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Reforming budgetary support to agriculture: GHG emission impacts, co-benefits and trade-offs[1]

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Abstract

Agriculture is among the sectors the most exposed to climate change, but it is also an important source of greenhouse gas (GHG) emissions. Reforming agricultural support is increasingly considered a viable means to increase agriculture's contribution to climate change mitigation, while fulfilling broader food systems policy objectives related to food security and livelihoods.

This study investigates the impact on GHG emissions from a set of global policy reform scenarios that reorientate governments' budgetary transfers to agriculture, using the METRO-PEM computable general equilibrium model. This model has the specificity of directly integrating the latest data on agricultural support from the OECD, analysed at policy line level, into the modelling framework.

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.

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.

[1] This paper complements the methodological paper by the same authors presented at the 26th Conference on Global Economic Analysis and entitled: "Agricultural support and climate change mitigation: Data and modelling application". A more complete version of this work has been published in December 2023 as an OECD Working paper, which is the most recommended for citation:
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The opinions expressed and arguments employed herein are those of the authors and do not necessarily reflect the official views of the OECD or of its Member countries.

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1. Introduction

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 (IPCC, 2019). The sector 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. There is room for transforming the sector as it is the beneficiary of significant public support, receiving USD 851 billion of transfers annually across the OECD and major emerging economies in 2020-2022. Of this total, USD 518 billion is paid by governments, USD 297 billion of which goes to individual producers and shapes their production decisions (OECD, 2023).

Yet, current agricultural policies are not well-adapted to address these challenges. Only a small share of the estimated support for agriculture addresses these priorities in a coherent and efficient way (OECD, 2022). Over the past two decades, the share of support devoted to general services to the sector declined from 16% (in 2000-2002) to 12.5%. The total budget devoted to general services accounted for USD 106 billion in 2020-2022, but only a quarter of it was dedicated to R&D, a category with a strong potential to raise productivity while lowering the emissions intensity of production. In the meanwhile, production and trade distorting support measures are still widespread and inflate prices for consumers, and 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, Assessing the Environmental Impacts of Agricultural Policies, 2020).

For that reason, 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. 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, A multi-billion-dollar opportunity – Repurposing agricultural support to transform food systems, 2021; Gautam, et al., 2022). However, existing studies often lack specificity in the policy design and less attention has been given to exploiting co-benefits and limiting trade-offs associated with such reforms.

The present paper 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 paper follows-up on previous methodological developments needed to conduct this type of assessment (Valin, Henderson, & Lankoski, Agricultural support and climate change mitigation: Data and modelling application, 2023). The value-added of the proposed approach is the full coupling to the OECD PSE database to the CGE model used, 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. Compared to previous analysis, this study also 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 briefly 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. Results are then presented in Section 4 and discussed in Section 5.

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.

