MIND STEP

# MODELLING INDIVIDUAL DECISIONS TO SUPPORT THE EUROPEAN POLICIES RELATED TO AGRICULTURE

# Deliverable D6.4: Policy evaluation

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| DATE OF APPROVAL: | dd.mm.yyyy |
| | |
| CALL H2020-RUR-2018-2 | Rural Renaissance |
| WORK PROGRAMME Topic RUR-04-2018 | Analytical tools and models to support policies related to agriculture and food - RIA Research and Innovation action |
| PROJECT WEB SITE: | |



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# LIST OF ACRONYMS

| | |
|---|---|
| ABM | Agent Based Model |
| AgriPoliS | Agricultural Policy Simulator |
| CAP | Common Agricultural Policy |
| CAPRI | Common Agricultural Policy Regional Impact |
| $CO_2$eq | CO2 equivalent |
| EC | European Commission |
| EU | European Union |
| FADN | Farm Accountancy Data Network |
| FarmDyn | a dynamic mixed integer bio-economic farm scale model |
| F2F | Farm to Fork |
| FSS | Farm Structure Survey |
| GAEC | Good Agricultural and Environmental Conditions |
| GAMS | General Algebraic Modelling System |
| GHG | Green House Gasses |
| GLOBIOM | Global Biosphere Management Model |
| IDM | Individual Decision Making |
| IFM-CAP | Individual Farm Model for Common Agricultural Policy Analysis |
| INRAE MC | INRAE MultI-Crop model |
| IPCC | The Intergovernmental Panel on Climate Change |
| MAGNET | Modular Applied GeNeral Equilibrium Tool |
| MACCS | Marginal Abatement Cost Curves |
| MIND STEP | Modelling INdividual Decisions to Support The European Policies related to agriculture |
| N | Nitrogen |
| NUTS | Nomenclature of territorial units for statistics (French: “Nomenclature des Unités Territoriales Statistiques”)<br>NUTS 1: major socio-economic regions<br>NUTS 2: basic regions for the application of regional policies<br>NUTS 3: small regions for specific diagnoses |
| SSP | Shared Socioeconomic Pathways (SSP) |

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# EXECUTIVE SUMMARY

This deliverable presents the testing of the MIND STEP toolbox to perform an integrated ex-ante policy assessment based on the various spatial scales and economic, environmental and social dimensions of the models in the toolbox. We applied the toolbox to examine two benchmark scenarios for EU agriculture in 2030, regarding climate mitigation and reduction of mineral nitrogen fertiliser use, key issues identified by the MIND STEP stakeholders. These scenarios link different models and activities across the MIND STEP project.

The new modelling possibilities offered by the MIND STEP toolbox are based on the bioeconomic and technology rich farm model FarmDyn and other micro-models that have been added to the set of micro- and macro-models frequently used by the European Commission (IFM-CAP, CAPRI, GLOBIOM, MAGNET). The micro-models include farm management changes and therefore allow more realistic assessment of scenario impacts. The modelling work in MIND STEP has not only improved the representation of farmer behaviour, technological options, and management practices at Individual Decision Making level, but has also established improved linkages with the sectoral models MAGNET, CAPRI, and GLOBIOM, which is a stated objective of the MIND STEP project.

Notwithstanding these improvements, the model results can still exhibit a rather wide range of possible outcomes. This wide range can in particular be attributed to data uncertainty and different levels of mitigation technologies represented in the models.

The analysis of the results of the  GHG mitigation and mineral N fertilizer use reduction strategies provide valuable information for future policy formulation within the Common Agricultural Policy (CAP). A gradual implementation of combined approaches of taxation and subsidies emerge as a potential strategy to balance income stability and environmental objectives. Particularly relevant is the role that evolving technology may have in achieving sustainable agricultural practices.

Finally, Deliverable 6.4 also sheds light on three main areas for refining the MIND STEP toolbox: (i) improving accuracy in representing farm-level impacts and incorporating structural changes; (ii) improving data quality, especially with regard to the specific costs of each region and sector and the mitigation potentials of new technologies; and (iii) enhancing model alignment and transparency. Addressing these methodological aspects will ultimately strengthen the quality of model-based scientific advice for the CAP, aimed at a nuanced and adaptable implementation of sustainable agricultural practices.

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# 1. INTRODUCTION

This report describes the testing of the MIND STEP toolbox to perform an integrated ex-ante policy assessment based on the various spatial scales and economic, environmental and social dimensions of the models in the toolbox. We applied the toolbox to examine two benchmark scenarios for EU agriculture in 2030, regarding climate mitigation and reduction of mineral fertiliser use, key issues identified by the MIND STEP stakeholders. These scenarios link different models and activities across the MIND STEP project. For instance, the individual farm models developed under Task 3.3 and Task 3.4 and the improved IFM-CAP, GLOBIOM and MAGNET models from WP5 help to provide a better representation of the farm heterogeneity, a more detailed assessment of mitigation potentials, costs and adoption of mitigation technologies and aspects of structural change.

The key arguments behind these two scenarios can be found in the European Green Deal (European Commission, 2019), a comprehensive policy framework that integrates environmental, economic and social dimensions to combat environmental degradation and promote a sustainable and resilient Europe. Its main goal is to transform Europe into the world's first climate-neutral continent by 2050. By adopting the European Climate Law (EU Regulation, 2021) under the Green Deal, the member states committed to cutting net GHG emissions in the EU by at least 55% by 2030, compared to 1990 levels. This target is legally binding. Importantly, the Green Deal recognises that Europe cannot become climate neutral without integrating sustainable natural resource management into various EU policies. This is particularly relevant for agricultural policy in the Farm to Fork (F2F) strategy (European Commission, 2020a ), a key pillar of the Green Deal, which main goals are to:

- ensure sufficient, affordable and nutritious food within planetary limits;
- halve the use of pesticides and fertilisers and sales of antimicrobials;
- increase the amount of land devoted to organic farming;
- promote more sustainable food consumption and healthy diets;
- reduce food loss and waste;
- improve animal welfare.

The Green Deal also strengthens the protection of the environment by introducing a Zero-pollution strategy that resulted in the EU Action Plan "Towards a Zero Pollution for Air, Water and Soil" (European Commission, 2021a), and updating the Soil strategy (European Commission, 2021b). In addition, through the EU Biodiversity strategy for 2030 (European Commission, 2020b) reiterates the call for full integration of biodiversity objectives into other sectors, such as agriculture.

The Common Agricultural Policy (CAP) currently represents approximately 33% of the EU budget. Consequently, the CAP can play a decisive role in stimulating sustainable agricultural practices and improving ecosystem services provided by agroecosystems. In this way, the CAP could contribute to achieving several objectives of the F2F strategy and the EU Biodiversity Strategy for 2030. The last two CAP programs show this interest and include three levels of environmental and climate commitments, ranging from mandatory (lowest level) to optional (highest level). For example, the CAP 2023-2027 program has three mechanisms:

- Improved conditionality (compared to the previous CAP conditionality), linking direct income support with environmentally friendly agricultural practices known as “Good Agricultural and Environmental Conditions” (GAEC).
- Eco-schemes, which support many types of voluntary actions that go beyond conditionality and other obligations, including practices related to better nutrient management, agroecology, agroforestry and carbon farming.
- Strategic Plans, the main innovation of the current CAP, designed by the EU countries to achieve the Specific Objectives (SO) of the CAP. Three of the ten strategic objectives refer directly to climate and the environment:

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- SO4: contribute to climate change mitigation and adaptation, including reducing GHG emissions and improving carbon sequestration;
- SO5: promote sustainable development and efficient management of natural resources such as water, soil and air;
- SO6: contribute to the protection of biodiversity, improve ES and preserve habitats and landscapes.

The use of a model toolbox including models on various scales and sustainability dimensions is not new. Combined model use and model comparison have been widely analysed in the literature, including Helming et al. (2023), Gonzalez-Martinez et al. (2021), Jongeneel et al. (2020), Frank et al. (2019) and Hutchings et al. (2018). In particular, the main hurdles relate to the different background, approaches and objectives of the different models, as well as the different networks of model users and developers, programming language and IT solutions. MIND STEP takes a new step in this integrated modelling process, with the addition of individual decision making through agent-based and farm-level models. Furthermore, it improves the coherence and micro-economic underpinnings of the macro-scale models frequently used by the European Commission. Finally, the combined use of the models in the MIND STEP toolbox enlarges the scope of the analyses and enables answering more complex questions. Therefore the scenario applications and results presented here are a new and valuable source of information for policymakers and model users, and can contribute to better informed decision making.

As a reading guide the following is important to keep in mind. Chapter 2 describes the scenarios definition process and the two selected scenarios. Chapter 3 starts with a summary of the models from the MIND STEP toolbox that are used in this deliverable. Paragraph 3.2 gives some general background to the baseline assumptions towards 2030, that will be used as comparison base for the counterfactual scenarios. For the interested reader baseline details of the market models CAPRI, MAGNET and GLOBIOM are presented as well. Paragraph 3.3 presents the economic, environmental and social indicators considered in this deliverable. Chapters 4 and 5 describe in detail the scenarios (storylines, models used, scenarios and corresponding taxation and subsidy strategies and their variants) and report and discuss the results. Key model results of the greenhouse gas mitigation scenario and the mineral nitrogen fertilizer use reduction scenario are summarised in paragraph 4.4.1 and paragraph 5.4.1 respectively. The reader who is interested in detailed model results is referred to paragraphs 4.4.2 to 4.4.4 for detailed model results regarding the greenhouse gas mitigation scenario and to paragraphs 5.4.2 to 5.4.6 regarding the mineral nitrogen fertilizer use reduction scenario. Otherwise it is also possible to go from key model results in paragraph 4.4.1 and paragraph 5.4.1, immediately to the discussion of model results in paragraphs 4.5 and 5.5. Chapter 6 provides the policy recommendations and a roadmap for further model enhancements.

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# 2. HOW WE DEFINED THE TWO SCENARIOS

In the first part of the project we identified key policy objectives, related policy questions and benchmark scenarios that should be addressed by the MIND STEP toolbox (Coderoni et al., 2021). Figure 1 illustrates the five-step process that was used to facilitate the definition of policy questions and scenarios. This process involved three groups: the project research group, the policy-expert team, and the MIND STEP core stakeholders' group, including public and private stakeholders. Figure 1The stakeholders' engagement led to a comprehensive definition of the policy objectives and brought up two major recommendations: (1) prioritising environmental issues and (2) jointly analysing the economic and environmental performances (at the farm and the territorial levels). The outcome of the process was a list of key policy questions and related benchmark scenarios with a particular preference for environmental and low-carbon scenarios.

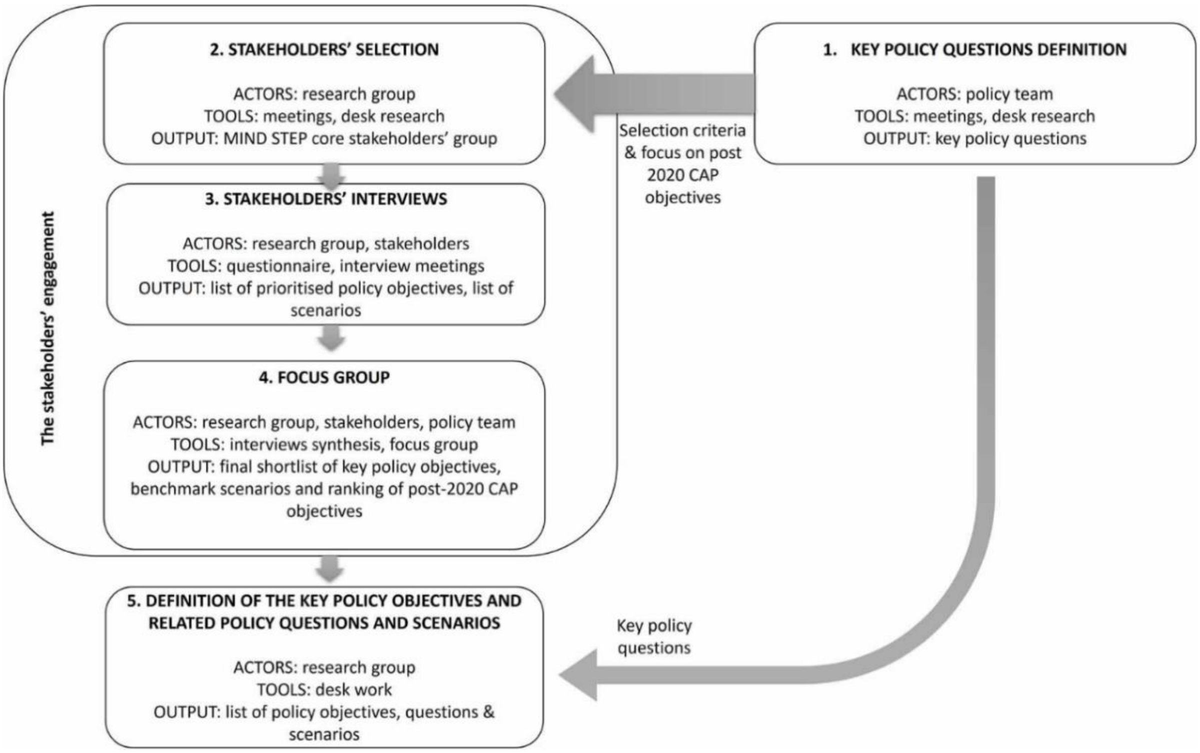


*Figure 1. Actors, tools and output of each step of the proposed approach (Coderoni et al., 2021)*

Subsequently, we defined the greenhouse gas mitigation scenario and the mineral nitrogen (N) fertiliser input use reduction scenario, considering previous research and the new modelling possibilities offered by the micro-models in the MIND STEP toolbox, as described in chapter 3. The resulting scenario storylines of the two scenarios are described in chapters 4 and 5 respectively.

Regarding previous research, we found a large number of publications focussing on impacts of climate change scenarios, including Frank et al. (2019) and OECD (2018). Frank et al. (2019) applies four different well-known, global, top-down economic-models, to provide a comprehensive assessment of the potential contribution of the agricultural sector to ambitious GHG mitigation efforts on the supply and demand sides, namely the integrated assessment model IMAGE, the partial equilibrium models CAPRI and GLOBIOM and the computable general equilibrium MAGNET. The models include market effects, but impacts at farm level are missing. Also economic and environmental impacts of reducing

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use of mineral N fertilisers can be found in the literature. Wesseler (2022) gives an overview of studies assessing the economic impacts of F2F, including the policy objective to reduce nutrient losses by at least 50%, implying a reduction of mineral N fertiliser use by at least 20% by 2030. Sud (2020) assesses price elasticities of N from mineral fertilizers. Helming et al. (2023) assessed the economic and environmental impacts of a tax on N from mineral fertiliser on a representative dairy and arable farm in a region in the Netherlands. It was found that a tax on N from mineral fertiliser has relatively large income effects, while the impacts on various environmental indicators are relatively limited.

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# 3. MIND STEP TOOLBOX

## 3.1. Model overview

This section provides some general information on the selected models in the MIND STEP toolbox used to model the scenarios. The list of models and their main characteristics are presented in Table 1.

*Table 1 Selected models in the MIND STEP toolbox and their main characteristics*

| Name of the model | Partner responsible | Type of model | Spatial coverage | Scope (macro/micro) | Smallest scale of analysis |
|---|---|---|---|---|---|
| | | | | | |
| 1 MAGNET | WUR | General equilibrium | Global | Economy-wide (all sectors) | National |
| 2 CAPRI | THUENEN | Partial equilibrium | Global | Agricultural sector | EU NUTS2 (regional farm) |
| 3 GLOBIOM | IIASA | Partial equilibrium | Global | Agricultural and forestry sectors | 5 arcminute grid |
| 4 FarmDyn | UBO / WUR | Optimisation model | Dairy and arable farms in the EU FADN | Individual farm (representative or typical farms) | EU NUTS2 (average dairy & arable farms[1]**)** |
| 5 IFM-CAP | JRC-SEVILLA | Optimisation model | ~80000 farms in the EU FADN | Individual farm | Individual farm |
| 6 INRAE MC | INRAE/UCSC | Simulation exercise | EU NUTS 3 (France, Italy) | Individual Farm | Individual farm (arable) |

*1. FarmDyn can also run individual dairy and arable farms.*

The MIND STEP toolbox covers individual decision making (IDM) at farm level, as well as models that operate at market- or sector level. The latter include the general equilibrium model MAGNET and the partial equilibrium models CAPRI and GLOBIOM. These three models permit the simulation of economy-wide (MAGNET) or sectoral (CAPRI, GLOBIOM) effects of policies or technological change on markets, resource allocation, or agricultural incomes, aggregated at a global or EU level (Figure 2).

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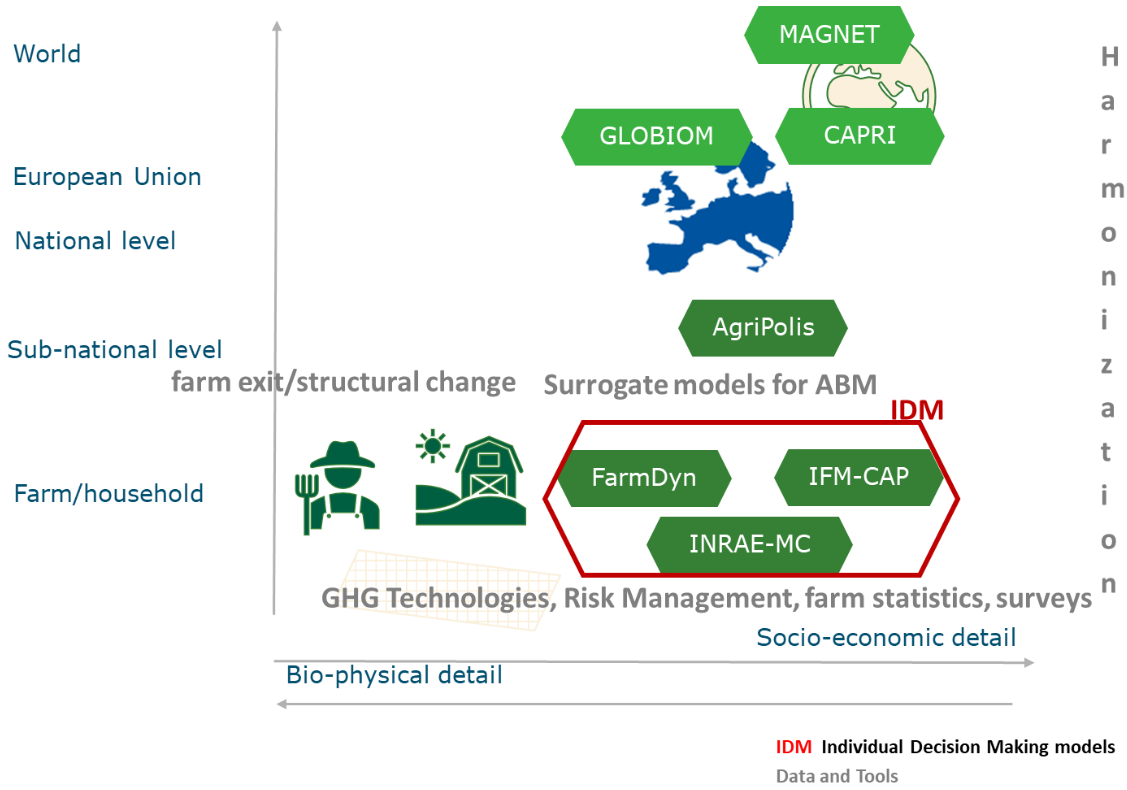


*Figure 2 Scales, levels of detail (scopes), and linkages of models in the MIND STEP toolbox*

It is the addition of the Individual Decision Making (IDM), the farm-level optimisation models FarmDyn, IFM-CAP and the farm level, econometric simulation INRAE-MC model in the MIND STEP toolbox, which allows a deeper insight into the adjustment processes that take place, whether on representative or typical farms (FarmDyn), or on individual farms (IFM-CAP, INRAE-MC) included in the Farm Accountancy Data Network (FADN). The advantage of IDM models is that they include heterogeneity between farms and can identify which type of farms would take up a new technology or benefit from a certain policy (see e.g. Britz et al. 2021 and Müller et al. 2023). However, FarmDyn and IFM-CAP cannot take into account aggregate effects at sector- or markets levels, which are typically computed by the three “global” aforementioned models. For example, income effects of taxation measures to decrease environmental emissions from agricultural production, on so-called continuing farms that stay in the sector, might be dampened by higher output prices because of a reduction in supply at the sector level. Or the other way around, increased cultivation of protein crops may be beneficial for the environment and for certain farmers at current prices and policies, but if a larger number of farms supply the market with these crops, prices will likely drop, thus slowing down the uptake of this measure by more farmers. Especially the technology rich model FarmDyn can also be used to generate technology specific parameters of mitigation potentials and costs to be used as input in the large scale models. For these reasons, the modelling work in MIND STEP has not only improved the representation of farmer behaviour, technological options, and management practices at IDM level, but has also established linkages with the sectoral models MAGNET, CAPRI, and GLOBIOM, which is a stated objective of the MIND STEP project.

