon-containing fertilisers	CO_2	*not covered*	NA	0%*
3.J	Other	CO_2, CH_4, N_2O	*not covered*	NA	0%*
TOTAL	**Agriculture METRO-PEM (UNFCCC/FAO)**			**5 717**	96%
	Agriculture IPCC (FAO Tier 1)			***5 901***	*100%*
4.	**Land Use, Land Use Change, and Forestry**				
4.B	Cropland	CO_2	Land (organic soils drainage)	669	
4.C	Grassland	CO_2	Land (organic soils drainage)	46	
TOTAL	**METRO-PEM**			**6 432**	

Note: Global Warming Potentials (GWP) from last IPCC report (6th Assessment Report) are used, i.e. 27.0 for CH_4 and 273 for N_2O. Percentage in last column may not sum to 100% due to rounding. * Liming, urea application and other emissions are not reported by FAOSTAT and shares are estimated based on UNFCCC estimates.
Source: METRO-PEM, based on FAOSTAT.

Besides mineral soil carbon emissions, accounting of soil organic carbon has been included as part of the model emissions, and a dedicated bookkeeping module was built for this purpose (Annex E). This module, based on SOC reference data and emission factors sourced from the IPCC 2019 revised guidelines, allows to represent a total stock of 288 Gt of carbon stored in cropland, grassland and forest soils. Because in the base year, the model is considered at the equilibrium, SOC stocks are also considered stabilised, and the initial level of emissions is considered null and not featured in Table A C.1. Nevertheless, deviation from the base year affects the carbon stocks, based on the variation in the area of crops and their tillage practice. Data on tillage practice per region and crop, when available, was based on FAOSTAT and sourced from the literature, as indicated in Annex E. Once SOC stock variation are computed in METRO-PEM, related annual GHG emissions can be calculated by dividing the stock difference by a reference period of 20 years, which is the IPCC recommendation for a Tier 1 accounting of SOC.[35]

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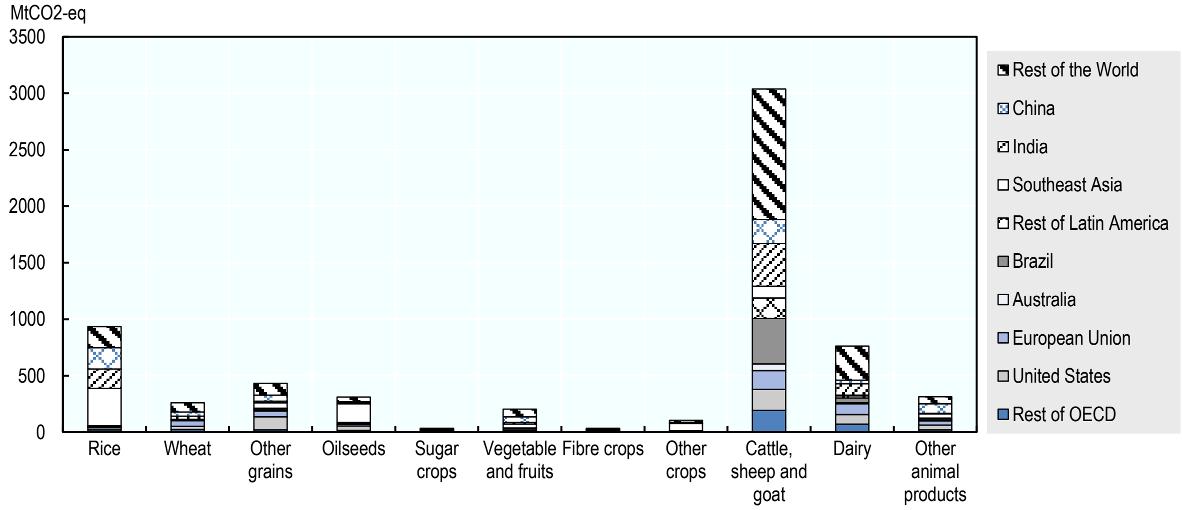
[35] This means that the time horizon for the policy simulation is considered to be up to 20 years. This assumption appears reasonable but should be kept in mind. Beyond that time horizon, SOC related emission flows would be stopped according to the simplified IPCC Tier 1 model, and emissions would then need to be annualised differently.

Figure A C.1 shows the global emissions accounts obtained in the model, split by sector and region for the base year 2017. The non-dairy ruminant sector represents the largest share of emissions (55%), followed by dairy ruminant (15%) and rice cultivation (13%).

Finally, a critical component of LULUCF emissions is related to land use change. Because METRO-PEM is static, the base year land use change emissions cannot be calculated in the model. However, a simple module was designed to compute these emissions in the case of a policy shock, by comparing land use change between the scenario and the counterfactual base year. Two sources are covered: i) emissions from deforestation, generated or saved in tropical areas and ii) emissions (or sequestration) associated with the (non) economic use of agricultural land, also sometimes termed as foregone sequestration. The methodologies used for these calculations are presented in Annex F and the results are presented as part of an exploratory analysis on the role of land use change (Box 1).

Figure A C.1. Overview of agriculture GHG emissions in METRO-PEM by sector and region

MtCO$_2$-eq. Base year 2017



Note: Sources accounted for are all agricultural emissions covered in Table 2.3, including CO$_2$ from organic soil drainage. GWP from IPCC AR report are used (27.0 for CH$_4$ and 273 for N$_2$O).
Source: METRO-PEM based on UNFCCC and FAOSTAT data.

Annex D. Calibration of marginal abatement costs in METRO-PEM

To represent GHG emissions abatement possibilities in agriculture through the adoption of lower emission-intensity technologies and practices, the METRO-PEM model production functions were modified to introduce latent technologies. For this purpose, the production function structure was split into two parallel branches of nested CES, at the level of the Land-Input-Animal node, to duplicate elements of the initial production function for the different technologies. The resulting two bundles of factors, associated with specific emission factors, were set in substitution through an additive CES functional form.[36] For the production function initialisation, factor volumes of each sector is mostly associated to the default technology, whereas the low-emission technology is only allocated a small quantity (typically 0.1%) of the total factor volume, because the technology is not assumed to be used. Two parameters are then used to calibrate the low technology adoption possibilities: the relative emission intensity of the alternative technology compared to the default one, and the substitution elasticity between the two technologies in the additive CES function. The first parameter can be determined based on the techno-economic information associated to the available technologies. The substitution elasticity is determined using the abatement cost curves chosen as reference.

For the current model version, abatement options are calibrated on information from the non-CO_2 marginal abatement cost curves published by the US Environmental Protection Agency (US EPA, 2019[30]). That study covers all sectors of the economy and includes three distinct sources in the case of agriculture: livestock (enteric fermentation and manure management), cropland soil and rice cultivation emissions. The abatement levels from the EPA curves are based on an explicit combination of technologies and calculated at different time horizons – 2020, 2030 and 2050 – and at different emission prices. Mitigation technologies considered are the following:

- *Livestock — enteric fermentation:* six mitigation options are considered:
    - improved feed conversion, through increased amount of grain in livestock rations, and inclusion of dietary additives.
    - antibiotics to promote increase weight gain and reduce feed intake requirement
    - bovine Somatotropin (bST) to increase milk production of dairy cattle – an option only applied in regions using growth hormones for animal rearing
    - propionate precursors added to daily animal feed, which reduces methane produce in the animal rumen
    - antimethanogen vaccines (option still under early development)
    - intensive grazing leading to higher quality of animal grass-based nutrition.
- *Livestock — manure management:* Mitigation is entirely based on the construction of manure digesters, with six types of digesters considered, suited to different farm size, climatic and economic conditions: complete-mix digesters, plug-flow digesters, fixed-film digesters, covered lagoons, dome digesters and centralised digesters. These are applied to dairy cattle farms and hog farms.
- *Cropland soil emissions:* mitigation options included are:[37]
    - no till farming (for their N_2O emissions effect)[38]

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[36] An additive CES (or ACES) function, is an alternative formulation of the CES function, allowing to keep the sum of the sub-element variables equal to the aggregated variable. More discussion on additive CES and CET are available in Zhao et al. (2020[75]).

[37] The fertiliser management options are only simulated in the EPA analysis for the five following crops: barley (and rye), maize (including green maize), sorghum, soybean (and lentils and other beans) and wheat (and oats). Therefore, the mitigation potential of this source is underestimated for cropland, while additional potential could also be obtained on grassland with better management.

[38] This possible interaction with the tillage assumption taken in scenario 2-b is not considered when implementing the combined scenarios 4-a and 4-b. The effect on C sequestration is not considered here for this option, while the effect on N_2O is not considered in scenario 2-b. In reality, the two sources are affected by tillage practices, but the interactions are complex (Guenet et al., 2020[80]).

  - reduced fertilisation by 20% (at constant global production)[39]
  - increased fertilisation by 20% (at constant global production)[39]
  - split nitrogen fertilisation, i.e. fertilisers are applied in three separated dates in smaller proportion instead of all-at-once.
  - nitrification inhibitors
  - full residue incorporation[40]
- *Rice cultivation:* mitigation in the EPA study was evaluated based on a review of large set of scenarios mixing many adjustments options for rice as to water management regime, residue management, tillage, and fertiliser management.

All the options above were then assessed as to their technical adoption potential, based on typical farm size, and region of implementation, and economic costs were used to determine the final shape of the marginal abatement cost curves.

For this analysis, the abatement used in Scenario 3-c assumes a price of USD 50 per tCO_2-eq, and the related abatement in the US-EPA dataset is estimated to be 409 $MtCO_2$ at global level in 2020 (303 $MtCO_2$ for regions covered by the scenario 3-c), which corresponds to an abatement of −7% of the baseline emissions. This abatement level remains similar for the year 2030 but falls at −5% by 2050 due to the increase of GHG emissions in the baseline. The model is calibrated to the abatement cost curves for 2020 and the USD 50 price, by applying carbon prices shocks on the production block of the model – isolated from the rest of the model – and assuming constant production level for purpose of the abatement targeting, similar to the approach used for abatement cost curves calculation. Because the emission levels in METRO-PEM and the EPA database slightly vary (due to different base year, sources and global warming potentials used per gas), the calibration of abatement in the model is based on the relative changes in emissions from each source. Elasticity values are determined for each technology alternative by emission source, so that the relative change in emissions corresponds to the targeted value for the price of USD 50 per tCO_2-eq on the abatement cost curve.

The results of the calibration by region are shown in Figure A D.1 below and are applied homogeneously in METRO-PEM: to all crop fertiliser emissions for cropland soil mitigation, to all ruminant for enteric fermentation, to all livestock for manure management, and to all rice cultivation for rice emissions mitigation.

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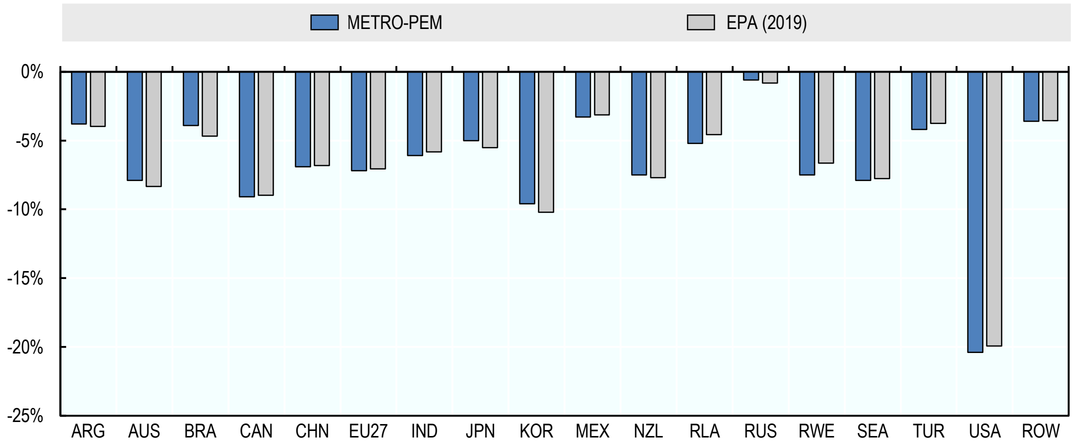
[39] The yield effects are not transposed to METRO-PEM itself. The simulations used here assume a constant production of crops, therefore implementing all the implicit assumption supporting the EPA MACCs on this source is non-trivial, and would require instead an integrated modelling approach.

[40] As for the no till assumption, impacts of this practice on soil organic carbon are not considered here. Benefits from this option could be greater as residue incorporation increase C in the soil.

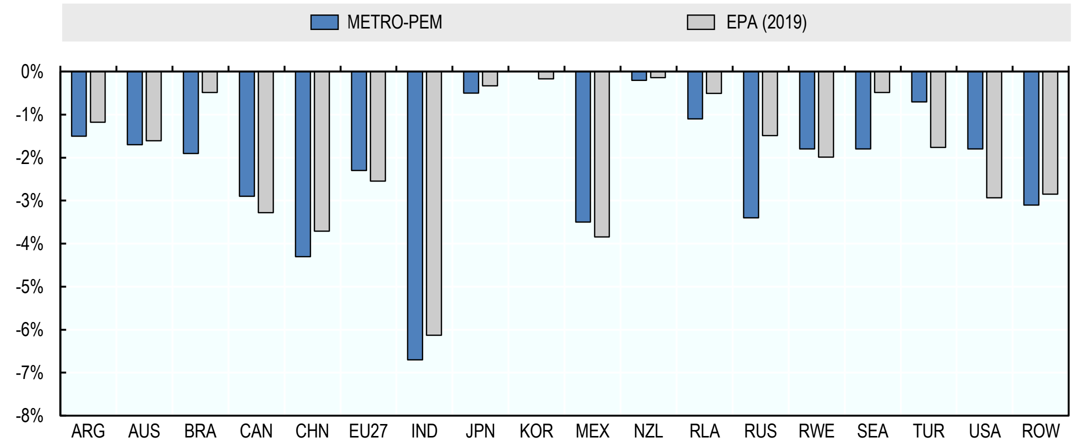
Figure A D.1. Change in GHG emissions at calibration in METRO-PEM and EPA (2019)

Relative change by source at USD 50 per tCO_2-eq, compared to the baseline

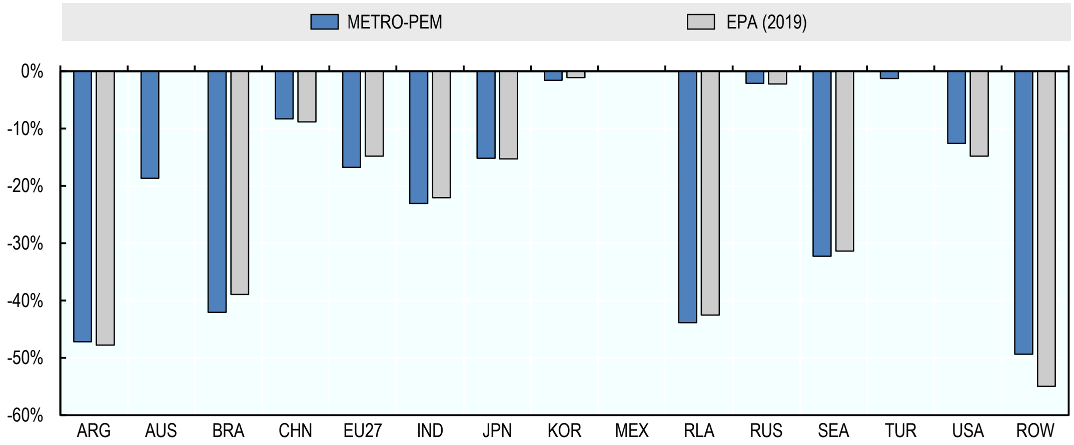
a) Livestock



b) Cropland



c) Rice cultivation



Note: METRO-PEM is only run for the production equation block for the calibration, with base year in 2017. EPA (2019) data are based on 2020 data. Regions' definitions can be found in Annex A. For Australia, no abatement value is provided for rice cultivation in the EPA study.
Source: METRO-PEM and EPA (2019).

