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Mitigating climate change in the agriculture, forestry and other land use (AFOLU) sectors: A literature review on policy effectiveness

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Mitigating Climate Change in the Agriculture, Forestry and Other Land Use (AFOLU) Sectors: A Literature Review on Policy Effectiveness

Lauren Lee and Ada Ignaciuk

Governments have introduced a wide range of policies that can directly or indirectly contribute to the mitigation of greenhouse gas (GHG) emissions in the agriculture, forestry and other land use (AFOLU) sectors. This report synthesises the findings of studies on the effectiveness of these policies in OECD and G20 countries. Policies that prevent the removal or reduction of large carbon sinks, such as ecosystem protection measures, are found to mitigate the most GHG emissions per hectare on average. Technology standards present high GHG mitigation potential per hectare while government investment in research and development can improve productivity and reduce emissions intensity. Subsidies, which directly and indirectly support climate mitigation in AFOLU and are the most used instrument in these sectors, can also reduce GHG emissions, though at a lower average level. The effectiveness of these and other reviewed mitigation policies, however, depends on contextual factors, including the presence of other existing policies, and environmental, social, and economic conditions. Some policies can also generate co-benefits or undesirable social, environmental, and economic impacts. More efforts are needed to evaluate the different effects of direct and indirect mitigation policies to better reflect the policy context and to consider their alignment with other government objectives.

Key words: Environmental policy, Climate change, Mitigation

JEL codes: Q15, Q18, Q28, Q54, Q58

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Key messages

- Governments have introduced a wide range of policies that can directly or indirectly contribute to the mitigation of greenhouse gas (GHG) emissions in the agriculture, forestry and other land use (AFOLU) sectors. However, the mitigation effectiveness of many of these policies has not been established, making it difficult to monitor and evaluate their contribution to overall mitigation efforts.
- This report synthesises the findings of studies in OECD and G20 countries on the GHG mitigation effectiveness of production and land-use-related policies that either primarily aim to reduce GHG emissions (direct mitigation policies) or that target other objectives but may indirectly result in emissions reduction (indirect mitigation policies). The main findings of this literature review are the following:
    - Instruments aiming to conserve natural ecosystems through zoning policies like protected areas are reported to be the most effective at reducing emissions per hectare, compared with other types of public policies. Reviewed studies with quantitative estimates of GHG mitigation indicate that zoning policies mitigate on average about 86 tCO_2eq per hectare per year.
    - Technology standards are reported to have a high GHG mitigation potential. This can only be estimated by *ex ante* studies, as their mitigation potential remains, to date, largely not realised. In particular, biofuels with carbon capture and storage technology standards have been estimated to mitigate on average 30 tCO_2eq per hectare per year.
    - Government investment in research and development can improve productivity and reduce emissions intensity. Reviewed studies with quantitative estimates find that it can mitigate 28 tCO_2eq per hectare per year on average.
    - Subsidies, which directly and indirectly support climate mitigation in AFOLU can also reduce emissions, but at a lower average level. Reviewed studies with quantitative estimates find that they can mitigate 5.3 tCO_2eq per hectare per year on average.
- The effectiveness of these and other reviewed mitigation policies depend on contextual factors including the presence of other existing policies, and environmental, social, and economic conditions. In some cases, the costs of regulatory policies may be many times the costs of economic policies; in other cases, regulatory policies may be considered to have de-facto no cost. These location-specific conditions should be accounted for when designing mitigation pathways in AFOLU activities.
- Direct and indirect mitigation policies can, however, have negative social or economic impacts such as reduced agricultural productivity, farm income, competitiveness loss, or increased burden on taxpayers.
- More efforts are needed to evaluate the effectiveness and efficiency of direct and indirect mitigation policies, particularly on subsidies designed for climate purposes, given that they are the most used instruments, and on policies that indirectly contribute to mitigation, as they may be unaccounted for in climate strategies.

Executive summary

Governments have introduced a wide range of policies aimed at climate mitigation or other environmental improvements with indirect mitigation effects in the agriculture, forestry and other land use (AFOLU) sectors. However, the mitigation effectiveness of many of these AFOLU policies has not been established, making it difficult to monitor and evaluate their contribution to overall mitigation efforts.

This literature review analyses the effects of direct and indirect mitigation policies and classifies their effects by policy instrument type.[1] The analysis is based on approximately 190 studies collected using the Web of Science, government websites, and OECD reports, covering effects of policies on mitigation in OECD or G20 countries or globally. More than half of the identified studies are *ex ante* analyses.

This review finds that:

- Policies that prevent the removal or reduction of large carbon sinks, such as ecosystem protection measures, mitigate the most GHG emissions per hectare. For instance, zoning policies have demonstrated notable mitigation potential, with area-based emission estimates of on average 86 tCO_2eq per ha per year.
- Technology standard regulations for improved biofuel technologies like second-generation biofuels and carbon capture and storage have the potential to be effective mitigation instruments with average mitigation estimates of 30 tCO_2eq per ha per year. However, these quantitative estimates are largely based on predictive (*ex ante*) studies. The anticipated mitigation benefits are not yet realised due to various challenges, including technological barriers.
- Government investments in research and development (R&D) were estimated to have an average mitigation potential of 28 tCO_2eq per ha per year. Though few studies assessed mitigation effect of R&D per hectare, studies often focused on improvements in agricultural practices for soil quality, productivity, and breeding programmes. Additionally, R&D can support mitigation efforts through increased total factor productivity, reducing emissions intensities as well as cropland expansion.
- Policies targeting agricultural practices, often through subsidies, generally exhibit lower marginal abatement potential when compared with zoning ecosystem protection policies. Subsidies were, on average, estimated to mitigate 5.3 tCO_2eq per ha per year according to the reviewed literature. At the same time, these instruments are often used to support other policy objectives like food production, rural development, and farm income.

The average mitigation for each policy type reported above should be seen as indicative only, since the mitigation effectiveness of these and other analysed direct and indirect mitigation policies is highly context dependent. It can be influenced by local factors such as climate, topography, ecosystems, land use, and farm systems. These location-dependent effects are especially apparent for instruments targeting specific practices or land use. The policy context also shapes the effectiveness of those policies, including through interactions of AFOLU policies with other mitigation policies; for example, while policy overlap may improve the scope of mitigation policies, thus improving total mitigation, it may also reduce the marginal cost-effectiveness of individual instruments.

Some of the policies can also generate undesirable social, environmental, and economic impacts. Flanking policies can be used to reduce or buffer these effects and may increase their political acceptance. At the same time, some policies may be reported to have mixed effects on mitigation, but these policies may be necessary to achieve other policy goals beyond climate change mitigation and contribute to a balanced policy package.

[1] This review focuses on policies with the primary aim of reducing GHG emissions and policies that may not be aimed at but nonetheless result in emissions reduction. The scope does not capture the breadth of all agriculture or forestry policies, and some of which may have the potential to increase GHG emissions. Additionally, this report focuses on policies which relate to production and land use, and therefore does not capture many policies which may target consumption, diets, supply chains and waste.

The report also identifies gaps in the literature. It suggests that further research should aim to reflect policy contexts more accurately, particularly in *ex ante* modelling studies. Future studies should evaluate the overall costs and benefits of policies across multiple dimensions, including climate change, environmental, social, and economic effects. Additionally, this review found limited quantitative mitigation estimates of policies per unit of input or output; therefore, further analysis of mitigation effects per unit could strengthen the assessment of policies, particularly those incentivising agroecological practices. More systematic *ex post* policy assessments relating to climate change mitigation are also needed, as these assessments accounted for less than half of the reviewed literature. This includes causal econometric policy evaluations in the AFOLU sectors, that only represented 4% of studies in the reviewed literature.

1. Introduction

Climate change mitigation is a pressing priority for many governments. Many OECD governments have set ambitions to achieve climate change goals, including net zero greenhouse gas (GHG) emissions. To achieve such goals, governments can leverage mitigation opportunities across many sectors, including the agriculture, forestry, and other land use (AFOLU) sectors.

This report contributes to efforts to assess the GHG mitigation effects of AFOLU policies by synthesising conclusions from the literature on policy instruments. Other efforts have been undertaken to review the literature, though often focusing on specific policy instruments (Del Grosso et al., 2014[1]), the effects of technical measures rather than policies (MacLeod et al., 2015[2]; Intergovernmental Panel on Climate Change, 2022[3]), or more generally on environmental effects (DeBoe, 2020[4]). Additionally, many studies focused on specific topics, including water quality and fertiliser use rather than policy instruments.

This work seeks to assess the body of evidence developed to date regarding how policy makers can support climate mitigation goals without compromising other socio-economic and environmental objectives within the AFOLU sectors. While there are still relatively few policies specifically targeting climate change in AFOLU, numerous existing policies impact greenhouse gas (GHG) emissions and carbon sequestration.

More specifically, this literature review examines studies of AFOLU policies that[2]:

- primarily aim to reduce GHG emissions (direct mitigation policies)
- target other policy objectives, though may indirectly result in emissions reduction (indirect mitigation policies).

For example, emissions trading systems are considered direct mitigation policies as they aim to reduce emissions. Fertiliser regulations are viewed as indirect mitigation policies because they target fertiliser use and practices, but have emissions-reducing co-benefits through reduced production, use, and soil and ecosystem degradation.

The scope of this review does not assess all AFOLU policies. It is limited to those which affect production and potentially support mitigation.[3] However, it is important to note that some policies not considered in the scope of this review may affect GHG emissions and unintentionally undermine mitigation efforts. For example, these policies may include some agricultural support policies such as subsidies for emission intensive inputs like fossil fuels (Henderson and Lankoski, 2019[5]). While the scope of this paper focuses on the production-related policies which support mitigation, coherent policy actions including reorienting policies which induce emissions, and considering supply chains, consumption and waste are needed to meet climate targets.

[2] The scope of policies included in this paper matches the scope of policies included in OECD PIMA-AFOLU (Policy Inventory for Mitigation Actions in Agriculture, Forestry and Other Land Use Sectors) database. The types of policies included were primarily due to governments identifying that they potentially support mitigation, and the availability of studies.

[3] In particular, OECD (2024[144]) reviews the literature on the effect of agriculture support policies, which can in some cases induce GHG emissions.

The analysis is structured according to a taxonomy of policy instruments developed by the OECD Inclusive Forum on Climate Mitigation Approaches (IFCMA). In broad alignment with the IFCMA, policies can be classified into specific types of instruments (OECD, 2024[6]) (see Table 1.1): *economic instruments* including subsidies, taxes, and trading systems; *regulatory instruments* encompassing performance standards, technology standards, and framework regulations; and *other instruments* comprising of government investments and consumption, information instruments, and voluntary agreements.