Examples for such linkages are depicted in Figure 3**Error! Reference source not found.**. By including a range of technology and management options for greenhouse gas (GHG) emission reduction (e.g. feed additives, grassland management, extension of number of lactation periods), FarmDyn was used to

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generate improved versions of marginal abatement cost curves (MACC) in the MAGNET model to depict the additional cost for GHG mitigation at sector level. At the same time, cost structures of these new technologies were directly included in the GLOBIOM model. Subsequently, the aggregate models were shocked with the policy scenarios for GHG mitigation and on mineral N fertilizer use reduction identified above and the resulting price effects were fed back into FarmDyn. MIND STEP Deliverable 5.2 (Krisztin et al. 2023) provides detailed insights with regard to the realized model improvements and linkages.

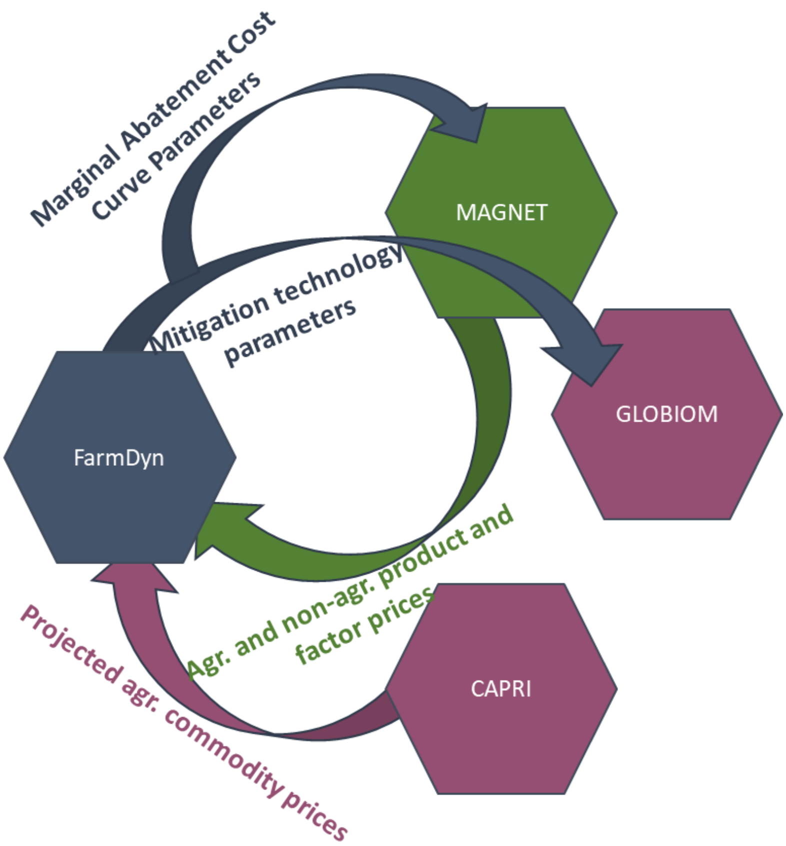


*Figure 3 Linkages between the sector/markets models (MAGNET, GLOBIOM and CAPRI) and the Individual decision making model FarmDyn in the MIND STEP Toolbox*

## 3.2. Baseline

An important feature of the market-level simulation models is that they not only allow policy scenarios to be compared in a base-year, but also calculate potential future trajectories for the model results. A baseline in this context is a projection of future developments, which includes usually rather moderate assumptions about the developments of the model's drivers, such as general economic developments, technical change, population growth, and policy changes. It is also often labelled as "business-as-usual" or "middle-of-the-road" scenario. Agricultural commodity prices may show absolute changes for each commodity, but the price-ratios between different commodities usually do not change substantially under such assumptions. This baseline serves as a reference for additional (cumulative) scenarios, where novel technologies or policies, or more extreme climate change effects are taken into account.

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The baselines for the MAGNET, CAPRI, and GLOBIOM market-level models are based on similar assumptions about economy-wide drivers, such as average GDP or population growth. Therefore, the baselines used in this deliverable focus primarily on the trend. Despite the different approaches for baseline construction, these differences disappear once the relative deviations of a scenario from the baseline are calculated. The following sections provide an outline of the general assumptions behind the baselines.

### 3.2.1. MAGNET

Magnet: MAGNET's baseline is developed on the basis of the following assumptions: a) GDP and Population, factor productivity (i.e. land productivity and availability) and globalisation level are built following the so-called Shared Socioeconomic Pathways (SSP) (Riahi et al. 2017), i.e. generic narratives of different future perspective on the basic socioeconomic variables. In particular, this case study is based on SSP2, the "Middle of the road" assumption. The timeframe is (up to) 2030, with starting year is 2014. Feed efficiency in the livestock sector is instead calibrated on the IMAGE model (Stehfest et al. 2014). Finally, the baseline assumes the implementation of CAP policies (first and second pillar), specific blending targets for first generation biofuels and the existence of an Emission trading system setting the prices of a ton of CO2qu at 35 euros in 2020, 85 euros in 2025 and 130 euros in 2030.

### 3.2.2. CAPRI

The CAPRI database comprises of historical time series from various sources, mainly EuroStat and FAO. For future periods, the results from the DG AGRI outlook is used, which is based on the Aglink-COSIMO model. Generating baseline projections in CAPRI involves the construction of independent trends on all series, providing initial forecasts and statistics on the goodness of fit or indirectly on the variability of the series. Second, plausibility constraints like identities (e.g. production = area * yield) or technical bounds (like non-negativity or maximum yields) are imposed and specific expert information given on the MS level is introduced. In a third step, expert information on aggregate EU markets in included, which, typically comes from the AgLink model or GLOBIOM. This external data is not available for all individual countries in CAPRI, but for larger regions. Finally, Results from external projections on market balance positions (production, consumption, net trade etc.) and on activity levels for EU aggregates (EU15, EU12) are added. Currently, these projections are provided by Aglink-COSIMO model projections. The baseline of Aglink-COSIMO integrates the market outlook results from DG-AGRI, but is also globally harmonised, so that it also enters the baseline generation for the market model of CAPRI. As DG-AGRI is often the main client of the CAPRI projections for the EU, it was deemed sensible to pull the projections towards the DG-AGRI baseline wherever the constraints of the estimation problem and potentially conflicting other expert sources allow for it.

### 3.2.3. GLOBIOM

The baseline scenario corresponds to the SSP2 middle-of-the-road scenario without land-based climate mitigation efforts (Fricko et al. 2016; O'Neill et al. 2014). Population and GDP projections were implemented in GLOBIOM based on the SSP database (https://tntcat.iiasa.ac.at/SspDb/). Income elasticities are calibrated to mimic FAO projections of diets (Alexandratos and Bruinsma 2012). We assume moderate reductions in food waste and losses over time add to the availability of agricultural products (FAO 2011). Technological change for crops is based on crop specific yield responses function to GDP per capita growth estimated for different income groups using a fixed effects model (Nelson et al. 2024). Fertilizer use and costs of agricultural production increase in proportion with yields. Productivity changes through technological change in the livestock sector and transition towards more efficient livestock production systems takes place at a moderately fast pace. Details on the SSP2 drivers and scenario implementation are also provided in Fricko et al. (2016).

## 3.3. Indicators

The indicators in the MIND STEP toolbox that are considered most important for the scenarios are mentioned in Table 2.

Not all indicators are covered by all models. The farm models (FarmDyn, IFM-CAP and INRAE-MC model) focus on potential changes in farm management, farm income and emissions (GHG, N-surplus) on the farm. The agricultural sector models (CAPRI, GLOBIOM) focus on agricultural production, consumption, trade, producer and consumer surpluses, and agricultural emissions at sector and regional level. In addition to impacts on agricultural production and consumption and GHG emissions, the economy-wide MAGNET model adds impacts on the total economy, such as GDP and employment. MAGNET also add results on total calorie intake specified by products. Please note that in MAGNET indicators are measured in monetary terms, while in all other models the indicators are assessed in physical terms.

*Table 2 Indicators in the MIND STEP toolbox considered most relevant for the scenarios grouped by sustainability impacts, as defined in the MIND STEP indicator framework.*

| **Impacts** | |
|---|---|
| **Economic** | Total agricultural primary production and per sector<br>Total agricultural primary consumption and per sector<br>Crop yield per hectare<br>Producer and consumer surpluses<br>Price of agricultural primary goods<br>Land prices<br>Net trade of livestock products and arable products<br>Farm income<br>GDP by farm size<br>Total calories<br>Calories of animal products |
| **Environmental** | Agricultural land use<br>Feed use<br>N use from mineral fertilisers<br>N use from animal manure<br>Total N surplus<br>Total GHG emissions<br>GHG emission from agriculture<br>Carbon price |
| **Social** | Employment |

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# 4. SCENARIO 1: GREENHOUSE GAS MITIGATION SCENARIO

## 4.1. Storyline

The “Green Deal” has become the leitmotif of EU policies with the von der Leyen Commission’s proposal to raise the GHG reduction target to 55% in 2030 compared to 1990, and thus speed up the path towards a climate-neutral European economy by 2050. In the EU, agriculture is responsible for about 13% of GHG emissions caused by enteric fermentation, agricultural soils, and fertilization (Eurostat, 2020). Hence, climate policy measures in the agricultural sector are of great importance to achieve the EU's ambitious climate target of net zero emissions in the Agriculture, Forestry, and other Land Use (AFOLU) sector by 2035 and across all economic sectors by 2050.

The EU currently spends more than a third of its budget on the CAP , and thus having a powerful tool to transform the agricultural sector into a sustainable and climate-friendly sector. Until the CAP 2023-2027, EU agricultural policies and related budgets have paid little attention to climate mitigation measures.

From the point of view of economic theory, a tax on GHG emissions would be the best option to cost-effectively direct the change in technologies for low-GHG production systems. According to IPCC (2023) Economic instruments have been effective in reducing emissions. By 2020, over 20% of global GHG emissions were covered by carbon taxes or emissions trading systems (IPCC, 2023). However, it is expected that application to the agricultural sector has large impacts on agricultural production, income and number of farms due to limited substitution possibilities in the short term. Therefore, the introduction of a tax on GHG emissions in the agricultural sector will likely encounter resistance, making its political implementation challenging.

Another approach to reducing GHG emissions would be to use the existing spectrum of CAP 2023-2027 financing and tools to incentivise climate-friendly agricultural production. One option would be to provide a subsidy towards more specific measures, financed from the current basic payment of the first pillar of the CAP. For example, subsidies for the deployment of abatement technologies to reduce direct GHG emissions, especially in the livestock sector.

Considering the above, the MIND STEP toolbox addresses the GHG mitigation scenario by investigating the effects on non-CO2 GHG emissions at the farmgate level of: (1) a tax strategy to steer the transition towards more efficient production systems in terms of GHG, (2) a subsidy strategy financed with the direct payments of the first pillar of the CAP.

To this end, the scenario considers different farm management measures and abatement technologies to mitigate GHG emissions and GHG emission sources, among others: a) enteric fermentation, b) emission from stables and manure storage, c) pasture droppings, d) emissions from manure application, and e) emissions from mineral fertilizer applications and upstream emissions related to purchased inputs.

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## 4.2. Models used and strategies and variants

From an impact-assessment perspective, it is relevant to identify the isolated and combined effects of the four strategies on a wide range of indicators. Particularly, policies to reduce GHG emission (this Chapter) and use of mineral fertilisers (Chapter 5) can have effects on the EU wide agricultural production, in terms of trade balances, through leakage effects in other parts of the world, and of course on the European farm landscape as well. Particularly the latter is complex, with multiple type of farms having varying response to policies. This multi-scale approach in Chapters 4 and 5 allow policymakers to gain a comprehensive understanding of the potential consequences of the policies and make informed decisions that balance economic, environmental, and agricultural considerations.

We summarise the four strategies considered in the GHG mitigation scenario with their variants and the models used to estimate their effects, in Table 3. To cover a wide range of indicators, the models used to assess the GHG mitigation scenario are the global, market models MAGNET and GLOBIOM and the farm model FarmDyn. Per strategy and variant changes in market prices of agricultural inputs and outputs from MAGNET are used as input in the FarmDyn model. FarmDyn results in this report should be considered as average results for continuing farms with total acreage of land equal to the base[1]. This also accounts for other farm models in this report, except farm exit modelling in Germany in IFM-CAP (Chapter 5). The models are described in MIND STEP Deliverable Report 5.2 (Krisztin et al. 2023).

**TAXATION**

So far As mentioned above, from the point of view of economic theory, a tax on GHG emissions would be the best option to cost-effectively direct the change in technologies for low-GHG production systems. Furthermore, a tax is also in line with the “polluter pays” principle (Lankoski et al. 2019). Carbon prices in ETS sectors are currently 85 euro per ton CO2eq. It is expected that carbon prices in the ETS sector will increase to about 130 euro per ton CO2-eq in 2030[2]. In line with this the strategy TAXATION assumes a maximum tax of 130 euro per ton CO2-eq emission in the agricultural sector as well. As an alternative strategy a taxation level of 65 euro per ton CO2eq emission in the agricultural sector is assumed.

**TAXATION and REDISTRIBUTION**

A tax increases net revenues for the government. To stimulate extensive agricultural production systems, it can be considered to redistribute the tax to the agricultural sector via an uniform payment per ha of utilised agricultural area (cropland and pasture). It is expected that the tax redistribution via an uniform payment per ha will mitigate extreme agricultural income and price effects. As more land will be kept into production and as the uniform payment per ha is also not linked to a specific GHG mitigation technology,  environmental improvements will be dampened as well.

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[1] Under the different strategies and variants, the number of continuing dairy farms with total acreage of land equal to the base, will be different from the total number of dairy farms in the base. This depends on the number of dairy farms that exit the sector and the number of farms that buy extra land to increase their total acreage of land. This process of structural change at farm and sector level is not explicitly modelled, but is indicated by changes in milk production as provided by the market models GLOBIOM and MAGNET, see also discussion paragraph 4.5.

[2] https://ariadneprojekt.de/media/2023/01/Ariadne-Documentation_ETSWorkshopBruessel_December2022.pdf

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**SUBSIDY**

A third strategy that is assessed in this deliverable is a subsidy on CO2eq emission reduction in the agricultural sector. This strategy is economically more feasible for the agricultural sector as compared to the TAXATION strategy. Implementation based on voluntary participation of producers is possibly also more easy to organize as compared to measuring CO2eq emission and taxing all producers.

**SUBSIDY and ADJUSTMENT VIA CAP DIRECT PAYMENT**

Another obvious difference between tax and subsidy strategy is that the tax increases net government revenue, while a subsidy decreases them. Furthermore, a subsidy strategy violates the "polluter pays" principle and thus might be considered unfair if other agents in the economy are subject to environmental taxes or costly command-and-control measures (Lankoski, et al., 2019). The strategy SUBSIDY and ADJUSTMENT VIA CAP DIRECT PAYMENT is supposed to circumvent these problems via strengthening performance based agricultural policies. The strategy involves a budget neutral subsidy on CO2eq emission technologies to be financed via an adjustment of direct payments. The subsidy on CO2eq emission reduction is assumed equal to 65 and 130 Euro subsidy per ton $CO_2$eq emission reduction. To reach budget neutrality, an adjustment of the direct payment per MS is assumed. The adjustment depends on total $CO_2$eq emission reduction per MS and subsidy rate uniform for all MS in the EU.

Budget neutral financing of the subsidy on CO2eq emission reduction at MS level in variants 65CO2eq_SUB_DP and 130CO2eq_SUB_DP is achieved via adjustment of MS specific direct payments in Pillar 1 of the CAP. The MS specific reduction of the basic payment in the latter variants is calculated as total CO2eq emission reduction from agriculture (mio ton CO2eq emission reduction) times subsidy (euro per ton CO2eq emission reduction) divided by total agricultural area in a country (mio ha). The MS specific total CO2eq emission reduction from agriculture is taken from MAGNET results, the total agricultural area in a country eligible for direct CAP payment is taken from EU statistics and assumed constant while the subsidy on CO2eq emission reduction is specific per variant given the SUBSIDY and ADJUSTMENT VIA CAP DIRECT PAYMENT strategy.

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*Table 3 Scenario strategies and models used*

| **GHG Scenario strategy** | **Description** | **Name strategy** | **Models used** |
|---|---|---|---|
| TAXATION | 65 and 130 Euro tax on $CO_2$eq emission in the agricultural sector in the EU | 65CO2eq_TAX<br>130CO2eq_TAX | MAGNET,GLOBIOM, FarmDyn |
| TAXATION and REDISTRIBUTION | 65 and 130 Euro tax on $CO_2$eq emission in the agricultural sector in the EU. The national tax revenues are redistributed to the agricultural sector for each MS via a uniform payment per ha of utilised agricultural area (cropland and pasture) | 65CO2eq_TAX_RE<br>130CO2eq_TAX_RE | GLOBIOM |
| SUBSIDY | 65 and 130 Euro subsidy on $CO_2$eq emission reduction in the agricultural sector in the EU without budget neutral finance. | 65CO2eq_SUB<br>130CO2eq_SUB | MAGNET, FarmDyn |
| SUBSIDY and ADJUSTMENT VIA CAP DIRECT PAYMENT | 65 and 130 Euro subsidy on $CO_2$eq emission reduction in the agricultural sector in the EU with budget neutral financing of the subsidy, which is assumed to happen at MS level via adjustment of MS specific direct payments in Pillar 1 of the CAP. The adjustment depends on $CO_2$eq emission reduction and subsidy budget needed per MS. | 65CO2eq_SUB_DP<br>130CO2eq_SUB_DP | MAGNET, FarmDyn |

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## 4.3. GHG emission accounting, technical measures, adoption and Indicators

Details regarding the sources and data used for GHG emission accounting by each model are given in Table 4. FarmDyn and GLOBIOM have detailed representation of bio-physical and agronomic dynamics with detailed GHG emission accounting related to a rather detailed list of inputs e.g. different types of animals, qualities of animal feed and grassland use. A detailed description of the GHG emission accounting in FarmDyn and GLOBIOM can be found in Deliverable Report D5.2. Different from FarmDyn and GLOBIOM, the computable general equilibrium model MAGNET is not written in physical terms. Instead of detailed GHG emission accounting, CO2eq emissions are linked to the use of fossil fuels, fertilizers, land and output (for cattle sector).