Annex E. SOC accounting module for METRO-PEM

(Version 1.1: February 2023)

To allow for a more complete coverage of agricultural GHG emission accounts and the analysis of impacts from changes in agricultural practices in METRO-PEM, a dedicated module was designed to estimate variations in soil organic carbon associated with different management scenarios.

This module, built as a simplified bookkeeping approach, implements at the national level the IPCC Tier 1 methodology for the accounting of SOC in the model, while taking into account the specificities of different regions, current management practices, and crop specificities.

The purpose of this Annex is to provide more insights into the methodology used for this module. The current implementation corresponds to a first initial version that will progressively get enriched and refined, as more detailed data is integrated to the framework.

IPCC Tier 1 methodology

The calculation of the SOC content of a given land use is based on the Tier 1 model provided by the IPCC guidelines (IPCC, 2006[64]).

The formula applied is as follows (Equation 2.25):

$SOC = \sum_{(c,s,i)} (SOC_{REF} * F_{LU} * F_{MG} * F_{I} * A)$, where:

c, s, i are respectively the climate zones, soil types and management systems in the region

SOC_{REF} is the carbon stock of reference

F_{LU} is the land use factor informing on type of use among crop cover, flooded areas for rice, perennial crops, or set aside land,

F_{MG} is the management factor informing on tillage practice,

F_{I} is the input factor informing on level of fertiliser input and use of manure,

A is the land use area for climate zone c, soil type s and management type i.

For the application with METRO-PEM, the regional resolution cannot be finer than the national level, which is the level at which land use per activity is calculated. Therefore, SOC_{REF} is determined in the present setting at the national level, by aggregating at national level SOC data from the latest soil data inventories – the GSOCmap and GSOCseq products from FAO (FAO, 2022[41]) – using a cropland layer to compute the SOC average level. The land use information was based here on the European Space Agency (ESA) CCI Land Cover map for the year 2010 (ESA, 2017[65]).

The corresponding results for SOC_{REF} by METRO-PEM region is reported in Table A E.1. As expected, temperate and boreal regions (EU27, Japan, Rest of Western Europe) have higher soil organic carbon content than tropical regions (Brazil, Rest of Latin America, India). Humidity level also plays an important role in determining the level of initial SOC, as moist area can typically have twice the SOC content of dry areas, depending on the soil type (IPCC, 2006[64]).

Table A E.1. SOC reference level for cropland assumed for METRO-PEM region (tC/ha)

Region	SOC_{REF}	Region	SOC_{REF}
ARG	54	MEX	42
AUS	57	NZL	49
BRA	41	RLA	65
CAN	113	ROW	42
CHN	43	RUS	98
EU27	56	RWE	83
IND	24	SEA	51
JPN	77	TUR	44
KOR	47	USA	36

Note: For region acronyms, see Annex A.
Source: METRO-PEM based on GSOCseq (FAO, 2022[41]) and ESA CCI Land Cover (ESA, 2017[65]).

Land management factors

Default values of F_{LU}, F_{MG}, F_I are similarly all sourced from IPCC sources, and based on Table 5.5 and Table 6.2 of the 2019 Refinement to the 2006 IPCC guidelines (IPCC, 2019[66]). The values relevant for METRO-PEM only cover a subset of the range of management values provided by the IPCC.

For the land use coefficient F_{LU}, only cropland (not rice), paddy rice, grassland and forest are distinguished. The coefficients used by climate profile are shown in Table A E.2.

Table A E.2. Land use coefficient F_{LU} for SOC calculation

Land use	Climate zone	Moisture	F_{LU}
Cropland (not rice)	Temperate	Dry	0.76
	Temperate	Moist	0.69
	Tropical	Dry	0.92
	Tropical	Moist	0.83
	Tropical	Mountain	0.87
Rice	All	All	1.35
Grassland	All	All	1
Forest	All	All	1

Note: As in 2019 guidelines, tropical mountain data is inferred as an average of other tropical regions.
Source: based on Table 5.5 from IPCC (2019[66])

Crop management practice has strong impact on SOC, and depends in particular on the level of tillage. Here again, the IPCC coefficients from the Tier 1 methodology (IPCC, 2019[66]) are used, as summarised in Table A E.3. As can be seen in that table, full tillage is taken as a practice of reference, and reduced or no tillage increase SOC stock. Under reduced tillage, however, 2019 refinements to the IPCC guidelines do not consider a sequestration effect in dry climate conditions (to the difference of initial 2006 guidelines).[41] No tillage is still expected to bring much larger sequestration benefits than reduced tillage, and this in all climate conditions.

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[41] Reduced tillage is defined as follows in IPCC (2019[66]): “Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally leaves surface with >30% coverage by residues at planting.” No tillage is defined as follows: “Direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone. Herbicides are typically used for weed control.”

Table A E.3. Management coefficient F_{MG} for SOC calculation

Climate zone	Moisture	Full tillage	Reduced tillage	No tillage
Temperate	Dry	1	1.00*	1.04
Temperate	Moist	1	1.05	1.10
Tropical	Dry	1	1.00*	1.04
Tropical	Moist	1	1.04	1.10
Tropical	Mountain	1	1.02	1.07

Note: As in 2019 guidelines, tropical mountain data is inferred as an average of other tropical regions. * IPCC estimates of 0.99 was replaced by the value 1.00 due to the uncertainty margin, to avoid assuming C release when moving from full tillage to reduced tillage in dry areas.
Source: based on Table 5.5 from IPCC (2019[66]).

As to the last coefficient F_I, under the current approach, variation in the level of input to land is not represented and all input management in the model is considered as 'Medium inputs', which corresponds to the coefficient 1.[42]

In order to apply the right coefficients to each region in the model, each region is classified in its right climatic zone based on IPCC ecoregion maps as follows:

- Temperate dry: Argentina, China, Türkiye
- Temperate moist: Canada, European Union, Japan, Korea, New Zealand, Rest of Western Europe and United States.
- Tropical dry: Australia
- Tropical moist: Brazil, Rest of Latin America, Southeast Asia, Rest of the World
- Special cases: due to their location, India is classified half in Tropical dry and half in Tropical moist; Russia is assumed half in Temperate dry and half in Temperate moist; and Mexico is considered equally distributed between Temperate dry, and Tropical dry, moist and mountain.

Assumption on baseline tillage practices

In order to model the impact of changes in tillage practices, it is fundamental to set good assumptions on the level of tillage in each of the model region. Tillage data are not systematically collected and reported by countries. Two sources of information are used to set the base year tillage level in METRO-PEM: literature sources for specific regions (Derpsch et al., 2010[67]; Llanillo et al., 2013[68]; Kassam, Friedrich and Derpsch, 2018[69]) and the FAOSTAT database that also collect such data, but only obtained information for a limited number of countries. The assumptions taken for regions with available data are listed in Table A E.4.

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[42] Medium input is defined as follows in IPCC (2019[66]): "Representative for annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g. manure) is added. Also requires mineral fertilisation or N-fixing crop in rotation."

Table A E.4. Share of tillage practices assumed for annual crops in regions in METRO-PEM

Region	Conventional tillage	Reduced tillage	No-till	Source
EU27	70%	26%	4%	FAOSTAT (2017)
USA	28%	35%	37%	FAOSTAT (2016)
CAN	17%	24%	59%	FAOSTAT (2016)
RWE	56%	31%	13%	FAOSTAT (2016)
AUS	21%		79%	FAOSTAT (2017)
BRA	40%	10%	50%	Llanillo et al. (2013[68])
ARG	30%		70%	Derpsch et al. (2010[67])
RLA	28%		72%	Derpsch et al. (2010[67])
CHN	91%		9%	Kassam, Friedrich and Derpsch (2018[69])
IND	98%		2%	Kassam, Friedrich and Derpsch (2018[69])
MEX	100%			Kassam, Friedrich and Derpsch (2018[69])
NZL			100%	Kassam, Friedrich and Derpsch (2018[69])
RUS	91%		9%	Kassam, Friedrich and Derpsch (2018[69])
Other regions: JPN, KOR, SEA, TUR, ROW	100%			No data available. Assumed by default under conventional tillage

Note: Shares are only applied for a subset of annual crops. For region acronyms, see Annex A. For Kassam, Friedrich and Derpsch (2018[69]), estimates are derived from data on crop area extent under conservation agriculture practices.
Source: METRO-PEM based on FAOSTAT and literature sources.

The tillage shares gathered from the literature are applied in the SOC module of METRO-PEM for all annual crops except rice and fruits and vegetables. The sectors targeted are therefore: wheat, other grains, oilseeds, sugar crops (for temperate regions), and fibre crops. Paddy rice receives its own SOC calculation in the methodology. Additionally, perennial crops are allocated a coefficient of land use (F_{LU}) of 1 and are not associated with tillage assumption. Due to this, it is decided not to assume SOC changes related to tillage practices for sugar crops in tropical areas (mostly sugar cane), fruits and vegetables (due to fruits and nuts trees) and other crops (due to various forms of plantations).

SOC stock under different tillage practices

By applying the SOC module described above, based on FAOSTAT data for land use, it is possible to derive SOC stocks in different regions and activities for METRO-PEM base year 2017. The results, applied to cropland, grassland and forest only, are displayed in Table A E.5 below. The total stock at the base year represents 288.2 Gt of carbon. It is then possible to compute stock variation associated to a shock in the model, which varies crop areas, land use and, where specified in the scenario, tillage. When total land under economic use vary, the carbon stock associated to the extra land cover being converted or reverted is also considered.

Emissions associated to a change of carbon stocks are considered to be released over a time period of 20 years, and therefore calculated as follows:

$$\text{Emissions} = [\, C_{Stock}\ (\text{Scenario}) - C_{Stock}\ (\text{Base})\,] \times 44/12\ /\ 20$$

where C_{Stock} is the carbon stock in the baseline and the scenario, 20 years is the amortisation period for emissions, and 44/12 is the coefficient to convert C variation into CO_2.

Table A E.5. SOC carbon stock represented in METRO-PEM, by sector and region

Mt C

	EU27	USA	CAN	MEX	CHN	JPN	KOR	IND	SEA	RWE	AUS	NZL	TUR	RUS	BRA	ARG	RLA	ROW	WLD
Rice	34	46		2	1,785	163	48	1,412	2,682		6		6	25	111	15	96	2,423	8,855
Wheat	958	395	750	23	803	11	0	644	0	115	660	2	255	1,977	68	236	21	1,953	8,872
Other grains	1,102	961	405	324	1,485	7	2	524	460	98	349	3	110	1,189	670	354	77	4,465	12,584
Oilseeds	529	139	337	156	1,644	44	19	1,214	657	44	151	5	136	335	273	59	197	4,694	10,633
Sugar crops	659	1,001	1,075	23	727	8	4	591	1,211	36	151	0	60	843	1,239	834	44	2,351	10,858
Veg & fruits	64	20	1	28	51	4		95	121	7	24		11	84	360	17	33	217	1,137
Fibre crops	19	117	2	8	161	0	0	277	8	1	28	0	17	4	36	11	3	397	1,088
Other crops	24	4	2	29	167	3	1	120	682	0	30	0	11	19	113	12	104	710	2,031
Beef and lamb	892	5,688	1,339	2,200	14,897		2	9	736	428	14,376	141	233	3,578	5,134	3,230	2,862	38,971	94,717
Dairy	2,095	3,072	846	894	1,995		1	238	99	618	5,047	353	407	5,489	1,957	903	1,953	27,492	53,458
Forest	8,962	11,060	39,215	2,762	9,217	1,932	300	1,706	9,179	1,376	7,639	483	953	80,308	20,454	1,566	10,033	42,214	249,358
Total	15,338	22,503	43,973	6,449	32,930	2,174	377	6,829	15,834	2,724	28,460	987	2,200	93,851	30,415	7,237	15,422	125,887	453,591

Note: For region acronyms, see Annex A.
Source: METRO-PEM, based on IPCC Tier 1 methodology

Annex F. Land use change and living biomass emissions in METRO-PEM

Land use changes emissions are captured in METRO-PEM through two main pools: soils and living biomass. Soil emissions in the current approach are straight forward to derive from the model variables, because they are mostly influenced by the management of the soil under agricultural use, and the extent of agricultural land. Soil organic carbon emissions are influenced in METRO-PEM by tillage practices and by the expansion of cropland. Whereas emissions from drained organic soils are calculated assuming that shares of land associated with drainage remain constant within cropland, and within grassland. In addition, soil emissions directly correspond to flows, and can be added to direct non-CO_2 agricultural emissions, as emission factors for drained land are calculated on a per annum basis, and soil organic carbon can be assumed varying along a linear trend for 20 years according to the IPCC Tier 1 methodology.

Modelling GHG emissions from living biomass is more challenging to quantify, due to the uncertainties on land use change expansion dynamics, policy assumptions, as well as the static and aggregated nature of the METRO-PEM model. In this analysis, it is proposed to explore the direction and potential magnitude of these emissions using a simple back-of-the-envelope approach. Two main sources are tentatively covered: i) deforestation emissions, associated to the biomass clearing when agricultural land expands into forest; ii) foregone carbon sequestration associated to use of land for agriculture, compared to a counterfactual where land would be left to natural vegetation regrowth. Several assumptions are needed to derive land use change emission factors associated to these sources, briefly presented below. The modelling approach is also compared with others used in more advanced modelling frameworks in the final section of this Annex.

