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Agricultural support and climate change mitigation: Data and modelling application

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Abstract

Agriculture faces a complex and unique challenge in relation to climate change. It is among the sectors the most exposed to climate change, but it is also an important source of greenhouse gas (GHG) emissions, which requires rapid action. A significant public support is currently dedicated to the sector, including USD 500 billion in the form of government expenditure, 59% of which goes directly to individual producers. This current pool of budgetary support is a substantial resource, which policy makers could use to shape a more sustainable future agricultural sector.

This paper aims at identifying best agricultural policy reform options for climate change mitigation, by analysing the structure and impact of agricultural support on greenhouse gas emissions. It adds to the literature by integrating the latest data on agricultural support from the OECD, analysed at policy line level, into a computable general equilibrium framework, METRO-PEM, specifically designed for this type of assessments.

The three groups of reform options are investigated in the paper - removing budgetary support, decoupled producer support from production, with or without environmental cross compliance, and investing into targeted solutions, either via productivity growth or emissions abatement technologies.

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[3] A final version of this paper will be uploaded to the GTAP website ahead of the conference.

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). 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).

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 support 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 can also have negative environmental impacts triggered by intensification of production or increased use of land and resources allocated to agriculture (OECD, 2022; Henderson & Lankoski, 2020). 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, & UNEP, 2021; Gautam, et al., 2022). However, additional work is needed to improve upon these 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. 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. The emphasis is put on the role that reforms in government budget expenditures can play, and the role of market price support policies is not investigated here.

The value-added 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 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 paper is structured as follows: Section 2 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 introduced in Section 3. Future version of this draft will include results and discussion and will be uploaded ahead of the GTAP conference.

2. Model and data

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.

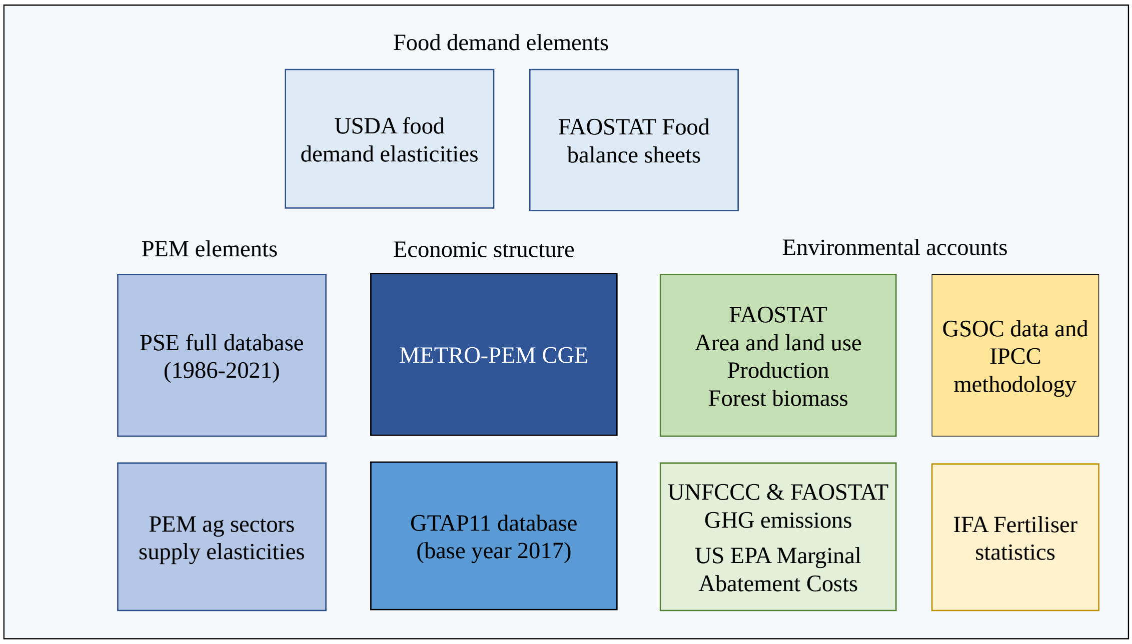
2.1. METRO-PEM main features

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 Policy Evaluation Model (PEM), a partial equilibrium (PE) model focused on the agricultural sector in the context of agricultural policy evaluation (OECD, 2001; OECD, 2005). In particular, PEM representation of land use and supply, along with some of its factor mobility assumptions are introduced in METRO-PEM. The similarities with the PEM framework also include the direct integration of the PSE database within METRO-PEM, which allows 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 1 below.