*Table 4 Sources of GHG (CO2eq) emissions considered and their data sources for each model*

| **Name of the model** | **Sources of $CO_2$eq emissions** | **Data used to calculate the $CO_2$ eq emission for the different sources** |
|---|---|---|
| MAGNET | $CO_2$ emissions are linked to the use of fossil fuels, fertilisers, land, and output (for cattle sector) | Fertiliser emissions are calculated based on IPCC (2006) data.<br>Data about $CO_2$ and non-$CO_2$ emissions come from GTAP[1] database. |
| GLOBIOM | Enteric fermentation, manure management, manure applied and dropped, fertilizer application, rice cultivation | Global Warming Potentials (GWP) from IPCC AR5 (2006) |
| FarmDyn | Feed use, storage and application of manure, grazing, application of mineral fertiliser, diesel use[2] | IPCC (2006) and GWPs from IPCC AR5 |

*1.GTAP database:* the global data base the Global Trade Analysis Project (GTAP) describing bilateral trade patterns, production, consumption and intermediate use of commodities and services.

*2.To avoid double counting, upstream emissions from purchased feeds and mineral fertiliser are not included in FarmDyn in this deliverable.*

Table 5 provides details regarding the farm management measures to reduce GHG emissions and the models considering them. GLOBIOM and FarmDyn cover different technical GHG mitigation options such as anaerobic digesters, livestock feed supplements, nitrogen inhibitors, etc. In GLOBIOM and FarmDyn it is assumed that the feed additive Bovaer reduces in the enteric fermentation step the emitted methane emission by 30%. MAGNET assumes a linear relationship between emission intensity (emissions over production) reduction and the carbon tax/subsidy (MAC). For milk production sector in MAGNET, the intercept and slope of this MAC function between emission intensity reduction and carbon tax/price are derived from country specific GHG emission reduction results from FarmDyn e.g. mimicking the GHG mitigation potentials and costs of feed additive Bovaer. Further details regarding mitigation potentials and costs and endogenous mitigation strategies in MAGNET, GLOBIOM and FarmDyn can be found in MIND STEP Deliverable Report 5.2 (Krisztin et al. 2023).

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*Table 5 Farm management measures included in the GHG mitigation scenario*

| **Farm management measures** | **Models** |
|---|---|
| Decrease concentrate share in ration/changes in feed ration | FarmDyn |
| Changes in use of N from mineral fertilizer/Intensive grazing | FarmDyn, GLOBIOM |
| Less young stock, increased number of lactations | FarmDyn, GLOBIOM |
| CO2 soil (e.g. crop rotation, catch crops, permanent grassland) | FarmDyn |
| Increased share of unproductive land (idle land) | FarmDyn |
| Feed additive to reduce GHG emissions (Bovaer, Nitraat) | FarmDyn, GLOBIOM |
| Manure and chemical fertiliser application techniques | GLOBIOM |
| feed with higher fat content ratio/adding vegetable oil to feed ration | FarmDyn GLOBIOM |
| Antibiotics[a] | GLOBIOM |
| Bovine somatotropin (bST)[b] | GLOBIOM |
| Propionate precursors | GLOBIOM |
| Anti-methanogen vaccination | GLOBIOM |
| Large-scale complete-mix digesters, Large-scale fixed-film digester, Large-scale plug-flow digesters, Small-scale digester, Centralized digester[c] | GLOBIOM |
| Large-scale covered lagoon/Peat meadow areas (e.g. higher ground water levels) | GLOBIOM |

## 4.4. Key results

### 4.4.1. Summary

TAXATION strategy (65CO2eq_TAX, 130CO2eq_TAX): summary of results from MAGNET, GLOBIOM and FarmDyn

- GHG emission from agriculture decreases around - 27% at a CO2eq price level of 130 euro/tonne (130CO2eq_TAX) in the EU27 but leads to a substantial reduction of primary agricultural production, caloric consumption and economic growth. Employment of skilled labour in primary agriculture decreases with more than 1% (MAGNET). The change in GDP is projected to be around -0.8% (MAGNET).
- Tax income equals about 22 bn euro in the 65CO2eq_TAX variant and about 39.6 bn euro in the 130CO2eq_TAX variant (GLOBIOM)
- The balance of trade worsens, with particular strength on the livestock sector (MAGNET)
- Adoption of technologies is the most important source of GHG emission reduction in the EU (GLOBIOM).
- Nevertheless, especially GHG intensive products like milk and cattle production decreases and fallow land is increasing as some cropland (-11%) and pastures (-14%) are being moved out of production as livestock production declines (GLOBIOM).

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- There are noticeable cross-country differences. The effect on primary agricultural production is particularly strong in Ireland and East Europe (Estonia, Latvia, Lithuania). In Ireland primary agricultural production decreases with around 26%. In East Europe this is between 10 and 15% (MAGNET).
- Most pronounced increases in prices are observed for ruminant products (beef, milk). In the 130CO2eq_TAX variant price of beef decreases with around 16% (GLOBIOM). For milk products this is about 14% (GLOBIOM).
- Although agricultural prices increase, food consumption in the EU is rather constant (GLOBIOM)
- Milk production per NUTS2 average continuing dairy farm in the EU is constant (FarmDyn). This is especially explained by the market-feedback as taken from MAGNET.
- Average in EU27 income decreases with around 4000 euro per Agricultural Working Unit (AWU) per average dairy farm in the 65CO2eq_TAX variant and with around 5000 euro per AWU per average dairy farm in the 130CO2eq_TAX variant (FAMDYN). This about 12 and 15% of average dairy farm income in 2018 respectively.
- In the 130CO2eq_TAX variant, land prices in the EU27 decrease with about 12% (MAGNET)

TAXATION and REDISTRIBUTION strategy (65CO2eq_TAX_RE, 130CO2eq_TAX_RE). summary of results from GLOBIOM

- Compared to variants without redistribution (variants 65CO2eq_TAX and 130CO2eq_TAX), the redistribution of the GHG tax (variants 65CO2eq_TAX_RE and 130CO2eq_TAX_RE) decreases agricultural non-CO2 mitigation potentials and increases GHG emissions.
- Hence, compared to the variants without redistribution, tax income increases to about 22.5 bn euro in the 65CO2eq_TAX_RE variant and about 42.8 bn euro in the 130CO2eq_TAX_RE variant (GLOBIOM)
- The redistribution of the GHG tax, buffers negative effects on production and areas
- Redistribution of GHG tax smoothens negative impacts on prices also on the demand side.

SUBSIDY and ADJUSTMENT VIA CAP DIRECT PAYMENT strategy (65CO2eq_SUB_DP 130CO2eq_SUB_DP). Summary of results from MAGNET and FarmDyn

- Compared to the TAXATION strategy, the 130CO2eq_SUB_DP strategy largely mitigates the economic damages, though it leads to less significant effects in terms of GHG emission reduction. In fact, impact on total, economy-wide GHG emission reduction reduces to less than 2%, while GHG emission from primary agriculture decreases with around 17% (MAGNET). Employment of skilled labour in primary agriculture increases with around 0.7%, while GDP is about constant as compared to the base (no change) (MAGNET)
- Milk and cattle production decreases with less than 0.5% and less than 1% in the 65CO2eq_SUB_DP and 130CO2eq_SUB_DP variants respectively (MAGNET).
- Prices of ruminant products (beef, milk) increases with around 1% and 3% in the 65CO2eq_SUB_DP and 130CO2eq_SUB_DP variants respectively (MAGNET).
- The redistribution of the direct payments of the CAP equals about 3.5 bn euro and 9.6 bn euro in the 65CO2eq_SUB_DP and 130CO2eq_SUB_DP variants respectively (MAGNET, own calculations)
- Milk production per NUTS2 average continuing dairy farm in the EU27 is constant (FarmDyn)
- dairy farm income increases around 3000 euro and 6000 euro per AWU per farm in the 65CO2eq_SUB_DP strategy and 130CO2eq_SUB_DP strategy respectively (FarmDyn). This increase in farm income on the NUTS2 average dairy farm in the EU, includes the market-

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feedback as taken from the market model MAGNET. In more detail the increase in farm income on the average dairy farm in the EU is explained as follows:

- Number of dairy cows per average dairy farm is constant (see above)
- Subsidy exceeding the average costs of CO2eq emission reduction per average dairy farm
- Higher market output prices especially milk, via slight reduction in milk output at aggregate level (MAGNET)
- Total revenue from milk and meat per average dairy farm increases.
- The sum of subsidy over average extra costs plus higher output prices exceed the decrease in direct payments per average dairy farm

- Within the dairy sector positive income effects of the SUBSIDY and ADJUSTMENT VIA CAP DIRECT PAYMENT strategy are lowest/highest on farms with relative low/high CO2eq emissions per ha (FarmDyn)
- Land prices in the EU27 increase with about 5% (MAGNET)

### 4.4.2. MAGNET

There are three variants of the GHG mitigation scenario evaluated through MAGNET: 1) an ad valorem equivalent tax acting directly on producers through the MACC (65CO2eq_TAX, 130CO2eq_TAX); 2) an ad valorem equivalent tax imposed through the MACC but subsidised from the government (65CO2eq_SUB 130CO2eq_SUB) and 3) an ad valorem equivalent tax imposed through the MACC, subsidised from the government but financed from the governments reducing the first pillar CAP budget (65CO2eq_SUB_DP 130CO2eq_SUB_DP).

All variants are imposed in a static framework adopted in 2030. The model, calibrated on 2014, is brought to 2030 with a baseline dynamic simulation based on basic socio-economic assumption of this short-term horizon, as described in paragraph 3.2. The three variants lead to different outcomes both for what concerns the agricultural sector and more in general concerning impacts on GDP and emissions abatement projections. Table 6 reports the main results at EU27 level. In general, agricultural prices are increasing while production is decreasing. Significant economic losses are expected in the variants in which the tax is imposed directly on the producers. Concerning the impacts on food consumption, animal calories are always reduced, due to their high CO2eq emission intensity which means they are more sensitive to CO2eq emissions-based taxes. General total calories intake is about constant, while 'animal calories' are decreasing, especially in the variants with taxation. Impacts on emissions reductions vary by variant, with the reductions being more significant in the taxation variants. In particular, while agriculture always reduce its emission, total economy-wide emissions reduce significantly only in the taxation variant. This is explained by the strong reduction in agricultural production. Indeed, in the taxation variants, the strong production changes in the agricultural sector propagates to the full economy (e.g. through less availability of agricultural goods for consumption and use as intermediate production factor). As such, direct taxation is more effective in terms of emission abatement, though that is also due to its higher economic costs both for the agricultural sector and for the overall economy. Indeed, while GDP losses in the government subsidised variants (65CO2eq_SUB, 130CO2eq_SUB) are negligible, there are significant losses in the direct taxation ones (up to almost 1% of EU GDP in the 130$eq case). The impacts on GDP, agricultural production and emissions of the variants with the CO2eq emission reduction subsidy financed from the first pillar CAP budget (65CO2eq_SUB_DP 130CO2eq_SUB_DP) slightly exceeds the impacts of the government subsidised variants (65CO2eq_SUB, 130CO2eq_SUB). This shows that in MAGNET the direct payment of the Pillar 1 of the CAP is rather decoupled from production.

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*Table 6 MAGNET Summary Results of EU27 (% change with respect to 2030 baseline)*

| | 65CO2eq_ TAX | 65CO2eq_ SUB | 65CO2eq_ SUB_DP | 130CO2eq_ TAX | 130CO2eq_ SUB | 130CO2eq_ SUB_DP |
|---|---|---|---|---|---|---|
| **Price Agri. Prim.** | 5.33 | 0.53 | 0.76 | 10.30 | 1.21 | 1.77 |
| **Production Agri. Prim.** | -2.53 | -0.16 | -0.35 | -4.55 | -0.36 | -0.80 |
| **Skilled labour (Agri. prim.)** | -1.23 | 0.50 | 0.33 | -1.94 | 1.14 | 0.74 |
| **Unskilled labour (Agri. prim.)** | -0.75 | 0.45 | 0.29 | -1.13 | 1.04 | 0.65 |
| **GDP** | -0,43 | -0,01 | -0,01 | -0,82 | -0,04 | -0,03 |
| **Total Emission (CO2eq)** | -15,77 | -1,33 | -1,34 | -23,87 | -1,79 | -1,82 |
| **Agri Emission (CO2eq)** | -19,05 | -12,47 | -12,63 | -27,00 | -16,77 | -17,12 |
| **Total Calories** | 0.14 | -0.06 | -0.07 | 0.33 | -0.12 | -0.15 |
| **Animal Calories** | -1.07 | -0.18 | -0.24 | -1.93 | -0.40 | -0.54 |

Impacts and trade-offs, while coherent with this general interpretation, vary at the country level. Indeed, the link between MAGNET and FarmDyn in the calibration of the MAC curve allowed for a detailed representation of each of the EU27 (and UK) structure in MAGNET, providing specific results for all these countries. Table 7 displays the regions in which the global MAGNET model is aggregated, with the European countries represented at country level and the rest of the world aggregated in macro areas.

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*Table 7 Acronyms of Region/Countries in MAGNET*

| Country/Region Code | Country/Region Name |
|---|---|
| CAN | Canada |
| USA | United States |
| BRA | Brazil |
| OSA | Other Latin America |
| FSU | Former Soviet Union |
| REU | Other Europe |
| MENA | Middle East and North Africa |
| SSA | Sub-Saharan Africa |
| CHN | China |
| AUT | Austria |
| BLX | Belgium-Luxemburg |
| IND | India |
| BGR | Bulgaria |
| SEA | South East-Asia |
| HRV | Croatia |
| OAS | Other Asia |
| GCM | Greece-Cyrpus-Malta |
| ANZ | Australia and New Zealand |
| CZE | Czech Republic |
| DNK | Denmark |
| EST | Estonia |
| FIN | Finland |
| FRA | France |
| DEU | Germany |
| HUN | Hungary |
| IRL | Ireland |
| ITA | Italy |
| LVA | Latvia |
| LTU | Lithuania |
| NLD | Netherlands |
| POL | Poland |
| PRT | Portugal |
| ROU | Romania |
| SVK | Slovakia |
| SVN | Slovenia |
| ESP | Spain |
| SWE | Sweden |
| GBR | United Kingdom |

Figure 4 shows the impact of prices of agricultural primary goods for each MAGNET country/Region. Prices impacts are not very significant outside of Europe (leakage effect) but are high in EU27. Several regions (Ireland in particular, with an increase of around 20%) are affected by a rise in agricultural prices, especially in the direct tax variants (65CO2eq_TAX, 130CO2eq_TAX). Between the two subsidy strategies (with and without government budget neutral financing via reduction of direct payment of pillar 1 of the CAP) The increase in agricultural prices is generally higher in the 65CO2eq_SUB_DP and 130CO2eq_SUB_DP variants as compared to the 65CO2eq_SUB and 130CO2eq_SUB variants. This is because of the small production effects of the direct payments. When considering single goods impacts, they can be slightly differentiated, for example the increase in prices for cattle is higher in Estonia and Latvia while milk price increases are the strongest in Croatia, Ireland, Slovenia, Latvia and Lithuania. The milk sector in Lithuania, in particular, has significant price increases in all the strategies and variants, which may be due to a stronger emission intensity respect to the rest of Europe.

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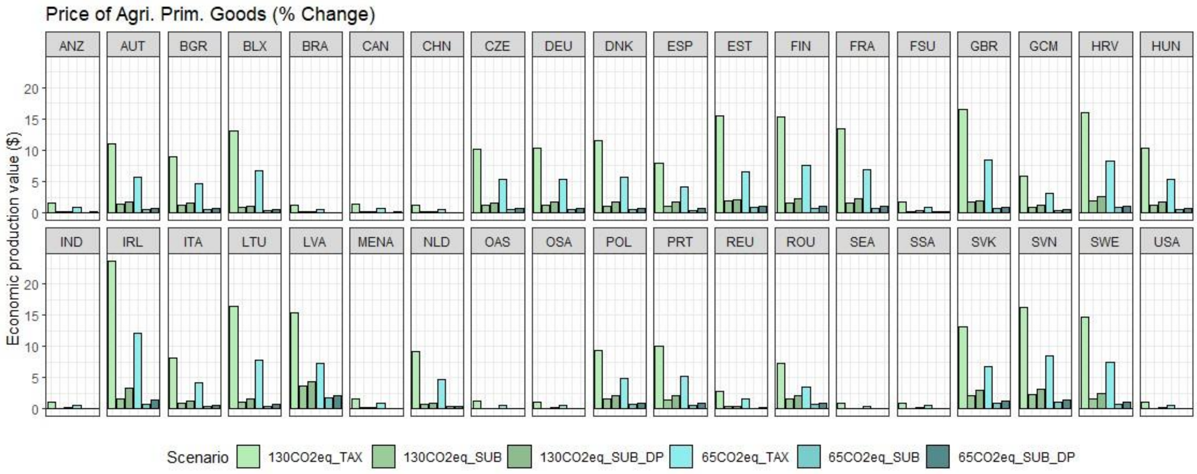


*Figure 4 Prices of Primary Agricultural % Change by strategy and variant*

The increase in agricultural prices is coherent with the overall decrease in production of agricultural products in European countries, as shown in Figure 5. Indeed, the highest losses are in the regions with the highest price increases, i.e. Ireland, Lithuania, Latvia and Estonia, in the direct tax variants (65CO2eq_TAX, 130CO2eq_TAX). Different agricultural products are nevertheless affected in different intensity and diversified by region. For example, the average decrease in milk production at European level equals about 2.5% and 4.5% in the 65CO2eq_TAX and 130CO2eq_TAX variants respectively. The decrease in milk production is however particularly strong in Ireland and East Europe (Estonia, Latvia, Lithuania). The European cattle production decreases with -8.9% and -15% in in the 65CO2eq_TAX and 130CO2eq_TAX variants respectively. The rest of the world, which is not affected by the tax variants, does not show significant impacts. Under the variants with a subsidy on CO2eq emission reduction, the negative impact is significantly lower.