Deforestation emissions

To estimate deforestation emissions, this analysis is focused on CO_2 emissions, which constitute the bulk of GHG emissions from land clearing.[43] To derive these on the basis of agricultural land use change outcomes, an assumption is needed on the share of agricultural land expanding into forest. This information is not calculated based on the area of managed forest in the model, because an important share of forest is unmanaged, and not accounted as part of the land uses explicitly represented in the CET functions of the METRO-PEM land use module (see Annex B). Remote sensing imagery has led to progress in estimating such coefficients for some specific crops, but large uncertainties still remain as to cropland in general, as well as the contribution of grassland expansion (Pendrill et al., 2022[42]). A simple methodology is then used here, comparing the historical trend in land use for agriculture, and the deforestation extent, using official statistics on land use, as collected by FAO. The analysis follows several steps:

1. First, regions are classified as subject to agriculture-driven deforestation or not, based on information from Curtis et al (2018[70]). According to that assessment based on remote sensing observations, regions with substantial commodity-driven deforestation (driver responsible for more than 1% of total forest tree losses) are Latin America, Africa and Southeast Asia, and Australia/Oceania.
2. For these regions, agricultural land expansion is estimated over the period 2011-2015, by summing up all crops harvested areas and pasture land. The agricultural land area change is determined at national level as a net change (positive or negative), and then added up at the regional level only for the expansion cases (positive) to obtain a gross regional agricultural land expansion trend.[44]
3. The agricultural expansion area is then compared with the deforestation share attributed in remote sensing to commodity-driven deforestation from Curtis et al (2018[70]), updated for the case of Southeast Asia with more recent estimate in Pendrill et al. (2022[42]). This allows to calculate a share of agricultural expansion going into forest. Note that for cases when deforestation attributed to agricultural commodity would exceed agricultural land expansion, a coefficient of 100% expansion

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[43] Forest fires associated to land clearing can also produce methane emissions as well as some GHG emissions precursors, but these come in relatively small fraction and are not accounted for here.

[44] This approach allows to discard countries where agricultural land is decreasing and that offsets the expansion trends in other countries in the same regional aggregate.

into forest is then assumed. On the contrary, if agricultural land decreased in 2011-2015, even if deforestation was observed, the coefficient associated to deforestation is considered to be 0%. That latter case occurs in particular for the following regions: Argentina, Australia and New Zealand, for which agricultural land expansion is therefore not associated with deforestation.[45]

4. The deforestation emissions $Em_{Def}(r)$ in region r are then simply estimated as:

$$Em_{Def}(r) = [Land_{Ag}(r,s) - Land_{Ag}(r,s_0)] \times Share_{Def}(r) \times EF_{Def}(r)$$

where

$Land_{Ag}(r)$ is the extent of agricultural land in the scenario s or in the base year (s_0)

$Share_{Def}(r)$ is the share of agricultural assumed to expand into forest, determined following the steps 1-3 above

$EF_{Def}(r)$ is the emission factor for living biomass above and below ground, based on the FAO Forest Resource Assessment inventories

Table A F.1 provides the assumption followed for the METRO-PEM regions on $Share_{Def}$ and EF_{Def}. Following that method, deforestation is only assumed in a few regions in the model, all based in the tropics, and well documented as hotspots of deforestation.

Table A F.1. Deforestation emission parameters for METRO-PEM regions

Region	Share of expansion of agricultural land into forest (2011-2015) $Share_{Def}$ (1)	Emission factor for living biomass EF_{Def} (tCO_2/ha) (2)	Marginal agricultural land expansion emission factor (tCO_2/ha) (3 = 1 x 2)
Southeast Asia	100%	340.5	340.5
Brazil	56.3%	382.1	215.2
Rest of Latin America	27.2%	463.5	126.0
Rest of the World	3.2%	276.0	8.8

Note: Regions not shown are currently not associated with agriculture-driven deforestation in the model.
Source: METRO-PEM

A second assumption required for deforestation emissions is the time horizon considered for amortisation, as land use change emissions are only released once, in contrast to other emissions sources. As the reform horizon considered for this analysis is rather long term, a time amortisation of ten years is assumed, which means land clearing emissions are divided by a factor 10. The impact of changing that assumption on deforestation emissions can be easily assessed, by simply rescaling deforestation emissions obtained by the inverse of the relative change in amortisation time. For instance, assuming 20 years amortisation instead of 10 would lead to divide all deforestation emissions by a factor 2.

Foregone carbon sequestration

Accounting for foregone carbon sequestration requires measuring what would happen to the carbon sink in land not used in agriculture, in the baseline and in the scenarios. Indeed, expanding agricultural land in non-forested areas also implies a carbon cost, in the case where natural vegetation is growing on that land. Conversely, land returned to nature from agriculture sequesters carbon through vegetation regrowing. This can be a particularly acute issue in the case of regrowing secondary forest or savannah type of vegetation in tropical areas. Estimating such sequestration allows to better capture the full land use emissions impact, even though it remains subject to a number of uncertainties and assumptions have to be made. Indeed, the capacity of land to sequester carbon in its natural state can be very site-specific, and management of this land also plays an important role. For instance, unused agricultural land can be actively managed to keep the land in a productive condition, subsequently preventing biomass regrowing.

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[45] This simplification is inaccurate in the case of countries like Argentina, where commodity driven deforestation is observed through remote sensing. However, capturing the causality chain for such deforestation trends would require to model land use change at subnational level, and take into account gross land expansion in the country, not available through national statistics, instead of net expansion as used in the current approach of this study.

Agricultural land can be lost to urban and built-up areas, degraded or regularly disturbed, which may lead to lose its capacity for carbon absorption (Potapov et al., 2021[71]). On the other side, active management of the land can significantly enhance the carbon uptake and biomass regrowing, and land restoration with forest plantations for instance leads to vegetation regrowing at rate largely exceeding those of natural forests.

Estimating the potential foregone carbon sequestration for this study follows a simple back-of-the-envelope calculation. Land use variations outside of forest are mapped with the IPCC estimates for above and below ground living biomass of a natural forest regrowth (less than 20 years) to derive the annual carbon capture effect, by ecological region. Table A F.2 shows the coefficient of vegetation regrowth assumed in the different regions. As per IPCC guidelines, dry matter above ground regrowth estimates (second column) are converted to tCO_2/ha by converting dry matter to tCO_2 (multiplying by 0.47 and 44/12) and adding below ground biomass regrowth with the root-to-shoot coefficient (third column). Recognising the various possible alternative fate of abandoned land discussed above, an additional conservative assumption is taken, and only half of the natural land is assumed to recover natural vegetation regrowing rate. This means a high-end estimate could then corresponds to twice the value in the last column of that table.

Table A F.2. Foregone carbon sequestration emission factors

Region	Natural vegetation regrowth (tonne dry matter per ha) (1)	Root-to-shoot ratio (2)	Marginal agricultural land expansion emission factor (tCO_2/ha) (3)
EU27	2.8	0.43	3.5
USA	2.3	0.43	2.8
CAN	2.1	0.39	2.5
MEX	2.3	0.37	2.7
CHN	2.5	0.37	3.0
JPN	2.8	0.43	3.5
KOR	3.3	0.43	4.1
IND	4.0	0.37	4.7
RWE	3.2	0.37	2.8
AUS	2.3	0.43	1.2
NZL	1.0	0.37	3.7
TUR	3.1	0.37	3.0
RUS	2.5	0.37	4.1
BRA	3.3	0.43	2.7
ARG	5.2	0.37	2.7
RLA	2.3	0.37	4.7
ROW	5.5	0.37	4.2

Note: Last column is obtained as (3) = (1) x [1 + (2)] x 0.47 x 44/12 x 0.5, assuming that only half of the marginal land is returning into natural forest vegetation regrowing. For region acronyms, see Annex A.
Source: METRO-PEM.

Comparison of land use change features with other modelling approaches

The developments made on METRO-PEM in the context of this paper represent a first step towards more advanced modelling of land use change in this type of CGE framework. The emphasis at this stage has been put on the production functions of the agricultural sector, their consistent calibration with the behaviour of the PEM model, and the suitability of the agriculture land use expansion responses. Other important aspects of land use change dynamics, such as the spatial location of land use change and emission factors, or the heterogeneity of land cover type and land productivity, have not been subject to specific developments in this version of the model, and were mostly represented through average coefficients and homogenous responses. For that reason, the results on land use change emissions in the discussion of Box 1 should be interpreted with care. Nevertheless, the approach taken here to estimate deforestation impacts of agriculture expansion relies on very recently published data based on remote sensing observation, which gives credit to the estimation. Further explanations are provided below on how some other modelling frameworks have approached different modelling elements.

Land use mobility

The present modelling approach distinguishes land use mobility by economic activities, similar to the approach in PEM, with nested CETs of land uses organised as presented in Figure A B.4. The following main aggregates can be distinguished: i) arable land, ii) other agricultural land (less mobile), iii) (managed) forest. Arable land is itself split between pasture land, and annual cropland categories. All these land use types can be transformed in each other. This approach with nested CETs is very common in CGE modelling frameworks, and also adopted in many other CGE models from the AgMIP community (MAGNET, FARM, GTEM, ENVISAGE) (Schmitz et al., 2013[61]), in GTAP-BIO (Taheripour and Tyner, 2013[72]), or in MIRAGE-BioF (Laborde and Valin, 2012[73]). Differences across models relate to the number of CET nodes, the elasticity values chosen, and the relative position of the different land uses in the CET nesting structure. In METRO-PEM, the choice has been made to keep “rice” and “other crops” separate from the “arable land” bundle, to better describe the specific role of permanent cropland and paddy rice in many regions, similar to the assumption in PEM. This assumption is less common in other models, which then assume similar land use change possibilities for these land uses as for other annual crops. As a matter of fact, it is common that land use nesting trees in CGE only contain two to three levels, where METRO-PEM contains four levels, also due to the separation of the role of managed forest from the rest of the tree.

Another important feature of METRO-PEM is the land supply elasticity allowing new land to be used for agriculture as well as forestry. This feature is also present in half of the AgMIP CGE models (Schmitz et al., 2013[61]), as well as in MIRAGE-BioF, but is not present in GTAP-BIO, FARM or GTAP, that assume that land use change occurs only between economic land use types – i.e. deforestation corresponds to the conversion of managed forest to cropland or pasture. The presence of an elasticity of expansion helps the model to replicate expansion in areas where the largest part of the agricultural land-forest interface corresponds to unmanaged forest (like in tropical regions). The parameterisation of this expansion remains very stylised for this version of the model, as only two categories of countries are represented – with low or high regulation (respectively, high or low elasticity of expansion). GTAP-BIO, as a comparison, classified regions in four categories of responsiveness, based on observation on historical land use from 2004-2010 (Taheripour and Tyner, 2013[72]). METRO-PEM elasticities of land supply can be 0.1 or 0.05 for the two regional categories whereas transformation elasticity magnitude is between 0.02 and 0.3 for the GTAP-BIO lower CET nest. Other models with land supply curve adopted more sophisticated approaches, with individual land expansion elasticity by region in the case of MIRAGE-BioF (Laborde and Valin, 2012[73]), and biophysical information derived from land supply curve from the IMAGE model in the case of MAGNET (Tabeau et al., 2017[74]).

In terms of functional form specification, it is also noteworthy that other approaches than the CET function have been adopted in some models, such as adjusted CETs or logit production functions, to directly convert area of land instead land rent volume, as done by default in CGEs (Zhao et al., 2020[75]). Partial equilibrium models, on their side, directly operates on biophysical land use dataset and can represent full matrices of land conversion possibilities with elasticities specific to each conversion pair and direction, for instance in GLOBIOM (Havlík et al., 2014[76]), but information is often lacking to calibrate elasticities at that level of detail. Last, more advanced functional forms have also been proposed such as the Fréchet function to better represent land use change patterns of agricultural activities in global applied models (Gouel and Laborde, 2021[77]). These different research tracks indicate future possible refinement possibilities for this type of model features.

Geographical resolution and parameters heterogeneity

Beside the assumptions taken for land use change behaviour, another important characteristic for land use modelling is the level of geographical precision of the land representation and the underlying biophysical parameters.

Currently, METRO-PEM follows a rather simple framework where each region is represented with a single pool of land, ruled by the CET nesting functions described above. However, several modelling frameworks have developed methods to decompose this land pool by agro-ecological zones (AEZs), which implies the possibility to distinguish within each economic region up to 18 land use sub-regions (Baldos and Corong, 2020[44]).[46] This approach was adopted in several CGE models (GTAP-BIO, MIRAGE-BioF, MAGNET) but is not implemented in METRO-PEM at this stage. One of the reasons is that the GTAP Centre did not publish underlying data for the version 11 of GTAP at the time where this study was prepared. Additionally, underlying dataset used to distribute land uses per AEZ type is based on data from the year 2000, which limits their relevance for regions that went through with rapid land use changes over the past 20 years.

Beside the AEZ approach, some partial equilibrium or integrated assessment optimisation models also adopted fully gridded representations of land use change, for instance GLOBIOM, IMAGE or MAgPIE, operating more or less at the square degree resolution (Schmitz et al., 2013[61]). These approaches, much more data intensive, allow for a more precise representation of land use change patterns at subregional level (e.g. land conversion constraints in protected areas). However, they also significantly increase the complexity of the calibration and the degree of uncertainty associated with the location of land use change responses to specific shocks. Datasets mobilised are also then older – for instance GLOBIOM is calibrated for the year 2000, and the model then projects land use in the future.

In the METRO-PEM version used in this analysis, such levels of geographical details do not exist, but emphasis was put instead on the use of the most recent data of land use, emission factors, carbon density or other biophysical characteristics (see above), for which regional averages were adopted. This makes the results coarser compared to the complexity of heterogeneous responses on the ground, but it also ensures these are more easily trackable and robust for a given set of behavioural parameters. Future work with METRO-PEM will investigate how an enhanced representation of spatial heterogeneity of land use can be added to the model, ensuring the most recent and established datasets can be used, and paying close attention to the robustness criteria mentioned above.

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[46] In practice, the number of AEZ per region is lower, as not all AEZ types are present simultaneously in each region.

Annex G. Representation of input-based PSE payments in METRO-PEM

As explained in Section 3.1.3, PSE data were implemented in METRO-PEM using a set of allocation rules taking into account specificities of each PSE category. In the case of the Category B payments, the specificities of policy programmes led to a finer analysis of the different policy descriptions inventoried in the PSE database, in order to identify the input or production factor to which the policy payments should be attributed in the model. The mapping of payments with the model variables is a first attempt to better take into account the specificities of the various programs within this category. This will be refined in the future, with a view to extending the analysis to some other categories of the PSE database for a fully consistent treatment.