Figure 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 a separate inputs – see 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 animal-based payments on GHG emissions.
- A new land factor mobility module replicating 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.

2.2. Greenhouse gas emission modelling

Considering the climate mitigation focus of this analysis, particular attention has been paid to the representation of GHG emissions associated to 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. 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, Gruere, Heffer, & Dobermann, 2022) to better allocate fertiliser emissions across sectors.

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). Three groups of sources are covered: livestock, cropland and rice cultivation. Abatement possibilities are represented in the model by an additional layer of a 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.

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 recommendations.

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 cover 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.

2.3. Representation of PSE data in METRO-PEM

For this analysis, primary data 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.[4] 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 to 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

[4] 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.

different production of factor use levels lead to deviation from the initial statistics. Last, relying on the initial dataset allows direct use of the detailed information at policy line level.

Table 1 below 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.

Table 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*	MPS, not modelled here, is by default limited to the representation of tariffs, like in GTAP
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, Chepeliev, Erwin, McDougall, & van der Mensbrugghe, 2019)

Beside 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.[5]

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 & Beghin, 2009; Moro & Sckokai, 2013). Although decoupled by design, these payments are however observed in practice to maintain a production incentive, therefore remaining partly coupled. Category F payments (based on non-commodity criteria) are currently not allocated in METRO-PEM, as it is also the case in GTAP.

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 based year of the GTAP database. Table 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)[6] covering more than half of these.

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 EU, 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 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 allows 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

[5] 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.

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

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.

Table 2. PSE payments data allocation by factor in METRO-PEM, by category

Million USD, year 2017

Cat.	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 West. Eur.[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 included here. ** 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 METROPEM 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)

Finally, it should be noted that, similar to the GTAP database, METRO-PEM data currently do not consider market price support (Category A1), nor does it cover the Consumer Support Estimate (CSE) or the General Services Support Estimate (GSSE), which are all part of the OECD data. CSE information could 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 also critical in the productivity improvements discussion, as it will be highlighted further below.

3. 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 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. 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 animal-based 2017 payments
2)	**Decoupling of budgetary producer support**	
2-b	Simple decoupling	Transfer of cat. A, B, C and D of budgetary support to category E.
2-c	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

3.1. 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, support is 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 support to the sector. 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.

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-based payments, that are considered as potentially most environmentally harmful. To these, also payments allocated on animal head basis 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. 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 animal-based 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.[7]

3.2. 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. As a result, a total of USD 167 billion of payment is reallocated across sectors and payment categories in the model.

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 to 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 applied as a conservation practice for all cereals (except rice), annually grown oilseeds, sugar beet and fibre crops. 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 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; Fuss, et al., 2018), with 80% of soil sequestration potential estimated to be below USD 20 per tonne CO_2 (Smith, et al., 2007).
- 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 as well as indirect land use adjustments. Although grassland

[7] The composition of the input-based payments in India in 2017 (USD 32 billion) is mostly composed of the following components: 36% irrigation subsidies (both through pumping electricity subsidy and investment support), 32% fertiliser subsidies, 26% short-term and long-term loan subsidies, and 6% crop insurance subsidies. In China, all payments classified as input-based in 2017 (USD 4 billion) correspond to crop and livestock insurance subsidies.

SOC can also be strongly influenced by land management and grazing intensity, no change of SOC is modelled in grassland under this scenario.

3.3. Targeted investments

In these scenarios, a part of the budgetary support is redirected towards innovation and investments targeting emission abatement technologies. This set of scenario 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 are estimated based on recent analysis from Baldos et al. (2018), revisiting the work on long term returns to R&D expenditures from Alton et al. (2011). 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), 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 and innovation systems amounted in 2017 to USD 15.5 billion (OECD, 2022) for the countries covered by our analysis, an increased public expenditure USD 1.5 billion per year would be required to achieve a 3% increase in TFP, which represents 1.5% of the budgetary support to general services. 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 budgetary support payments.

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 agriculture 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) 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). In this scenario, abatement costs are supported through the public budget with a subsidy amounted 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). The scenario also considers that costs are not borne by producers but by the public budget, which also implies that farmers 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. 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.

3.4. 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 on 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 USA.[8]

Results of these scenarios will be presented in the updated version to this draft ahead of the GTAP conference.

[8] 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.

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ANNEX A. List of model sectors and regions

METRO-PEM structure is based on GTAP database (Aguiar et al., 2019[4]). 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 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 2.

Table 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 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