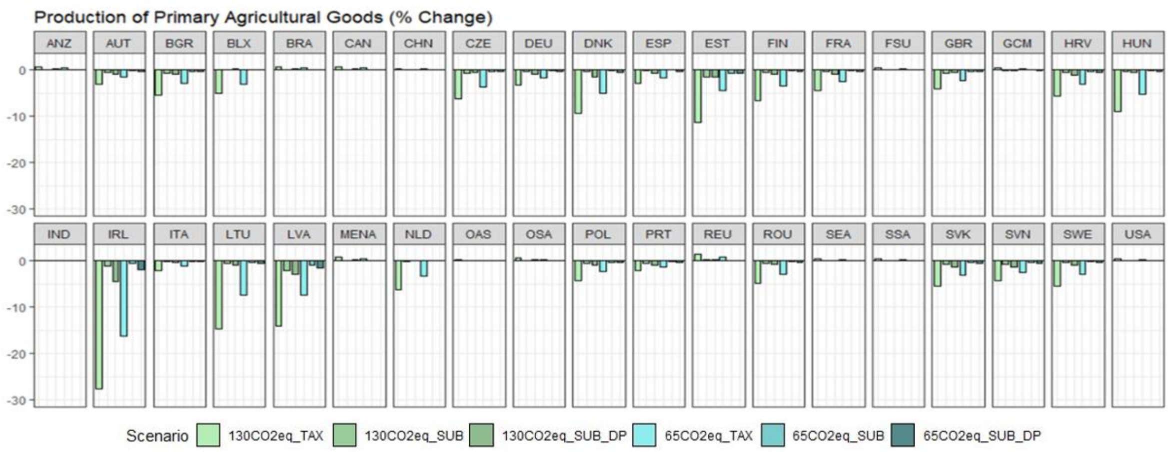


*Figure 5 Production of Primary Agricultural % Change by strategy and variant*

The lower regional production (and higher prices) are reflected in a change of the European Balance of trade. In particular, Table 8 shows an almost net distinction between European countries, with negative trade balance impacts (in red) and extra-EU countries with positive impacts (in green). The worsening of the trade balance is generally true for the agricultural product but differs in its intensity

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of the impact depending on the product and the region. For example, in the direct tax variants, cattle trade of balance is affected by a change of -21% and -37% for the 65CO2eq_TAX and 130CO2eq_TAX variants respectively. For dairy this is equal to -54% and -116%. With the subsidy variants the impacts on the trade balance is lower, with -1% and -3% for cattle and -7% and -15% for milk. Concerning the trade impacts for arable goods, Europe's demand for imports strongly increase in the direct taxation variants, i.e. 85% and 200% for paddy rice, 15% and 30% for wheat, 5% and 10% for grains (maize (corn), sorghum, barley, rye, oats, millets, other cereals) respectively for the for the 65CO2eq_TAX and 130CO2eq_TAX variants. On the other side, exports significantly reduce, e.g. -89% and -97% for paddy rice and around -10% and -20% for wheat and grain.

Imports demand increase significantly less with the subsidy on CO2eq emission reduction e.g. around 7% and 15% for paddy rice, 2% and 4% wheat, 0.7 and 2% for grains respectively for 65CO2eq_SUB and 130CO2eq_SUB variants. Exports are reduced also with the subsidy, but significantly less (e.g. -15% and -30 for paddy rice, of the entity of around -1% and -5% or less for wheat and grain.

These impacts translates to a general decrease in labour demanded in the agricultural sector, which is more evident in the regions in which production decreases more significantly. As such, labour impacts are mirroring production impacts, with higher losses in the 65CO2eq_TAX and 130CO2eq_TAX variants. Indeed, the stronger losses are reported in Ireland, Lithuania, Latvia, Estonia, Denmark and Finland, which were also the regions with the highest losses in production in the 65CO2eq_TAX and 130CO2eq_TAX variants.

All these impacts are then reflected in negative macroeconomic consequences for the European countries. Indeed, Significant losses are evident in the 65CO2eq_TAX and 130CO2eq_TAX variants. The map in Figure 7 shows e.g. in the case of Bulgaria, that loses up to 5% of GDP. Nevertheless, GDP impacts are negligible in the CO2eq emission reduction subsidy strategies and variants.

The difference in macroeconomic impact is mirrored by a different in the emission abatement capacity. Total emission reductions are substantially higher when the taxation is directly imposed on the final product (–16% and –24% for 65CO2eq_TAX and 130CO2eq_TAX variants respectively). Differences in regional emissions can be identified, for example, under the 130CO2eq_TAX variant total GHG emission in Ireland reduces up to –50%.

In the subsidy variants the change in total GHG emission is almost negligible, namely -1% and –2% for 65CO2eq_SUB and 130CO2eq_SUB variants respectively and also -1% and –2% for the budget neutral subsidy variants 65CO2eq_SUB_DP and 130CO2eq_SUB_DP. This difference in total GHG emission reduction is due to the additional decline in agricultural production in the taxation strategies. This lowers production and GHG emissions in the industries that are closely connected to the primary agricultural sector.

Emission reduction in the primary agricultural sector is substantially higher than the total emission reduction discussed above. In the taxation strategies, GHG emission in total agriculture decreases with about –19% and –27% in 65CO2eq_TAX and 130CO2eq_TAX variants respectively. This is around around –12% in both the 65CO2eq_SUB variant and (the budget neutral) 65CO2eq_SUB_DP variant and –17% in both the 130CO2eq_SUB variant and the (budget neutral) 130CO2eq_SUB_DP variant.

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*Table 8 Primary Agriculture Trade Balance Change (%)*

| | 65CO2eq_TAX | 65CO2eq_SUB | 65CO2eq_SUB_DP | 130CO2eq_TAX | 130CO2eq_SUB | 130CO2eq_SUB_DP |
|---|---|---|---|---|---|---|
| CAN | 2,22 | 0,29 | 0,41 | 4,32 | 0,66 | 0,96 |
| USA | 2,01 | 0,21 | 0,31 | 3,83 | 0,49 | 0,74 |
| BRA | 1,45 | 0,23 | 0,34 | 2,81 | 0,55 | 0,82 |
| OSA | 1,46 | 0,24 | 0,40 | 2,76 | 0,56 | 0,94 |
| FSU | 3,45 | 0,40 | 0,61 | 6,66 | 0,92 | 1,40 |
| REU | -0,52 | -0,01 | 0,01 | -0,65 | -0,01 | 0,04 |
| MENA | 0,07 | 0,11 | 0,20 | 0,22 | 0,26 | 0,48 |
| SSA | 2,36 | 0,34 | 0,51 | 4,59 | 0,79 | 1,21 |
| CHN | -0,21 | 0,01 | 0,03 | -0,37 | 0,03 | 0,08 |
| AUT | -1,57 | -0,63 | -0,93 | -3,14 | -1,47 | -2,19 |
| BLX | -3,65 | -0,36 | -0,42 | -6,61 | -0,87 | -1,00 |
| IND | 5,95 | 0,93 | 1,46 | 11,60 | 2,15 | 3,42 |
| BGR | -2,17 | -1,07 | -1,24 | -4,56 | -2,32 | -2,71 |
| SEA | 0,37 | 0,12 | 0,16 | 0,76 | 0,27 | 0,38 |
| HRV | -17,41 | -3,51 | -4,95 | -32,01 | -8,03 | -11,43 |
| OAS | -0,09 | 0,02 | 0,03 | -0,16 | 0,04 | 0,06 |
| GCM | -11,49 | -2,15 | -2,44 | -23,36 | -5,52 | -6,42 |
| ANZ | 0,75 | 0,15 | 0,24 | 1,42 | 0,35 | 0,56 |
| CZE | -58,20 | -6,54 | -5,63 | -104,06 | -13,89 | -11,93 |
| DNK | -9,98 | -0,48 | -1,42 | -19,09 | -1,21 | -3,54 |
| EST | -15,45 | -5,22 | -5,75 | -46,80 | -11,30 | -12,54 |
| FIN | -16,30 | -1,51 | -2,52 | -32,67 | -3,59 | -6,04 |
| FRA | -12,46 | -2,46 | -4,87 | -23,59 | -5,56 | -11,25 |
| DEU | -2,09 | -0,44 | -0,96 | -3,77 | -1,08 | -2,28 |
| HUN | -8,15 | -0,67 | -0,82 | -15,30 | -1,49 | -1,84 |
| IRL | 7,16 | -1,44 | -2,84 | 8,58 | -3,34 | -6,82 |
| ITA | -5,54 | -0,87 | -1,25 | -11,22 | -2,06 | -2,97 |
| LVA | -202,79 | -23,97 | -35,42 | -427,30 | -50,73 | -76,21 |
| LTU | -22,30 | -1,51 | -2,00 | -48,22 | -3,23 | -4,38 |
| NLD | -3,28 | -0,07 | 0,17 | -6,02 | -0,08 | 0,50 |
| POL | -6,04 | -21,04 | -29,50 | -43,16 | -47,21 | -66,04 |
| PRT | -3,48 | -0,66 | -0,99 | -7,02 | -1,58 | -2,42 |
| ROU | -7,42 | -1,59 | -1,90 | -13,56 | -3,58 | -4,33 |
| SVK | -17,01 | -5,45 | -7,47 | -34,79 | -12,34 | -17,04 |
| SVN | -0,69 | -1,62 | -2,10 | -1,68 | -3,70 | -4,83 |
| ESP | -9,59 | -0,39 | -1,61 | -19,62 | -1,26 | -4,64 |
| SWE | -6,36 | -0,89 | -1,33 | -12,19 | -2,04 | -3,10 |
| GBR | -3,79 | -0,93 | -0,98 | -6,93 | -2,15 | -2,27 |
| EU27 | -18,02 | -2,87 | -4,72 | -35,30 | -6,70 | -11,14 |
| EU28 | -13,08 | -2,20 | -3,42 | -25,45 | -5,12 | -8,06 |

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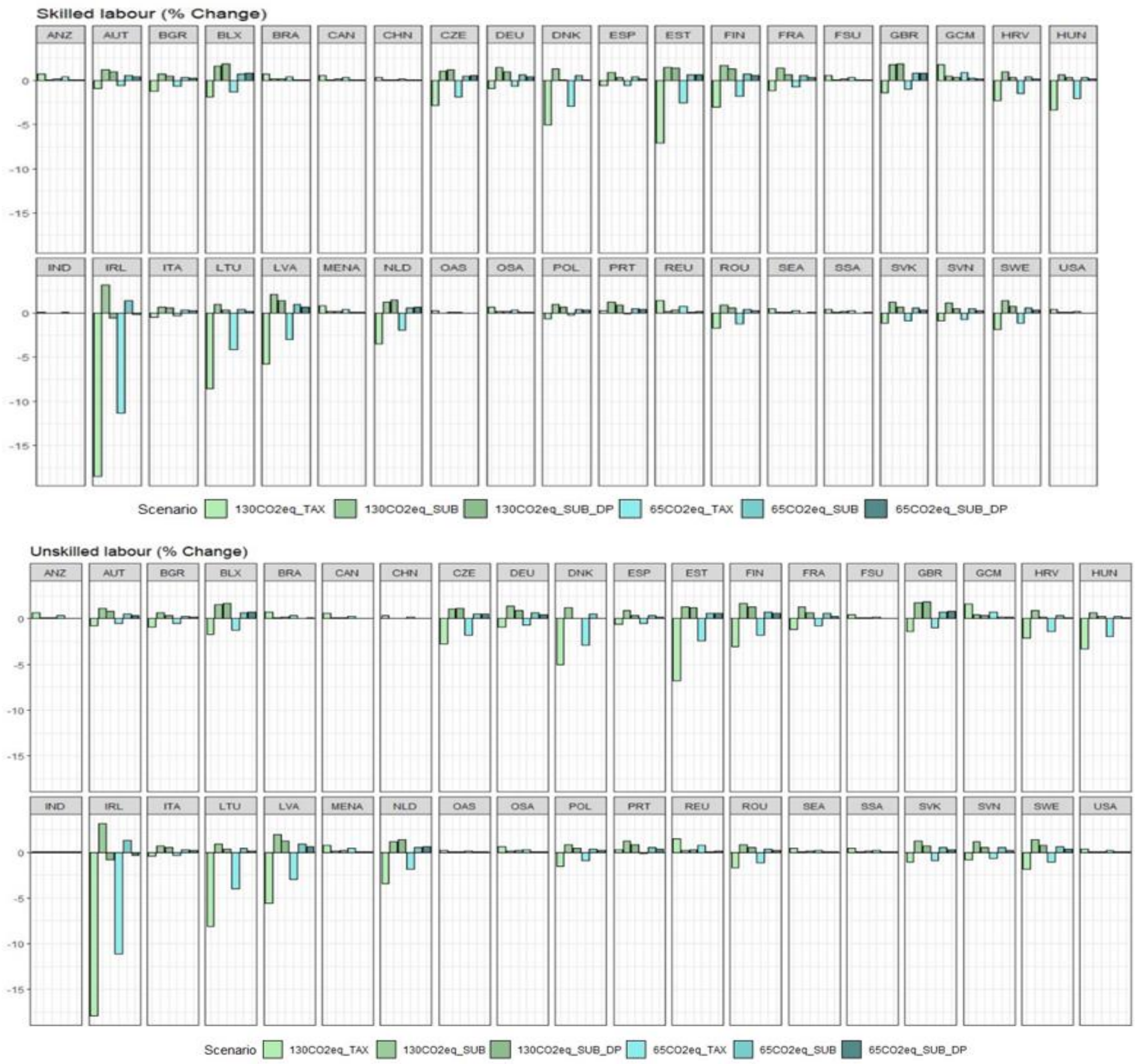


*Figure 6 Employment. Skilled and Unskilled labour demand. % Change by strategy and variant*

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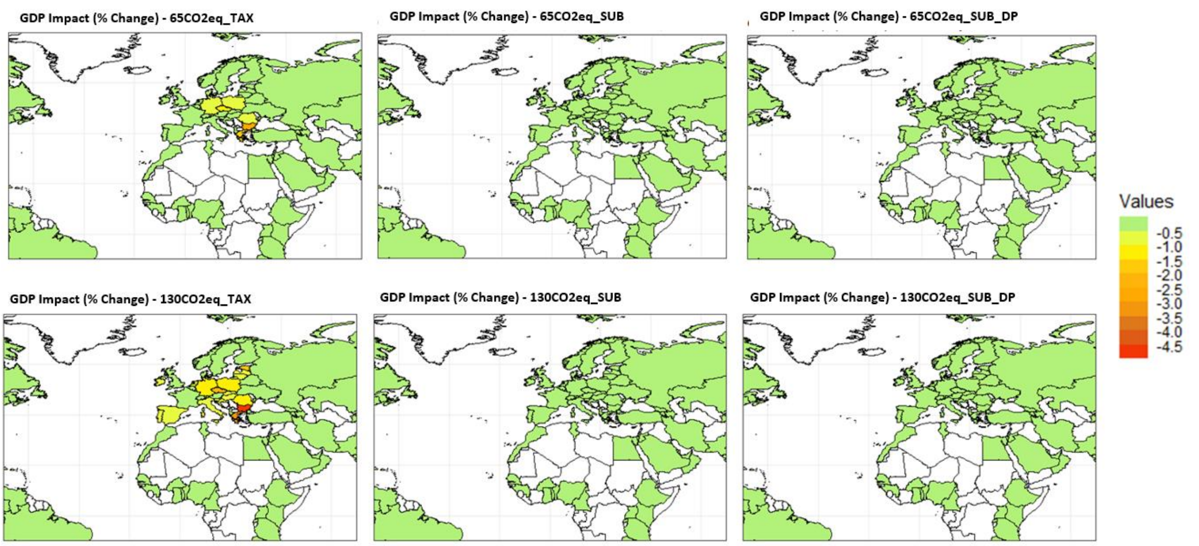


*Figure 7 GDP impacts*

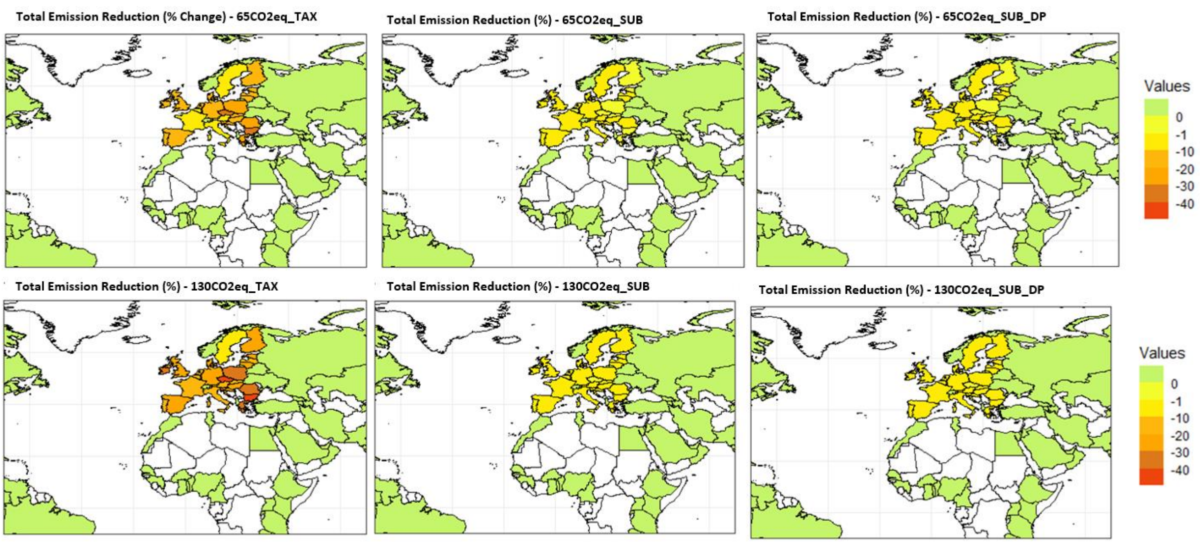


*Figure 8 Total Emission abatement by strategy and variant (% change)*

Emission abatement strategies have an impact on calories consumption, both general and animal based. In particular, calories consumption of highly emission intensive goods decline e.g. up to 2% in Czech republic and Slovakia for cattle and around 10% for milk in Ireland under the 130CO2eq_TAX variant. While animal calories decline in all the strategies and variants, the overall caloric consumption changes is complex and depends on the substitution preferences driven by other sectorial and macroeconomic impact. Here it is important to note that the strategies and variants are only applied to the primary agricultural sectors. For the EU27 as a whole the change in total calories consumption is neglectable. Largest decrease in total calorie consumption is found in Slovenia, namely around -2% in the 130CO2eq_TAX variant.

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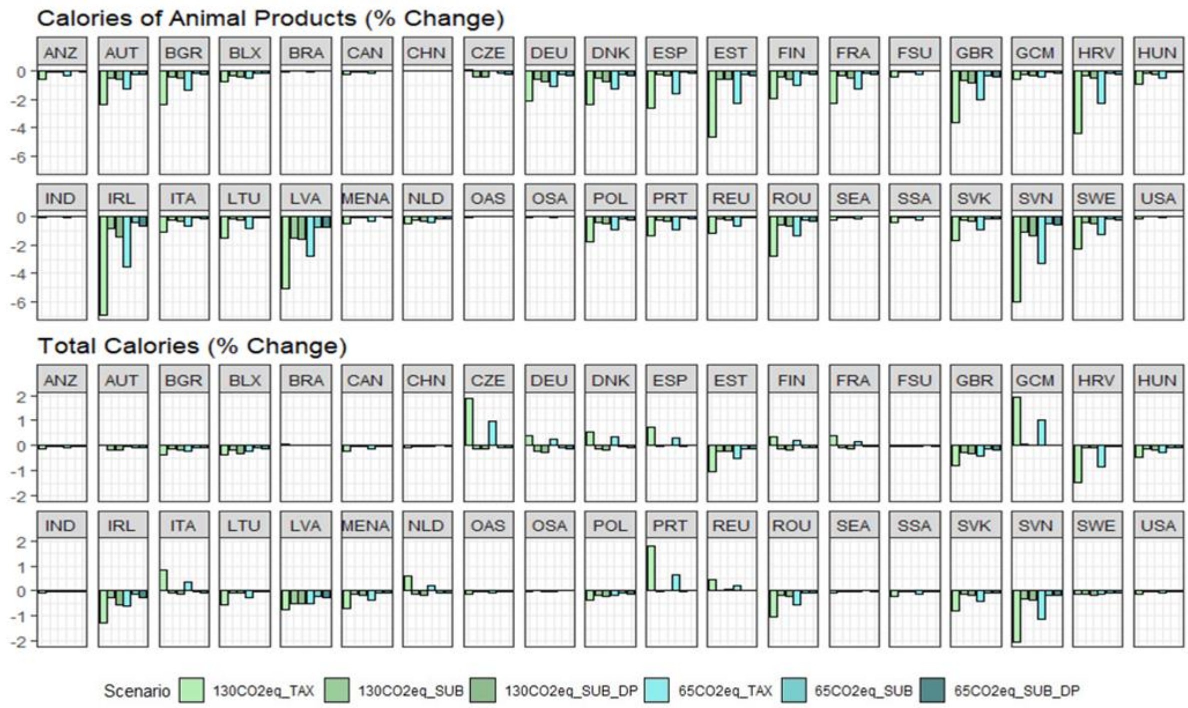


*Figure 9 Calories changes by strategy and variant (% change)*

Several conclusions can be derived on the policy implications of the strategy and variants. First, the taxation strategy the most effective measure in terms of GHG emission decline (up to - 27% in the 130CO2eq_TAX variant) but leads to a sharp reduction of agricultural production, economic growth caloric and employment as compared to baseline trends.