Table 1.1. AFOLU adapted IFCMA policy instrument type descriptions

Instrument category	Instrument type	Definition
Economic instruments	Subsidies	Budgetary transfers from governments to producers or consumers. Note that this definition excludes payments which contribute to gross-fixed public capital formation, which are captured under government investment and consumption (see below). E.g. producer payments
	Taxes	Compulsory, unrequited payments, in cash or in kind, made by non-government units to government units; they are described as unrequited because the government provides nothing in return to the individual unit making the payment. E.g. carbon taxes
	Trading systems	Market mechanisms that allow market participants (such as companies or households) which have or need a climate-relevant right, allowance or permit to buy and sell these rights, allowances or permits amongst themselves. E.g. carbon certificates generated through AFOLU activities
Regulatory instruments	Performance standards	Establish levels of performance, quality, or conduct in a particular area. The regulated agents have the freedom to choose technologies and methods to achieve the specified performance level. E.g. Nitrogen quantity regulations
	Technology standards	Requires or forbids a specific technology, process, product, or design. Often, they are also referred to as command-and-control standards. E.g. fuel efficiency standards
	Framework regulations	Prescribe requirements on production processes without mandating the use of specific inputs or technologies or prescribing a specific outcome. Often, these requirements are of a qualitative nature. They may also regulate the functioning of markets. E.g. zoning regulations like protected areas
Other instruments	Government investment and consumption	Relate to the allocation of financial resources by government units towards goods, services, and facilities like infrastructure and R&D, as well as the implementation of policies and rules that shape government expenditure choices and decision-making processes. E.g. R&D
	Information instruments	Instruments promoting technology choices and behavioural changes through the dissemination of information. E.g. education programmes
	Voluntary agreements	Agreements between a government authority and one or more private parties to achieve policy objectives or to improve performance beyond compliance to regulated obligations. E.g. covenants

Source: OECD (2024[7]).

Due to the vast number of studies on climate change mitigation, synthesising the available evidence to draw reliable and accessible conclusions for decision-makers is a challenging endeavour. This review began with a systematic literature review, followed by the application of the “snowball” technique. Additional references were drawn from the relevant publication by selected authors or suggested by internal reviewers and delegations. Further details on the methodology are provided in Annex A.

This work should be interpreted with the following considerations and caveats regarding the types of literature reviewed. Only production-related direct and indirect mitigation policies were assessed for their effects on mitigation. However, it should be recognised that these policies exist in broader contexts with other policies which may have conflicting environmental effects, or they may have multiple policy goals which extend beyond mitigation objectives. Additionally, the studies included in this review use various methodologies and assumptions and were primarily published after 2015. Some of the hypotheses are important; for example, over half were *ex ante* studies which assumed perfect policy implementation. Further considerations and caveats are described in Annex A.

The following section provides overall findings from the literature review. Subsequent sections offer more detailed observations per IFCMA instrument category (economic, regulatory, other) and instrument type. The final section will discuss some of the main socio-economic effects of reviewed policies and political feasibility considerations. Annex A includes the detailed methodology, caveats and considerations.

2. Overview of results

2.1. Scope of the reviewed literature

This literature review assessed the results of approximately 190 studies, categorising them according to the IFCMA policy typology. Sixty per cent of the studies analysed *economic instruments*, while *regulatory instruments* and *other instruments* accounted for roughly 30% and 10% of the studies, respectively (Table 2.1). Some studies assessed the effects of multiple instruments and were thus counted more than once.

More than half of studies analysed were *ex ante* analysis, usually focusing on predictions. Additionally, over half of assessments studied real policies, providing some insights into their effectiveness. Forty-two per cent of studies used modelling methodologies. An approximately equal number of studies assessed short-term (0-5 years), medium-term (6-15 years) and long-term (greater than 15 years) mitigation effects.

The review focused on policies from OECD and G20 countries and global studies. Studies from Europe accounted for more than half of the reviewed literature (see Annex A).

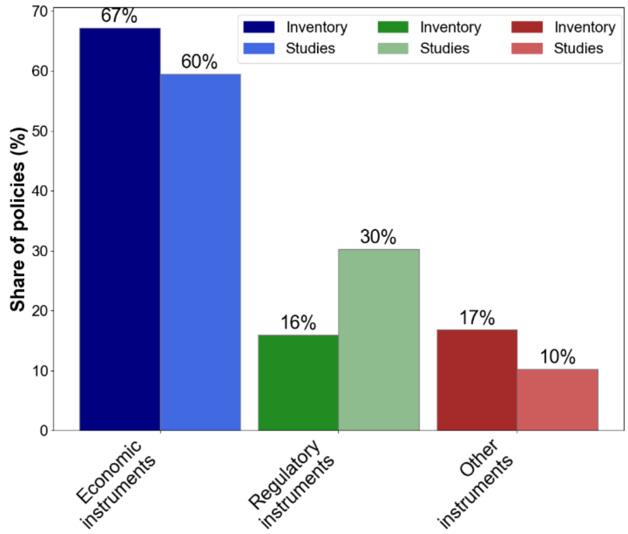
Table 2.1. Characteristics of reviewed studies by instrument type

	Count of studies		Type of assessment (%)		Methodology (%)	Type of policy studied (%)		Study time period (%)		
Instrument type	Number	Percentage	*Ex ante*	*Ex post*	Modelling	Hypothetical	Real	Short	Medium	Long
Subsidies	**68**	33	44	43	29	44	56	19	44	18
Taxes	**30**	15	93	0	80	97	3	20	23	33
Trading systems	**24**	12	54	42	38	33	67	29	25	17
Performance standards	**15**	7	60	33	67	47	53	47	13	33
Technology standards	**19**	9	84	16	42	74	26	16	5	42
Framework regulations	**26**	13	23	58	19	15	85	31	27	38
Gov. investments	**10**	5	40	50	50	30	70	40	10	50
Information instruments	**4**	2	25	75	0	0	100	25	50	0
Voluntary agreements	**7**	3	43	57	43	43	57	29	14	14

Note: Some categories do not add to 100% due to the methodologies or type of study. For example, literature reviews which synthesised findings of both *ex ante* and *ex post* studies were not counted.

The distribution of policy studies reviewed across the instrument categories approximately mirrors the distribution of direct and indirect mitigation policies reported in the Policy Inventory for Mitigation Actions in Agriculture, Forestry and Other Land Use Sectors (PIMA-AFOLU) (2024[7]) (Figure 2.1). Economic instruments emerged as the predominant focus of the reviewed literature, featuring in the majority of both policies in the inventory and studies included in the review, representing approximately 67% and 60% respectively. The *regulatory instruments* category accounted for about 16% of policies and 30% of studies. Finally, the *other instruments* category accounted for 17% of policies and 10% of studies.

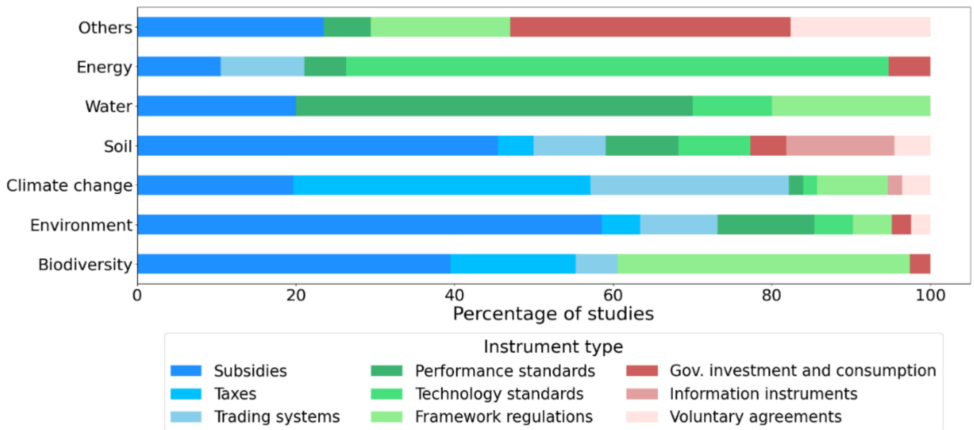
Figure 2.1. Share of reviewed policy studies and policy inventory instruments by instrument category



Note: Inventory data is from PIMA-AFOLU.
Source: OECD (2024[7]).

Studied policies target a variety of environmental domains,[4] and the percentage of studies varies by instrument type (see Figure 2.2). Studies on economic instruments accounted for the largest proportion of studies particularly for the environment and climate change domains. Tax and trading system studies accounted for the largest proportion of reported policies focusing on climate change. Studies on policies targeting the biodiversity domain primarily focused on economic instruments and framework regulations. Additionally, studies of policies targeting water and energy were primarily focused on regulatory policies.

Figure 2.2. Studies on economic instruments accounted for the largest proportion of literature across most environmental domains



[4] These environmental domains align with the domains of the mitigation inventory included in PIMA-AFOLU (OECD, 2024[7]).

2.2. Main findings of the review on GHG mitigation effects

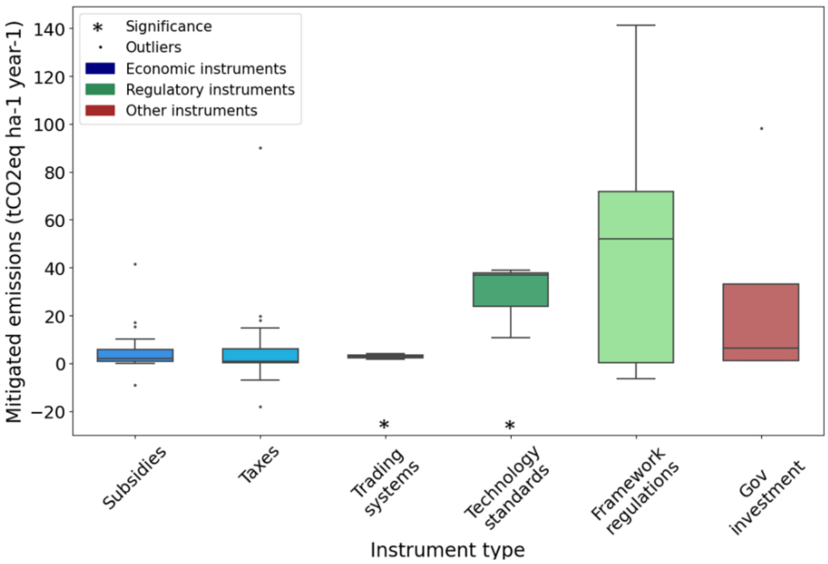
About 64% of the reviewed studies of direct and indirect mitigation policies found that these policies have a positive effect on climate change mitigation through reduced or prevented emissions, or carbon sequestration. However, some policies, despite aiming to address climate change, were not found to consistently reduce GHG emissions or had uncertain effects on mitigation. The next sections provide more detailed information on policy studies per instrument category.

The subset of studies which allowed for area-based mitigation was selected as a common unit for measurement for quantitative analysis as very few studies provided results in other comparable units such as per unit output or input. Many results were provided at a country or regional level, though such results could not be directly compared in this study due to the variation in size, scale and agricultural systems across the studied countries.

Studies that provided quantitative mitigation estimates per hectare revealed a wide variation in effectiveness across the different types of instruments (Figure 2.3).

- *Framework regulations*, and more specifically zoning policies, were observed to have the highest mitigation effects per hectare in the reviewed literature; framework regulations on average mitigated 47 $tCO_2eq\ ha^{-1}yr^{-1}$. The subset of zoning policies within framework regulations on average mitigated 85 $tCO_2eq\ ha^{-1}yr^{-1}$. These studies in general focused on protecting natural ecosystems, thus avoiding GHG emissions from the destruction or degradation of carbon sinks. Studies on zoning policies like protected areas often targeted tropical forests and wetlands.
- *Technology standards* also observed relatively high mitigation effects per hectare of on average 30 $tCO_2eq\ ha^{-1}yr^{-1}$; however, the results were primarily driven by predictive modelling estimates of second-generation biofuels using carbon capture and storage which estimated mitigated emissions of up to 39 $tCO_2eq\ ha^{-1}yr^{-1}$. A large share of studies focused on technology standards and assessed their mitigation effects in gCO_2 per kWh or in total mitigated emissions of a country; therefore, these studies could not be included in the analysis of area-based emission estimates.
- *Ex ante* studies on the *government investment and consumption* specifically for research and development policies also observed high mitigation potential of on average 28 $tCO_2eq\ ha^{-1}yr^{-1}$. However, like with *technology standards*, few studies assessed mitigation per hectare.