The PSE database contains for category B a total number of 1 469 programmes for the period 1986-2021, in which 633 were active and associated with payments in 2017. For each payment programme, a target was assigned depending on whether the programme would encourage the use of a particular farm input, be a more general producer payment across all forms of inputs, or target other objectives, for instance specific on-farm services or environmental benefits. Payments assigned to each target across the three categories B1, B2, and B3 are presented in Table A G.1 below. As can be seen in that table, targets are consistent with the PSE classification in B1, B2, B3 in many cases, but some cases may gain to be further explained. The following points should be noted:

- Intermediate inputs support contains most producer payments from category B1, but in the case of support to water consumption, programmes in B2 and B3 were also included when encouraging further extraction of water, in particular investment in irrigation infrastructure maintenance or expansion. Note that investment programmes aiming at improving water use efficiency are not accounted here, but rather under the “productivity and resilience” category. However, electricity subsidy programmes, when associated to water pumping, are accounted as a variable input subsidy to water use.[47]
- Production factors contain a mixed of different categories. For the case of labour, payments can be associated with B1 in the case of producer payments for hiring of seasonal workers, to B2 in the case of financial relief, or to B3 for technical assistance and training programmes. Animal payments are often categorised in category C in the PSE database (payments per animal head), but some input-based payments in Category B are also added in the model to headage payments, such as support for the purchase of breeding animals, or repopulation programmes. Similarly, land-based payments are classified under Category C in the PSE database, but some B2 payments associated to land restructuring investments are also added to land payments in METRO-PEM.
- The group of general input payments corresponds to programmes that are not associated with specific categories of inputs. They can relate to all forms of variable inputs under B1, any type of capital formation under B2, or any form of on-farm services under B3. It should be noted that insurances in the PSE database can be classified under Category B or Category C depending on whether they reduce a financial cost for the producer for purchasing an insurance (support to financial services under B1) or to factors such as land or animals (Category C) if calculated per area or animal head. However, the treatment of insurances will be the same in METRO-PEM independently of the category, as explained below.
- ‘Productivity and resilience’ contains all programmes targeted primarily at improving productivity gains: breeding improvement, risk management, pest and disease control, product quality enhancement, adaptation assistance, etc.
- The ‘other input programmes’ group includes programmes that cover an expenditure for other services. ‘Environment’ can be related to B1 (e.g. water conservation programme, more sustainable inputs), to B2 (investment in renewable energy or soil restoration) or B3 (environmental services extension). ‘Other on-farm services’ are left programmes oriented towards mix of services, biosafety assistance, public access to land, mostly under Category B3.

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[47] The water sector being currently merged with other sectors in METRO-PEM, these useful refinements on the data side do not have major implications for the results presented in this paper.

Table A G.1. Category B payment in 2017 by subcategory and target

Million USD

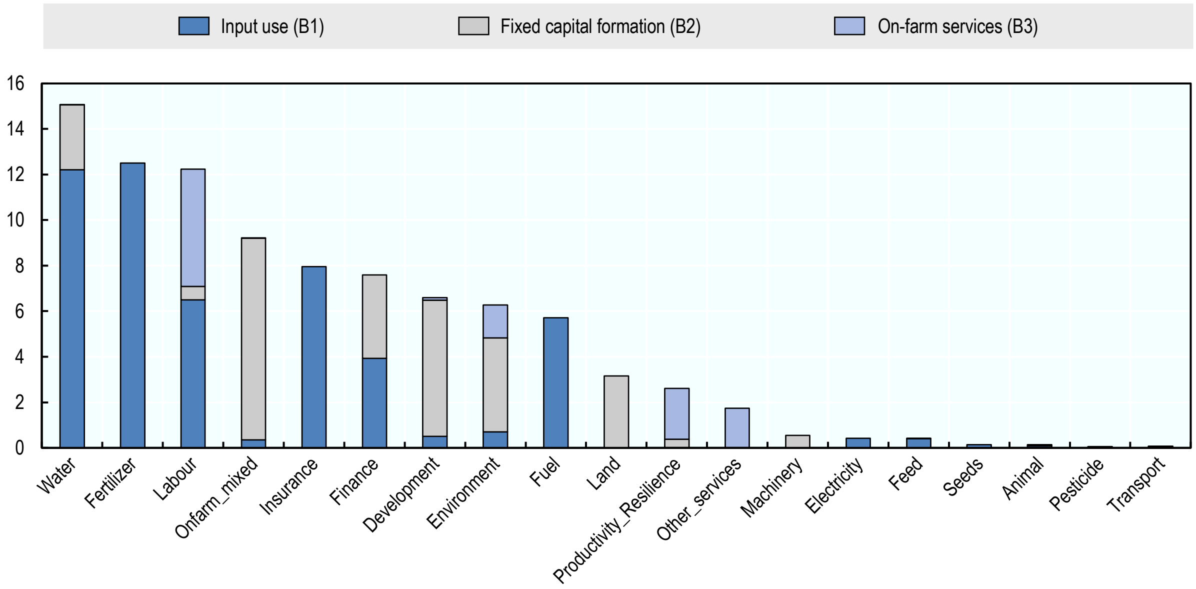
	Variable input use payment (B1)	Fixed capital formation payment (B2)	On-farm services payment (B3)	Total input payments (Category B)
Intermediate inputs				
Electricity	428	0	0	428
Feed	409	1	0	410
Fertiliser	12 502	0	0	12 502
Fuel	5 716	0	0	5 716
Pesticide	60	0	0	60
Seeds	139	0	0	139
Transport	58	0	0	58
Water	12 213	2 850	9	15 071
Production factors				
Animal	84	52	0	135
Labour	6 500	589	5 147	12 235
Land	0	3 158	0	3 158
Machinery	0	551	0	551
General input programmes				
Development	505	5 982	106	6 593
Finance	3 931	3 662	0	7 593
On-farm mixed	357	8 849	7	9 214
Insurance	7 957	0	0	7 957
Productivity and resilience	18	359	2 237	2 614
Other input programmes				
Environment	696	4 127	1 448	6 271
Other on-farm services	0	8	1 732	1 740
TOTAL	51 572	30 187	10 687	92 447

Source: METRO-PEM typology, based on PSE data payments by category.

The total volume of payments in Category B, organised along the typology above, is also represented in Figure A G.1.

Figure A G.1. Category B payments under the METRO-PEM typology, in 2017

Million USD, by decreasing volume of payment



Source: METRO-PEM typology, based on PSE data payments by category.

The attribution of the payments above to the factors in METRO-PEM is then handled as described in Table A G.2. The following main assumptions should be noted:

- The intermediate input categories is attributed to the corresponding intermediate consumption in the model, with the limitation of the current aggregation being used – water, electricity and fuel being presently merged within broader sectors – a specification to be revisited in the future.
- In the case of water, payments to water use are distinguished from payments to infrastructure (capital subsidy in the water sector).
- Factor payments (land, animal, capital, labour) are simply allocated to their respective production factors in each sector.
- General input payments are allocated based on the category of payments specified in the PSE database for the case of development programmes, financial service support and on-farm mixed producer payments. For payments in Category B1, payment is distributed proportionally across all inputs; for category B2, the payment is allocated to capital; and for category B3, the payment goes to labour.
- Insurances represent one exception to the approach above within the general input group. To avoid discrepancies with the treatment of Category C, which also contains some insurance programmes, insurance payments are allocated in METRO-PEM to land for crop sectors and to animal factors for livestock sector, to more consistently reflect the coupling effect to the use of these factors, including for insurances classified under Category B.
- Another special case is the allocation of productivity and resilience programmes. These programmes are typically expected to increase directly factors productivity, or to mitigate losses of factor productivity (pest control or resilience measures). Because it is not possible to quantify the productivity effect associated to these programmes, the choice is made to allocate these payments to capital formation (as a way to capture a knowledge capital effect). In practice, such approach indeed increases the purchase of capital and leads to savings in all other inputs used.
- In the case of environmental programmes, a different approach is taken. Many measures under that label correspond to payments covering additional costs to farmers, associated with constraints in the use of inputs. It is therefore assumed that such programmes match the costs incurred for farmers

and are overall cost neutral at farm gate price level, as the extra costs and the subsidy cancel each other. This assumption is considered for Categories B1 and B2, and a total of USD 4.8 billion are not allocated in the model to reflect this cost-neutral effect. However, one exception is made for the case of environmental technical assistance, for which programmes are not considered to match direct environmental investments, and payments are therefore kept allocated to labour, as it would be the case for other general on-farm services.

- Similarly, for 'other on-farm services', programmes are assumed to finance additional costs of compliance associated with the measures, and these payments are not allocated to the model (for a total of USD 1.7 billion).

Finally, as for other PSE Categories, all category B payments are allocated across sectors based on their SCT, GCT or ACT status (Section 3.1.3).

Table A G.2. Allocation of PSE payment types to METRO-PEM production factors

Payment type	Allocation in METRO-PEM database
Intermediate inputs	
Electricity	Subsidy on electricity use*
Feed	Subsidy proportionally allocated to all crop input to livestock
Fertiliser	Subsidy on fertiliser use
Fuel	Subsidy on fuel use*
Pesticide	Subsidy on manufactured products inputs (distinct from fertiliser input)
Seeds	Subsidy on crop input to crop (self-consumption)
Transport	Subsidy on transportation
Water	Subsidy on water use (PIV) or water sector capital (PIF/PIS)*
Production factors	
Animal	Subsidy on animal capital
Labour	Subsidy on labour
Land	Subsidy on land use
Machinery	Subsidy on general capital
General input programmes	
Development	Subsidy on all inputs (PIV), capital (PIF), labour (PIS)
Finance	Subsidy on all inputs (PIV), capital (PIF), labour (PIS)
On-farm mixed	Subsidy on all inputs (PIV), capital (PIF), labour (PIS)
Insurance	Subsidy on land (crops) or animal capital (livestock)
Productivity resilience	Subsidy on general capital
Other input programmes	
Environment	Not allocated for PIV and PIF, but allocated to labour for PIS (revenue effect)
Other services	Not allocated

Note: * these sectors are currently aggregated in the model for this specific study.
Source: METRO-PEM.

Annex H. Supplementary tables and figures

This annex provides additional tables on the nine scenarios simulated, by region and sector, as well as supplementary figures for the structure of support changes in the decoupling scenarios.

Table A H.1. Change in GHG emissions by scenario, region and source

$MtCO_2$-eq/year

	ARG	AUS	BRA	CAN	CHN	EU27	IND	JPN	KOR	MEX	NZL	RLA	RUS	RWE	SEA	TUR	USA	ROW	World
1-a) No budgetary support	0.4	0.3	-2.8	-7.5	-6.7	-29.7	-67.2	-1.3	-0.1	-1.6	0.1	-0.1	-2.3	-3.6	-2.8	-1.5	-8.6	2.3	-132.7
Rice Cultivation	0.0	0.0	0.0		-2.3	-0.2	0.4	-0.7	-0.2	0.0		0.0	0.0		0.1	0.0	-0.2	-0.1	-3.2
Synthetic Fertilisers	0.1	0.1	0.1	0.2	2.2	0.2	-36.0	-0.1		0.0	0.0	0.0	-0.3	0.0	-3.3	-0.2	1.0	0.9	-35.2
Enteric Fermentation	0.1	0.1	-1.9	0.1	-1.4	-9.3	-24.1	-0.1	0.0	-1.1	0.1	-0.1	-0.4	-1.4	-0.3	-0.2	0.1	0.2	-39.7
Manure Management	0.0	0.0	-0.1	0.0	-0.6	-2.1	-2.2	-0.1	0.0	-0.1	0.0	0.0	-0.1	-0.5	-0.1	0.0	0.0	0.0	-5.9
Manure left on Pasture	0.0	0.0	-0.5	0.0	-0.4	-1.4	-3.7	0.0	0.0	-0.3	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0	0.1	-6.5
Manure applied to Soils	0.0	0.0	-0.1	0.0	-0.3	-1.1	-0.8	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	-2.6
Burning - Crop residues	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	-0.2
Crop Residues	0.1	0.1	-0.1	0.1	-0.2	-0.3	-0.7	0.0	0.0	-0.1	0.0	0.0	0.0	-0.1	-0.1	-0.1	-0.1	0.2	-1.2
Drained organic soils	0.0	0.0	0.0	-0.8	0.0	-3.4	0.0	-0.2			0.0	0.0	-0.2	-0.3	0.8	0.0	-1.5	0.2	-5.6
Soil organic carbon	0.1	0.0	-0.3	-7.1	-3.5	-12.0	0.1	0.0	0.1	-0.1	0.0	0.0	-1.2	-1.1	0.2	-0.8	-7.7	0.6	-32.7
1-b) No potentially most climate-harmful payments	0.2	0.1	-2.1	0.4	-0.9	-11.3	-68.1	-0.7	0.0	-1.0	0.1	-0.1	0.0	-1.9	-3.3	-0.8	1.4	1.4	-86.9
Rice Cultivation	0.0	0.0	0.0		0.0	0.0	0.3	0.0	0.0	0.0		0.0	0.0		0.1	0.0	0.0	0.0	0.4
Synthetic Fertilisers	0.0	0.0	0.1	0.1	0.1	0.0	-36.1	-0.1		0.0	0.0	0.0	-0.1	0.0	-3.4	-0.2	0.6	0.5	-38.5
Enteric Fermentation	0.0	0.0	-1.6	0.0	-0.3	-7.6	-24.8	-0.1	0.0	-0.7	0.1	-0.1	-0.2	-1.2	-0.3	-0.2	0.2	0.2	-36.6
Manure Management	0.0	0.0	-0.1	0.0	-0.3	-1.7	-2.3	0.0	0.0	0.0	0.0	0.0	0.0	-0.4	-0.1	0.0	0.0	0.0	-5.2
Manure left on Pasture	0.0	0.0	-0.4	0.0	-0.2	-1.2	-3.8	0.0	0.0	-0.2	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0	0.1	-5.9
Manure applied to Soils	0.0	0.0	0.0	0.0	-0.2	-0.9	-0.9	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	-2.2
Burning - Crop residues	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	-0.2
Crop Residues	0.0	0.0	0.0	0.0	0.0	-0.2	-0.7	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1	0.2	0.1	-0.8
Drained organic soils	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1			0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.1	0.6
Soil organic carbon	0.1	0.0	0.0	0.2	0.1	0.3	0.3	-0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.1	-0.2	0.3	0.3	1.4
2-a) Simple decoupling	0.3	-0.1	-1.8	-6.3	-6.4	-16.6	-67.3	-1.0	-0.1	-0.9	0.0	-0.1	-0.4	-2.6	-3.0	-1.0	-5.2	0.5	-112.0
Rice Cultivation	0.0	0.0	0.0		-2.1	-0.1	1.0	-0.5	-0.1	0.0		0.0	0.0		0.3	0.0	0.0	0.0	-1.6
Synthetic Fertilisers	0.0	0.0	0.0	0.2	0.7	0.4	-36.1	-0.1		0.0	0.0	0.0	-0.3	0.0	-3.5	-0.2	1.0	0.2	-37.7
Enteric Fermentation	0.1	-0.1	-1.1	0.1	-0.8	-7.6	-24.7	-0.1	0.0	-0.6	0.0	-0.1	-0.2	-1.1	-0.3	0.0	0.1	0.2	-36.2
Manure Management	0.0	0.0	-0.1	0.0	-0.4	-1.6	-2.3	0.0	0.0	0.0	0.0	0.0	0.0	-0.4	-0.1	0.0	-0.1	-0.1	-5.2
Manure left on Pasture	0.0	0.0	-0.3	0.0	-0.3	-1.2	-3.8	0.0	0.0	-0.2	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0	0.0	-5.9
Manure applied to Soils	0.0	0.0	0.0	0.0	-0.2	-0.8	-0.9	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	-2.3
Burning - Crop residues	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	-0.2
Crop Residues	0.0	0.0	-0.1	0.0	-0.1	0.0	-0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.0	-0.1	-0.1	0.1	0.0	-0.8
Drained organic soils	0.0	0.0	0.0	-0.7	0.0	-1.3	0.1	-0.2			0.0	0.0	0.0	-0.2	0.8	0.0	-0.9	0.0	-2.4
Soil organic carbon	0.0	0.0	-0.2	-5.9	-3.1	-4.3	0.1	0.0	0.1	0.0	0.0	0.0	0.0	-0.7	0.1	-0.7	-5.3	0.2	-19.8