Moreover, since production declines significantly, also the balance of trade worsens as the strategies and variants are only applied to the MS of the EU27. The worsening of the balance of trade especially concerns the highly emission intensive goods (milk and beef). The subsidy strategies and variants (65CO2eq_SUB; 130CO2eq_SUB; 65CO2eq_SUB_DP; 130CO2eq_SUB_DP) largely mitigates the economic damages at macro scale, though it leads to less significant effects in terms of GHG emission reduction, especially when considering total GHG emission. Finally, there are noticeable cross-country differences on the response of the considered strategies and variants that are worthy to take into account.

### 4.4.3. GLOBIOM

GHG emission from agricultural could be reduced in the EU by up to 33-34% in the 130CO2eq_TAX variant in 2030 across the different mitigation wedges (Figure 10). GLOBIOM results show that the adoption of the four novel FarmDyn based mitigation technologies (application of feed additive Bovaer, use of vegetable oils, increased number of lactations of the cows and use of concentrates with low enteric fermenation factor ) may deliver an additional 8-9% reduction in agricultural GHG emissions by 2030 in the 130CO2eq_TAX variant[3]. The novel livestock mitigation technologies from

[3] The so-called UBO parameterizaton of the FarmDyn technologies is considered the default set-up in this section, see MIND STEP Deliverable Report 5.2.

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FarmDyn are cost-effective, particularly when GHG prices surpass the threshold of 65 EUR/t$CO_2$e. The additional mitigation potential primarily comes from the feeding of bovaer, which reduces methane emissions from cattle, and the enhanced utilization of vegetable oil in animal feeding practices.

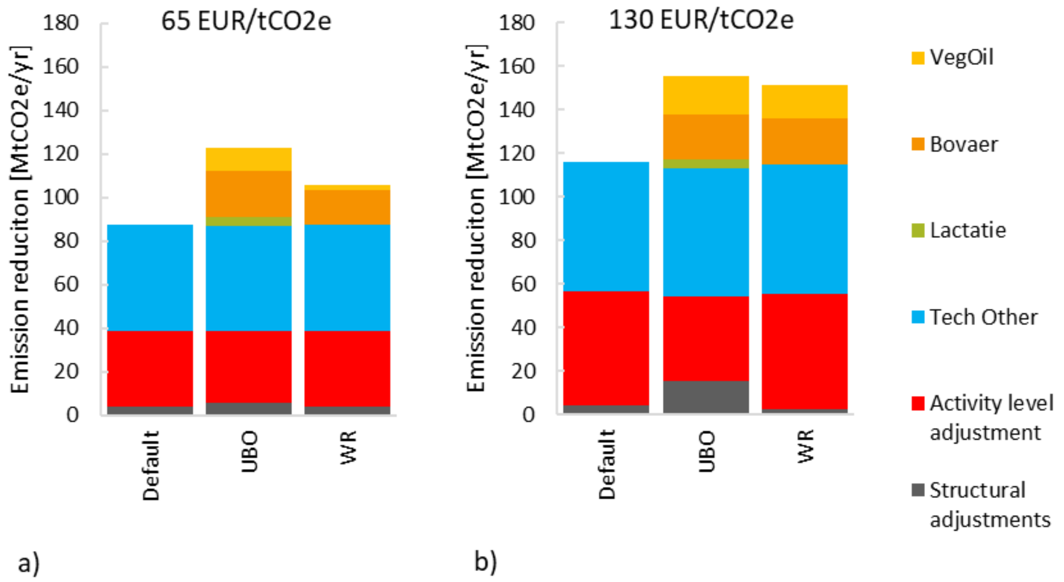


*Figure 10. Agricultural non-$CO_2$ mitigation potential decomposed by mitigation wedge for the taxation strategy and two variants (a) 65 Euro/t$CO_2$eq and (b) 130 Euro/t$CO_2$eq*

*Notes:*

- *Default – without new Farmdyn technologies, UBO – with new Farmdyn technologies from University of Bonn, WR – with new Farmdyn technologies from Wageningen Research.*
- *(65 EUR/tCO2eq) equal (65CO2eq_TAX); (130 EUR/tCO2eq) equal (130CO2eq_TAX)*

Across EU regions, Central and Western EU member states offer largest emission reduction potentials (-43% in the 130CO2eq_TAX variant), followed by Southern (-36% in the 130CO2eq_TAX variant), and Eastern (-32% in the 130CO2eq_TAX variant) EU member states. Across the different agricultural mitigation wedges (technology adoption, structural changes, and adjustment in activity levels) the adoption of new technologies emerges as the most important source of GHG emission reduction in the European Union. In variant 130CO2eq_TAX, it contributes some 100 Mt$CO_2$e/year (-22% emission reduction) by 2030 (Figure 11), 40% of which is sourced from the novel FarmDyn technologies and here most importantly Bovaer and enhanced feeding of vegetable oils.

The adoption of the FarmDyn mitigation technologies differs across member states (Figure 11). A mitigation potential of around 22 Mt$CO_2$e/year by 2030 can be achieved in Central and Western EU member states (out of a total mitigation potential of around 71 Mt$CO_2$e/year) while mitigation potentials tend to be smaller in absolute terms in Eastern and Southern EU countries (around 8 Mt$CO_2$e/year) who nonetheless benefit from the implementation of these technologies (Figure 11a). The portfolio of mitigation technologies is similar across regions and only Southern and Baltic countries have slightly higher potentials from a decrease in agricultural production levels (Figure 11b). Total mitigation potentials in the South, East, North and Baltic regions equal around 38, 26, 16 and 5 Mt$CO_2$e/year) respectively.

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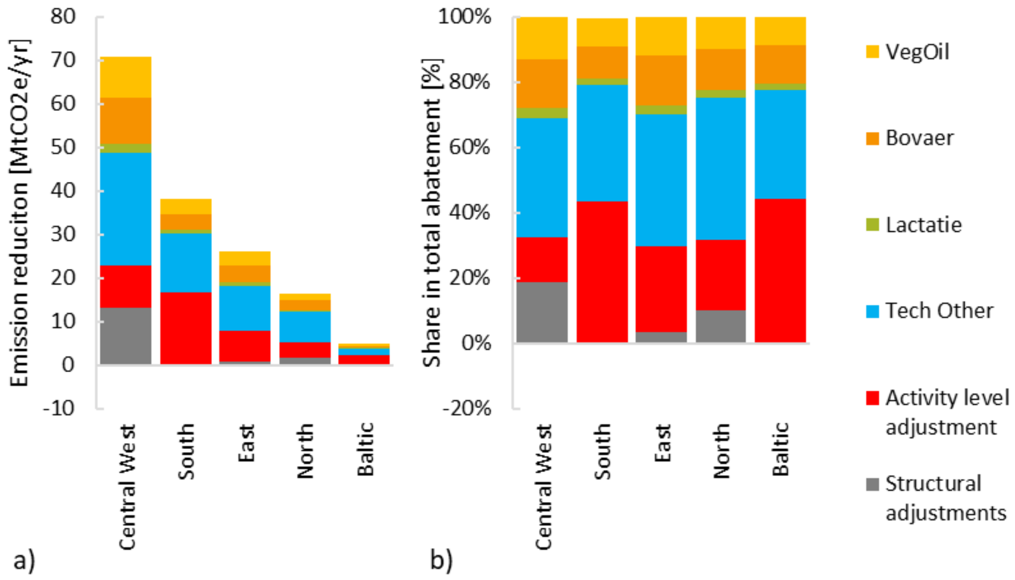


*Figure 11. Agricultural non-$CO_2$ mitigation potential decomposed by mitigation option across EU regions for the 130CO2eq_TAX variant*

*Note: (a) absolute mitigation potentials in $MtCO_2e$ and (b) relative share of different mitigation options in total abatement.*

The implementation of the GHG taxation strategies also increases the production costs of GHG-intensive products, particularly beef and milk, within the European Union. Hence, the second largest source of GHG abatement is related to the reduction in production levels of GHG-intensive products i.e. beef. In the 130CO2eq_TAX variant reduction in agricultural production provided an additional 40 $MtCO_2e$/year (-8%) GHG emission reduction. The decrease in agricultural production in the EU27 however also drives some reallocation of production outside the EU and related GHG emission increases (GHG leakage effects, 20 $MtCO_2e$ /year, +4% emissions in the 130CO2eq_TAX variant). Further intensification of agricultural production within the EU through structural adjustments does not yield significant GHG savings. These results underscore the important role that technological advancements can play in achieving the EU's GHG reduction targets.

The redistribution of the GHG tax to farmers (variants 65CO2eq_TAX_RE and 130CO2eq_TAX_RE) at member state level on a per hectare basis has some interesting implications for GHG abatement potential within the European Union. In variant 130CO2eq_TAX_RE, the redistribution reduces the effectiveness of the GHG emission tax as in the 130CO2eq_TAX_RE variant domestic GHG mitigation potential in the EU approximately - 16% below the GHG mitigation potential in the EU in the 130CO2eq_TAX variant (Figure 12). A notable advantage of the redistribution scheme is that farmers receive compensation, which, in turn, leads to less pronounced decreases in EU production levels. Additionally, emission leakage to the rest of the world is also slightly reduced in variant 130CO2eq_TAX_RE as compared to variant 130CO2eq_TAX. The adoption of technologies for GHG reduction by farmers remains largely unaffected.

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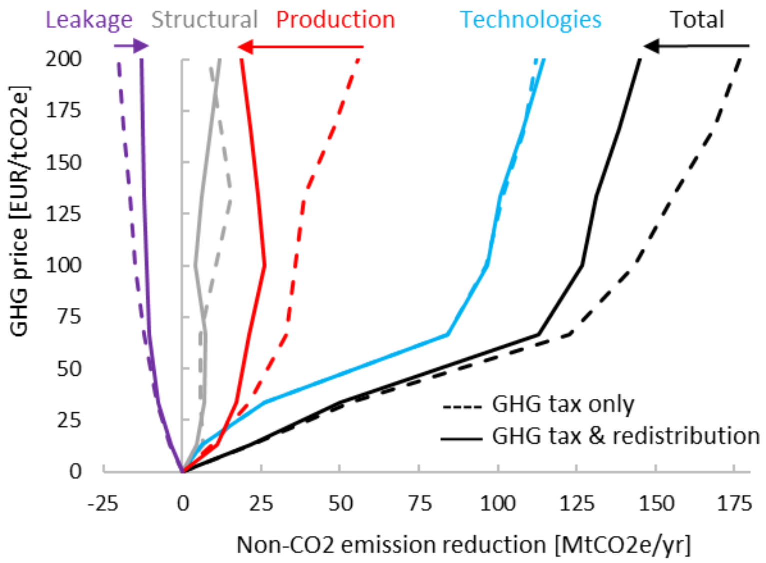


*Figure 12. Agricultural non-$CO_2$ mitigation potential decomposed by mitigation mechanism across GHG price variants (from 0 euro/ton CO2eq to 200 euro per ton CO2eq) with and without redistribution of carbon tax.*

*Note: Dashed lines –GLOBIOM including new UBO Farmdyn technologies and GHG tax, solid lines - GLOBIOM including new UBO Farmdyn technologies and redistribution of GHG tax revenues on a per ha basis. Structural – mitigation coming from changes in management, location, or international trade, Technologies – mitigation coming from adoption of technologies, Production – mitigation coming from changes in activity levels, Total – total EU mitigation potential, Leakage – GHG leakage to rest of the world.*

To conclude, the redistribution of GHG taxes (variants 65CO2eq_TAX_RE and 130CO2eq_TAX_RE) within the EU can play an important role in mitigating negative production effects resulting from a GHG tax on agricultural emissions even though it may reduce the overall cost-effectiveness of the mitigation strategy. While GHG taxes impose additional financial burdens on agricultural producers, the redistribution scheme acts as a mitigating factor by partially compensating for the cost increases incurred by farmers due to GHG pricing. It helps to maintain some of the otherwise abandoned agricultural areas under production thereby also limiting potential GHG leakage effects to the rest of the world.

**Production and area**

GHG tax on agricultural emissions increases production costs of GHG intensive products. In the 130CO2eq_TAX variantespecially beef (-12%) and milk (-9%) production decreases while non-ruminants (pig and poultry) producers are hardly affected in the EU (Figure 13). Impacts are more pronounced going from the 65CO2eq_TAX variant to the 130CO2eq_TAX variant. Especially in the 130CO2eq_TAX variant fallow land is increasing as some cropland (-11%) and pastures (-14%) are being moved out of production as livestock production declines. However, the redistribution of the GHG tax under variants 65CO2eq_TAX_RE and 130CO2eq_TAX_RE, buffers negative effects on food and feed production and agricultural areas and farmers receive a per hectare compensation which reduces overall agricultural land abandonment. Production and area of oilseeds might even increase under variants 65CO2eq_TAX_RE and 130CO2eq_TAX_RE including the redistribution of tax via a uniform payment per ha of utilized agricultural area – cropland and pasture.

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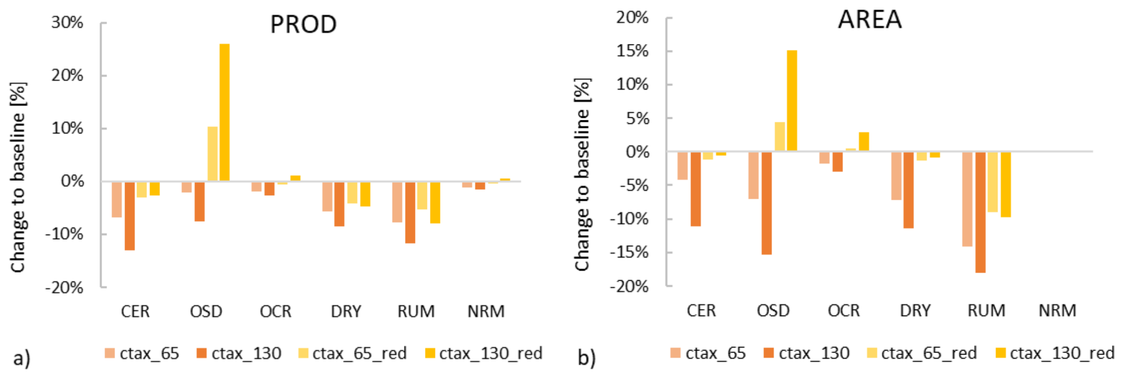


*Figure 13: Production (a) and area (b) changes (% difference with baseline)*

*Notes:*

- *CER (cereals), OSD (oilseeds), OCR (other crops such as potatoes, beans, chick peas etc.), DRY (dairy), RUM (beef), NRM (pork, poultry, eggs).*
- *ctax_65 equal 65CO2eq_TAX; ctax_130 equal 130CO2eq_TAX; ctax_65_red equal 65CO2eq_TAX_RE; ctax_130 _red equal 130CO2eq_TAX_RE*

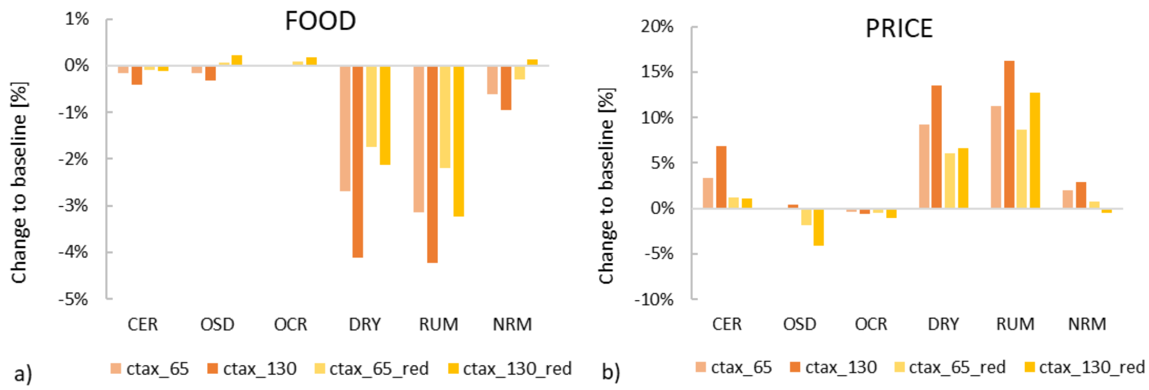


*Figure 14: Food consumption (a) and price (b) changes (% difference with baseline)*

*Notes:*

- *CER (cereals), OSD (oilseeds), OCR (other crops such as potatoes, beans, chick peas etc.), DRY (dairy), RUM (beef), NRM (pork, poultry, eggs).*
- *ctax_65 equal 65CO2eq_TAX; ctax_130 equal 130CO2eq_TAX; ctax_65_red equal 65CO2eq_TAX_RE; ctax_130 _red equal 130CO2eq_TAX_RE*

Similarly, effects can be observed on the demand side. Prices of dairy and beef products increase with around 12 and 15% in the 130CO2eq_TAX variant. Under the same variant prices of cereals increase with around 7%. As consumers are rather price inelastic in the EU due to the high incomes, responses to the GHG emission taxation strategies are much less pronounced on the demand side as compared

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to the supply side. Here, mainly GHG intensive products like milk (-4%) and beef (-4%) experience some decreases in consumption levels as prices increase. When redistributing the GHG tax to farmers (variants 65CO2eq_TAX_RE and 130CO2eq_TAX_RE) this compensates part of the negative effects of the GHG tax on food prices. As a result consumption decreases are less pronounced for (-2% milk, -3% beef) as compared to the taxation variants without redistribution.

### 4.4.4. FarmDyn

Individual dairy farms in EU FADN are grouped to NUTS2 average dairy farms, using their weights. Altogether the FarmDyn database contains 202 average EU dairy farms (excluding the UK), using FADN bookkeeping data from 2018, with the sample of 11072 farms representing 294964 farms in the European Union.[4] Table 9 gives weighted means at national (NUTS0) level as well as the EU27 average, showing the large heterogeneity in the selected farm characteristics. For example, average number of dairy cows per farm ranges from 12 cows per farm in Romania to 293 cows per farm in Slovakia. Livestock density ranges from 0.3 cows per ha in Slovakia to 2.4 cows per ha in Italy to 36.5 cows per ha in Malta. Milk production per cow ranges from 4390 kg in Romania to 9200 kg in Denmark. Share of grassland ranges from 0 in Malta and 34% in Bulgaria to 98.2 % in Ireland. Finally, Farm Net Value Added (FNVA per farm) ranges from 17180 euros per farm in Romania to 584923 euros per farm in Slovakia. This indicator is defined as gross farm income minus depreciation (FADN code: SE415). Annual Work Units (AWU) range from 1.4 in Romania to 33.8 in Slovakia and is defined as full time equivalents. Average Farm Net Value Added per AWU in the EU of the dairy farms in the sample equals about 33109 euro per AWU.