Figure 2.3. Conservation focused policies achieved through zoning policies classified as framework regulations may have the largest mitigation potential per hectare



Note: Significance is assessed using a t-test against a null hypothesis of no mitigation effects at a 95% significance level.
The line in the middle of the box plot represents the median value.
Source: 33 reviewed studies with estimates of mitigation per hectare.

- *Subsidies* were observed to have smaller positive mitigation effects per hectare among reviewed studies. The relatively smaller mitigation effects of subsidies are likely a result of the smaller changes in land use and farming practices when compared with, for example, prevented deforestation from zoning policies. Additionally, these subsidies primarily apply to agricultural land which, by comparison to natural ecosystems, likely has lower mitigation capacity. On average, 5.3 $tCO_2eq\ ha^{-1}yr^{-1}$ can be mitigated through the use of subsidies.
- Studies on carbon taxes included in the *taxes* instrument type also observed lower average results of approximately 6 $tCO_2eq\ ha^{-1}yr^{-1}$. The low mitigation results may stem from the non-commodity specific analysis of results. For example, many studies model the implementation of an agricultural GHG emissions tax, and present aggregated country results rather than disaggregating the effects on emission intensive subsectors, such as livestock. In the analysis, the aggregated country-level mitigation results were then converted to emission per hectare by accounting for all agricultural area in a country. However, this conversion to area-based mitigation results for comparison against other studies can obscure sector-specific results for emission intensive subsectors like livestock or intensive farming systems.

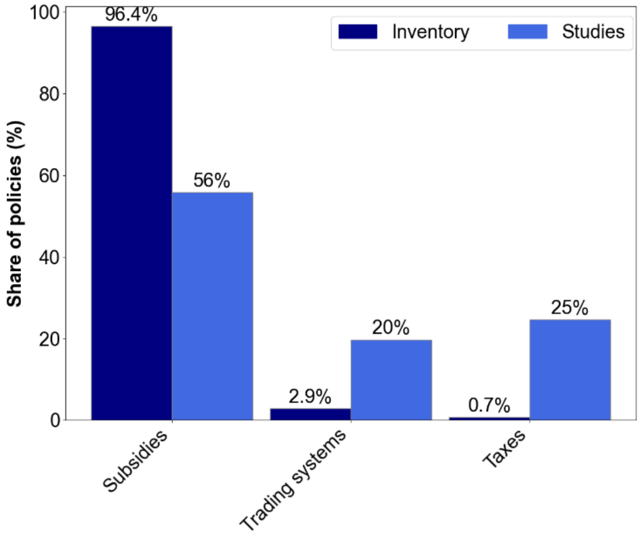
The following three sections provides a more in-depth assessment of the coverage and findings of the literature review by instrument types.

3. Reported effects of economic instruments

Economic instruments are the most widely used instruments, accounting for about 67% of all policies included in PIMA-AFOLU (OECD, 2024[7]). Instrument types included within this category are *subsidies, taxes*, and *trading systems*.

Within the economic instruments category, subsidies have been the most analysed for their effects on GHG emissions, making up about 56% of the reviewed studies (Figure 3.2). This significant focus on subsidies is unsurprising, given policymakers' keen interest in this type of instrument. Additionally, subsidies represent a substantial portion of the PIMA-AFOLU policy inventory, accounting for about 96% of economic instruments.

Figure 3.1. Share of reviewed policy studies and policy inventory instruments by *economic instrument type*



Note: Inventory data is from PIMA-AFOLU.
Source: OECD (2024[7]).

Researchers used a wide range of methodologies and approaches to study subsidies, conducting an approximately equal distribution of *ex ante* and *ex post* analysis. While about 56% of studies on subsidies assessed the mitigation effects of existing or historical policies, many studies assessed the impacts of potential subsidies as those are increasingly used to promote environmental goals (OECD, 2024[7]). Taxes and emission trading systems also account for a large share of studies found in this review. Studies on carbon taxes were entirely *ex ante* hypothetical modelling studies, while emission trading systems had approximately equal distribution of *ex ante* and *ex post* studies (Table 2.1).

3.1. Subsidies

Subsidies target a wide range of environmental and social goals. The instruments with the highest number of studies are *payments for land conservation* and *producer payments*, accounting for 7% and 48% of studies on economic instruments respectively.

Subsidies on average were observed to mitigate 5.3 $tCO_2eq\ ha^{-1}yr^{-1}$ when comparing quantitative results per hectare (Figure 2.3). In general, subsidies supporting natural ecosystems more consistently observed positive mitigation results. In addition to some positive mitigation results, subsidies which result in land use change or support some practices had more uncertain or mixed results on mitigation; context-specific conditions relating to land use change or the complex results of policies affecting multiple agronomic and environmental systems simultaneously may cause these mixed and uncertain effects. Therefore, the effectiveness of subsidies in mitigating GHG emissions is highly dependent upon the instrument's goal, mode of GHG mitigation, design, location, and system specific conditions.

Farmer participation in subsidy schemes is an important factor influencing the overall mitigation effectiveness of subsidies. Higher compensation rates for the adoption of agri-environmental practices boosts adoption. Often, farmers may require subsidies to meet their minimum payment rates to adopt new practices (Gars et al., 2024[8]). One way to increase these compensations to match this threshold is to consider stacking rewards for multiple environmental outcomes (Lankoski et al., 2015[9]). Social factors and individual characteristics can also influence farmers' participation in subsidy schemes. For example, Dessart, Barreiro-Hurlé and van Bavel (2019[10]) recommend segmenting and targeting policies according to farmer traits including their resistance to change, risk tolerance and degree of moral and environmental concern. Additionally, policy makers may increase participation through targeted timing such as major life events when farmers are likely to be more receptive to new ideas and change (Verplanken and Roy, 2016[11]).

While producers generally favour subsidies to support their GHG emission mitigation efforts, policy makers should consider subsidy lock-in[5] effects. Subsidies may effectively reduce GHG emissions, but their effectiveness may decline as agricultural practices and systems evolve. Popp, Feindt and Daedlow (2021[12]) confirmed that the quantity of funding and the policy's age both increase the probability of subsidy lock-in. Well-designed subsidies can use sunset clauses to avoid lock-in, explicitly stating the expiration date of the policy (Sovacool, 2017[13]). However, this may also lower the attractiveness of the subsidy depending on the amount of funding, reducing adoption of targeted mitigation practices or inputs.[6]

3.1.1. Subsidies observed to have positive effects on GHG mitigation

Almost two-thirds of reviewed studies reported positive mitigation effects of subsidies which is unsurprising given the scope of the review. For instance, most of the assessments found subsidies that target efficient fertiliser use and application, soil carbon sequestration and afforestation effectively support GHG mitigation. Also, many *producer payments* to support practices such as measures to reduce methane emission intensities of livestock (Banks and Cawley, 2021[14]; Cawley and Banks, 2022[15]), and soil and biodiversity conservation (Alix-Garcia, Shapiro and Sims, 2012[16]; Sims and Alix-Garcia, 2017[17]) also support mitigation efforts.

[5] Policy lock-in is a situation in which the removal or reversal of a policy is made difficult.

[6] Subsidy lock-in is of particular concern for subsidies with large emission increasing effects. In general, large emission increasing effects were not observed in this review of direct and indirect mitigation policies.

While many of the analysed studies on *payments for land conservation* subsidies observed that the policies reduced GHG emissions, the degree to which they mitigated emissions varied. For example, Alix-Garcia, Shapiro and Sims (2012[16]) observed that in Mexico, a federal payment for ecosystem services programme which compensates landowners for forest conservation had small mitigation effects. While they estimated that the policy reduced deforestation by 50%, the average rate of deforestation of land not enrolled in the programme was also low. Alix-Garcia, Sims and Yañez-Pagans (2015[18]) confirmed similar effects on deforestation, noting that environmental gains were higher in areas with low poverty. Groom, Palmer and Sileci (2022[19]) evaluated the effectiveness of Norway's partnership with Indonesia for payments for land conservation through "reducing carbon emissions from deforestation and forest degradation" (REDD+). They found that from 2011 to 2018, 0.65% more dryland forest cover was retained in moratorium areas, mitigating 67.8-86.0 $MtCO_2eq$ at an effective carbon price of USD 5 per tCO_2. Overall, studies in this review indicate that policies which are appropriate to their environmental, economic and social context and prevent land use change from natural ecosystems to agriculture effectively mitigate GHG emissions, especially in high-carbon ecosystems like tropical forests, mangroves, peatlands, seagrass meadows, and grasslands (Shin et al., 2022[20]).

In some cases, *payments for land conservation* may be more cost-effective mitigation policies compared to regulatory policies like *zoning* instruments.[7] Souza-Rodrigues (2018[21]) modelled the demand for deforestation on private land in Brazil and found that payments for land conservation and land taxes were about 8 times less costly than regulatory zoning policies requiring land owners to conserve 80% of private land under the Forest Code when comparing farmers' lost surplus. However, payments targeting only small landholders with the intent to reduce local poverty and promote conservation were unable to effectively promote mitigation due to the unequal distribution of land (Souza-Rodrigues, 2018[21]). Sims and Alix-Garcia (2017[17]) compared the effects of payments for land conservation and protected area zoning regulations in Mexico; they observed that payments for land conservation are likely more cost-effective than protected areas if the subsidy attracts landowners to enrol land that has equivalent environmental benefits but lower conservation costs. However, if land opportunity costs are positively correlated with deforestation risk, then payments for land conservation will attract land that is both low-cost to protect and has low mitigation additionality benefits.

Additionally, regional environmental factors can affect the cost-effectiveness of mitigation policies which support natural ecosystems. For example, Busch et al. (2019[22]) observed that payments for land conservation more commonly fund reforestation activities on land that is flatter, lower elevation, inside protected areas, and with lower potential agricultural revenue.

The cost-effectiveness of subsidies is also dependent on interactions with other policies; Baccour, Albiac and Kahil (2021[23]) confirmed that policy overlap from multiple mitigation policies reduces the marginal cost-effectiveness of mitigation. While multiple policies targeting different pathways for mitigation are necessary to achieve climate goals, policy overlap increases the marginal cost of abatement. Including transaction costs in policy assessments can help to more accurately identify cost-effective policy leverage points (Baccour, Albiac and Kahil, 2021[23]).

Subsidies that increase the use of environmentally beneficial inputs or practices relative to all other inputs may have strong environmental benefits relative to other AFOLU subsidies, in general (DeBoe, 2020[4]). These subsidies can correct input price distortions by internalising environmental externalities and decrease the relative cost of mitigation-effective inputs or practices. For example, Switzerland's support programmes for conservation tillage have been effective in reducing soil erosion and supporting soil conservation (Prasuhn, 2022[24]), reducing the amount of GHGs that were likely released from damaged soils and enhancing the ability of soils to sequester carbon.

Subsidies which reward mitigation outcomes may be more effective compared to practice-based subsidies in reducing GHG emissions, though monitoring of such policies can be costly (OECD, 2022[25]). For example, OECD (2022[25]) showed that results-based payments for reduced nitrogen runoff supported more cost-effective methods of mitigation because nitrogen reduction efforts were allocated to production with relatively high abatement potential. However, direct measurement of mitigation results may be much more costly at the farm level, increasing the burden of reporting on farms and decreasing uptake of desired

[7] Payments for land conservation are defined as payments for the removal of land from production for conservation purposes on private land. Zoning policies include conservation land-use restrictions on public land.

practices. Additionally, outcome-based schemes may have lower participation as farmers may perceive them as having high and uncontrollable non-compliance risks compared to practice-based schemes (Latacz-Lohmann, Schilizzi and Breustedt, 2011[26]; Gars et al., 2024[8]).