	ARG	AUS	BRA	CAN	CHN	EU27	IND	JPN	KOR	MEX	NZL	RLA	RUS	RWE	SEA	TUR	USA	ROW	World
2-b) Green decoupling	-8.4	-3.4	-28.2	-16.9	-12.2	-39.2	-83.6	-1.4	-0.3	-4.5	-1.7	-3.7	-17.8	-4.5	-16.9	-1.6	-24.5	2.6	-266.3
Rice Cultivation	0.0	0.0	0.0		-2.1	-0.1	1.0	-0.5	-0.1	0.0		0.0	0.0		0.3	0.0	0.0	0.0	-1.6
Synthetic Fertilisers	0.0	0.0	0.1	0.2	1.0	0.6	-35.9	-0.1		0.0	0.0	0.0	-0.3	0.0	-3.5	-0.2	1.6	0.3	-36.0
Enteric Fermentation	-3.7	-1.3	-6.1	0.3	-4.7	-10.7	-31.8	-0.1	-0.1	-2.5	-1.5	-2.1	-0.6	-1.6	-1.7	-0.4	-0.6	1.5	-67.7
Manure Management	-0.1	-0.2	-0.2	0.0	-1.0	-2.2	-2.9	-0.1	0.0	-0.1	-0.1	-0.1	-0.1	-0.5	-0.3	-0.1	-0.3	0.0	-8.1
Manure left on Pasture	-1.0	-0.1	-1.7	0.0	-1.2	-1.6	-4.9	0.0	0.0	-0.8	-0.2	-0.5	0.0	-0.1	-0.4	-0.1	0.0	0.5	-12.1
Manure applied to Soils	0.0	0.0	-0.1	0.0	-0.5	-1.1	-1.1	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.2	-0.1	0.0	-0.1	0.0	-3.4
Burning - Crop residues	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	-0.1
Crop Residues	0.0	0.1	-0.1	0.1	-0.1	0.0	-0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.0	-0.1	-0.1	0.5	0.0	-0.2
Drained organic soils	0.1	0.0	0.0	-0.7	0.0	-1.3	0.0	-0.2			0.0	0.0	-0.1	-0.1	1.2	0.0	-0.8	0.1	-1.9
Soil organic carbon	-3.7	-2.0	-20.2	-16.9	-3.6	-22.8	-7.3	-0.2	0.0	-1.0	0.0	-1.1	-16.8	-2.0	-12.3	-0.8	-24.7	0.2	-135.2
3-a) Agriculture productivity	-1.7	-1.6	-5.9	-2.1	-11.1	-8.5	-20.6	-0.4	-0.2	-1.4	-0.3	-1.4	-1.6	-1.1	-5.4	-0.5	-12.6	-4.6	-80.9
Rice Cultivation	0.0	0.0	0.0		-0.6	0.0	-0.5	0.0	0.0	0.0		-0.1	0.0		-1.8	0.0	-0.1	0.0	-3.0
Synthetic Fertilisers	-0.1	-0.1	-1.0	-0.4	-7.3	-2.0	-3.2	0.0		-0.3	0.0	-0.1	-0.3	-0.2	-1.7	-0.3	-3.4	-2.0	-22.5
Enteric Fermentation	-0.9	-1.3	-3.5	-0.6	-1.8	-3.5	-13.6	-0.2	-0.1	-0.7	-0.2	-0.9	-0.4	-0.6	-0.3	-0.2	-4.6	0.0	-33.2
Manure Management	0.0	-0.1	-0.1	-0.2	-0.6	-1.1	-1.2	-0.1	0.0	-0.1	0.0	0.0	-0.1	-0.2	-0.3	0.0	-1.9	-0.1	-6.3
Manure left on Pasture	-0.3	-0.1	-1.0	0.0	-0.6	-0.5	-2.1	0.0	0.0	-0.2	0.0	-0.2	0.0	0.0	-0.2	0.0	-0.4	-0.1	-5.7
Manure applied to Soils	0.0	0.0	-0.1	-0.1	-0.3	-0.6	-0.5	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1	0.0	-0.4	0.0	-2.4
Burning - Crop residues	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	-0.1	0.1
Crop Residues	0.1	0.0	0.0	-0.1	0.3	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.1	-0.5	-0.5	0.1
Drained organic soils	0.0	0.0	0.0	-0.1	0.0	-0.2	0.0	0.0			0.0	0.0	-0.1	0.0	-1.9	0.0	-0.3	-0.4	-3.2
Soil organic carbon	-0.4	0.0	-0.4	-0.6	-0.3	-0.7	0.1	0.0	0.0	-0.1	0.0	0.0	-0.7	-0.1	0.7	-0.1	-1.0	-1.4	-4.8
3-b) Livestock productivity	-3.2	-3.5	-16.8	-2.3	-14.0	-14.9	-21.9	-0.7	-0.3	-3.1	-0.7	-3.3	-2.5	-2.2	-5.9	-1.6	-21.3	-8.4	-126.5
Rice Cultivation	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0		-0.1	0.0	0.0	0.0	-0.2
Synthetic Fertilisers	-0.1	0.0	-0.3	-0.1	-0.5	-1.1	-0.3	0.0		-0.1	-0.1	0.0	-0.1	-0.1	-0.2	0.0	-2.1	-0.3	-5.4
Enteric Fermentation	-2.4	-2.9	-12.2	-1.5	-7.4	-8.4	-16.8	-0.4	-0.2	-2.1	-0.5	-2.3	-1.5	-1.4	-2.5	-1.0	-10.7	-4.9	-79.2
Manure Management	-0.1	-0.3	-0.5	-0.4	-2.8	-2.7	-1.6	-0.3	-0.1	-0.2	0.0	-0.1	-0.4	-0.4	-1.3	-0.2	-4.6	-0.6	-16.5
Manure left on Pasture	-0.7	-0.2	-3.4	0.0	-2.4	-1.1	-2.7	0.0	0.0	-0.6	-0.1	-0.6	-0.1	-0.1	-0.9	-0.2	-0.8	-2.0	-16.1
Manure applied to Soils	-0.1	0.0	-0.4	-0.2	-1.3	-1.4	-0.6	-0.1	0.0	-0.1	0.0	-0.1	-0.4	-0.1	-0.5	-0.2	-1.1	-0.3	-6.8
Burning - Crop residues	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	-0.1
Crop Residues	0.0	0.0	-0.1	-0.1	0.0	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	-1.6	-0.1	-2.3
Drained organic soils	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0			0.0	0.0	0.0	0.0	-0.4	0.0	-0.2	-0.1	-0.9
Soil organic carbon	0.2	0.0	0.0	0.0	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	-0.2	-0.1	0.9
3-c) Abatement technologies	-5.6	-5.7	-9.0	-4.0	-43.4	-23.6	-61.3	-2.8	-0.9	-3.3	-2.8	-7.1	-1.0	-3.6	-81.4	-2.2	-66.6	-2.5	-326.7
Rice Cultivation	-1.1	-0.1	-2.3		-12.5	-0.6	-29.6	-2.0	-0.1	0.0		-2.9	0.0		-70.6	0.0	-2.1	-0.1	-123.8
Synthetic Fertilisers	-0.2	-0.1	-0.6	-0.5	-8.5	-1.8	-7.6	0.0		-0.4	0.0	0.0	-0.7	-0.1	-0.5	-0.2	-4.2	-0.1	-25.5
Enteric Fermentation	-3.2	-4.6	-4.6	-2.8	-14.5	-14.9	-18.8	-0.4	-0.4	-2.2	-2.3	-3.2	-0.3	-2.6	-6.7	-1.4	-39.7	-1.6	-124.4
Manure Management	-0.1	-0.4	-0.1	-0.5	-2.7	-2.6	-1.7	-0.3	-0.2	-0.1	-0.1	-0.1	0.0	-0.6	-1.1	-0.1	-14.6	-0.1	-25.3
Manure left on Pasture	-0.9	-0.3	-1.2	0.0	-3.8	-2.6	-2.9	0.0	-0.1	-0.7	-0.4	-0.9	0.0	-0.1	-1.4	-0.3	-3.4	-0.6	-19.7
Manure applied to Soils	0.0	0.0	-0.1	-0.1	-1.3	-1.4	-0.6	-0.1	-0.1	0.0	0.0	0.0	0.0	-0.1	-0.4	-0.1	-4.2	0.0	-8.6
Burning - Crop residues	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.1
Crop Residues	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.6	0.0	0.8
Drained organic soils	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0			0.0	0.0	0.0	0.0	0.9	0.0	0.2	0.0	1.2
Soil organic carbon	-0.1	0.0	-0.2	0.0	0.0	0.1	-0.2	0.0	0.0	0.0	0.0	-0.1	0.1	0.0	-1.8	0.0	0.7	0.1	-1.4

	ARG	AUS	BRA	CAN	CHN	EU27	IND	JPN	KOR	MEX	NZL	RLA	RUS	RWE	SEA	TUR	USA	ROW	World
4-a) Policy mix - all regions	-15.6	-11.3	-55.9	-23.0	-64.1	-73.2	-153.9	-4.4	-1.3	-10.0	-4.6	-13.2	-21.1	-9.6	-97.9	-5.1	-107.8	-8.8	-680.8
Rice Cultivation	-1.1	-0.1	-2.3		-14.0	-0.6	-23.9	-2.2	-0.2	0.0		-2.9	0.0		-66.1	0.0	-2.0	-0.1	-115.5
Synthetic Fertilisers	-0.2	-0.2	-0.8	-0.4	-7.6	-2.1	-39.4	-0.1		-0.4	0.0	-0.1	-1.0	-0.2	-4.0	-0.5	-4.0	-0.2	-61.3
Enteric Fermentation	-8.2	-7.7	-24.4	-4.0	-23.6	-31.3	-64.5	-0.9	-0.6	-6.1	-3.8	-6.8	-2.4	-5.1	-9.6	-2.6	-48.3	-5.3	-255.1
Manure Management	-0.2	-0.8	-0.8	-0.8	-6.0	-7.0	-5.9	-0.6	-0.3	-0.3	-0.1	-0.2	-0.6	-1.4	-2.5	-0.4	-18.5	-0.6	-47.1
Manure left on Pasture	-2.3	-0.5	-6.6	0.0	-6.7	-4.9	-10.0	0.0	-0.2	-1.9	-0.6	-1.9	-0.2	-0.3	-2.4	-0.5	-4.0	-2.2	-45.3
Manure applied to Soils	-0.1	-0.1	-0.6	-0.3	-2.8	-3.6	-2.3	-0.1	-0.1	-0.2	0.0	-0.2	-0.5	-0.4	-1.0	-0.3	-5.0	-0.3	-17.7
Burning - Crop residues	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	-0.2
Crop Residues	0.0	0.0	-0.1	0.0	-0.1	-0.2	-0.5	0.0	0.0	-0.1	0.0	0.0	0.1	-0.1	0.0	-0.1	-0.7	-0.1	-1.8
Drained organic soils	0.0	0.0	0.0	-0.7	0.0	-1.3	0.0	-0.2			0.0	0.0	0.0	-0.2	1.6	0.0	-0.9	0.0	-1.6
Soil organic carbon	-3.5	-2.0	-20.3	-16.7	-3.2	-22.3	-7.3	-0.3	0.0	-1.0	0.0	-1.1	-16.5	-2.0	-13.9	-0.7	-24.4	0.2	-135.1
4-b) Policy mix - OECD	-0.1	-10.2	-3.6	-22.6	-7.6	-71.5	-68.0	-4.4	-1.3	-2.7	-4.3	-0.4	-0.8	-9.4	-4.8	-4.9	-106.3	-5.5	-328.4
Rice Cultivation	0.0	-0.1	0.0		-2.1	-0.5	1.0	-2.2	-0.2	0.0		0.0	0.0		0.2	0.0	-2.0	0.0	-5.9
Synthetic Fertilisers	0.0	-0.1	-0.1	-0.4	0.5	-1.9	-36.1	-0.1		0.0	0.0	0.0	-0.4	-0.2	-3.6	-0.5	-3.8	0.0	-46.7
Enteric Fermentation	-0.1	-6.8	-2.3	-3.8	-1.3	-30.6	-25.3	-0.9	-0.6	-1.8	-3.6	-0.3	-0.3	-5.0	-1.1	-2.5	-47.6	-3.5	-137.3
Manure Management	0.0	-0.7	-0.1	-0.8	-0.7	-6.6	-2.3	-0.6	-0.3	-0.1	-0.1	0.0	-0.1	-1.4	-0.4	-0.4	-18.2	-0.4	-33.2
Manure left on Pasture	0.0	-0.5	-0.7	0.0	-0.5	-4.7	-3.9	0.0	-0.2	-0.6	-0.6	-0.1	0.0	-0.3	-0.3	-0.5	-4.0	-1.4	-18.3
Manure applied to Soils	0.0	0.0	-0.1	-0.2	-0.3	-3.4	-0.9	-0.1	-0.1	-0.1	0.0	0.0	0.0	-0.4	-0.2	-0.2	-4.9	-0.2	-11.3
Burning - Crop residues	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	-0.2
Crop Residues	0.0	0.0	-0.1	0.0	-0.1	-0.1	-0.6	0.0	0.0	-0.1	0.0	0.0	0.1	0.0	-0.1	-0.1	-0.5	0.0	-1.7
Drained organic soils	0.0	0.0	0.0	-0.7	0.0	-1.3	0.1	-0.2			0.0	0.0	0.0	-0.2	0.6	0.0	-0.8	0.0	-2.5
Soil organic carbon	0.0	-2.0	-0.2	-16.7	-3.1	-22.3	0.1	-0.3	0.0	0.0	0.0	0.0	-0.1	-2.0	0.1	-0.7	-24.3	0.1	-71.3

Source: METRO-PEM.