The individual farm model FarmDyn applies 4 variants: 65CO2eq_TAX , 130CO2eq_TAX 65CO2eq_SUB_DP and 130CO2eq_SUB_DP. Changes in market input and output prices in Farmdyn in the different tax and subsidy variants as compared to the baseline are derived from MAGNET price changes between baseline and respective tax and subsidy variants. FarmDyn has only been applied to the average dairy farm on NUTS2 level in the EU.

Figure 15 shows changes in farm income per AWU. Average in EU27 income decreased with 3938 euro per AWU per farm in the 65CO2eq_TAX variant and with 4780 euro per AWU per farm in 130CO2eq_TAX variant respectively. Detailed results show a range from average -9781 euro in Luxembourg to -967 euro in Romania in the 65CO2eq_TAX variant and -13666 euro in Ireland to -1965 euro in Slovakia in 130CO2eq_TAX variant. The negative effects of the tax variants on farm income are dampened by the changes in market input and output prices from MAGNET. The EU average increase in the price of milk was 8.9 % and 18 % in the 65CO2eq_TAX variant 130CO2eq_TAX variant respectively and 1 % and 2% in the 65CO2eq_SUB_DP variant 130CO2eq_SUB_DP variants respectively[5].

[4] In this deliverable the sample of dairy farms includes specialist dairy farms with more than 5 cows and milk yield above and below a certain threshold.

[5] FarmDyn does not consider the 65CO2eq_SUB and 130CO2eq_SUB variants. It is assumed that production and GHG emission effects are similar, only the income effect differs.

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*Table 9 Dairy farms descriptive statistics*

| NUTS0 | Cows [LU per farm] | Arable Land [ha per farm] | Grassland [ha per farm] | Milk yield ['00 kg/cow/year] | Share of Grassland [%] | Farm Net Value Added (FNVA) [EUR per farm] | Annual Work Units per farm | FNVA per AWU | Livestock density [LU/ha] | n (number of farms in FADN) |
|---|---|---|---|---|---|---|---|---|---|---|
| AT | 21.4 | 5.4 | 21.3 | 67.3 | 80.7 | 39068 | 1.6 | 23937 | 0.8 | 669 |
| BE | 82.5 | 19.8 | 38.0 | 78.3 | 59.7 | 96993 | 1.9 | 50012 | 1.4 | 205 |
| BG | 33.2 | 8.4 | 12.1 | 45.0 | 34.0 | 37606 | 2.6 | 14676 | 1.6 | 45 |
| CZ | 139.3 | 155.2 | 152.6 | 68.1 | 54.8 | 326741 | 14.0 | 23404 | 0.5 | 110 |
| DE | 72.5 | 34.2 | 40.7 | 72.0 | 60.3 | 96803 | 2.2 | 44991 | 1.0 | 2530 |
| DK | 179.6 | 89.2 | 66.2 | 92.1 | 39.8 | 277524 | 3.3 | 83597 | 1.2 | 391 |
| EE | 116.0 | 106.0 | 181.0 | 73.0 | 81.0 | 128151 | 5.9 | 21558 | 0.4 | 98 |
| ES | 60.2 | 6.5 | 21.4 | 75.8 | 72.3 | 61890 | 1.9 | 33155 | 2.2 | 766 |
| FI | 42.5 | 18.9 | 51.2 | 88.1 | 71.7 | 53923 | 2.1 | 25101 | 0.6 | 229 |
| FR | 65.4 | 38.3 | 57.0 | 67.7 | 60.2 | 62167 | 1.9 | 32012 | 0.7 | 847 |
| HR | 20.5 | 14.1 | 10.3 | 52.0 | 39.3 | 39817 | 2.3 | 17222 | 0.8 | 131 |
| HU | 119.1 | 81.5 | 40.0 | 62.3 | 26.4 | 189153 | 8.2 | 23158 | 1.0 | 67 |
| IE | 84.2 | 1.2 | 63.1 | 57.5 | 98.2 | 77828 | 1.7 | 46350 | 1.3 | 298 |
| IT | 57.6 | 10.1 | 14.3 | 65.8 | 47.2 | 131149 | 2.0 | 64652 | 2.4 | 613 |
| LT | 21.9 | 13.4 | 37.0 | 54.8 | 74.7 | 21872 | 2.0 | 10900 | 0.4 | 219 |
| LU | 82.0 | 35.0 | 67.0 | 76.0 | 64.3 | 100926 | 1.9 | 54193 | 0.8 | 193 |
| LV | 25.0 | 13.0 | 48.0 | 57.0 | 82.0 | 24449 | 2.2 | 11130 | 0.4 | 242 |
| MT | 73.0 | 2.0 | 0.0 | 69.0 | 0.0 | 58273 | 2.5 | 23728 | 36.5 | 71 |
| NL | 101.6 | 9.0 | 49.1 | 85.8 | 84.7 | 123447 | 1.9 | 63924 | 1.7 | 355 |
| PL | 21.9 | 14.1 | 11.2 | 57.0 | 43.7 | 27463 | 1.9 | 14223 | 0.9 | 2082 |
| PT | 36.0 | 6.9 | 9.9 | 68.9 | 36.0 | 35438 | 1.9 | 18872 | 2.1 | 239 |
| RO | 12.0 | 3.4 | 5.9 | 43.9 | 39.5 | 17180 | 1.4 | 12614 | 1.3 | 180 |
| SE | 89.7 | 35.1 | 115.0 | 84.6 | 72.4 | 106317 | 2.8 | 37504 | 0.6 | 320 |
| SI | 20.7 | 4.4 | 14.3 | 53.6 | 74.9 | 19718 | 1.8 | 10952 | 1.1 | 138 |
| SK | 293.0 | 348.5 | 557.1 | 65.3 | 57.8 | 584923 | 33.8 | 17303 | 0.3 | 34 |
| EU27 | 52.5 | 19.6 | 33.5 | 66.1 | 60.7 | 68102 | 2.0 | 33109 | 1.1 | 11072 |

*Source: own calculations from FADN, bookkeeping year 2018.*

Variants 65CO2eq_SUB_DP and 130CO2eq_SUB_DP include the effects of the decrease in direct payment on farm income change. The decrease in direct payment in the 65CO2eq_SUB_DP variant ranges from 7.9 euro per ha in Bulgaria to 107.6 euro per ha in the Netherlands. The decrease in direct payment in 130CO2eq_SUB_DP variant ranges from 20.23 euro and 274.6 euro per ha, also in Bulgaria and the Netherlands. Nevertheless, average income per AWU in the EU27 increases around 3301 euro and 6341 euro per AWU per farm in the 65CO2eq_SUB_DP variant and 130CO2eq_SUB_DP variant respectively. Within the 130CO2eq_SUB_DP variant this ranges from an average increase of 2188 euro per AWU per farm in Croatia to 16870 euro per AWU per farm in Denmark. The positive income effects of the budget neutral subsidy variants result from a complex interplay of changes in market input and output prices, changes in direct payment, average costs of farm management adjustments in FarmDyn and the subsidy of 65 euro or 130 euro per ton CO2eq emission reduction. However, regional differences can be significant. Especially under variant 65CO2eq_SUB_DP the income effects are

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especially small or negative in the Eastern European countries and Portugal, see also Figure 16. Conversely, the effects of a carbon tax on income seem to be more intense in Western European countries.

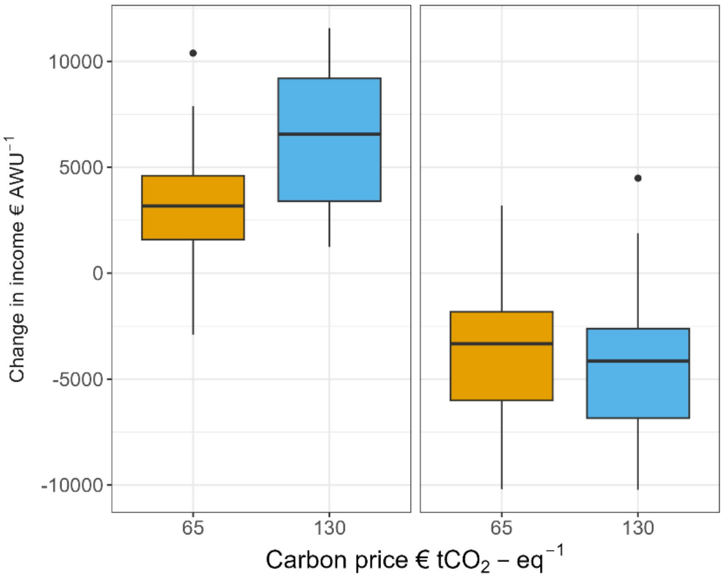


*Figure 15 changes in farm income per AWU. Left panel 65CO2eq_SUB_DP and 130CO2eq_SUB_DP variants. Right panel 65CO2eq_TAX and 130CO2eq_TAX variants*

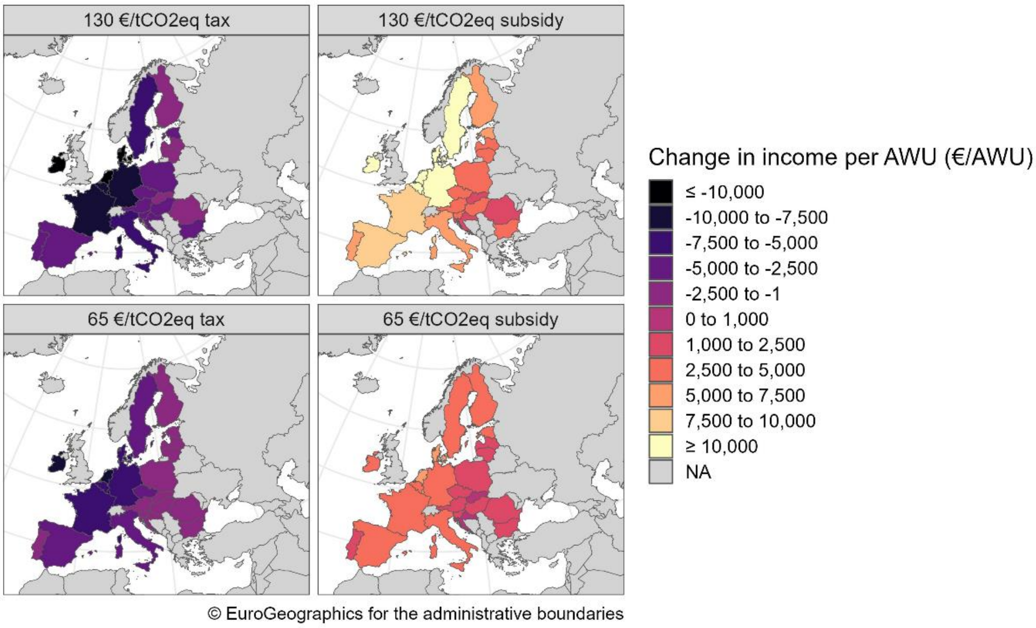


*Figure 16 Change in income (Farm Net Value Added) per MS per strategy and variant*

*Note: 130€/tCO2eq tax equals 130CO2eq_TAX; 65€/tCO2eq tax equals 65CO2eq_TAX; 130€/tCO2eq tax subsidy equeals 130CO2eq_SUB_DP; 65€/tCO2eq tax subsidy equals 65CO2eq_SUB_DP*

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Average decrease in use of N from mineral fertilisers equals 63.12% and 72.25% per dairy farm in the 65CO2eq_TAX and 130CO2eq_TAX variants respectively. The decrease in N from mineral fertilisers range from 8 to 50 % in Lithuania, Spain, Portugal, the Netherlands, Malta, Finland, and Poland to above 50 % in the rest. Average decrease in use of N from mineral fertilisers equal 18.60% and 24.11% per dairy farm in 65CO2eq_SUB_DP and 130CO2eq_SUB_DP variants. Decreases ranges between 8% and 25 % in Spain, Poland, France, Czechia, Italy, Bulgaria, Austria, Netherlands and Finland, while the rest is above 25 %.

The explanations are complex and diverse, due to the interplay of especially initial ha of arable land and grassland, number of dairy cows, milk yield, crop and grassland yield, and interplay between N and P content in animal manure and demand for N and P on the farm. In countries with high share of arable land in total area of grassland and arable land and relatively low yields of arable crops, the variants with taxation provoke an increase of idle arable land on the average dairy farm. Examples are Latvia, ...., Denmark and Germany. Idle grassland increases on dairy farms with low grassland yield and low livestock density. Examples are farms in Ireland, Italy...., Low yields of grassland and arable crops also lead to over-fertilisation of N from animal manure, within legal manure application limits. Given the taxation and subsidy variants this can be used as buffer to substitute with mineral fertiliser. A high share of grassland and high grassland yield provokes high demand of N and the buffer of N from animal manure to substitute with mineral fertiliser is not available. In that case, the impact of the variants on N from mineral fertiliser reduction is low. An example is the Netherlands. An uncertainty factor is the quality of FADN data regarding crop yields, especially roughage crops. Overall the use of mineral fertiliser is low on farms with low grassland and crop yields. The potential impact of the tax on CO2eq emission on mineral fertiliser use is large. The use of mineral fertiliser is relatively high on farms with high grassland and high crop yields. The potential impact of the tax on CO2eq emission on mineral fertiliser use is low.

GHG emission (GWP) decreases between 24 and about 30% in all countries, especially driven by the reduction in methane from enteric fermentation by Bovaer (Figure 17). Figure 17 shows a wide range of changes in N surplus and application of N from mineral fertiliser, especially in the taxation variants.

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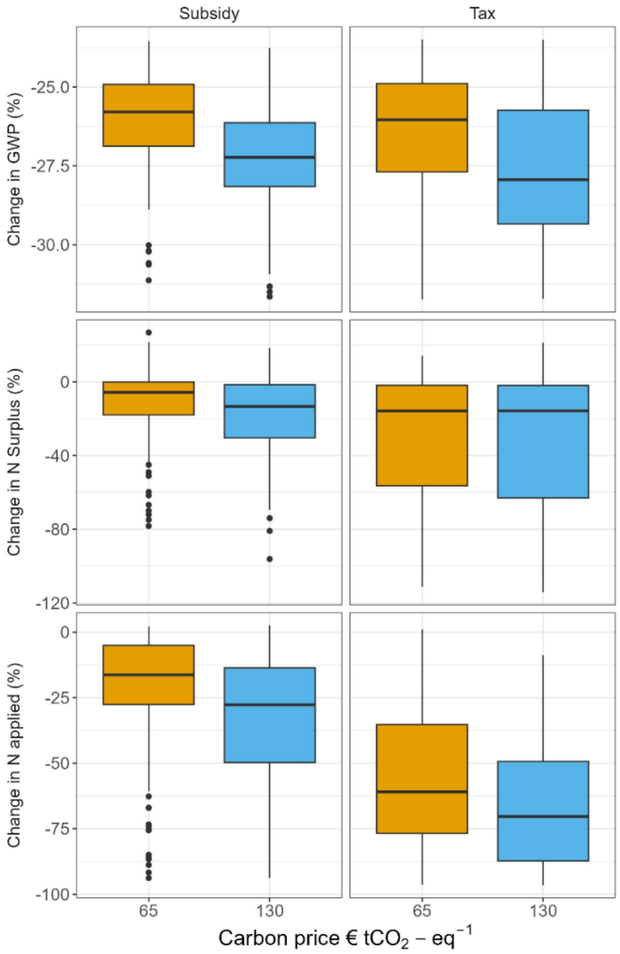


*Figure 17 EU average percentage changes in GWP,N-surplus and N applied from mineral fertilisers per strategy and variant.*

*Note: Left panel 65CO2eq_SUB_DP and 130CO2eq_SUB_DP variants. Right panel 65CO2eq_TAX and 130CO2eq_TAX variants*

As can be seen in Figure 18 in about all countries the tax strategies tend to have more impact on the reduction of GWP, with some exceptions like Poland, France and Slovakia. Again this is an interplay of the mechanisms in FarmDyn, including the GHG accounting system in FarmDyn and the sharp increase in prices of milk and meat from MAGNET, especially under the taxation variants.