3.1.2. Subsidies observed to have mixed impacts on GHG emissions

Some, *producer payments* and *payments for land conservation* had uncertain GHG mitigation benefits in about 43% and 22% of studies included in this review, respectively, due to their complex direct and indirect effects on land use. Land use changes induced by these policies can increase uncertainty, as mitigation effects are influenced by location-specific and system-specific factors. For example, Bluwstein, Braun and Henriksen (2015[27]) modelled a sustainable increase in organic farming in Denmark, finding that reducing livestock intensity and increasing cropland for human consumption could effectively mitigate GHG emissions while maintaining sufficient food production. Conversely, policies converting natural areas to agricultural land can increase emissions by removing or degrading carbon sinks like biomass and soil organic carbon (DeBoe, 2020[4]).

Certain types of *payments for land conservation*, which exclude land for production, may have mixed effects on GHG emissions. These payments can support mitigation directly through for example, afforestation, soil carbon sequestration and erosion reduction. However, if large amounts of land are removed from production, they may lead to agricultural intensification on remaining land, with mixed GHG emission impacts (Henderson and Lankoski, 2019[5]). Afforestation payments can also negatively affect biodiversity if they enable large-scale monoculture planting regardless of the needs of local communities and socio-economic context (Shin et al., 2022[20]; Ohashi et al., 2019[28])

If policies result in land abandonment, their impact on GHG emissions may be mixed. Some studies suggest it increases emissions; for instance, Laporta, Domingos and Marta-Pedroso (2021[29]) found that payments for land conservation in Montado agro-forestry systems in Portugal, prevented grazing intensification and land abandonment, which would have induced 1.5 tCO_2eq ha^{-1} $year^{-1}$. While abandoned land might support carbon sequestration through natural regeneration of grassland and native species, in Montado systems, it often leads to shrub encroachment, increasing wildfire risks and being ineffective carbon sinks (Nunes et al., 2019[30]). In addition, uncovered soils due to land abandonment may also induce emissions through increased soil erosion (Alliance Environment, 2018[31]). In contrast, Novara et al. (2017[32]) estimated that soil carbon sequestration on abandoned agricultural land mitigated about 62 tCO_2eq ha^{-1} in Sicily, Italy.

Organic farming's effect on GHG mitigation is complex and multifaceted. It can directly reduce emissions by minimising chemical inputs like fertilisers; for instance, Menegat, Ledo and Tirado (2022[33]) found that synthetic nitrogen fertilisers emitted about 1.13 $GtCO_2eq$ in 2018 globally, accounting for 10.6% of agricultural emissions. Indirectly, organic farming may support mitigation through other environmental benefits including maintaining biodiversity (Gong et al., 2022[34]; Shin et al., 2022[20]; Mondelaers, Aertsens and Van Huylenbroeck, 2009[35]), minimising water pollution (Tuomisto et al., 2012[36]), supporting climate adaptation to droughts (OECD, 2016[37]), enhancing farmers' and consumers' health (OECD, 2016[37]), and supporting farmers' profitability (Reganold and Wachter, 2016[38]). However, the indirect mitigation effects of these environmental benefits are challenging to evaluate.

The evaluated effects of organic farming are strongly dependent on the scope of the analysis. Some local observations suggest that organic farming may be beneficial for achieving lower greenhouse gas emissions per unit of area (Skinner et al., 2014[39]). However, land devoted to organic agriculture at this time represents only 2% of the global agricultural area, and uncertainties continue to exist as to the outcomes of its implementation at large scale (Seufert and Ramankutty, 2017[40]). For example, Gaudaré et al. (2023[41]) modelled that the global expansion of organic crops without the complementary practices of widespread cover cropping and enhanced residue recycling would reduce soil organic carbon stocks 0.23 t C $ha^{-1}yr^{-1}$; but with the complementary practices, soil organic carbon stocks would be preserved.

Additionally, organic systems generally provide lower yields than farming systems that rely on synthetic inputs (i.e. non-organic agricultural systems, hereafter referred to as conventional systems) (Kirchmann, 2019[42]; Ponisio et al., 2015[43]; de Ponti, Rijk and van Ittersum, 2012[44]; Seufert, Ramankutty and Foley, 2012[45]). Therefore, yield-scaled mitigation analysis in contrast find organic production to have higher emissions per unit than conventional systems (Skinner et al., 2014[39]; Kirchmann, 2019[42]). However, there are few robust empirical comparable yield-scaled mitigation analyses (Sanders and Heß, 2019[46]), and some studies often focus on limited components of agricultural systems, therefore not accounting for all agricultural emissions of conventional or organic production systems (Skinner et al., 2014[39]).

This organic-to-conventional yield gap has given rise to extensive debate on the potential of organic farming to supply sufficient amounts of food, especially without incurring major land-use changes (Debuschewitz and Sanders, 2022[47]). This debate has also resulted in differing views by policy makers on organic production; policies encouraging organic production are considered part of environmental and mitigation efforts by some governments but not others.

Assessing the net impact of subsidies that indirectly promote land use change requires considering environmental, social, and economic systems. Moreover, trade flows and other environmental and social factors must be considered, as for example, livestock intensification may not result in decreased land use within the region or by trade partners as some models assume (Simmons, Cowie and Brock, 2020[48]).

3.2. Taxes

In 2024, few AFOLU carbon taxes currently exist, and the scope of their emissions coverage is very limited in the AFOLU sectors. Carbon tax policies account for only about 1% of AFOLU policies in the policy inventory (OECD, 2024[7]).[8] Moreover, no current emission taxes apply the polluters pay principle to the AFOLU sectors for major emission sources including CH_4 and N_2O,[9] and many systems offer exemptions for fuels like gasoline and propane[10] (OECD, 2024[7]). For example, the Canadian Federal Fuel Charge impacts producers through natural gas and propane prices, with small per-farm costs ranging from 0.05-0.38% of the average farm’s expenses (Agriculture and Agri-Food Canada, 2021[49]). Therefore, existing systems may have limited mitigation effects.

As there are very few AFOLU carbon tax policies, most studies that review mitigation effectiveness of taxes are *ex ante* studies that are based on scenarios, which may not accurately reflect the actual GHG reduction effects (see Table 2.1). Implementing such policies would also necessitate substantial changes to food systems, including appropriate monitoring and verification of farm level emissions. Additionally, academics often use carbon pricing modelling as a tool to compare mitigation cost effectiveness, which may partially explain the large number of theoretical studies.

About 95% of modelling studies concluded that carbon taxes are effective instruments to mitigate GHG emissions, encouraging the adoption of emission abatement technologies and practices. For example, Mollgaard et al. (2023[50]) modelled a Danish carbon tax of DKK 750 per tonne CO_2eq; the tax resulted in about 45% of emissions reductions relative to 1990 emissions levels with existing abatement technology. Henderson et al. (2021[51]) projected that by 2050, a global AFOLU carbon tax, targeting non-CO_2 emissions from agriculture and CO_2 emissions from LULUCF sources would reduce emissions by 5.8 $GtCO_2$eq, with the greatest mitigation effects from avoided deforestation.

Modelling analysis has found carbon taxes to be more effective at reducing GHG emissions than equivalent emission abatement subsidies. Henderson et al. (2021[51]) found that a global AFOLU carbon tax would be twice as effective as an equivalent emission abatement subsidy; the tax would incentivise high-emitting producers to either abate emissions or cease production, which a subsidy would not achieve. This model-based finding is consistent with observations in other sectors that carbon taxes are more effective than subsidies at mitigating emissions (Guo and Huang, 2021[52]). In addition, taxes directly target emissions, whereas agricultural subsidies typically mitigate emissions more indirectly through supporting practices and inputs. The effectiveness of these practices and inputs can be diminished or is more uncertain due to

[8] Theoretical studies on carbon taxes in AFOLU sectors often apply GHG emission taxes for CO_2, CH_4 and N_2O. Current policies which include AFOLU may tax fuel.

[9] In 2024, Denmark reached a political agreement to implement the Green Tripartite Agreement and is in process of implementing a farm livestock emissions tax by 2030 (Food Nation, n.d.[145]).

[10] Some carbon tax policies like in South Africa exempt agriculture from the tax and allow the AFOLU sectors to generate credits to offset the tax. These credits are categorised as *tradable certificates* under the IFCMA typology (OECD, 2024[7]).

other environmental or social factors (see Section 3.1). Additionally, AFOLU carbon taxes in most studies theoretically impacts all producers, while subsidies often affect a smaller subset of producers, reducing their relative mitigation impact.

Although carbon taxes can contribute to GHG mitigation, they may induce carbon leakage, which can reduce the overall effectiveness of the policy (Condon and Ignaciuk, 2013[53]). Leakage occurs when mitigation gains from a carbon tax are partially offset by increased production elsewhere due to the higher production cost for traded goods; more generally, leakage is a result of general equilibrium effects resulting from incomplete tax coverage.[11] Leakage may alter trade flows and reduce the effectiveness of GHG mitigation. However, leakage is not guaranteed and depends on market and policy design factors but is more likely with taxes than other instruments due to larger asymmetries in policy coverage[12] (Gruère et al., 2023[54]). High carbon tax rates more aggressively target emissions, but can lead to greater emission leakage and adverse effects on producers and consumers (Stepanyan et al., 2023[55]; Himics et al., 2018[56]; Frank et al., 2021[57]). When a small number of countries adopt a carbon tax, leakage can be significant, and up to 50% (Henderson and Verma, 2021[58]). However, most studies found that observed carbon tax leakage rates did not exceed the estimated GHG mitigation gains.

3.3. Trading systems

AFOLU tradable certificates[13] used in trading systems exhibit positive or mixed mitigation effectiveness in the reviewed literature. More specifically, about 38% of assessments reported mixed results.

Assessments of trading systems that report successful GHG mitigation often do so by highlighting the number of credits created, which represent the quantity of CO_2eq tonnes mitigated. For example, California's Cap-and-Trade Program has generated 9 $MtCO_2$eq of offsets from livestock digesters and 205 $MtCO_2$eq of offsets from forest projects over 2013-23, accounting for approximately 85% of total offset credit issuances (United States Department of Agriculture, 2023[59]). Similarly, Australia issued credits for about 141 million $MtCO_2$eq from 2013-2023 (Clean Energy Regulator, 2024[60]).

Theoretical studies often view the tradable permits as efficient, but real-life assessments are often more critical. For example, Grafton et al (2021[61]) modelled the cost-efficiency of different types of forest carbon projects across many countries and found that forest conservation projects are likely to be more cost efficient than afforestation projects, with an estimated global average cost of USD 13-24 per tCO_2. However, studies that deem tradable certificates as ineffective often question the additionality, accuracy, and integrity of the allocated carbon credits (MacKenzie, 2018[62]; Hawkins, 2014[63]; Macintosh and Butler, 2023[64]). They highlight that projects that are likely to occur without the policy are incorrectly included in assessments as additional (Macintosh and Butler, 2023[64]).

Effective tradable certificate policies must ensure the long-term additionality of future credits as improvements in production technologies and practices reduce emission intensities (MacKenzie, Ohndorf and Palmer, 2011[65]). Periodic revaluation and amendments should be included in the monitoring and assessment criteria of policies (Climate Change Authority, 2020[66]). This policy assessment mechanism allows for adjustments to baseline emissions to ensure future projects granted emission credits are additional. Grafton et al (2021[61]) suggest that permanence concerns for current and future forestry credits could be buffered by using subsidies like payments for ecosystem services.