Table A H.2. Relative change in key global sustainability indicators by scenario and region

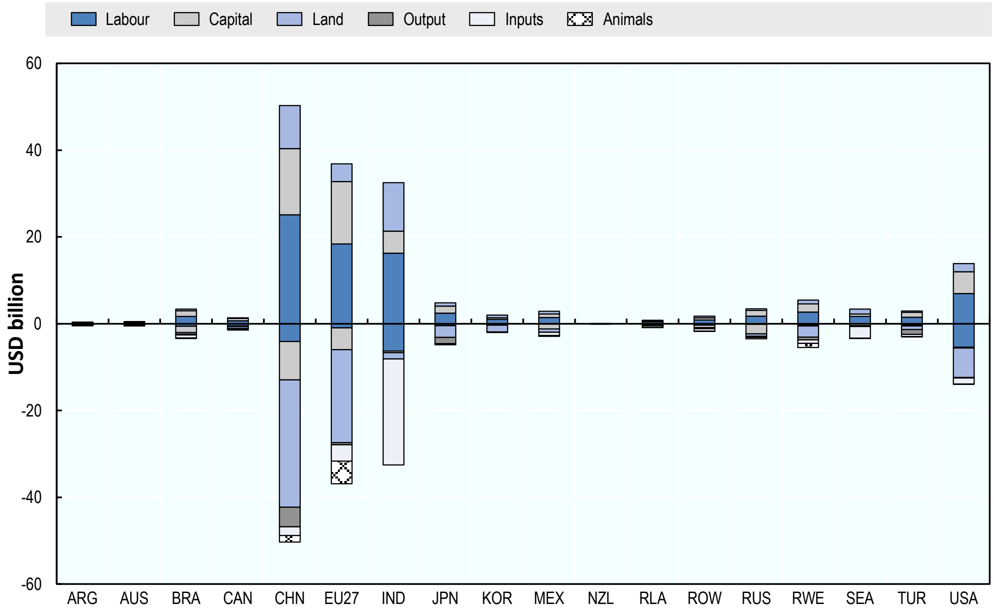
	ARG	AUS	BRA	CAN	CHN	EU27	JPN	KOR	MEX	NZL	RLA	RUS	RWE	SEA	TUR	USA	ROW	WLD
1-a) No budgetary support																		
Production	0.2%	0.8%	-0.3%	0.6%	-0.5%	-1.1%	-0.6%	-0.3%	-1.5%	0.5%	0.1%	-0.8%	-2.1%	-0.2%	-1.5%	0.0%	0.3%	-0.5%
Food CPI	0.3%	0.6%	0.7%	0.7%	0.8%	1.3%	0.7%	1.1%	1.1%	0.3%	0.5%	1.1%	1.7%	0.7%	1.2%	0.6%	0.5%	0.9%
Calorie availability	-0.1%	-0.2%	-0.3%	-0.3%	-0.8%	-0.7%	-0.4%	-0.4%	-0.5%	-0.1%	-0.3%	-0.7%	-0.7%	-0.4%	-0.6%	-0.1%	-0.2%	-0.7%
Gross farm receipt	0.8%	0.9%	-0.5%	0.5%	-3.1%	-8.5%	-5.2%	-3.9%	-3.2%	1.4%	0.5%	-1.9%	-9.4%	0.5%	-3.0%	-2.1%	1.1%	-2.4%
Agr. VA (value)	1.4%	3.8%	1.5%	4.6%	1.6%	4.3%	0.0%	3.5%	1.5%	2.3%	1.8%	2.5%	5.0%	1.2%	-1.3%	3.0%	1.4%	1.7%
Agr. VA (volume)	0.1%	0.0%	-0.2%	0.0%	-0.5%	-1.1%	-1.0%	-0.7%	-0.8%	0.3%	0.2%	-0.8%	-1.5%	0.2%	-0.5%	-0.7%	0.2%	-0.3%
Farm labour	0.3%	-0.5%	0.0%	0.1%	-0.6%	-0.1%	-0.8%	-0.3%	-0.2%	0.4%	0.3%	-0.1%	-1.3%	0.2%	-0.3%	0.0%	0.2%	-0.1%
GHG emissions	0.3%	0.3%	-0.5%	-10.0%	-1.0%	-6.7%	-3.8%	-1.0%	-1.7%	0.4%	-0.1%	-1.7%	-6.6%	-0.4%	-2.3%	-1.6%	0.1%	-2.1%
Agricultural land	0.1%	0.1%	0.0%	-1.9%	-1.3%	-4.6%	-6.2%	-2.2%	-0.7%	0.1%	0.1%	-0.7%	-4.5%	0.2%	-0.9%	-1.2%	0.0%	-0.4%
Fertiliser use per ha	0.8%	1.4%	0.9%	5.8%	2.2%	5.9%	6.8%	4.1%	0.8%	0.9%	0.9%	0.8%	5.8%	-5.3%	0.3%	5.6%	0.8%	-0.1%
1-b) No potentially most climate-harmful payments																		
Production	0.2%	0.6%	-0.2%	0.3%	-0.2%	-0.6%	-0.6%	-0.1%	-1.0%	0.3%	-0.1%	-0.2%	-1.8%	-0.3%	-1.3%	0.3%	0.2%	-0.4%
Food CPI	0.1%	0.3%	0.3%	0.3%	0.2%	0.7%	0.4%	0.3%	0.6%	0.2%	0.3%	0.4%	1.1%	0.5%	0.9%	0.3%	0.3%	0.6%
Calorie availability	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.3%	-0.3%	-0.1%	-0.3%	-0.1%	-0.2%	-0.2%	-0.5%	-0.3%	-0.4%	0.0%	-0.1%	-0.4%
Gross farm receipt	0.5%	1.4%	0.1%	0.8%	-0.1%	-0.5%	-1.0%	0.2%	-0.8%	0.8%	0.4%	0.0%	-1.9%	0.2%	-2.0%	0.7%	0.7%	-0.1%
Agr. VA (value)	0.6%	2.0%	0.5%	1.5%	0.2%	2.2%	-1.3%	0.4%	0.4%	1.2%	0.8%	0.2%	2.4%	0.6%	-1.7%	1.2%	0.8%	0.6%
Agr. VA (volume)	0.2%	0.3%	0.1%	0.4%	0.0%	0.1%	-0.5%	0.1%	0.0%	0.2%	0.2%	0.1%	-0.4%	0.1%	-0.3%	0.3%	0.2%	0.0%
Farm labour	0.2%	0.4%	0.1%	0.4%	0.0%	0.1%	-0.5%	0.1%	0.0%	0.2%	0.3%	0.1%	-0.4%	0.1%	-0.2%	0.0%	0.1%	0.1%
GHG emissions	0.2%	0.1%	-0.4%	0.5%	-0.1%	-2.5%	-2.2%	0.0%	-1.1%	0.2%	-0.1%	0.0%	-3.4%	-0.4%	-1.2%	0.3%	0.1%	-1.4%
Agricultural land	0.1%	0.0%	0.0%	0.1%	0.0%	-0.3%	-2.5%	0.1%	-0.1%	0.1%	0.1%	0.0%	-0.6%	0.1%	-0.2%	0.1%	0.0%	0.0%
Fertiliser use per ha	0.5%	1.0%	0.3%	0.7%	0.0%	0.4%	1.7%	0.2%	0.0%	0.5%	0.6%	0.3%	0.0%	-5.6%	-1.7%	0.6%	0.5%	-1.5%
2-a) Simple decoupling																		
Production	0.0%	0.1%	-0.4%	0.2%	-0.1%	0.3%	-0.1%	0.1%	-0.6%	-0.2%	-0.4%	-0.1%	-0.5%	-0.4%	-0.9%	0.2%	0.0%	-0.3%
Food CPI	0.0%	0.1%	0.0%	0.0%	-0.4%	-0.2%	-0.1%	-0.2%	0.2%	0.0%	0.1%	0.3%	0.0%	0.2%	0.1%	0.0%	0.1%	0.1%
Calorie availability	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.2%	0.0%	-0.1%	0.0%	-0.1%	-0.2%	-0.2%	-0.2%	0.0%	0.0%	-0.1%	-0.2%
Gross farm receipt	0.2%	0.6%	-0.2%	0.5%	-0.7%	0.2%	-0.9%	0.0%	0.1%	-0.2%	-0.2%	0.4%	1.3%	0.2%	-0.2%	0.1%	0.2%	0.2%
Agr. VA (value)	-0.3%	0.3%	-0.5%	-0.7%	-1.5%	-1.5%	-4.6%	-0.8%	-1.1%	-0.2%	-0.5%	0.0%	-2.5%	-0.4%	-3.4%	-0.7%	0.1%	-0.9%
Agr. VA (volume)	0.0%	0.0%	0.1%	1.0%	0.3%	1.5%	1.0%	0.6%	0.6%	-0.1%	0.0%	0.4%	2.2%	0.1%	0.4%	0.7%	0.0%	0.4%
Farm labour	0.2%	0.2%	0.2%	0.8%	0.8%	2.6%	1.4%	3.8%	1.8%	-0.1%	0.2%	1.2%	5.1%	0.3%	0.4%	0.0%	0.0%	0.7%
GHG emissions	0.2%	-0.1%	-0.4%	-8.4%	-0.9%	-3.7%	-3.0%	-0.5%	-1.0%	0.1%	-0.1%	-0.3%	-4.6%	-0.4%	-1.6%	-1.0%	0.0%	-1.7%
Agricultural land	0.1%	0.0%	0.3%	-1.3%	-1.1%	-1.7%	-4.6%	-1.4%	-0.1%	0.1%	0.2%	-0.4%	-2.4%	0.2%	-0.6%	0.0%	0.0%	-0.2%
Fertiliser use per ha	-0.1%	0.3%	0.1%	5.4%	1.1%	3.0%	5.0%	2.5%	0.0%	-0.8%	-0.4%	0.4%	5.0%	-6.0%	-0.2%	4.3%	0.1%	-1.1%
2-b) Green decoupling																		
Production	-0.7%	0.2%	-0.3%	0.5%	-0.2%	0.2%	-0.1%	0.0%	-0.9%	-0.9%	-0.6%	-0.2%	-0.6%	-0.4%	-1.0%	0.3%	0.0%	-0.4%
Food CPI	1.0%	0.4%	0.3%	0.1%	-0.1%	0.1%	0.0%	0.2%	0.6%	0.5%	0.5%	0.5%	0.4%	0.3%	0.4%	0.1%	0.2%	0.4%
Calorie availability	-0.4%	-0.2%	-0.1%	-0.1%	-0.1%	-0.2%	-0.2%	-0.1%	-0.3%	-0.2%	-0.3%	-0.3%	-0.3%	-0.2%	-0.1%	0.0%	-0.1%	-0.3%
Gross farm receipt	1.9%	1.7%	0.3%	1.1%	-0.3%	1.0%	-0.5%	1.0%	0.9%	0.9%	0.6%	0.9%	2.3%	0.5%	0.3%	0.8%	0.3%	0.7%
Agr. VA (value)	2.0%	2.1%	0.1%	0.2%	-0.9%	-0.1%	-4.1%	0.9%	0.0%	2.2%	0.6%	0.7%	-0.6%	-0.1%	-3.0%	0.3%	0.3%	-0.1%
Agr. VA (volume)	-0.9%	-0.4%	-0.1%	1.1%	0.1%	1.1%	0.9%	0.3%	-0.1%	-1.3%	-0.3%	0.2%	1.5%	0.0%	0.3%	0.5%	0.1%	0.1%
Farm labour	0.1%	0.3%	0.3%	1.0%	0.9%	2.7%	1.5%	3.8%	1.7%	-0.4%	0.2%	1.2%	5.1%	0.3%	0.4%	0.0%	0.1%	0.7%
GHG emissions	-6.2%	-4.3%	-5.6%	-22.6%	-1.8%	-8.8%	-4.0%	-2.6%	-4.6%	-4.3%	-3.8%	-13.6%	-8.2%	-2.1%	-2.6%	-4.6%	0.1%	-4.1%
Agricultural land	2.1%	2.1%	1.8%	-0.9%	0.7%	-1.2%	-4.7%	-1.2%	1.2%	1.7%	3.1%	0.4%	-1.3%	0.5%	0.1%	1.1%	0.1%	0.6%
Fertiliser use per ha	0.9%	1.0%	0.5%	5.8%	1.4%	3.7%	5.2%	2.7%	0.2%	1.1%	0.0%	0.9%	5.6%	-5.9%	0.1%	4.8%	0.1%	-0.7%