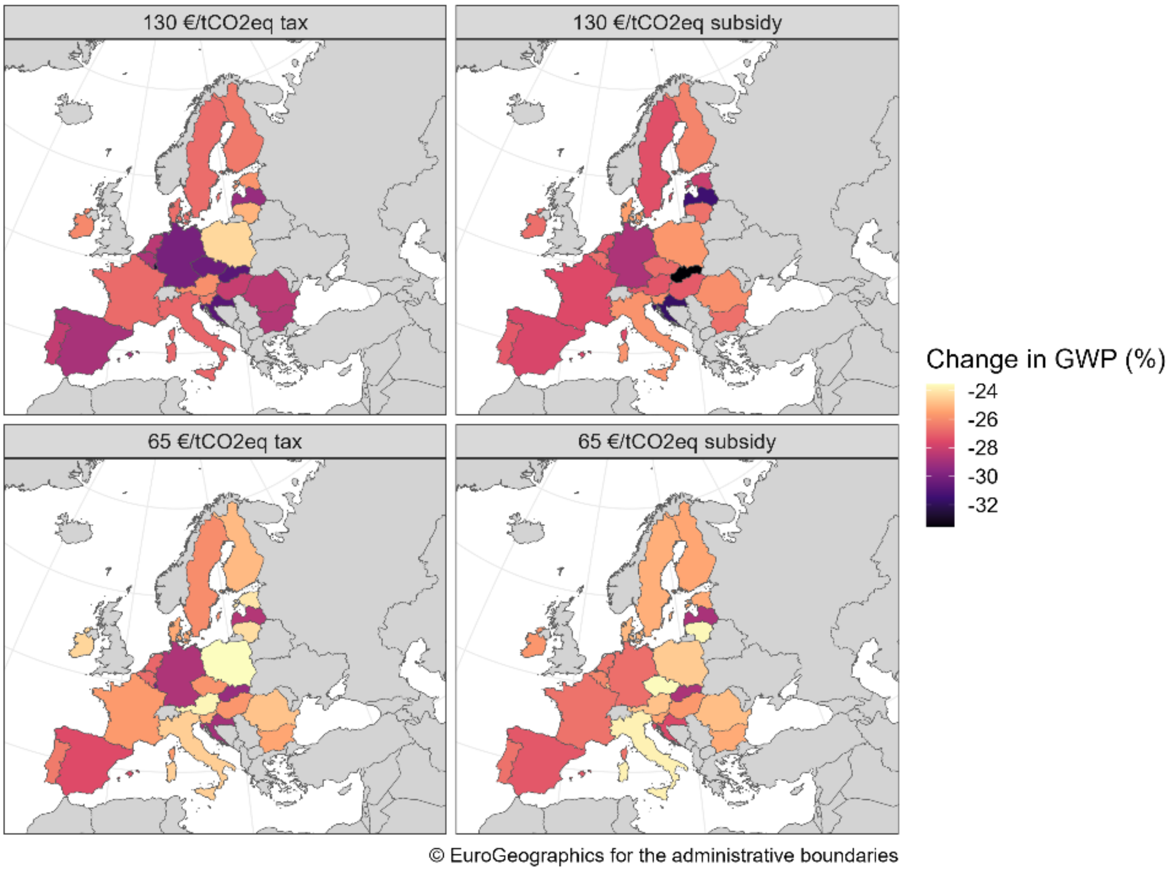


*Figure 18 Percentage changes in GWP per Member State per strategy and variant*

*Note: 130€/tCO2eq tax equals 130CO2eq_TAX; 65€/tCO2eq tax equals 65CO2eq_TAX; 130€/tCO2eq tax subsidy equeals 130CO2eq_SUB_DP; 65€/tCO2eq tax subsidy equals 65CO2eq_SUB_DP*

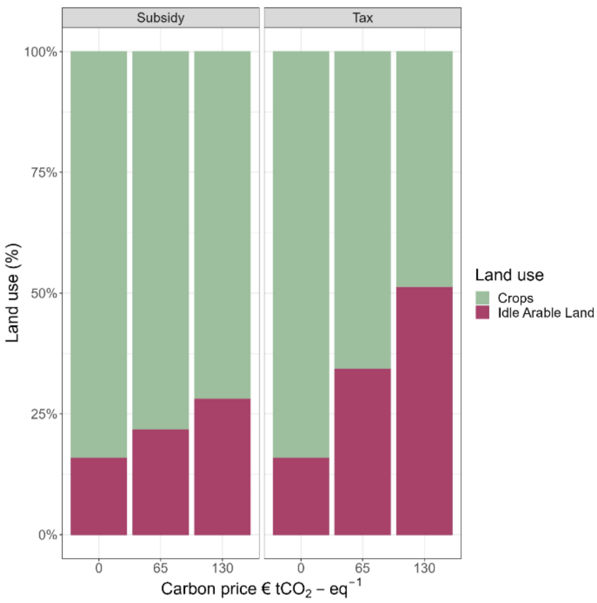


*Figure 19 Changes in cropping plan of arable land per strategy and variant*

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Figure 19 shows a large increase in fallow or idle arable land on the average dairy farm in the EU27. This is especially the case in the taxation variants. The decrease in own production for feeding the cattle herd on arable land is compensated by buying more feed from outside the farm. This can be explained, as under the taxation and subsidy variants decreasing own feed production is reducing the tax payment on GHG emission/increasing the subsidy from CO2eq emission reduction, while upstream GHG emissions from purchased feeds are not directly accounted to the farmer. The same mechanism is driving the change in grassland use, see Figure 20. In this version of FarmDyn, 4 types of grassland technologies are included, differentiated by grazing and silage grass and by high and low yield grassland yield. To minimizes CO2eq emission on the dairy farm, idle grassland is increased by decreasing the share of grassland dedicated to silage grass, while total acreage allocated to grazing slightly increases as well. Grazing switches to more intensive grazing technologies from 8.5 kg DM/ha to 10 kg DM/ha. The decrease in silage grassland is explained by the relative high energy use and related GHG emission per ha. Again, due to the design of the variants, own feed production is replaced by purchased feed.

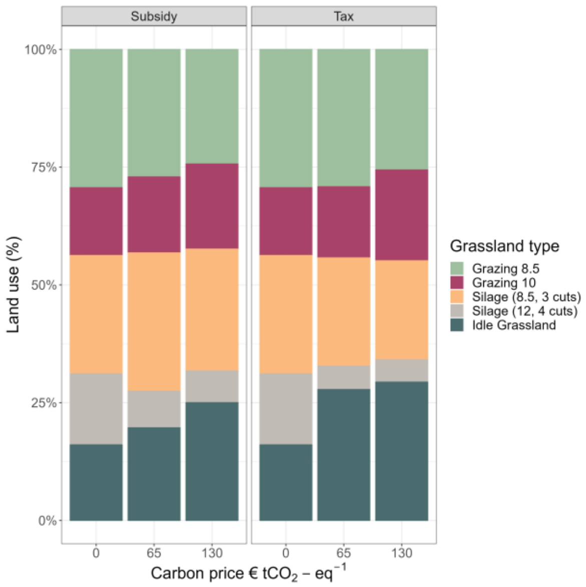


*Figure 20 Changes grassland use*

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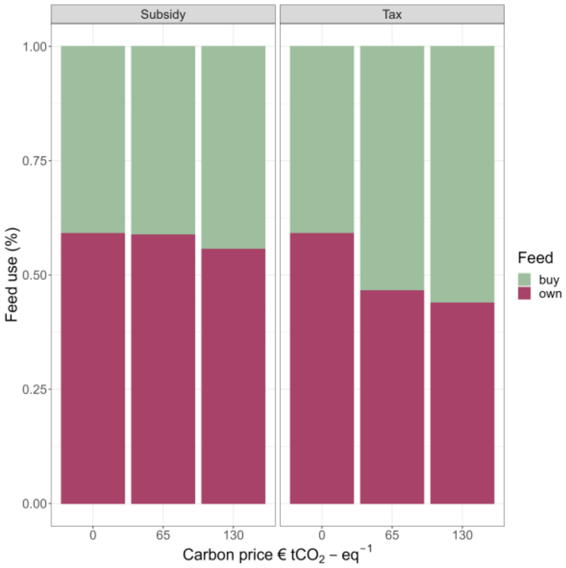


*Figure 21 Changes in share of own and bought feeds in total feed use on the average dairy farm in the EU27*

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## 4.5. Discussion of model results

**Comparison of model results:**

In TAXATION strategy 130CO2eq_TAX, GHG emission reduces with around 33-34% and 27% in GLOBIOM and MAGNET respectively. The difference can be explained as for the agricultural sector a whole GLOBIOM considers more and less costly GHG mitigation technologies as compared to MAGNET. The total tax revenue is about equal between MAGNET and GLOBIOM, see Table 10. Also in TAXATION strategy 130CO2eq_TAX, production of beef decreases with around 12% in GLOBIOM, while this is around 15% in MAGNET. Primary milk production decreases with about 9% in GLOBIOM, while in MAGNET this is around 5%. Change in cereals production in GLOBIOM equals around -12% in GLOBIOM, while the change in cereals production in MAGNET equals around -10%. More pronounced differences can be found in price developments of beef. In TAXATION strategy 130CO2eq_TAX a price increase of almost 60% is projected in MAGNET, while GLOBIOM projects a price increase of around 15%. Also for dairy the market price elasticities seems to be more inelastic in MAGNET as compared to GLOBIOM.

*Table 10 Differences between selected model results. EU27 agricultural sector. Percentage difference or difference in bn euro compared to base. 130CO2eq_TAX variant.*

| Name of model | GHG emission reduction (%) | Tax revenue (bn euro) | Changes in Production (changes in prices between brackets) (%) | GDP (EU economy wide) / Income (average EU dairy farm) (%) |
|---|---|---|---|---|
| 1 MAGNET | 27 | 40.9 | -5 (+18) (milk)<br>-15 (+59) (beef) | -0.82 (GDP) |
| 2 GLOBIOM | 33 | 39.6 | -9 (+14) (milk)<br>-12 (+15) (beef) | |
| 3. FarmDyn | | | 0 (+18) (milk) | -15 (Income) |

### Discussion of model results

Including structural change it is expected that compared to the decrease in the number of dairy farms in the baseline, the TAXATION strategy would accelerate the baseline trend, while especially the SUBSIDY strategy and (to a lesser extent) the SUBSIDY and ADJUSTMENT VIA CAP DIRECT PAYMENT strategy would dampen the baseline trend. The magnitude of the deviations from the baseline is indicated by the sector level changes in milk production in MAGNET and GLOBIOM. With different number of dairy farms leaving the sector per strategy and variant, also the number of dairy farms that continue farming and grow or not grow in ha or milk production will be different per strategy and variant. This is however a slow process explained by the concept of sunk costs in agricultural production (Balmann et al., 2006). Aggregated policy outcomes crucially depend on sunk costs, feedback mechanisms on (local) input and output factor markets and general interaction between farms. MIND STEP Deliverable report 4.5 presents an approach to couple the technology rich, bio-economic farm model FarmDyn to the Agent Based Model (ABM) AgriPoliS using surrogate models. It is shown that the coupled models show stable results with a plausible level of interaction on the land market and dynamics for farm structural change over a 25-year simulation period.

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In the taxation and subsidy strategies in this deliverable, CO2eq emission from imported feed used at the dairy farm is not accounted for. This partly explains why in the farm model FarmDyn the dairy farms prefer to produce less feed on own land and increase share of purchased feeds in the feed ration, instead of decreasing number of dairy cows.

### Policy recommendations

- The TAXATION strategy achieves the highest CO2eq emission reduction, albeit at high economic costs. The long-term outlook suggests a dampening of income effects at continuing farms as production at sector level will decrease and prices increase.
- A gradual implementation of the SUBSIDY and ADJUSTMENT VIA CAP DIRECT PAYMENT strategy allows farmers and markets time to invest and adjust and to find the optimal subsidy levels to circumvent overcompensation of income.
- Re-evaluation of the farm specific base GHG emission levels over time would result in an eventual phasing-out of the SUBSIDY strategy once the reduction potential has been reached.

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# 5. SCENARIO 2: MINERAL NITROGEN FERTILIZER USE REDUCTION

## 5.1. Storyline

The reduction of nutrient losses in agriculture is a stated objective of ongoing EU-wide policy strategies to address the existing high levels of nutrient pollution in the environment. The EU F2F strategy aims at a reduction of nutrient losses by at least 50%, while ensuring that there is no deterioration in soil fertility, implying a reduction of fertiliser use by at least 20% by 2030. This will be achieved by implementing and enforcing the relevant environmental and climate legislation in full, by identifying with Member States the nutrient load reductions needed to achieve these goals, applying balanced fertilisation and sustainable nutrient management and by managing nitrogen and phosphorus better throughout their lifecycle.

There are several conceivable policy measures to achieve this objective, such as imposing restrictions on fertiliser use, by supporting famers in switching to less input-intensive practices, or by creating market incentives for the reduction of fertiliser use, to name just a few. We explore a tax on fertilisers as a market-based measure, which would create an incentive for farmers to reduce the application levels and to invest in fertiliser saving technologies.

Taking inspiration from the climate mitigation potential literature (e.g. IPCC 2023), we opt to tax mineral N fertilizers based on the emissions of CO2 equivalents arising from their application in the field (namely N2O) and their production (CO2). Typical taxation rates for CO2 equivalents range from 15 - 220 USD/tCOeq in the IPCC scenarios for 2030 (see e.g. Rogelj et al., 2018). For this reason we consider CO2 tax levels ranging from 10 to 200 Euro per ton of CO2 equivalent. To be more precise N-taxation equivalents are calculated for CO2 taxation levels of 10, 25, 50, 75, 100, 125, 150, 200 Euro/tCO2eq.

The tax on mineral N fertilizer can be based on either the taxation of the CO2 equivalents of N2O emissions solely at the farm application level (applied strategy) or the combined taxation of CO2 equivalent emissions at the application and production levels (combined strategy). This results in increases of nitrogen fertiliser prices between 3% and 61% if only the emissions from fertiliser application are considered, while an increase of 132% would be achieved at a level of 200Euro/tCO2eq if also emissions from fertilizer production are included. The tax on mineral N fertilizer considered are shown in Table 11.

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*Table 11 Translation of CO2 taxes into taxes on mineral N fertilizer in Applied and Combined strategies (Multipliers on the price of N from mineral fertilizer, 2019 prices)*

| | Mineral N Fertilizer tax | |
|---|---|---|
| CO2 Tax (Euro/tCO2eq) | Applied (derived from CO2eq emission during application) | Combined (derived from CO2eq emission during application and production of mineral N fertilizer) |
| 10 | 1.03 | 1.07 |
| 25 | 1.08 | 1.17 |
| 50 | 1.15 | 1.33 |
| 75 | 1.23 | 1.50 |
| 100 | 1.30 | 1.66 |
| 125 | 1.38 | 1.83 |
| 150 | 1.45 | 1.99 |
| 175 | 1.53 | 2.16 |
| 200 | 1.61 | 2.32 |

As in the greenhouse gas mitigation scenario, the considered mitigation options are (i) nitrogen inhibitors, and (ii) precision farming techniques, such as auto- or split-fertilization. This highlights the role of mitigation technologies in helping to achieve the EU's Green Deal targets on chemical inputs.

Just like in the GHG mitigation scenario, the taxation strategy is extended by considering how the levied tax can be used as a means of compensating the agricultural sector for the income losses. This underlines that the tax should not be seen as a penalty and it is supposed to mitigate for potential incurred production losses. We consider four variants for this repayment of taxes:

1. The simplest case is where no repayment to the agricultural payment is happening.
2. Each member state repays its agricultural sector by a simple per hectare of cropland distribution of the tax. In this setting larger farms would get larger repayments in total (as in not per hectare), since farm with relatively more cropland get a larger total sum of the levied tax.
3. The repayment is also per hectare, but distributed per hectare of cropland and grassland (that is total agricultural area).
4. The tax revenue is used to subsidies mitigation technologies. This represents a policy where farmers applying mitigation technologies can apply for the tax compensating subsidy.

## 5.2. Models used, policy strategies, and variants

From an impact-assessment perspective, it is relevant to identify the isolated and combined effects of the alternative policy measures on multiple indicators. Particularly, a tax on fertilization can have effects on the EU wide agricultural production, in terms of trade balances, through leakage effects in other parts of the world, and of course on the European farm landscape as well. Particularly the latter is complex, with multiple type of farms having varying response to policies.

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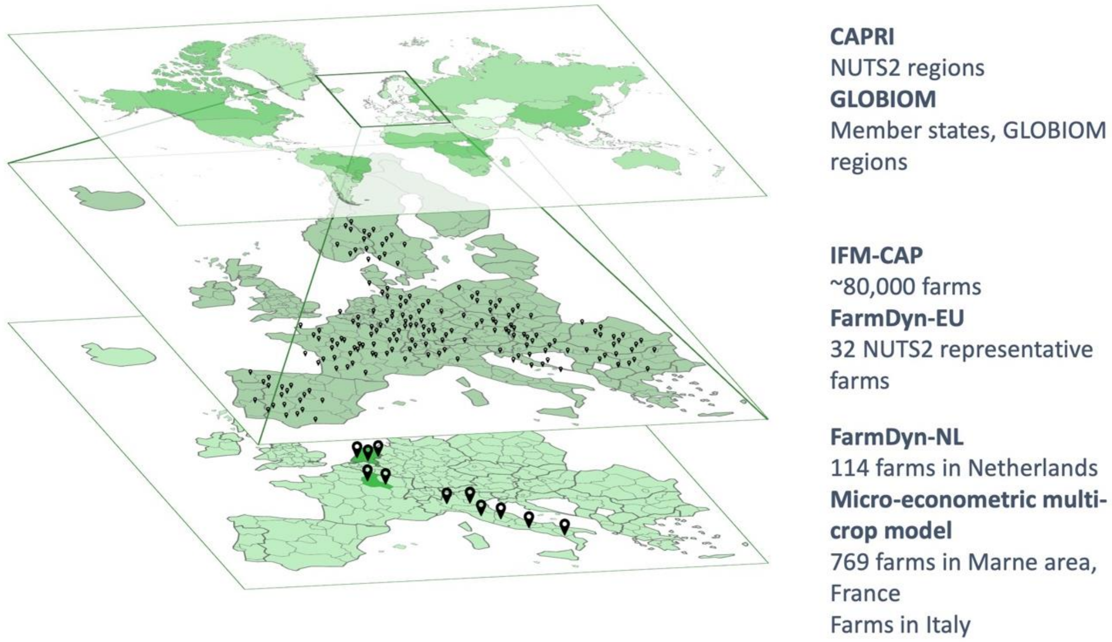


*Figure 22 Overview of model coverage*

To effectively assess the effectiveness and associated impacts of fertiliser taxation, we use multiple component models of the MIND STEP modelling toolbox to provide a broad and comprehensive assessment. The suite of models comprising GLOBIOM, CAPRI, FarmDyn, IFM-CAP, and the econometric model in France and Italy (INRAE-MC) operates at different spatial and thematic scales. Together, these models form a hierarchy of spatial and thematic scales, enabling a holistic assessment of nitrogen taxation's impacts, from the global market down to individual farms in France and the EU.

All models cover the full set of N taxation variants, both on the application and on the combined application and production side. The tax revenue repayments were considered for income support by IFM-CAP, CAPRI, and GLOBIOM. Tax revenue repayment to subsidy mitigation technologies is implemented in GLOBIOM. This is summarised in Table 12 below. The considered levels of taxation are shown in Table 13.

*Table 12 Models used and overview of coverage of taxation variants by models*

| Taxation variant | FarmDyn | **Empirical multi-crop model** (INRAE-MC) | IFM-CAP | CAPRI | GLOBIOM |
|---|---|---|---|---|---|
| **N taxation Euro/tCO2eq** | YES | YES | YES | YES | YES |
| **Mitigation technologies (N inhibitors, precision farming)** | NO | NO | NO | YES | YES |
| **Tax revenue repayment (income support)** | NO | NO | YES | YES | YES |
| **Tax revenue repayment (subsidy mitigation technologies)** | NO | NO | NO | NO | YES |

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To stress the importance of including market feedback in farm models, FarmDyn is executed for average NUTS2 dairy and arable farms across the EU (see Table 1) with and without agricultural input and output price changes to account for the mentioned market effects. For this, the results of the corresponding taxation variants from CAPRI at national level are used, which has a different commodity classification. The procedures necessary to re-shape the CAPRI result tables into a format required by FarmDyn are explained in more detail in Deliverable 5.3 (Müller et al. 2023).

*Table 13 Scenario strategies and models used*

| Reduction scenario strategy | Description | Name strategy | Models used |
|---|---|---|---|
| TAXATION | Between 3 and 132 % tax on N mineral fertilizer prices, based on emissions originating from fertilizer application and production (Table 11) | 3 % – 132 % | GLOBIOM, CAPRI, FarmDyn, IFM CAP, INRAE-MC |
| TAXATION and AREA BASED REDISTRIBUTION | Between 3 and 132 % tax on N mineral fertilizer prices. The national tax revenues are redistributed to the agricultural sector for each MS via a uniform payment per ha of utilised agricultural area (cropland and pasture). | 3 % – 132 %, area redistribution | GLOBIOM, CAPRI, IFM-CAP |
| TAXATION and COMPLIANCE BASED REDISTRIBUTION | Between 3 and 132 % tax on N mineral fertilizer prices. The national tax revenues are redistributed to mitigation technologies as an additional incentive per ha mitigation technology (cropland and pasture). | 3 % – 132 %, area redistribution | GLOBIOM |

## 5.3. Technical measures, adoption and Indicators

Mitigation technologies were considered by the CAPRI and GLOBIOM models, who both represent smart farming and Nitrogen inhibitors mainly for reducing Nitrogen emissions. Otherwise, the mitigation technologies employed by both models correspond exactly to the ones presented in Section 4.3 (see fertilizer-related entries in Table 5).

Different models report different results. An overview of the model indicators is provided in Table 14.