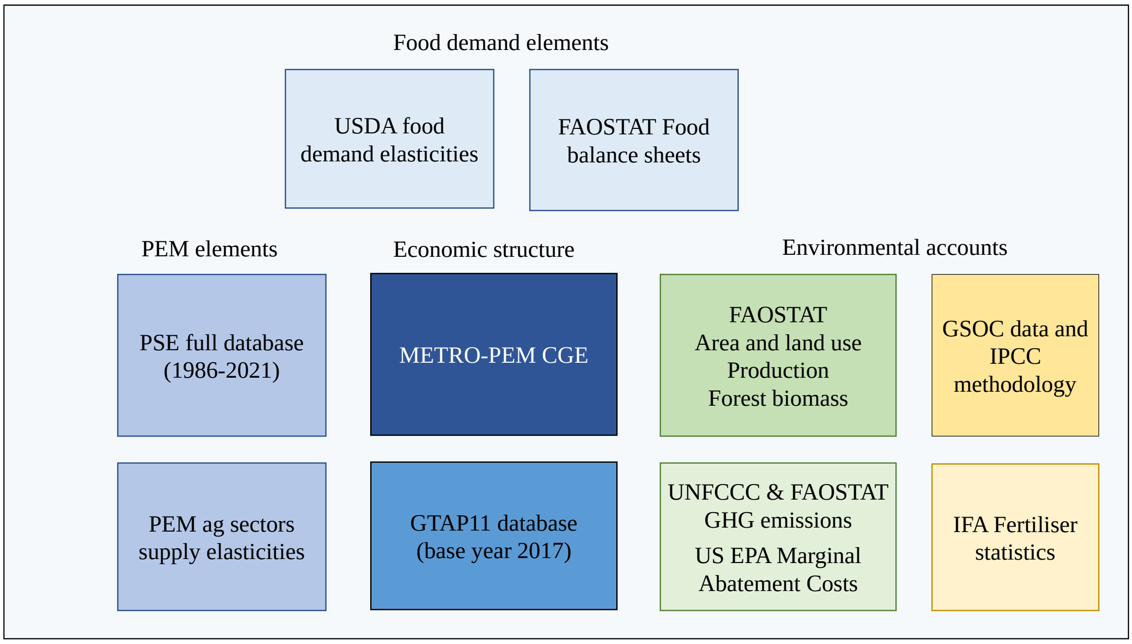
2.1. METRO-PEM main features

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 (Valin, Henderson, & Lankoski, 2023).

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).
- 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.

For more details on the model specification, see Valin, Henderson and Lankoski (2023b).

2.2. 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 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.

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]

[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 tariffs data. The OECD data on General Services Support Estimates (GSSE) and Consumer Support Estimates (CSE) are also not currently integrated into the GTAP database.

[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

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)

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.

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).

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)

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 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. 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.[7] 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

[7] 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). More detail on input payments (category B) and their treatment in METRO-PEM data are provided in methodological Annex G in Valin, Henderson and Lankoski (2023b).

source of these emissions.[8] 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.[9]

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:

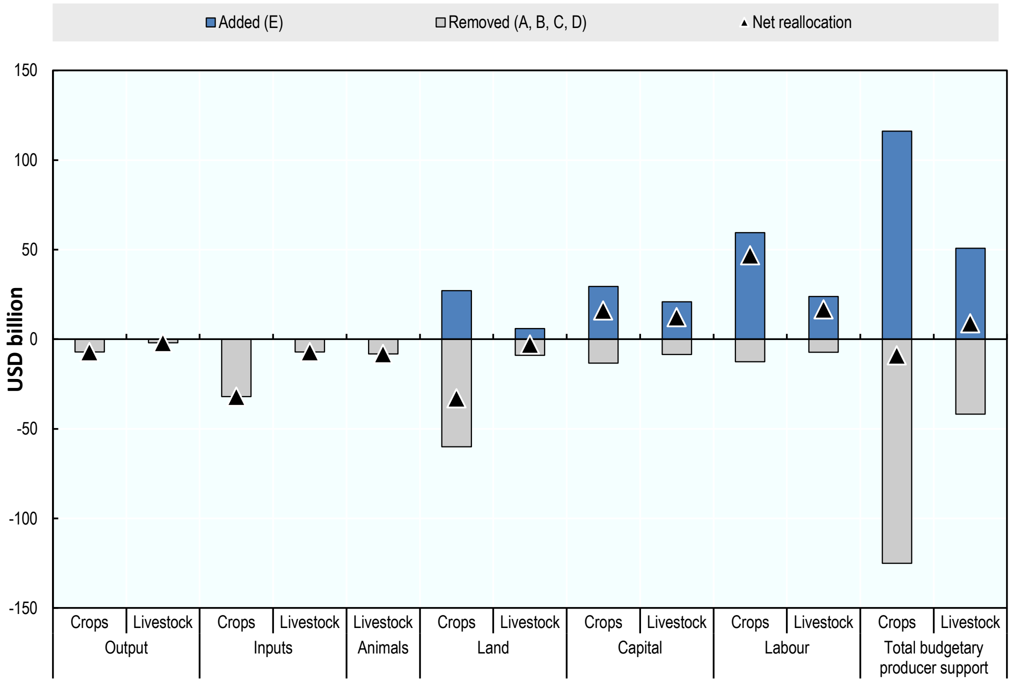
2-a) Simple decoupling. In this scenario, budgetary support that is coupled to production (output, input and factor payments with production requirement) is reallocated as payments that are less distortive for production (land payments without production requirement, payments to general capital or farmer 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.[10] As a result, a total of USD 167 billion of payment is reallocated across sectors and payment categories in the model. The impact of the scenario on payments to output, inputs and the different production factors is illustrated in Figure 2 and Figure 3.

[8] [8] 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. 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.

[9] 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.

[10] 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.