Accurately assessing the additionality of a tradable certificate is challenging. Robust project assessment systems may inhibit participation due to high cost and administrative burden on applicants and governments (Richards and Huebner, 2012[67]; Verschuuren, 2018[68]). Some protocols either lack

[11] Incomplete tax coverage refers to unequal application of emission taxes; for example, this may refer to differing tax rate across countries, but may also refer to the lack of measurement and coverage of certain products and emission sources.

[12] Four primary factors affect the likelihood of policy leakage: 1) the policy's impact on production, 2) domestic demand elasticity and rate of substitution with foreign products, 3) domestic and trade partners' pollution intensity differences, and 4) international market conditions of the affected commodities (Gruère et al., 2023[54]).

[13] Tradable certificates refer to AFOLU generated credits that are sold in a private market whose demand is partially or fully driven by policies (e.g. regulations or taxes).

additionality requirements or include conditions that do not accurately reflect additionality (MacKenzie, 2018[62]). For example, some forestry tradable certificate policies have no additionality requirement (Richards and Huebner, 2012[67]), while others use "barrier tests" to evaluate whether the applicants face a financial, technical, institutional, organisational, cultural, or social barrier to implement the project. However, these tests have a limited ability to accurately assess additionality as they are often vague and manipulatable (Richards and Huebner, 2012[67]).

While additionality requirements are necessary to ensure effective mitigation, requirements should balance additionality restrictions with the mitigation potential of projects. Murray (2015[69]) found that in the United States, the agricultural mitigation potential of the California Cap and Trade system was limited due to restrictions on project activity types. Previously, many mitigation project categories relevant to the AFOLU sectors did not qualify as verified emission reduction activities. Murray (2015[69]) concluded that more than 83% of agricultural emissions, primarily from nitrous oxides from fertiliser management and enteric fermentation, would not be captured as eligible projects, greatly limiting the agricultural mitigation effectiveness of the policy.

Underestimated costs and adoption barriers may prevent producers from participating in carbon credit generation. Murray (2015[69]) found that high transaction costs, and non-market factors like producers' values (e.g. "farming as a way of life" [p.3]) inhibit participation in carbon markets. Additionally, carbon markets can increase uncertainty for producers, impacting operation decisions.

As with many types of policies like carbon taxes and regulatory instruments, leakage also can reduce the mitigation effectiveness of trading systems. For example, payments for forestry credits can preserve one area of forest but may result in deforestation of another area (Grafton et al., 2021[61]).

4. Reported effects of regulatory instruments

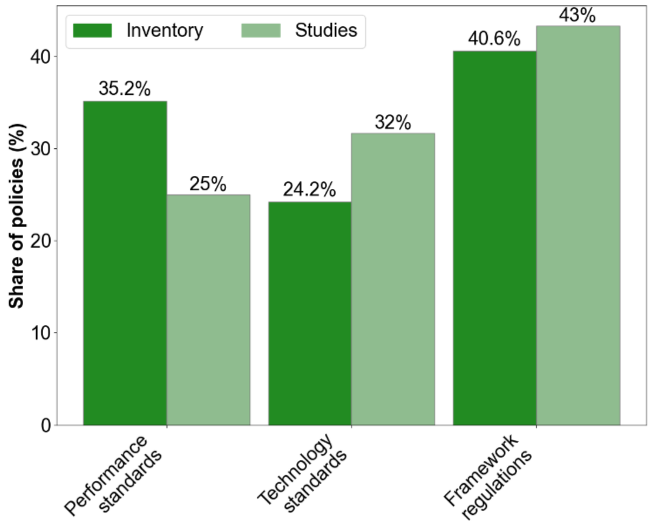
Regulatory instruments are commonly used in AFOLU sectors, accounting for about 16% of instruments in the policy inventory (OECD, 2024[7]). Types of regulatory instruments include performance standards, technology standards and framework regulations.

Studies on the mitigation effectiveness of regulatory instruments were about evenly distributed across the instrument types, and roughly matched the proportion of regulatory policies in PIMA-AFOLU. The reviewed studies focused on the following instruments: maximum pollution standards, low-carbon fuel/feedstock standards, zoning and market regulations and other enabling policies. These regulations targeted or affected emission sources rather than downstream consumption and waste. Common policy targets were natural ecosystem conservation, livestock and biofuels. Framework regulations account for the largest proportion of studies on regulatory policies (43%), and also account for a similar proportion of policies in PIMA-AFOLU (41%) (Figure 4.1).

Few or no studies on mitigation impacts were found for the following instruments: GHG emissions standards, energy efficiency standards, building codes, and bans and phase-outs.

In general, about 60% the reviewed studies on regulatory instruments observed a positive contribution to GHG mitigation, while 40% of studies observed mixed results. Studies on regulatory instruments primarily focused on livestock, pollution, and carbon fuel/feedstock regulations. The following subsection discusses the results of these studies by type of regulatory instrument.

Figure 4.1. Share of reviewed policy studies and policy inventory instruments by *regulatory instrument* type



Note: Inventory data is from PIMA-AFOLU.
Source: OECD (2024[7]).

4.1. Performance standards

In line with expectations, regulatory instruments which directly target GHG emissions or emission sources are observed to have positive effects on mitigation in over 73% of the reviewed studies. These instruments include a wide range of pollution or GHG standards. Although there are few assessments, all suggest that setting "pollution" or "emissions" targets indeed supports mitigation objectives (Department of Agriculture Food and the Marine, 2022[70]; Boezeman, Vink and van Hinsberg, n.d.[71]; Foldal et al., 2019[72]; Frank et al., 2021[57]; Baillie et al., 2016[73]; Zhang et al., 2017[74]; Muller and Neal, 2018[75]). These assessments in general focus on regulations which target livestock and water quality.

Regulations pertaining to the use of chemical inputs may support mitigation efforts and are present in all OECD countries (Vojtech, 2010[76]). Cech, Leisch and Zaller (2022[77]) find that synthetic pesticide production is energy intensive and can result in greater GHG production emissions than synthetic fertilisers per kg of production. Therefore, many countries use policies to limit their use[14] like the EU's high-level *Directive on the sustainable use of pesticides*. Under the directive are regulatory requirements including restrictions on their application and purchase, resulting in reduced production. Regulations limit the use of pesticides by prohibiting aerial spraying of pesticides in the EU and other countries, and strictly controlling their application in other countries through licenses and permits (Vojtech, 2010[76]). Additionally, pesticide use regulations can indirectly support carbon sinks through improved ecosystem health.

Fertiliser regulations may also support mitigation through methods including limiting the total amount, type, and application method. Fertilisers are often targeted in indirect mitigation policies both due to their emission intensive production and resulting soil N_2O emissions from excess soil nitrogen concentrations and soil microbial activity. For example, Denmark's prohibition of soil preparation ahead of spring sown crops bans broad spreading of liquid manure, and the application of manure to bare fields in autumn and winter; this contributes to larger regulatory goals to limit nitrogen pollution (Sud, 2020[78]). The European Commission's (2013[79]) evaluation of the prohibition concluded that it reduced 739 tonnes of nitrogen per year due to reduced tillage and bans on manure application in autumn and winter on bare fields.

[14] Many of the high-level policies which aim to restrict the use of inputs like fertilisers and pesticides are classified as *performance standard regulations*, as they set requirements and goals limiting the use of inputs. Many sub-measures under these high-level performance standard policies may be achieved using additional technology standard regulations.

The EU Nitrate Directive is one example of a policy that sets pollution caps but allows flexibility on the methods used to meet the limits, provided that the caps are not exceeded (European Commission, n.d.[80]). It aims to protect water quality from nitrates pollution from agricultural sources. The directive limits the amount of organic nitrogen that farmers can apply to their land based on their stocking rate and the type of crops they grow. This may limit emissions of N_2O from fertiliser application and can also reduce CH_4 emissions from reduced enteric fermentation and manure application. Countries can apply their own policies and measures but must ensure the limits are not exceeded (Velthof, 2010[81]).[15] Velthof et al. (2014[82]) modelled the impacts of the Nitrate Directive and found that in 2008, it had the largest reduction of N_2O emissions of 20% in the Netherlands, 12% in the United Kingdom, and 12% in Denmark.

Policies which set regulatory targets at the regional level may be more cost-effective than policies which set targets at the farm level (Tarruella et al., 2023[83]). Tarruella et al. (2023[83]) modelled Swiss dairy farms and observed that regional targets allow more flexibility for heterogeneous abatement costs across farms when compared to farm-level targets. They concluded that regional targets may allow for 10% GHG emissions reductions at 88% lower costs than farm-level targets.

4.2. Technology standards

Technology standards are often used in AFOLU sectors to ban inefficient technologies, or set standards for the new, desirable ones. The reviewed studies focussed on low-carbon fuel standards and observed positive mitigation affects, particularly for technologies which used agricultural residues, bioproducts like manure and carbon capture and storage. About 58% of reviewed studies observed mixed results, particularly for biofuel policies which use energy crops (Román-Figueroa and Paneque, 2015[84]; Deppermann et al., 2014[85]; Calvin et al., 2021[86]; Johnson et al., 2023[87]; Pelton et al., 2021[88]). About 84% of studies on technology standards were *ex ante*.

From a technical perspective, a review by MacLeod et al (2015[2]) concludes that measures that improve fertiliser use efficiency, cattle breeding and energy efficiency in mobile machinery may be among the most cost-effective mitigation improvements. Some instruments which promote these measures are classified as technology standards; however, limited studies were found in this review to synthesise findings of technology standard instruments on these policy targets.

Fuel production using crop residues, manure-based biogas, and emerging technologies such as lignocellulosic biomass can effectively reduce emissions. For example, Oehmichen and Thrän (2017[89]) estimate that manure-based biogas can mitigate about 1.448 $kgCO_2eq$ per kWh of power generated (emitting 839 CO_2eq per kWh of power generated) from improved manure management and substitution of electricity from the German electrical grid. Wong, Zhang and Kumar (2016[90]) concluded that GHG emissions from hydrogenation-derived renewable diesel (HDRD) produced from agricultural wheat and barley straw residues were about 61% lower than fossil fuel-based diesel. Therefore, regulatory fuel standards which support these technologies could theoretically support large GHG emission reductions. Despite the positive mitigation potential associated with these technologies, they have low adoption. Adoption barriers may include lack of institutional support and adoption incentives, and technology uncertainty (Gruere and Asai, 2023[91]). Additionally, the costs of developing and implementing mitigation technologies are often underestimated by researchers (Gruere and Asai, 2023[91]).

In general, models of biofuels produced using energy crops observed more mixed mitigation results. For example, Deppermann et al. (2014[85]) modelled the impact of biofuel policies on emissions mitigation scenarios. They observed that more aggressive biofuel mitigation policies increase demand for energy crops. This resulted in increased crop prices and emissions leakage. A large proportion of the European Union's energy crops were imported, increasing the global trade impacts of biofuel policies. Del Grosso

[15] Some EU Member States, including Ireland and the Netherlands, can apply for a derogation from the Nitrate Directive. A derogation is an exemption that allows farmers to farm at higher stocking rates than the normal limit if they follow certain environmental measures. However, the derogation level for both countries will decrease in 2024, due to insufficient improvement in water quality. This will require some farmers to reduce their herd size or find more land to comply with the new limit. Ireland expects that the reduction in herds could be around 17%, depending on the milk yield and the availability of land (Department of Agriculture Food and the Marine, 2022[70]). Due to the Nitrate Directive and other regulatory factors, the Netherlands expects up to 30% reduction in livestock numbers by 2035 unless other measures will be taken (Boezeman, Vink and van Hinsberg, n.d.[71]).

et al. (2014[1]) used a life cycle analysis (LCA) and estimated that the carbon intensity of European biodiesel produced from seed oils was 23 $gCO_2eq.MJ^{-1}$ when accounting for by-products which is lower than petroleum diesel (80.7 $gCO_2eq.MJ^{-1}$). However, their assessment did not include soil carbon or indirect land use change. Additionally, they estimated the total carbon intensity of the production of biodiesel (when attribution of GHG costs were not split into the by-products of oil seed cake and glycerol) to be 90.5 $gCO_2eq.MJ^{-1}$, which exceeds petroleum diesel.