	ARG	AUS	BRA	CAN	CHN	EU27	JPN	KOR	MEX	NZL	RLA	RUS	RWE	SEA	TUR	USA	ROW	WLD
3-a) Agriculture productivity																		
Production	1.0%	0.7%	0.9%	-0.6%	1.1%	0.7%	0.4%	0.7%	1.1%	1.6%	0.8%	1.1%	0.5%	1.5%	1.9%	0.0%	-0.9%	0.6%
Food CPI	-2.2%	-2.0%	-2.7%	-1.7%	-2.9%	-2.0%	-1.5%	-2.6%	-1.9%	-1.6%	-2.1%	-2.0%	-2.0%	-2.8%	-2.8%	-1.6%	-0.9%	-2.1%
Calorie availability	1.0%	0.8%	1.1%	0.6%	1.6%	0.8%	0.4%	0.8%	0.8%	0.7%	1.1%	1.1%	0.6%	1.5%	1.2%	0.3%	0.4%	1.0%
Gross farm receipt	-5.6%	-6.0%	-4.9%	-6.2%	-5.3%	-5.7%	-4.9%	-5.8%	-4.6%	-3.5%	-5.1%	-4.9%	-5.5%	-5.3%	-4.4%	-5.6%	-2.5%	-4.6%
Agr. VA (value)	-5.6%	-7.4%	-5.4%	-8.1%	-5.5%	-6.3%	-5.8%	-6.8%	-5.1%	-4.5%	-5.7%	-5.1%	-6.4%	-5.5%	-4.4%	-6.7%	-2.7%	-4.9%
Agr. VA (volume)	1.4%	1.6%	1.3%	0.4%	1.5%	1.4%	1.3%	1.5%	1.4%	2.2%	1.4%	1.4%	1.3%	1.6%	1.9%	1.1%	-0.6%	1.1%
Farm labour	-2.0%	-1.8%	-1.6%	-2.5%	-1.5%	-1.7%	-1.8%	-2.0%	-1.7%	-1.0%	-2.0%	-1.5%	-1.9%	-1.5%	-0.7%	0.0%	-0.5%	-1.2%
GHG emissions	-1.2%	-2.0%	-1.2%	-2.8%	-1.6%	-1.9%	-1.1%	-1.2%	-1.4%	-0.6%	-1.4%	-1.2%	-2.0%	-0.7%	-0.8%	-2.4%	-0.2%	-1.3%
Agricultural land	-0.8%	-1.0%	-0.7%	-0.5%	-0.5%	-0.4%	-0.2%	-0.8%	-0.7%	-0.2%	-0.9%	-0.4%	-0.6%	-0.6%	-0.3%	-0.9%	-0.1%	-0.4%
Fertiliser use per ha	-2.7%	-3.2%	-2.9%	-3.1%	-4.1%	-3.2%	-3.5%	-3.9%	-2.6%	-3.5%	-3.1%	-3.1%	-3.1%	-3.2%	-2.2%	-3.4%	-1.7%	-3.3%
3-b) Livestock productivity																		
Production	0.8%	0.2%	0.6%	-0.4%	0.5%	0.3%	0.2%	0.4%	0.6%	3.5%	0.5%	0.4%	0.3%	0.2%	1.2%	-0.4%	-0.3%	0.3%
Food CPI	-3.0%	-1.4%	-2.4%	-1.4%	-1.7%	-1.5%	-0.8%	-1.3%	-1.6%	-2.0%	-1.6%	-2.0%	-1.6%	-1.1%	-1.9%	-1.4%	-0.3%	-1.3%
Calorie availability	1.5%	0.9%	0.9%	0.6%	0.9%	0.9%	0.4%	0.4%	0.8%	1.0%	0.9%	1.0%	0.6%	0.5%	0.9%	0.4%	0.1%	0.6%
Gross farm receipt	-6.6%	-4.5%	-3.1%	-4.2%	-2.6%	-5.4%	-3.3%	-3.5%	-3.6%	-4.0%	-3.2%	-5.1%	-5.5%	-1.9%	-3.3%	-4.9%	-0.8%	-2.8%
Agr. VA (value)	-5.9%	-6.8%	-3.6%	-5.9%	-2.8%	-5.8%	-3.1%	-3.7%	-3.8%	-5.4%	-3.6%	-4.5%	-6.0%	-1.8%	-2.7%	-5.4%	-0.9%	-2.8%
Agr. VA (volume)	0.9%	0.9%	0.7%	0.0%	0.6%	0.7%	0.2%	0.3%	0.7%	3.9%	0.6%	0.5%	0.7%	0.1%	0.9%	0.1%	-0.3%	0.5%
Farm labour	-2.1%	-1.7%	-1.1%	-1.8%	-0.4%	-1.5%	-1.0%	-1.1%	-1.3%	-1.2%	-1.2%	-1.4%	-2.1%	-0.4%	-0.4%	0.0%	-0.2%	-0.5%
GHG emissions	-2.4%	-4.4%	-3.3%	-3.1%	-2.0%	-3.3%	-2.2%	-2.6%	-3.2%	-1.7%	-3.3%	-1.9%	-3.9%	-0.7%	-2.5%	-4.0%	-0.4%	-2.0%
Agricultural land	-1.1%	-1.7%	-1.0%	-0.5%	-1.2%	-0.5%	0.1%	-0.1%	-1.0%	-0.4%	-1.8%	-0.5%	-0.9%	-0.2%	-0.4%	-1.2%	-0.1%	-0.6%
Fertiliser use per ha	-1.0%	-0.9%	-0.5%	-0.7%	-0.3%	-0.9%	-0.4%	-0.4%	-0.3%	-0.7%	-0.5%	-1.2%	-0.8%	-0.4%	-0.2%	-1.6%	-0.3%	-0.5%
3-c) Abatement technologies																		
Production	0.1%	0.1%	0.5%	0.0%	0.0%	0.1%	-0.1%	0.0%	0.0%	0.2%	0.1%	0.0%	0.0%	0.3%	0.1%	0.3%	0.0%	0.1%
Food CPI	-0.2%	-0.2%	-0.5%	-0.2%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.2%	-0.2%	0.0%	-0.1%	-0.3%	-0.1%	-0.3%	0.0%	-0.1%
Calorie availability	0.1%	0.1%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.3%	0.0%	0.1%	0.0%	0.1%
Gross farm receipt	-0.3%	-0.6%	-0.3%	-0.5%	-0.1%	-0.2%	-0.2%	-0.1%	-0.4%	-0.6%	-0.3%	-0.1%	-0.3%	-0.5%	-0.2%	-0.6%	-0.1%	-0.2%
Agr. VA (value)	-0.5%	-1.7%	-1.1%	-1.5%	-0.3%	-0.5%	-0.4%	-0.2%	-0.6%	-1.3%	-0.6%	-0.2%	-0.8%	-0.8%	-0.2%	-2.1%	-0.1%	-0.5%
Agr. VA (volume)	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%
Farm labour	0.0%	-0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
GHG emissions	-4.1%	-7.2%	-1.8%	-5.3%	-6.3%	-5.3%	-8.3%	-6.9%	-3.4%	-6.9%	-7.2%	-0.8%	-6.5%	-10.2%	-3.4%	-12.6%	-0.1%	-5.1%
Agricultural land	0.3%	0.8%	1.8%	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%	0.6%	0.7%	0.0%	0.1%	0.4%	0.1%	0.4%	0.0%	0.2%
Fertiliser use per ha	-1.1%	-2.5%	-1.9%	-3.1%	-3.1%	-2.0%	-0.4%	0.0%	-1.5%	0.8%	-0.9%	-0.8%	-1.0%	-1.1%	-0.9%	-2.4%	0.0%	-2.1%

	ARG	AUS	BRA	CAN	CHN	EU27	JPN	KOR	MEX	NZL	RLA	RUS	RWE	SEA	TUR	USA	ROW	WLD
4-a) Policy mix - all regions																		
Production	0.2%	0.4%	0.8%	0.2%	0.4%	0.7%	0.1%	0.3%	-0.3%	2.7%	0.0%	0.2%	-0.3%	0.0%	0.3%	0.2%	-0.3%	0.0%
Food CPI	-2.3%	-1.2%	-2.5%	-1.5%	-2.0%	-1.6%	-1.0%	-1.3%	-1.2%	-1.7%	-1.4%	-1.6%	-1.4%	-1.0%	-1.7%	-1.6%	-0.2%	-1.1%
Calorie availability	1.1%	0.8%	1.0%	0.6%	0.9%	0.8%	0.1%	0.3%	0.5%	0.9%	0.7%	0.8%	0.3%	0.6%	0.8%	0.4%	0.1%	0.4%
Gross farm receipt	-5.3%	-3.5%	-3.2%	-3.6%	-3.1%	-4.4%	-4.0%	-2.7%	-3.0%	-3.8%	-3.0%	-4.2%	-3.2%	-1.9%	-3.3%	-4.6%	-0.6%	-2.4%
Agr. VA (value)	-4.8%	-6.5%	-4.7%	-7.5%	-4.1%	-6.9%	-7.5%	-3.3%	-4.5%	-4.7%	-3.8%	-4.3%	-7.8%	-2.6%	-5.9%	-7.3%	-0.7%	-3.5%
Agr. VA (volume)	0.0%	0.5%	0.8%	1.3%	0.8%	2.0%	1.2%	0.7%	0.7%	2.5%	0.3%	0.6%	2.4%	0.3%	1.2%	0.7%	-0.2%	0.6%
Farm labour	-2.1%	-1.4%	-0.6%	-0.7%	0.5%	1.3%	0.5%	2.8%	0.4%	-1.6%	-1.0%	-0.1%	3.4%	-0.2%	0.0%	0.0%	-0.1%	0.2%
GHG emissions	-11.5%	-14.3%	-11.0%	-30.6%	-9.4%	-16.4%	-13.1%	-10.1%	-10.2%	-11.3%	-13.3%	-16.2%	-17.4%	-12.3%	-8.0%	-20.4%	-0.5%	-10.6%
Agricultural land	1.1%	1.0%	2.5%	-1.3%	-0.4%	-1.5%	-4.5%	-1.4%	0.3%	1.8%	1.8%	-0.1%	-2.1%	0.7%	-0.2%	0.2%	-0.1%	0.2%
Fertiliser use per ha	-1.4%	-2.6%	-2.0%	1.8%	-2.0%	0.7%	4.3%	2.3%	-1.7%	0.8%	-1.5%	-1.1%	3.9%	-7.3%	-1.0%	0.9%	-0.2%	-3.2%
4-b) Policy mix - OECD																		
Production	-0.3%	1.1%	-0.6%	0.8%	-0.3%	1.1%	0.3%	0.6%	-1.3%	3.2%	-0.6%	-0.3%	0.1%	-0.6%	0.4%	0.5%	-0.2%	-0.3%
Food CPI	-0.1%	-0.9%	-0.1%	-1.4%	-0.6%	-1.5%	-0.8%	-1.1%	-0.2%	-1.5%	-0.1%	0.1%	-1.2%	0.0%	-1.5%	-1.4%	-0.1%	-0.5%
Calorie availability	0.1%	0.6%	0.0%	0.6%	0.0%	0.7%	0.1%	0.3%	0.0%	0.8%	0.0%	-0.1%	0.3%	-0.1%	0.8%	0.4%	0.0%	-0.1%
Gross farm receipt	-0.5%	-1.8%	-0.7%	-2.7%	-1.1%	-3.5%	-3.6%	-2.3%	-1.4%	-2.5%	-0.7%	0.0%	-2.6%	-0.3%	-2.9%	-4.2%	-0.3%	-1.1%
Agr. VA (value)	-1.0%	-3.7%	-1.1%	-6.2%	-1.8%	-6.0%	-7.1%	-2.8%	-2.8%	-2.6%	-1.1%	-0.5%	-7.0%	-0.9%	-5.6%	-6.7%	-0.3%	-2.1%
Agr. VA (volume)	-0.2%	1.1%	-0.1%	1.7%	0.2%	2.3%	1.3%	0.8%	0.1%	2.9%	-0.1%	0.2%	2.6%	0.0%	1.3%	0.9%	-0.1%	0.4%
Farm labour	0.0%	-0.7%	0.1%	-0.4%	0.8%	1.5%	0.6%	2.9%	1.2%	-1.2%	0.0%	1.1%	3.5%	0.1%	0.1%	0.0%	-0.1%	0.5%
GHG emissions	-0.1%	-12.9%	-0.7%	-30.1%	-1.1%	-16.0%	-12.9%	-9.8%	-2.7%	-10.7%	-0.4%	-0.6%	-17.0%	-0.6%	-7.7%	-20.1%	-0.3%	-5.1%
Agricultural land	0.0%	1.3%	0.2%	-1.2%	-1.2%	-1.4%	-4.5%	-1.4%	-0.6%	1.8%	0.1%	-0.5%	-2.1%	0.1%	-0.2%	0.3%	-0.1%	-0.1%
Fertiliser use per ha	-0.3%	-2.3%	0.0%	1.9%	1.0%	0.9%	4.4%	2.4%	-0.2%	0.8%	-0.5%	0.2%	4.0%	-6.2%	-1.0%	1.1%	-0.1%	-1.7%

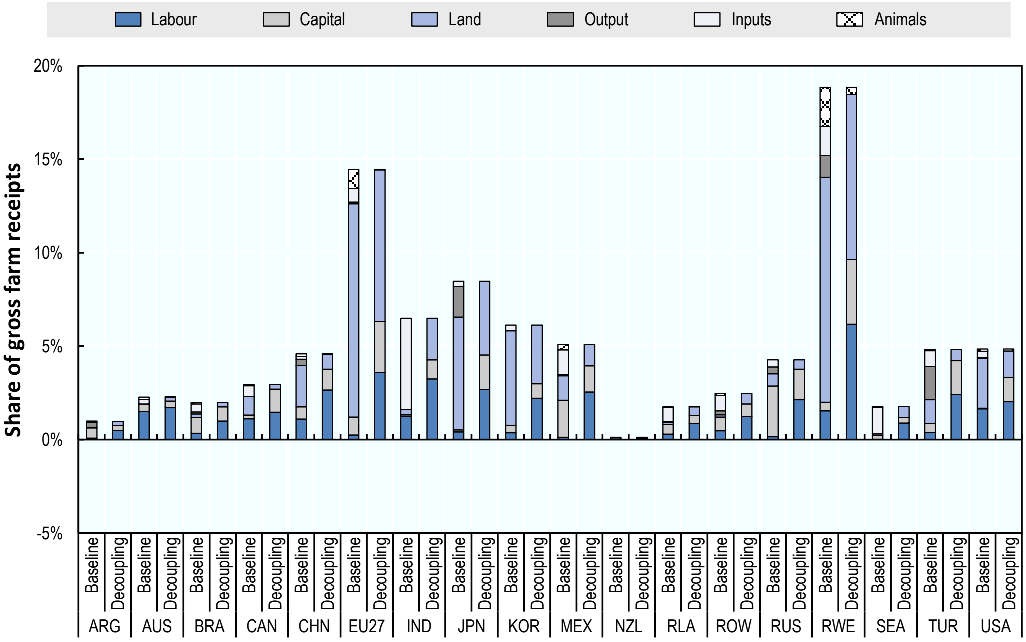
Note: Region codes are available in Annex A. CPI = consumer price index. Agr. VA = Agricultural value added. Real value added corresponds to agricultural value added in volume.
Source: METRO-PEM.

Figure A H.1. Total transfers by payment forms and regions in the decoupling scenarios



Notes: ARG=Argentina, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, EU27=European Union (without United Kingdom), IND=India, JPN=Japan, KOR=Korea, MEX=Mexico, NZL=New Zealand, RLA=Rest of Latin America, ROW=Rest of the World, RUS=Russia, RWE=Rest of Western Europe, SEA=Southeast Asia, TUR=Türkiye, USA=United States, WLD=World.
Source: METRO-PEM simulations, based on PSE database and scenario assumptions.

Figure A H.2. Total transfers by payment forms and regions in the decoupling scenarios



Notes: ARG=Argentina, AUS=Australia, BRA=Brazil, CAN=Canada, CHN=China, EU27=European Union (without United Kingdom), IND=India, JPN=Japan, KOR=Korea, MEX=Mexico, NZL=New Zealand, RLA=Rest of Latin America, ROW=Rest of the World, RUS=Russia, RWE=Rest of Western Europe, SEA=Southeast Asia, TUR=Türkiye, USA=United States, WLD=World.
Source: METRO-PEM simulations, based on PSE database and scenario assumptions.