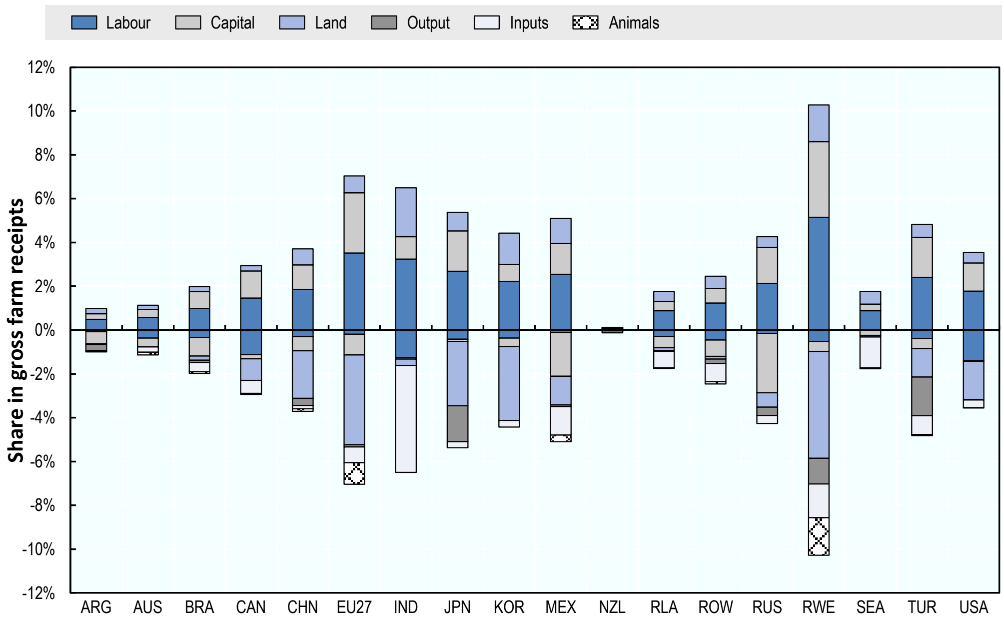
Figure 2. Total transfers across output, input and factors payments in the decoupling scenarios



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. 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 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 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.[11]

[11] 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.

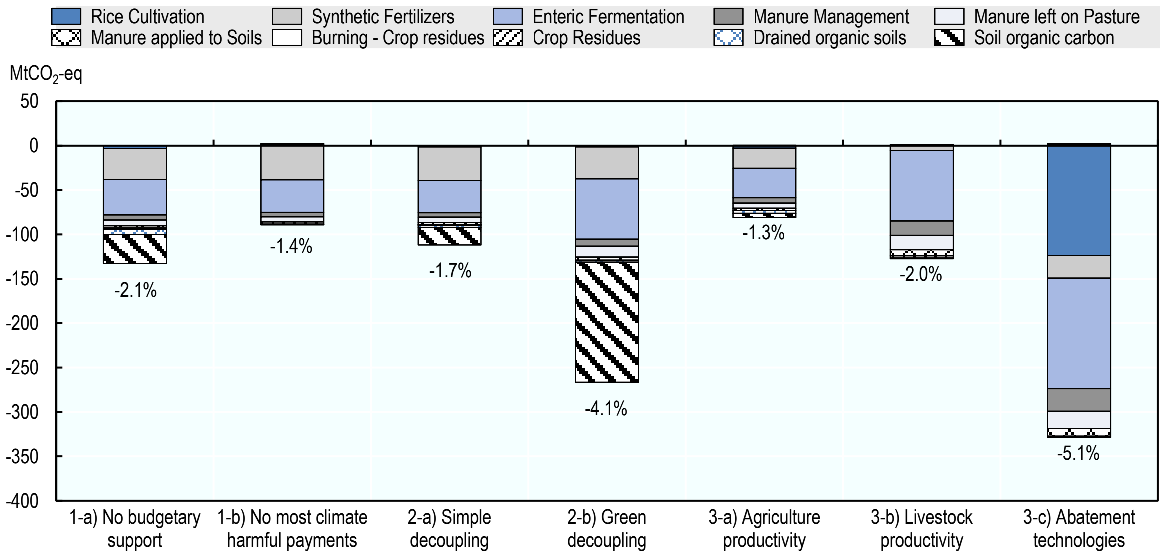
4. Results

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). 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.

Figure 4. Global GHG emission changes for all scenarios



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

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, 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.[12] 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 (Valin, Henderson, & Lankoski, 2023b).

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 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.