4.3. Framework regulations

Studies on *framework regulations* were in general, observed to positively contribute to GHG mitigation efforts in about 70% of studies. About 85% of studies on framework regulations studied current or historical policies.

Zoning policies which effectively prevent the degradation of natural carbon sinks are observed to be among the most effective area-based mitigation instruments (see Figure 2.3). Ferraro et al., (2015[92]) estimated that protected areas in Brazil, Costa Rica, Indonesia and Thailand stored at least 1 000 $MtCO_2$ and provided ecosystem services worth at least USD 5 billion. Cheng, Sims and Yi (2023[93]) analysed panel data of Chinese Nature Reserves and observed that from 1980-2010, reserves maintained natural land cover. Miteva, Murray and Pattanayak (2015[94]) concluded that Indonesian protected areas reduced mangrove loss between 2000 and 2010 by 14 000 ha, mitigating about 13 $MtCO_2eq$. However, the effectiveness of protected areas varied, as Indonesian species management protected areas were not observed to reduce mangrove deforestation (Miteva, Murray and Pattanayak, 2015[94]).

Social and environmental factors can affect the mitigation additionality and effectiveness of zoning policies. Busch et al. (2019[22]) observed that deforestation is most likely to occur in areas of intermediate to high forest cover. Additionally, factors including proximity to cities, flatter land, and greater potential for agricultural revenue increase the risk of deforestation (Busch et al., 2019[22]). However, regions with high mitigation potential via conservation may have greater policy implementation and permanence risks; Doelman et al. (2019[95]) observed that high investment risks and weak governance may greatly reduce the effectiveness of policies in regions like Sub-Saharan Africa.

Market regulations can affect GHG emissions, but their impact may be hard to assess and varies by market and issue. Market regulations can support GHG mitigation through restricting practices and commodities. For example, a market regulation which restricts deforestation in certain areas can support mitigation efforts by preserving carbon sinks and healthy ecosystems (Gruère et al., 2023[54]).

The EU dairy quota is an example of a market regulation instrument which was found by some studies to reduce emissions, or rather to prevent additional emissions. After the phase out of the dairy quota in 2015, in seven countries, dairy cattle numbers were observed to increase by 2018 compared to 2008 (Kotyza et al., 2022[96]). This likely induced emissions from enteric fermentation and manure. In contrast, in some countries, dairy cattle herd sizes declined due to increased pressures from competition (Kotyza et al., 2022[96]). In Ireland, the removal of the dairy quota increased the number of dairy cows by about 46% by 2020 (Henn et al., 2023[97]). That said, the removal of the dairy quota also resulted in productivity gains, lowering the per unit GHG emissions (Läpple, Carter and Buckley, 2021[98]). However, it is unlikely that the productivity gains were sufficient to offset the large increase in livestock numbers observed.

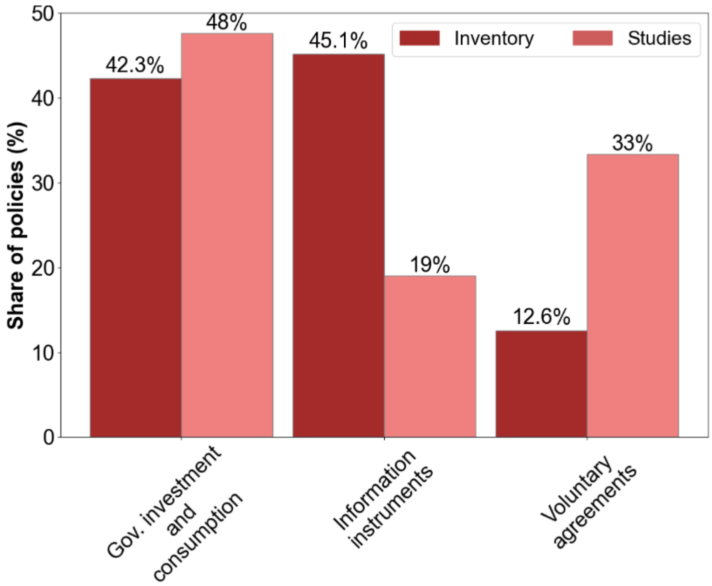
Some regulatory instruments may have secondary aims to reduce GHG emissions but may instead induce emissions. One example is on-farm feed requirements for Swedish organic milk producers (Aggestam and Buick, 2017[99]). The policy requires organic dairy farmers to produce a higher proportion of on-farm feed, and is intended to promote self-sufficiency, reduced reliance on external inputs, and mitigate transportation emissions. However, Aggestam and Buick (2017) found that this instrument increases GHG emissions as organic on-farm vehicle-related emissions exceed the emission savings from international transport of feed inputs.

5. Reported effects of other instruments

The *other instruments* category accounts for about 17% of the policy inventory (OECD, 2024[7]), and had the fewest number of mitigation studies within the reviewed pool. Half of the studies *on other instruments* focused on the government investments in consumption instrument type and a third focused on the voluntary agreements instrument type.

Few studies were found on the mitigation effectiveness of information instruments. However, information instruments account for a larger percentage of the policy inventory at about 45% of policies (Figure 5.1). Causal impacts of information instruments on GHG mitigation are challenging to evaluate as many factors influence producers' decisions including economic incentives and social factors. Additionally, many policy assessments may not target GHG effects and may instead study other outcomes like change in behaviour.

Figure 5.1. Share of reviewed policy studies and policy inventory instruments by *other instruments* type



Note: Note: Inventory data is from PIMA-AFOLU.
Source: OECD (2024[7]).

5.1. Government investment and consumption

Research and development (R&D) is a common instrument within *government intervention and consumption,* accounting for about 42% of policies (OECD, 2024[7]).

About three-quarters of studies on R&D instruments concluded positive effects on emissions reduction with an average mitigation of 28 tCO2eq $ha^{-1}yr^{-1}$, but their effectiveness varies. Some studies observed strong mitigation benefits, often focusing on improvements in agricultural practices for soil quality, productivity, and breeding programmes (Fleming-Muñoz, Preston and Arratia-Solar, 2020[100]; Gruère et al., 2023[54]; Baldos, 2023[101]; Dooley, Christoff and Nicholas, 2018[102]; Fisher, 2016[103]). Other assessments observed positive but less effective mitigation impacts (Blaustein-Rejto et al., 2022[104]; Laborde et al., 2021[105]).

R&D can support mitigation efforts through increased total factor productivity. Fuglie et al. (2022[106]) modelled that crop productivity improvements from R&D could reduce cropland expansion by 2050 by about half. Additionally, R&D can improve productivity by decreasing the emission intensity of agricultural inputs, including pesticides, through the development of more pest-resistant seed varieties (OECD, 2016[37]).

Publicly funded R&D was likely essential for the development of some mitigation practices. Fleming-Muñoz, Preston and Arratia-Solar (2020[100]) evaluated the benefits of publicly funded research on mitigation through genetic markers in low methane animals and emissions mitigation management practices. They concluded that without strong government funding, previous livestock mitigation-related R&D developments would have been unlikely to occur. Therefore, continued government funding for R&D is critical for emission mitigation, innovation, and productivity developments in the livestock sector.

The mitigation potential of agricultural R&D could increase with additional public funding. Baldos (2023[101]) modelled positive net economic benefits when doubling US public investments in agriculture. Blaustein-Rejto et al. (2022[104]) found that in the United States, enteric fermentation accounts for 28% of agricultural emissions, but receives less than 2% of dedicated research funding. They observed that majority of funding was allocated to soil carbon sequestration, in particular, cover crops. Therefore, R&D could support mitigation by reducing GHG emissions intensities of the most emission-intensive commodities (Blaustein-Rejto et al., 2022[104]).

5.2. Information instruments

While direct effects of information instruments on emissions are difficult to assess, information instruments may also act as a flanking policy to enhance other policy efforts. For example, in Poland, vocational training, skills acquisition and advisory services on environmental issues were observed to influence on-farm decision-making, helping to increase the aid provided under the Rural Development Programme (RDP) (Instytut Technologiczno-Przyrodniczy and Instytut Uprawy Nawożenia i Gleboznawstwa, 2024[107]).

Information instruments can utilise social values to “nudge” farmers to adopt mitigation practices. For example, Kuhfuss et al. (2016[108]) observed that French farmers were two times more likely to maintain agri-environmental practices after the end of their contract without compensation if they were told that 80% of surveyed farmers intended to do so. However, conveying information that few farmers adopted a targeted practice may reduce adoption (Dessart, Barreiro-Hurlé and van Bavel, 2019[10]). Therefore, policy makers should consider the responses of farmers to information instruments when publishing education campaigns and data.

Policy makers should consider the trade-offs of the recommendations provided by governments through information instruments. For example, Paterson and Holden (2019[109]) assessed feasibility of the Irish Dairy Carbon Navigator tool which provides recommendations to farmers to lower their carbon footprint. They found that some recommendations like extending the grazing season reduces the carbon footprint of dairy farms, lowering emissions per unit output, but increasing total emissions and total eutrophication.

5.3. Voluntary agreements

More than half of reviewed studies concluded mixed or uncertain mitigation effects of *voluntary agreements*, though evidence is scarce and primarily driven by results on *voluntary carbon markets* and *covenants* (United States Department of Agriculture, 2023[59]; Paul et al., 2023[110]; Biró and Szalmáné Csete, 2020[111]; Kreft et al., 2023[112]).

Although voluntary agreements can lower GHG emissions, the review of literature suggests that their effectiveness is limited. This suggestion supports previous OECD findings on the environmental benefits of voluntary policies (Gruère et al., 2023[54]; Lankoski et al., 2015[9]). This may be due, in some cases, to low participation and lack of commitment from stakeholders (Paul et al., 2023[110]). For example, voluntary carbon markets face similar issues and outcomes as regulatory emissions trading systems (see Section 3.3) (United States Department of Agriculture, 2023[59]; Paul et al., 2023[110]). Official carbon creditors disclose the number and criteria of credits generated. In comparison, private carbon offsets may raise more doubts about permanence, as they lack long-term monitoring and face accountability and governance challenges (Paul et al., 2023[110]).

Covenants can be effective in mitigating GHG emissions (Ignaciuk and Boonstra, 2017[113]), although their effectiveness may be dependent on the regulatory constraints rather than voluntary actions for some instruments. Covenants are legally binding and enforceable agreements made voluntarily between the government and private sector. The government sets emission reduction targets and allows some freedom to the private sector to choose the methods used to achieve the targets. However, failure of the private sector to achieve the emission reduction targets results in government enforcement of regulations. These regulations are often included in the covenants.

To ensure the integrity of covenants, strong monitoring and enforcement measures are necessary. For instance, the Netherlands uses mineral accounts to monitor and enforce proper manure disposal of hog and poultry farms. Fines are imposed on producers who do not comply with the rules (Van Grinsven, Tiktak and Rougoor, 2016[114]).