Annex I. Results decomposition and sensitivity analysis

In order to better interpret the results obtained for the different policy simulations, this section provides complementary model results aimed at decomposing the contribution of different scenario components, as well as better understanding the role of specific model parameters.

Decomposition of the impact of budgetary support

The current policy simulations from Group 1 and 2 consider shocks on a broad range of budgetary support categories – output-based payments, payments on different types of inputs or factors, payments based on historical production - either by removing all or a part of them simultaneously (Group 1), or by transferring them across categories (Group 2).

To better understand the role of each type of instrument, the shock of scenario 1-a is decomposed into each component of the support. The results are used to compute the relative change of production and agricultural (non-CO_2) GHG emissions, relative to an increase of 1% of the rate of support of production. This metric gives a good representation of the sensitivity of production and emissions to the support. Because the shock is global and applied to all agriculture, the results are however contingent to the initial support distribution between regions and sectors. To partly address this issue, land payments are shocked separately for cropland and grassland, and output payments are also distinguished by main group.

Results are illustrated in Figure A I.1. These indicate that production reacts the most to a change in output-based payments (in particular if targeted to livestock), in variable input-based payments (with payments on fertiliser less effective than payments on other variable inputs),[48] and in capital-based and headage payments. However, when looking at GHG emission response to payments, the hierarchy is changed, as the source of emissions can be related to the use of specific factors or inputs. As a telling illustration, the response of emissions is now highest in the case of payment to fertilisers, due to nitrous oxide emissions. Other variable inputs support also generates emissions increase, in particular in the livestock sector when feed is supported. Beside variable input payments, the second most impactful category is livestock headage payments, considering animals are in the modelling the direct source of emissions. This is followed by output-based payments to livestock. In comparison, payments to land, capital or labour have rather marginal impacts on non-CO_2 emissions.

These observations form the basis to conclude that variable input-based, livestock headage and output-based payments are the potentially most climate harmful forms of budgetary support to the producer.

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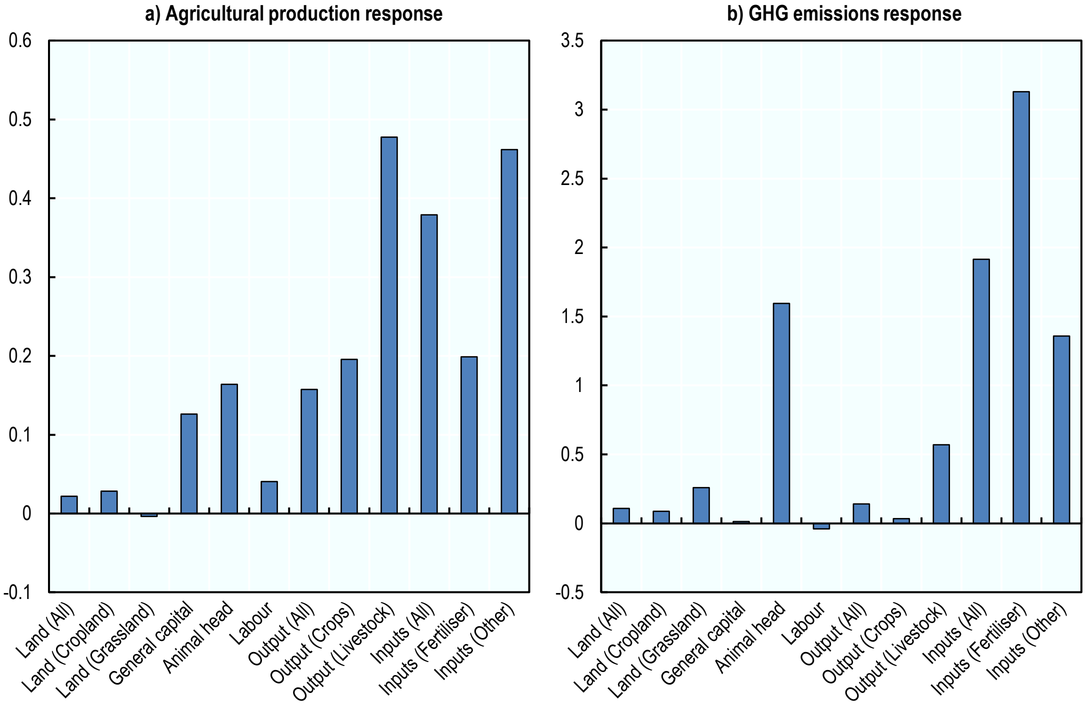
[48] Elasticities between land and fertilisers are here based on the initial PEM assumption that assume quite high level of fertiliser use in the base year, and therefore relatively limited impact of marginal change in fertilisation rates on productivity, compared to the situation of developing regions.

Figure A I.1. Response of agricultural production and GHG emissions to change in level of support, by type of instrument

Relative change for a 1% increment in total budgetary support, as a share of global production, based on current support geographical and sectoral allocation



Note: 'inputs' here designates 'variable inputs'.
Source: METRO-PEM simulations

Sensitivity analysis

In order to understand the sensitivity of the results to model parameter choice, additional simulations were performed to assess what the results would be with different parametrisation. These simulations reproduce the same set of policy scenarios, but differ from the main results presented in the paper ("Central case"), through the following parameter adjustments:[49]

- *Land expansion elasticity* (σ_{Land} in Annex A) is varied from a value of zero (no land expansion), and 50% of the central case value, to 200% of the central case value.
- *Labour and capital supply elasticities* are also varied through changes of a pair of parameters: i) the elasticity of substitution between the land-input factor and the other inputs bundle (σ_{VA} in Annex A), ii) the elasticity of transformation between the labour and capital factors across economic sectors. Adjusting these two parameters simultaneously (by 200% or 50%) strongly increases or decreases (respectively) the overall supply elasticity of the sector.

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[49] Parameters were here varied once at a time to test the model sensitivity. A combination of parameter changes, or a more advanced sensitivity analysis set-up such as a Monte-Carlo analysis, could lead to greater deviation from the central results.

- *Land intensification elasticities*: These elasticities correspond to the substitution between land and fertiliser for crops, and between land and feed for livestock (σ_{LdInt} in Annex A). Elasticities are also adjusted by factors of 50% and 200%.
- *Demand elasticities*: Demand elasticities for agricultural and food products are adjusted by 50% and 200%.
- *Trade elasticities*: Similarly, trade elasticities for agricultural and food product imports are adjusted by 50% and 200%. This is applied both to the substitution between domestic products and imports, and between imports of different countries of origin (Armington elasticity).

The policy shocks were applied across all the different parameters variations explained above. To better understand the potential impacts on the results from the central case, the scenario outputs for three different parameters are analysed: i) GHG emissions (Table A I.1), ii) food calorie availability (Table A I.2), and iii) real value added (Table A I.1).

The results of the sensitivity analysis simulations show that the results are overall relatively robust to the changes in the parameters tested. For instance, emission variations (Table A I.1) in Scenario 1-a remain in the range -1.6-2.4%, whereas the range is -1.1-1.6% for scenario 1-b. Similar range of variation appear for scenario of Group 2, and in Scenario 3-a, whereas the livestock productivity scenario 3-b appears relatively less sensitive to assumption changes. In the case of the abatement technology scenario 3-c, stronger variation can be observed, but these are mostly due to the fact that changing initial elasticities breaks the initial marginal abatement cost curve calibration. Considering these variations, the combined scenarios show relatively less variation, with a range of -10.3-10.7% for Scenario 4-a and -4.7-5.5% for Scenario 4-b.

Results on food availability also appears sensitive to the initial parameter assumptions, but the variation range remains much smaller. For instance, for Scenario 1-a, the variation range is -0.5-1.0%, whereas for Scenario 1-b, more moderate changes are observed (-0.3-0.6%). The parameter having most impact on food availability is demand elasticities, considering it determines the flexibility with which global demand, and then supply, can be reduced for a given price to the consumer.

Results on real value added also show rather limited variations. Results remain in the range of -0.2-0.4% for scenario 1-a and 0.0-0.1% for scenario 1-b. The productivity scenarios are more notably sensitive to assumption variation in the case of real value added results.

Overall, the sensitivity analysis shows that results remain relatively robust to changes in the targeted parameters. More importantly, the hierarchy of the scenarios is unchanged when these parameters are affected, which shows that the overall paper findings are not dependant on the choice of these parameters.

Table A I.1. Relative change in global agricultural GHG emissions, by scenario and sensitivity assumption

	Central case	Land expansion elasticity			Labour and capital supply elasticities	
		0	/ 2	x 2	/ 2	x 2
1-a) No budgetary support	-2.1%	-1.6%	-1.8%	-2.4%	-1.9%	-2.3%
1-b) No potentially most climate-harmful payments	-1.4%	-1.4%	-1.4%	-1.3%	-1.2%	-1.6%
2-a) Simple decoupling	-1.7%	-1.6%	-1.7%	-1.9%	-1.4%	-2.2%
2-b) Green decoupling	-4.1%	-4.1%	-4.1%	-4.2%	-3.6%	-4.8%
3-a) Agriculture productivity	-1.3%	-1.0%	-1.2%	-1.4%	-1.3%	-1.1%
3-b) Livestock productivity	-2.0%	-1.9%	-1.9%	-2.0%	-1.8%	-2.0%
3-c) Abatement technologies	-5.1%	-5.1%	-3.6%	-5.1%	-5.6%	-4.3%
4-a) Policy mix — all regions	-10.6%	-10.5%	-10.5%	-10.7%	-10.3%	-10.7%
4-b) Policy mix — OECD	-5.1%	-5.0%	-5.0%	-5.2%	-4.7%	-5.5%
	Land intensification elasticities		Demand elasticities		Trade elasticities	
	/ 2	x 2	/ 2	x 2	/ 2	x 2
1-a) No budgetary support	-1.9%	-2.1%	-2.0%	-2.2%	-2.0%	-2.1%
1-b) No potentially most climate-harmful payments	-1.1%	-1.6%	-1.3%	-1.5%	-1.3%	-1.4%
2-a) Simple decoupling	-1.5%	-2.0%	-1.7%	-1.8%	-1.7%	-1.8%
2-b) Green decoupling	-4.2%	-4.2%	-4.0%	-4.3%	-4.1%	-4.2%
3-a) Agriculture productivity	-1.2%	-1.4%	-1.5%	-1.0%	-1.3%	-1.2%
3-b) Livestock productivity	-1.9%	-2.1%	-2.2%	-1.6%	-2.0%	-2.0%
3-c) Abatement technologies	-5.1%	-3.6%	-5.1%	-5.1%	-5.1%	-3.6%
4-a) Policy mix — all regions	-10.5%	-10.7%	-10.7%	-10.3%	-10.6%	-10.6%
4-b) Policy mix — OECD	-4.9%	-5.4%	-5.1%	-5.1%	-5.1%	-5.1%

Source: METRO-PEM simulations.

Table A I.2. Relative change in global calorie availability, by scenario and sensitivity assumption

	Central case	Land expansion elasticity			Labour and capital supply elasticities	
		0	/ 2	x 2	/ 2	x 2
1-a) No budgetary support	-0.7%	-0.6%	-0.7%	-0.7%	-0.7%	-0.7%
1-b) No potentially most climate-harmful payments	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
2-a) Simple decoupling	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.1%
2-b) Green decoupling	-0.3%	-0.3%	-0.3%	-0.3%	-0.4%	-0.3%
3-a) Agriculture productivity	1.0%	1.1%	1.0%	1.0%	1.2%	0.9%
3-b) Livestock productivity	0.6%	0.6%	0.6%	0.6%	0.7%	0.5%
3-c) Abatement technologies	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
4-a) Policy mix - all regions	0.4%	0.3%	0.4%	0.4%	0.4%	0.4%
4-b) Policy mix- OECD	-0.1%	0.0%	0.0%	-0.1%	-0.1%	0.0%

	Land intensification elasticities		Demand elasticities		Trade elasticities	
	/ 2	x 2	/ 2	x 2	/ 2	x 2
1-a) No budgetary support	-0.7%	-0.7%	-0.5%	-1.0%	-0.7%	-0.7%
1-b) No potentially most climate-harmful payments	-0.4%	-0.4%	-0.3%	-0.6%	-0.4%	-0.4%
2-a) Simple decoupling	-0.2%	-0.2%	-0.1%	-0.3%	-0.2%	-0.2%
2-b) Green decoupling	-0.3%	-0.3%	-0.2%	-0.5%	-0.3%	-0.3%
3-a) Agriculture productivity	1.1%	1.0%	0.7%	1.6%	1.0%	1.0%
3-b) Livestock productivity	0.6%	0.6%	0.4%	0.9%	0.6%	0.6%
3-c) Abatement technologies	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
4-a) Policy mix - all regions	0.4%	0.3%	0.3%	0.5%	0.3%	0.4%
4-b) Policy mix- OECD	0.0%	-0.1%	0.0%	-0.1%	-0.1%	0.0%

Table A I.3. Relative change in real value added, by scenario and sensitivity assumption

	Central case	Land expansion elasticity			Labour and capital supply elasticities	
		0	/ 2	x 2	/ 2	x 2
1-a) No budgetary support	-0.3%	-0.2%	-0.3%	-0.4%	-0.3%	-0.3%
1-b) No potentially most climate-harmful payments	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
2-a) Simple decoupling	0.4%	0.4%	0.4%	0.4%	0.2%	0.6%
2-b) Green decoupling	0.1%	0.2%	0.1%	0.1%	0.0%	0.4%
3-a) Agriculture productivity	1.1%	1.1%	1.1%	1.0%	1.3%	0.8%
3-b) Livestock productivity	0.5%	0.5%	0.5%	0.4%	0.6%	0.4%
3-c) Abatement technologies	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4-a) Policy mix - all regions	0.6%	0.7%	0.7%	0.6%	0.6%	0.8%
4-b) Policy mix- OECD	0.4%	0.5%	0.4%	0.4%	0.3%	0.6%

	Land intensification elasticities		Demand elasticities		Trade elasticities	
	/ 2	x 2	/ 2	x 2	/ 2	x 2
1-a) No budgetary support	-0.3%	-0.3%	-0.3%	-0.4%	-0.3%	-0.3%
1-b) No potentially most climate-harmful payments	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
2-a) Simple decoupling	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
2-b) Green decoupling	0.1%	0.2%	0.2%	0.1%	0.1%	0.1%
3-a) Agriculture productivity	1.0%	1.1%	0.9%	1.3%	1.1%	1.1%
3-b) Livestock productivity	0.5%	0.5%	0.3%	0.7%	0.5%	0.5%
3-c) Abatement technologies	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4-a) Policy mix - all regions	0.6%	0.7%	0.6%	0.8%	0.6%	0.7%
4-b) Policy mix- OECD	0.4%	0.4%	0.4%	0.5%	0.4%	0.4%

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