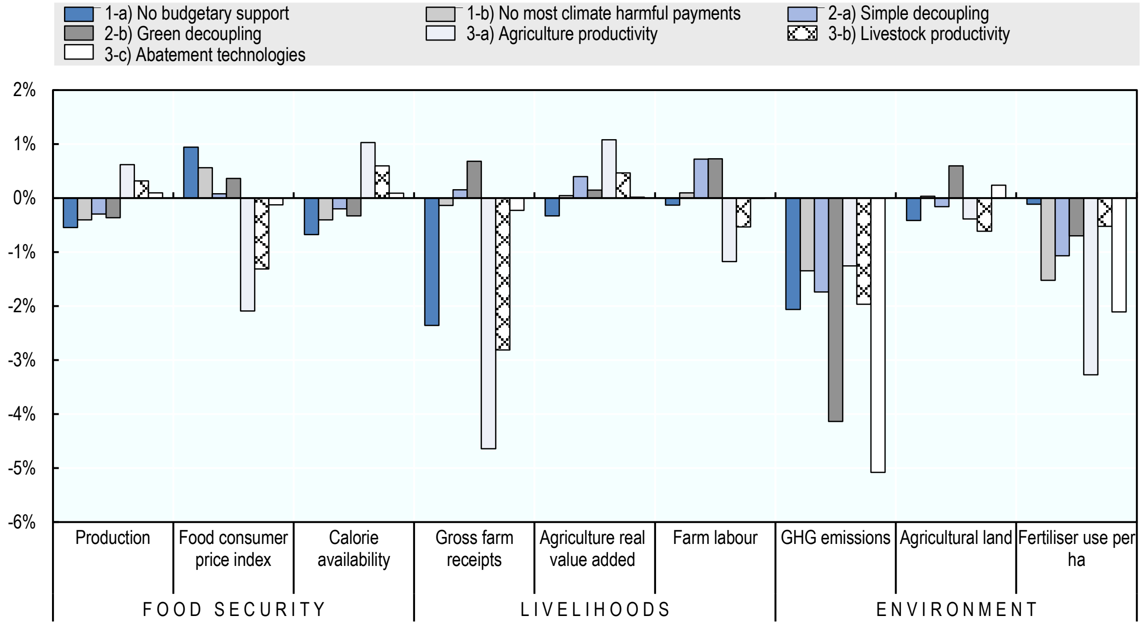
The GHG emission results give a good indication of the relative performance of the scenarios. However, it should be noted that emissions from potential indirect land use changes are not represented, as only emissions tied to agricultural practices are accounted for. The potential implication of adding land use change emissions on the scenario results is discussed in Valin, Henderson and Lankoski (2023b).

[12] 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.

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 5.

Figure 5. 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.

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.[13] 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%).

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

[13] This land expansion effect can potentially offset some of the emission savings achieved with these scenarios due to biomass clearing from land use change – see discussion in Valin, Henderson and Lankoski (2023b).

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),[14] 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 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.[15] 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

[14] 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.

[15] 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.

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. 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 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.[16] 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; Fuss, et al., 2018), 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, Ray, Baldos, & Hertel, 2022).
- 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.

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

[16] 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.

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.

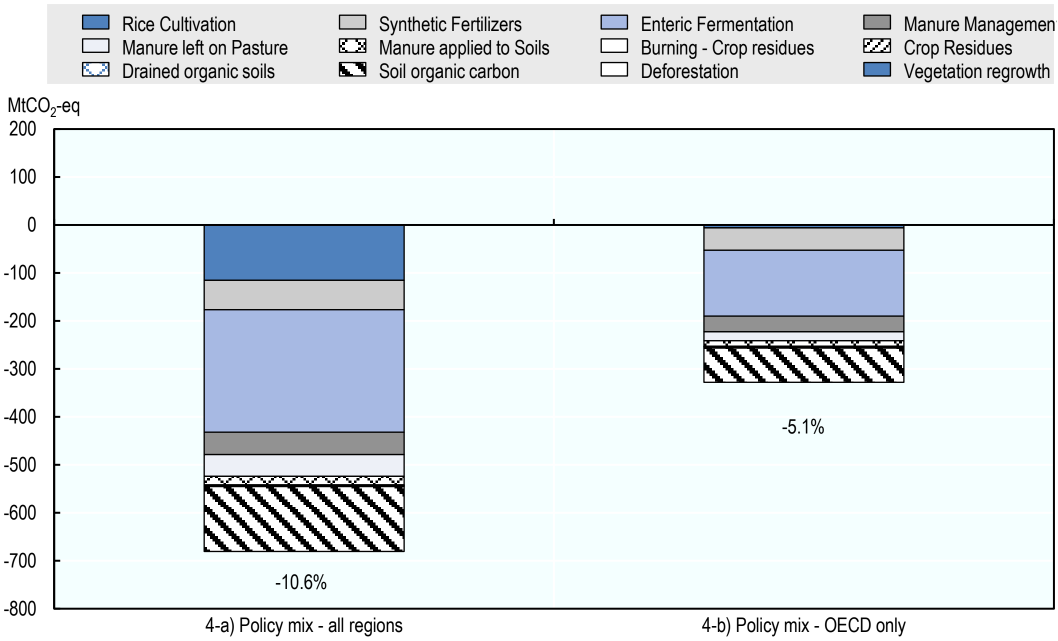
Table 4. Emissions abatement cost-efficiency of public budget expenditure, by scenario