Voluntary instruments may help address some social or funding concerns of policies. They may have lower negative distributional effects than taxes or regulations and have greater support from participants. Additionally, the instruments may be lower cost to governments, allowing for greater funding allocation to other mitigation instruments including subsidies, administrative costs and public investments like R&D and infrastructure.

6. Social and economic impacts of direct and indirect mitigation policies

Like all policies, direct and indirect mitigation policies may have intended and unintended socio-economic effects. Various changes in the social and economic spheres are also caused by indirect mitigation instruments which have GHG emissions reduction as a secondary objective. These effects include, climate change adaptation costs, income distribution of farmers, food prices, and health benefits.

Mitigation policies can reduce adaptation costs for both governments and producers. They can directly facilitate the adoption of climate change adaptation practices through for example, subsidies for more resilient and diverse crop varieties (Ignaciuk, 2015[115]). This can reduce the expected decline in farm profitability from climate change impacts. By reducing GHG emissions, mitigation policies can also reduce the severity and frequency of climate change damages, preventing some future crop and productivity losses. For example, in the United States, mitigation benefits are estimated to be USD 980 million in 2050 due to reduced incidence and damages of drought (Boehlert et al., 2015[116]). Thamo et al. (2019[117]) observe that in Australia, farm profitability is much more negatively affected by climate change than a carbon pricing policy. Additionally, policies such as environmental taxes and regulations can discourage agricultural land expansion, reducing the area requiring costly future adaptation and mitigation measures (Lungarska and Chakir, 2018[118]).

Policies may have different effects on prices, impacting producer incomes and consumer affordability. For example, policies including carbon taxes and environmental regulations may result in a larger increase in the price of ruminant products relative to other commodities. The OECD (2019[119]) modelled that a global consumption tax would be a large cost burden to both consumers and most producers. In contrast, Valin, Henderson and Lankoski (2023[120]) modelled that increased public funding for R&D could increase production and agricultural value added while decreasing food prices for consumers (although farm jobs also decreased).

While taxes may effectively mitigate emissions, they can have negative income effects on farmers. For example, Mardones and Lipski (2019[121]) modelled the implementation of an agricultural carbon tax in Chile. They observed that a tax reduces emissions but also lowers production, decreasing real GDP. It also could disproportionately affect poorer households compared with richer households. However, the financial burden would be higher for the wealthier households, if the tax is uniformly applied to all sectors (Mardones and Lipski, 2019[121]). In British Columbia, Canada, the provincial carbon tax was estimated to reduce net farm income-to-receipts ratios by 8-12 cents per dollar of farm receipts despite the exemption for on-farm gasoline and diesel (Olale et al., 2019[122]). The reduced net income relative to farm receipts was primarily driven by increased price of commercial feed, labour interest and depreciation costs relative to other provinces from 2000-2015 (Olale et al., 2019[122]). In contrast, Agriculture and Agri-Food Canada estimated that provincial and federal carbon pricing policies have small direct effects on farm income; the most affected activities were from propane and natural gas used for grain drying and the horticulture. On average, carbon pricing was estimated to decrease net operating income by 5% in greenhouse systems (Agriculture and Agri-Food Canada, 2020[123]). Average per-farm costs associated with emission pricing for grain drying activities were estimated to be 0.05-0.38% of net farm operating costs (Agriculture and Agri-Food Canada, 2021[49]).

Negative distributional impacts of carbon taxes may be reduced through coupling with flanking policies. For example, well targeted agricultural subsidies could buffer the tax's negative distributional effects on low-income producers (Grosjean et al., 2016[124]). Mittenzewi (2020[125]) analysed the effects of pairing a carbon tax with support policies for small farms to reduce the negative distributional effect of a tax in Norway. They observed that alone, the carbon tax would have a 7.9% reduction in 2025 compared to 2014 emissions, and with the small-farmers support it would decrease to 5.7% (subsidy alone has a 3.4% reduction), however the acceptability of the policy would rise.

Tax rebates and revenue neutral tax policies are other examples of flanking policies that may reduce negative distributional effects of carbon taxes. Such rebates may have progressive effects due to the elasticity of fossil fuel demand. For example, Ollier and De Cara (2024[126]) modelled the distributional effects of emission tax and rebate schemes in EU agricultural systems. They found that a flat rate tax rebate has progressive income effects while a rebate proportional to pre-policy emissions levels results in virtually unchanged inequality relative to pre-policy levels (Ollier and De Cara, 2024[126]).

Reducing agricultural emissions can generate large and positive net social and economic benefits, which can be partially reallocated to compensate farmers for adopting improvements to agricultural systems which support mitigation. For example, Giannadaki et al. (2018[127]) modelled that a 50% reduction in agricultural emissions could prevent more than 200 000 deaths per year, with economic benefits of many billions of USD. Raissi et al. (2021[128]) found that in Mexico, increasing the carbon price could prevent 11 600 deaths from local air pollution by 2030. Vandyck et al. (2020[129]) concluded that air quality co-benefits range from – USD 48 to USD 561 per tCO_2eq abated across sectors in 2030.

Fertiliser reduction policies contribute to the reduction of nitrogen oxide (NO_x) air pollutants (Almaraz et al., 2018[130]). NO_x contributes to many negative environmental effects including the formation of acid rain, PM2.5 air pollution, and increased ground level ozone (Mauzerall et al., 2005[131]). Instruments which reduce application of synthetic fertilisers like fertiliser and water quality regulations, or subsidies for organic farming can mitigate NO_x emissions. Mauzerall et al. (2005[131]) estimated that the health costs in the United States range from USD 64 -USD 315 per tonne of NO_x emitted.

7. Future work

The present review, while comprehensive, can help identify possible knowledge gaps and areas for future work. Notably, less than half of the reviewed studies conducted *ex post* analysis, particularly for indirect mitigation policies as they do not aim to mitigate emissions. As these indirect mitigation policies account for a considerable proportion of AFOLU mitigation-supporting policies identified by PIMA-AFOLU, further efforts should be made to assess their mitigation effects, including by conducting causal econometric analysis. This gap is highlighted by OECD (2025[132]) which reviews *ex post* empirical studies across many sectors, including AFOLU.

Further efforts are needed to facilitate robust and systemic *ex post* analysis. Challenges include administrative burden for producers and governments, data collection and reporting, and analytical challenges including counterfactual consistency and incorporation of other effects. Therefore, policy makers should build-in assessment requirements into policies to drive targeted capacity building for producers and government policy mitigation assessments.

Additionally, few of the reviewed studies analysed mitigation effects using comparable units like emissions per unit of input or output. Further efforts to compare the mitigation effects of instruments using different units and frameworks will help to better identify effective and context-relevant characteristics for mitigation policies. Further empirical work could also help determine if policy effectiveness is linear or if it saturates, as well as estimate cost effectiveness of mitigation policies, and scalability.

Future work is also needed to provide a more holistic understanding of the effect of all existing policies on a broader set of metrics. For example, the scope could include the entirety of food systems, including supply chains, consumers, and waste. Also, analysing and identifying the most harmful emission inducing policies could allow policy makers to more efficiently target and reorient mitigation efforts.

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Annex A. Methodology and caveats

Methodology

The literature review was conducted using peer-reviewed academic and grey literature. Studies included in this paper were identified initially using a systematic literature review. Using the Web of Science, publications from the years 2015-2023 for OECD member countries were selected in the following web of science categories: Economics or Agricultural Economics Policy, Environmental Sciences, Environmental Studies, Food Science Technology, Water Resources or Ecology, Forestry, Green Sustainable Science Technology, and Biodiversity Conservation or Forestry. The search terms selected were "mitigation," "agriculture," and "policy." This search yielded 269 publications which were manually sorted for relevance according to Table A A.1. No robustness exclusion criteria were applied due to the limited number of studies applying econometric methodologies; correlational studies may conclude larger effects than causal studies and may perhaps overstate the actual effect of the policies. Additional papers were included using the snowball method on relevant papers, policy assessments shared by OECD delegations, OECD publications, and relevant work from researchers' and reviewer's relevant libraries. About 190 relevant studies were identified and included in the report to provide supporting evidence and bridge gaps relating to relevance for GHG mitigation. Although few examples were found due to the search being conducted in English, relevant non-English literature was translated using Google Translate.

More than half of assessed papers provided quantitative estimates, but most estimates were not presented in meaningfully comparable units of emissions per hectare or per unit of input or output. The most used comparable unit was tCO_2eq mitigated per hectare per year. Therefore, only studies that provided area-based mitigation measurements, or measurements which could be converted to area-based measurements were included in the quantitative analysis of Figure 2.3. For example, some studies estimated tonnes of CO_2eq mitigated from water quality regulations, but it was difficult to assess the relevant amount of land regulated from the paper. Therefore, such studies were not included in the quantitative analysis in Figure 2.3. Studies which estimated total mitigated emissions of a country for policies that applied to all agricultural were converted to area-based estimates using the country's total agricultural area as reported by the World Bank. Reported mitigation effects were converted into annual effects if not provided by the study; for example, the cumulative mitigated emissions were divided by the number of years of the policy.

Table A A.1. Literature review inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Empirical study or review of direct or indirect mitigation policies or practices targeted by policies	
Type of study: peer reviewed article, book, report	Type of study: working paper
AFOLU sectors	Non-AFOLU sectors
OECD, G20 country or global	Non-OECD or G20 countries
Date range: within the last 10 years	Older than 10 years with exceptions for relevant studies identified through the snowball process.

Caveats and consideration

To interpret the findings of this review, understanding the context, limitations, and assumptions is necessary. Some of the below-mentioned caveats and limitations hold for policy assessment processes in general.

Literature review source selection

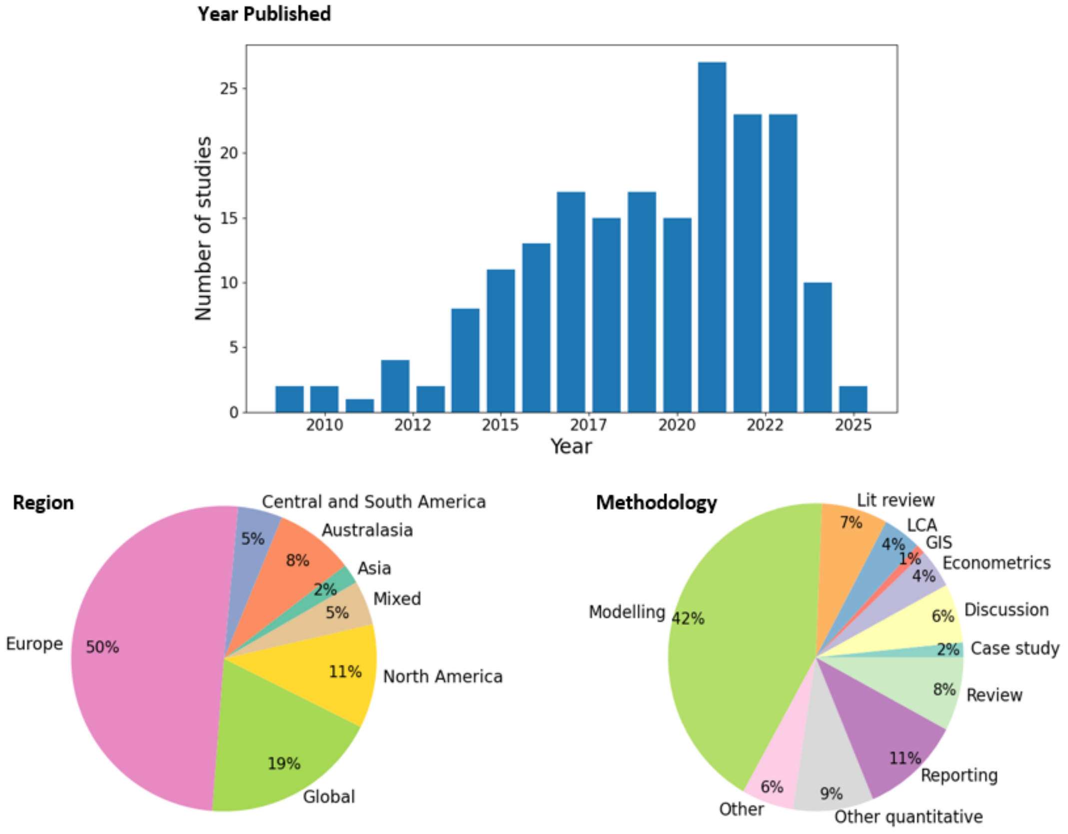
This paper focused on GHG emissions assessments and related studies of direct and indirect mitigation policies, in line with the policies included in PIMA-AFOLU. For example, policies that support the use of fossil fuels were not included due to their apparent emissions-inducing effects. This bias for policies intended to have positive environmental impacts resulted in bias of the policy assessment selection (Figure 2.3).