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 6. 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.[17]

Figure 6. Absolute change in GHG emissions by source for policy mix scenarios

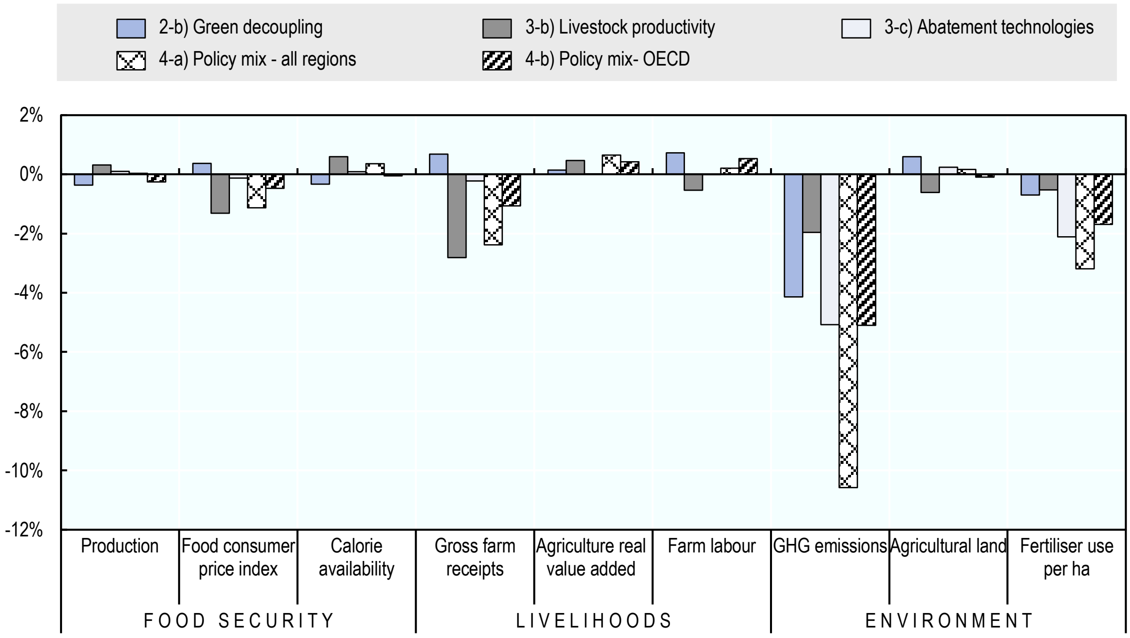


Source: METRO-PEM.

Figure 7 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.

[17] It should be noted that deriving additional land use emissions for these two scenarios does 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. For more details, see Valin, Henderson and Lankoski (2023b).

Figure 7. 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).

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. A sensitivity analysis conducted in Valin, Henderson and Lankoski (2023b) showed that the choice of the main parameters influences 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), a 5% increase of carbon input to the soil could sequester around 200 MtCO2/year in cropland (Sustainable Soil Management scenario 1, SSM1) versus 113 MtCO2/year in this analysis in the region considered. This potential could be increased to 500 MtCO2/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 GtCO2 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) 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).

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) 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, Ray, Baldos, & Hertel, 2022). 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), 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). 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. For instance, decomposing land use at the subnational level could also help to better capture land heterogeneity (e.g. by AEZ zones (Baldos & Corong, 2020), 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; Henderson, Frank, Havlik, & Valin, 2021) and more diverse sets of policies (Henderson, Frezal, & Flynn, 2020). 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, Mamun, Piñeiro, & Vos, 2021; Guerrero, et al., 2022). 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, Chepeliev, Erwin, McDougall, & van der Mensbrugghe, 2019). 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