The scope of this literature review is limited to policies relating to production in AFOLU sectors. However, production systems cannot exist in isolation, and are connected holistically to other environmental and social systems in addition to entire food chains from production, consumption, and food waste.[16] Policy makers' efforts to balance numerous policy goals, policy effects and interconnected natural, food, and market systems are reflected in numerous policies and strategic plans.[17]

Methodology of studies

Over half of the reviewed literature were *ex ante* studies. *Ex ante* studies may produce less precise estimates of mitigation effectiveness than *ex post* analysis as they often rely on assumptions and models that may not accurately capture present-day realities. The distribution of *ex ante* versus *ex post* varies greatly by instrument type (see Table 2.1). For example, about half of studies on subsidies and trading systems are *ex ante* while all studies on carbon taxes are *ex ante*.

Figure A A.1. Summary characteristics of reviewed studies



Note: These graphs comprise of 194 studies

[16] An example of on-going efforts to analyse policies relating to consumer demand at the OECD include the FCAN network. Recent work on food loss and waste policies includes a stocktake conducted through the Working Party on Agricultural Policies and Markets.

[17] Examples of such policies may include the French National Food Nutrition Climate Strategy (SNANC), Japan's Basic Plan for Food, Agriculture and Rural Areas, and Mexico's Law on Sustainable Rural Development.

Approximately 42% of assessments rely on modelling, which may not accurately reflect the actual policy impacts. For example, model assumptions may include limits on land expansion or disregard environmental heterogeneity. Some models suggest policies that could effectively mitigate emissions, but are politically unfeasible (Jansson et al., 2023[133]; Henderson et al., 2021[51]). Modelling time periods vary, although more than half of studies modelled affects up to 15 years into the future. While a few studies assessed mitigation effects on long time scales (up to 2100), such models are unlikely to be accurate. Additionally, social dynamics and agricultural systems may evolve at differing rates, further complicating the reliability of these models. Despite the challenges and caveats associated with modelling, future-focused analysis is necessary to inform policy makers as they build instruments for future policy effects.

Both correlative statistics and causal analysis are necessary to accurately assess the mitigation effects of policies. In general, assessments conducted by governments often provide reported statistics and correlations between policies and reported outcomes. Reported statistics and correlations can present less biased data as they do not include assumptions made during the process of analysis, though they may still present bias through the data collection and cleaning process. The limited analysis inherent to reported statistics limits the interpretation of causal policy effects. Causal analysis conducted through *ex post* econometrics and stylistic models were primarily conducted through academic studies. However, these studies can introduce more biased results as econometric models require additional assumptions and simplifications applied to collected data. As econometrics only accounted for about 4% of studies, further efforts should be made to conduct causal *ex post* policy analysis in the AFOLU sectors.

The system boundaries of the studies also varied greatly. The scope of studies ranged from local and farm-level effects of policies to country level and global models. Therefore, some studies may more accurately account for farm heterogeneity and farm systems but may also exclude from the analysis broader effects like trade and leakage.

Heterogeneity

The mitigation impacts of policies may be dependent on the degree to which policies account for heterogeneity and location-specific environmental, social, and economic factors. For example, subsidies that target agricultural practices may ineffectively mitigate or induce GHG emissions depending on the system in which they are implemented. Additionally, the targeted practices may affect farm-level production decisions, resulting in differing environmental effects depending on factors including the type of good produced, location specific conditions like soil type and precipitation, and land availability.

Regulatory instruments which account for heterogeneity may be more effective. Kaye-Blake et al. (2019[134]) modelled that in New Zealand, policies which accounted for heterogeneity of agricultural practices and the environment reduced total nitrogen losses by farms. Total nitrogen losses are strongly correlated to GHG emissions as nitrogen inputs like manure and fertilisers are GHG intensive and their excess application can increase soil N_2O emissions. Additionally, accounting for heterogeneity improved the cost-efficiency of nitrogen regulations (Kaye-Blake et al., 2019[134]). Therefore, caution should be taken when extrapolating specific instrument recommendations to different systems or larger areas.

Compliance

The effectiveness of policies in mitigating emissions is dependent on producer compliance. Compliance is critical for all policies, including economic instruments like subsidies, taxes, and emission trading systems, regulatory instruments, and contractual other instruments like covenants and voluntary carbon markets. To assess and ensure compliance, policies must include effective monitoring and enforcement activities.

Monitoring methods and tools must be economically feasible for both governments and producers to implement. The administrative burden of monitoring may inhibit producer participation. While monitoring is often necessary to ensure compliance and measure policy impacts, monitoring increases the cost of participation for producers (Kotnik, Klun and Slabe-Erker, 2020[135]). For example, complex regulatory frameworks may require producers to spend more time or hire aid to determine monitoring and reporting requirements. Additionally, high monitoring and reporting frequency requirements may be a barrier for producer participation in voluntary instruments and subsidy programmes (Carter, Scott and Mahallati, 2017[136]). However, technological improvements like digital tools can lower these transaction costs and may support increased participation by lowering participation barriers (OECD, 2022[25]). Efforts to support administrative simplification is becoming an increasing priority of many OECD member countries (Martini, 2023[137]).

Monitoring of some modes of mitigation may be costly to accurately assess. For example, many policies mitigate emissions through improving soil carbon sequestration or preventing further soil degradation. However, the technical methods required to measure soil carbon sequestration may be costly when implemented at the farm-level due to non-routine laboratory soil tests (Reijneveld et al., 2023[138]). While common large-scale methods may support monitoring of soil quality like satellite imaging and modelling, their accuracy may be insufficient at the farm level (Tardieu et al., 2021[139]). There for continued efforts to develop improved and lower cost tools for farm-level assessment and monitoring are necessary.

Policies should be assessed periodically to identify gaps to ensure effective mitigation. Assessments of policy impacts using monitoring data can inform policy developments, improving the mitigation, environmental and social impacts of policies.

Enforcement is often critical to compliance, influencing the mitigation effectiveness of policies. Enforcement is necessary to ensure honest and accurate monitoring and reporting, and fulfilment of policy requirements. It supports mitigation by ensuring that policies are implemented as intended. Sufficient levels of enforcement are necessary to prevent ineffective policy implementation, and non-compliance (Poulin et al., 2016[140]). For example, Arima et al. (2014[141]) estimated that targeted and increased enforcement efforts in the Brazilian Amazon avoided 10 653 km^2 of deforestation.

Many studies assume perfect policy implementation, and therefore may overestimate mitigation effects. Policy makers must consider the feasibility of policy implementation and maintenance while simultaneously balancing policy ambition, multiple policy goals and costs.

What is assessed?

Policy evaluations may focus on policy design rather than measure policy impacts; indicators used for these evaluations may monitor the administrative and financial implementation of instruments (Pe'er et al., 2020[142]). Additionally, indicators may primarily describe farm structures rather than policy impacts (Pe'er et al., 2020[142]). Such indicators poorly assess the effectiveness of the policy and provide little value for policy assessment and improvements. For example, many education and training instruments often measure the number of visitors or workshop participants (Blom et al., 2022[143]). While these metrics are one necessary component to assess the success of the instrument, they alone cannot be used to assess the programme effects on mitigation. Metrics for outreach do not measure adoption of a mitigation practice or farm-level improvements, making it difficult to conclude causal effects of education and training instruments on GHG emissions mitigation.

Indirect mitigation policies may not monitor indicators necessary to assess emission impacts. Indirect mitigation policies have non-emission targets like organic farming, biodiversity, producer income or water quality. Therefore, monitoring is typically only used to assess policy targets rather than additional policy benefits including GHG mitigation. This report finds that most emission assessments of indirect mitigation policies are conducted through academic research and modelling rather than *ex post* policy assessments. To accurately evaluate mitigation, increased monitoring is necessary, including the development and implementation of mitigation indicators for indirect mitigation policies.

Annex B. Additional reviewed studies not included in the references

Authors	Paper name	Journal	Year	Link
Abimbola, I. and D. Feliciano	Assessing the Area of Suitable Land for Climate Change Mitigation with Sitka Spruce (Picea sitchensis) in Scotland	Land	2022	10.3390/land11101753
Adenaeuer, L; Breen, J; Witzke, P; Kesting, M; Hayden, A; Donnellan, T	The potential impacts of an EU-wide agricultural mitigation target on the Irish agriculture sector	Climate Policy	2023	10.1080/14693062.2022.2105791
Agriconsulting	Italian Case Study - Evaluation of Climate Stability Measures in Emilia Romagna	European Evaluation Helpdesk for Rural Development	2016	https://eu-cap-network.ec.europa.eu/publications/italian-case-study-evaluation-climate-stability-measures-emilia-romagna_en#section--resources
Agriconsulting	Cross-cutting assessment of the effects of regional programmes in reducing greenhouse gas emissions	EU Cap Network	2024	https://eu-cap-network.ec.europa.eu/publications/cross-cutting-assessment-effects-regional-programmes-reducing-greenhouse-gas-emissions_en#section--resources
Albanito, F; Hastings, A; Fitton, N; Richards, M; Martin, M; Mac Dowell, N; Bell, D; Taylor, SC; Butnar, I; Li, PH; Slade, R; Smith, P	Mitigation potential and environmental impact of centralised versus distributed BECCS with domestic biomass production in Great Britain	Global Change Biology Bioenergy	2019	10.1111/gcbb.12630
Anderl, M. et al	BEWERTUNG DER AUSWIRKUNGEN DER SCHWERPUNKTBEREICHE Verringerung Treibhausgase Landwirtschaft (5D) Kohlenstoffspeicherung in Land- u. Forstwirtschaft (5E)	Umweltbundesamt	2019	https://info.bml.gv.at/dam/jcr:ab6a7a10-8f7d-4338-a68a-0a1f909b0bff/SPB%205D_5E_Treibhausgase%20und%20Kohlenstoffspeicherung.pdf
Andersen, M. and G. Bonnis	Climate mitigation co-benefits from sustainable nutrient management in agriculture: Incentives and opportunities	OECD Environment Working Papers	2021	10.1787/a2960c54-en
Austin, K.G. et al.	The Economic Costs of Planting, Preserving, and Managing the World's Forests to Mitigate Climate Change	Nature Communications	2020	10.1038/s41467- 020-19578-z.
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