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*Table 14 Overview of used toolbox models and indicators*

| Name of the model | Considered indicators |
|---|---|
| 1 GLOBIOM | N use, Agricultural land use, GHG emissions, Agricultural primary production, Net trade of agricultural products, Price of agricultural primary goods |
| 2 CAPRI | N use, N surplus, Agricultural land use, GHG emissions, Agricultural primary production, Net trade of agricultural products, , Price of agricultural primary goods, producer surplus |
| 4 IFM-CAP | N use, Agricultural land use, Agricultural primary production, Welfare |
| 5 FARM DYN | N use, N surplus, Agricultural land use, GHG emissions, Agricultural primary production, Farm management, Farm structure, Farm income |
| 6 INRAE-MC | N use, Agricultural land use, Agricultural primary production, gross margin |

## 5.4. Key results

### 5.4.1. Summary

This section presents key results for the mineral N fertilizer taxation scenario. For reasons of readability and clarity, the focus is on the highest taxation variant, namely a tax of 132% on the price of mineral N fertilizer.

**Reduction in mineral N fertilizer use at sector level:**

- Between -30% (CAPRI) and -11% reduction (IFM-CAP) of mineral fertilizer input at sector level at high levels of taxation
- Threshold to reduce mineral fertilizer use by 20% is between 23 and 66% tax on the price of mineral N fertilizer (CAPRI and GLOBIOM)
- Noteworthy variations across EU regions indicate spatial heterogeneity (CAPRI results indicate strongest reduction in Netherlands, while IFM-CAP suggests hotspots of input reductions across the EU).
- Precision farming emerges as a significant mitigation source (CAPRI).

**Reduction in mineral N fertilizer use at farm level:**

- Arable farms exhibit limited responses to taxation, with a <15% reduction in mineral N use even at the highest taxation rate (FarmDyn).
- Contrastingly, dairy farms show on average a 41% reduction due to the ability to substitute mineral N fertilizers owing to organic N surplus (FarmDyn).
- The impact on mineral N fertiliser use on Italian FADN arable crop farms equal around – 22%. This is mainly achieved by a decrease of mineral N fertilizer of 22% on cereals (soft and durum wheat, barley and corn)

**Income and yield implications:**

- Limited effects of fertilizer prices increase on arable crop yield levels, consistent with flat N-response curves for arable crops (FarmDyn).
- The impact on yields on Italian FADN arable crop farms can reach -6% on average for winter cereals (soft wheat, durum wheat and barley) and -4/5% for corn and soybean.

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- The highest tax strategy variant project income decrease in EU agriculture as a whole between 4% (IFM-CAP) and 14% (CAPRI). Depending on income definition.
- Without tax redistribution, average income losses on specialist COP and other fieldcrops farms equal around 10% and 7.5% respectively (IFM-CAP).
- The impact on crop returns (gross margin i.e. the difference between revenues and costs for the crops considered in the model) on Italian FADN arable crop farms equals -36%, as results of the decrease in yields and of the increase in fertiliser costs.
- Income (Farm Net Value Added) per AWU for average arable farms decrease by about 25% if output price changes are not taken into account and by about 12% if product price changes are taken into account (FarmDyn).
- In the case of dairy farms, farm incomes at highest tax rate decrease with around 6%. Farm income may increase by 2% if output (milk) price increases from the CAPRI model are taken into account (FarmDyn).
- Tax revenue collection, including the effect of the tax on the use of mineral N fertilizer, ranges from about 8 bn euro (GLOBIOM) to 11.4 bn euro (IFM-CAP). The difference can be mainly attributed to GLOBIOM not representing fruit and vegetable farms, as opposed to IFM-CAP.

**N-surplus and GHG emission implications:**

- Without tax revenue redistribution change in N surplus in EU27 equals around 20% at sector level (CAPRI). So, while the target of mineral N fertiliser recuction is reached (namely in CAPRI a reduction of about 30%), the targeted reduction of N losses of 50% is not reached (assuming that ammonia emission from application of mineral N fertilizer is limited). Among other this is explained by the use of organic fertilisers (animal manure).
- At the highest mineral N fertilizer taxation rate the decrease in nitrogen surplus equals around 25% on the average EU dairy farm (FarmDyn).
- The decrease in the N surplus on the average arable farm in the EU is highly sensitive to the use of animal manure on the farm and the assumptions regarding initial nutrient use efficiency. Sensitivity analysis show that decrease in the N surplus on the average arable farm in the EU could range between -30% and - 60%, with variation between these percentages.
- Increased nitrogen taxation leads to between 28 MtCO2eq. (CAPRI) and 51 MtCO2eq. (GLOBIOM) reduction of emissions from the agricultural sector in the EU.
- The reduction is accompanied by a 78 MtCO2eq. increase in emissions in the rest of the world, leading to a total of 27 MtCO2eq. global net increase of emissions from the taxation policy (GLOBIOM).
- If tax revenue repayment as basic income support is considered for crops and livestock the taxation of N fertilisers would have a global net zero effect in terms of MtCO2eq (GLOBIOM).
- When the taxation is redistributed as a subsidy to mitigation technologies, the emissions in the EU would not change substantially, however, global emissions would be reduced by 27 MtCO2eq (GLOBIOM).
- 

**Land use effects and implications:**

- Changes in land use observed across the EU due to taxation without redistribution can be large, e.g. a 35% reduction of cropland in the highest taxation strategy variant (GLOBIOM)
- Including redistribution policies largely dampens the changes in land use observed across the EU due to taxation.

**Impacts on structural change:**

- Impacts on land concentration and number of farms (structural change) are limited (IFM-CAP).

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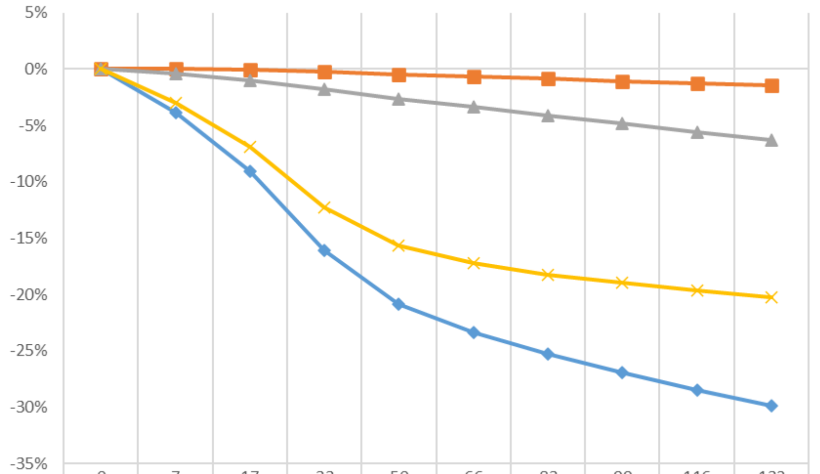
### 5.4.2. CAPRI

When executing the CAPRI model for the tax rates indicated for the taxation of emissions originating from N-fertilizer production and application (Table 11), the reduction in total N surplus ranges from 2.99-20.25% (Figure 23). The production of cereals and fodder are the most affected ones (Figure 27). This reduction of fodder production draws down animal herd sizes, therefore, decreasing meat production slightly. The sectoral welfare effects on consumer are non-significant, whereas the producer welfare is negatively affected.




| | 0 | 7 | 17 | 33 | 50 | 66 | 83 | 99 | 116 | 132 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mineral fertilizers | 0 | -3.92% | -9.07% | -16.07% | -20.83% | -23.39% | -25.30% | -26.88% | -28.44% | -29.86% |
| Manure | 0 | 0.01% | -0.08% | -0.25% | -0.46% | -0.65% | -0.87% | -1.07% | -1.29% | -1.48% |
| Crop residues | 0 | -0.40% | -0.98% | -1.81% | -2.65% | -3.38% | -4.15% | -4.87% | -5.61% | -6.29% |
| Surplus total | 0 | -2.99% | -6.93% | -12.27% | -15.67% | -17.24% | -18.22% | -18.95% | -19.64% | -20.25% |

*Figure 23 Reduced N fertilizer application in response to increased taxation of mineral N fertilizer in the EU, with mitigation technologies.*

*Note: Tax rates are calculated based on CO2 emission equivalents from fertilizer application and production (*Table 11*)*

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*Table 15 Mitigated global warming potential from the EU agricultural sector under taxation levels on mineral N fertilizer in the EU.*

| N-fertilizer tax rate, based on application emissions [%] | Perc. Change | Abs. change (1000t CO2 eq) | N-fertilizer tax rate, based on application and production emissions [%] | Perc. Change | Abs. change (1000t CO2 eq) |
|---|---|---|---|---|---|
| **3** | -0.28% | -1115 | **7** | -0.67% | -2676 |
| **8** | -0.77% | -3067 | **17** | -1.65% | -6572 |
| **15** | -1.46% | -5814 | **33** | -3.05% | -12139 |
| **23** | -2.21% | -8772 | **50** | -4.12% | -16400 |
| **30** | -2.82% | -11201 | **66** | -4.82% | -19178 |
| **38** | -3.43% | -13623 | **83** | -5.47% | -21739 |
| **45** | -3.86% | -15339 | **99** | -6.04% | -24017 |
| **53** | -4.27% | -16985 | **116** | -6.62% | -26338 |
| **61** | -4.62% | -18371 | **132** | -7.16% | -28464 |

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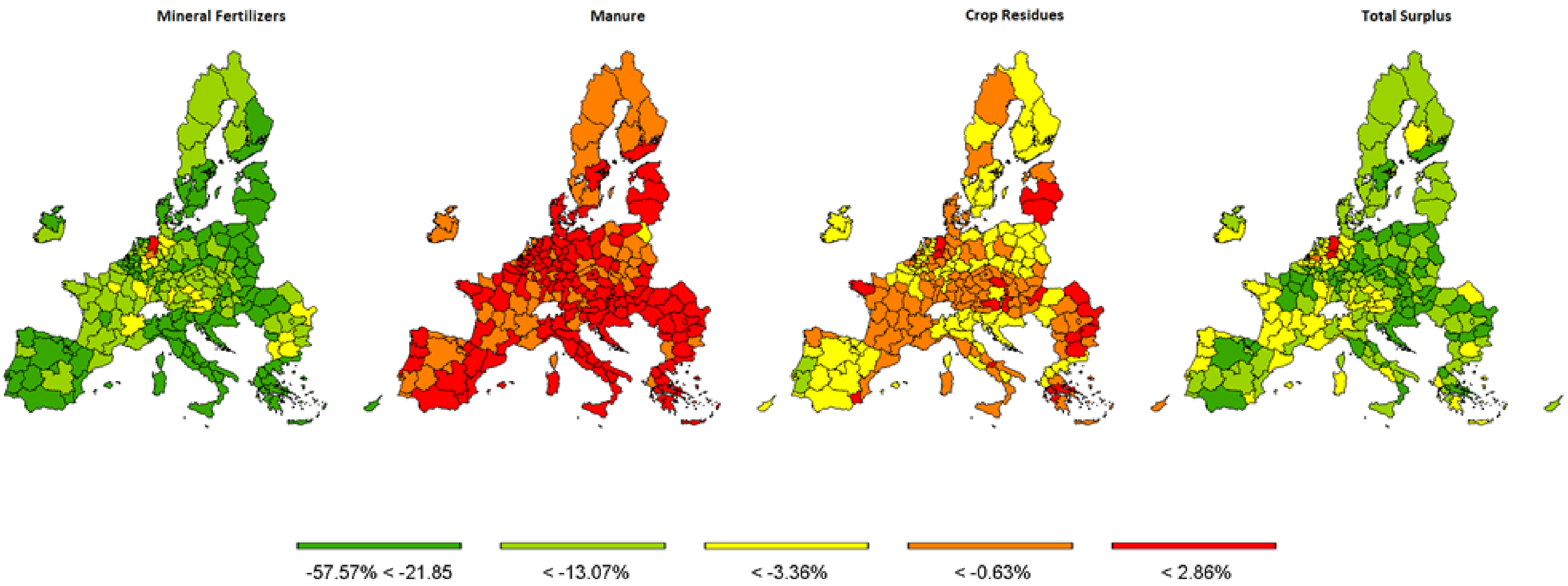


*Figure 24 Reduced N fertilizer application in response to 61% taxation on mineral N fertilizer at NUTSII level, with mitigation technologies.*

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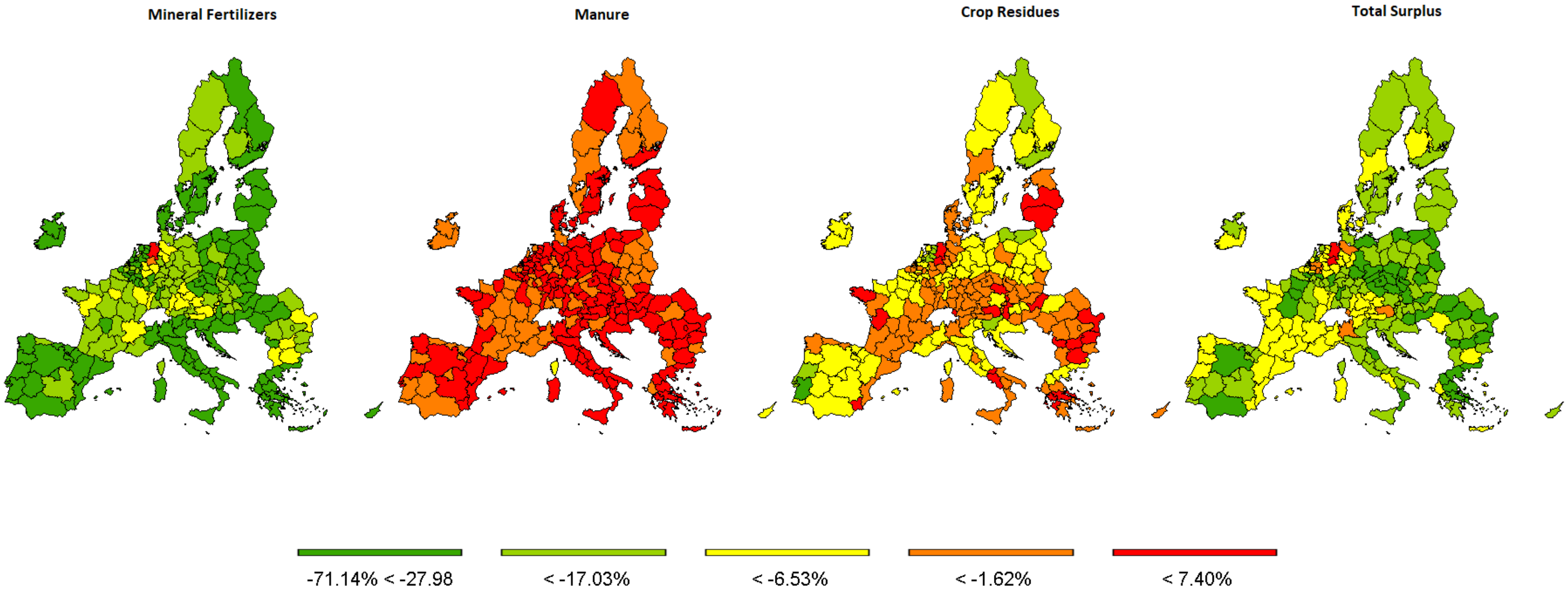


*Figure 25 Reduced N fertilizer application in response to 132% taxation on mineral N fertilizer at NUTSII level, with mitigation technologies.*

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The use of mineral N fertilizers reduces throughout the EU, except for the Weser-Ems region in Germany, known for its intensive livestock production. Here, the shift from crop to livestock production leads to increased feed production, the primary reason for higher mineral N fertilizer application. We also observe increased fertilization with manure in regions with ample manure availability. Changes in fertilization with crop residues are highly heterogeneous, contingent upon the regional context. Notably, reductions in total surplus are observed in all regions except for Weser-Ems and Muenster.

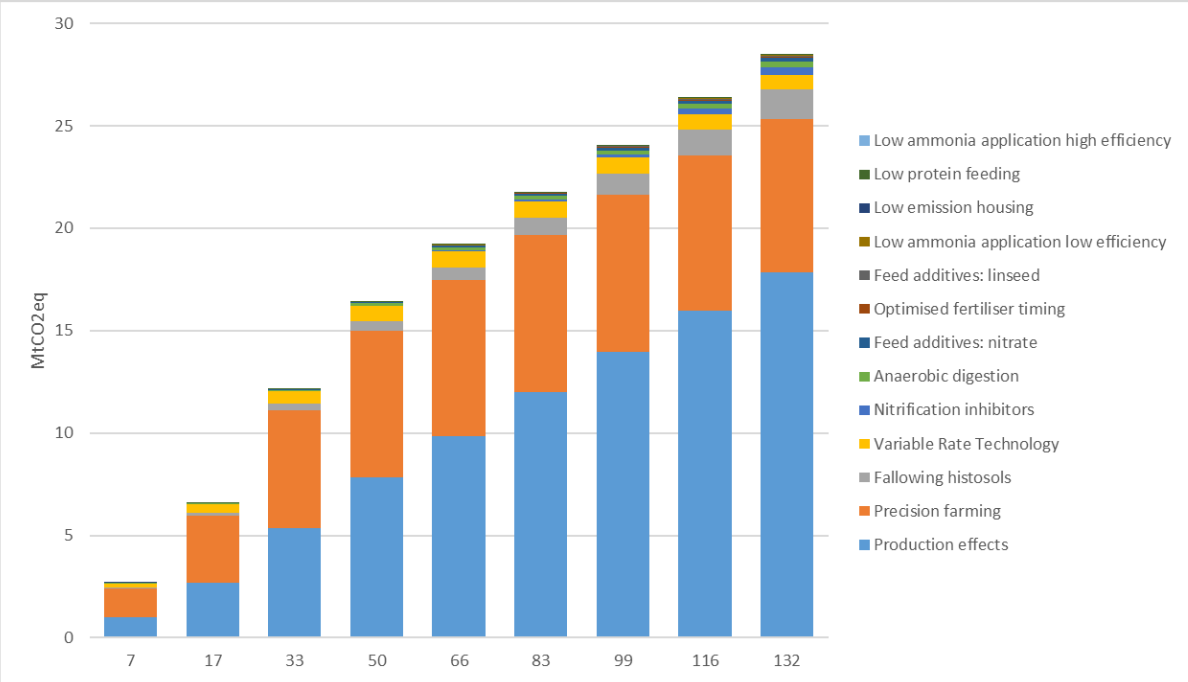


*Figure 26 The sources of mitigation under taxation of mineral N fertilizer in the EU, based on emissions from application and production.*

Under all variants, the technologies most widely adopted and having the largest mitigation effect are those targeting the use of mineral fertilizers, such as precision farming, variable rate technology, nitrification inhibitors, etc. Additionally, the practice of fallowing histosols also proves to be quite efficient.

Intriguingly, when examining the combined taxation variants, the proportion of reduced emissions attributed to mitigation technologies demonstrates a consistent rise until the imposition of a 75€/t of CO2 equivalent tax level (50% tax on the price of mineral N fertilizer). Following this threshold, the percentage of mitigated emissions ascribed to these technologies remains relatively constant. Beyond this point, the amplified volume of reduced emissions primarily arises from alterations in activity levels rather than further contributions from mitigation technologies.

This observation suggests that up to the 75€/t of CO2 eq. tax level, technological advancements and strategies aimed at mitigation play a progressively larger role in curbing emissions. However, once this tax level is attained, the subsequent reductions in emissions predominantly stem from changes in how activities are conducted rather than from additional advancements in mitigation technologies. This phenomenon underscores the significance of both technology and behavioural changes in achieving further reductions in emissions beyond a certain taxation threshold.

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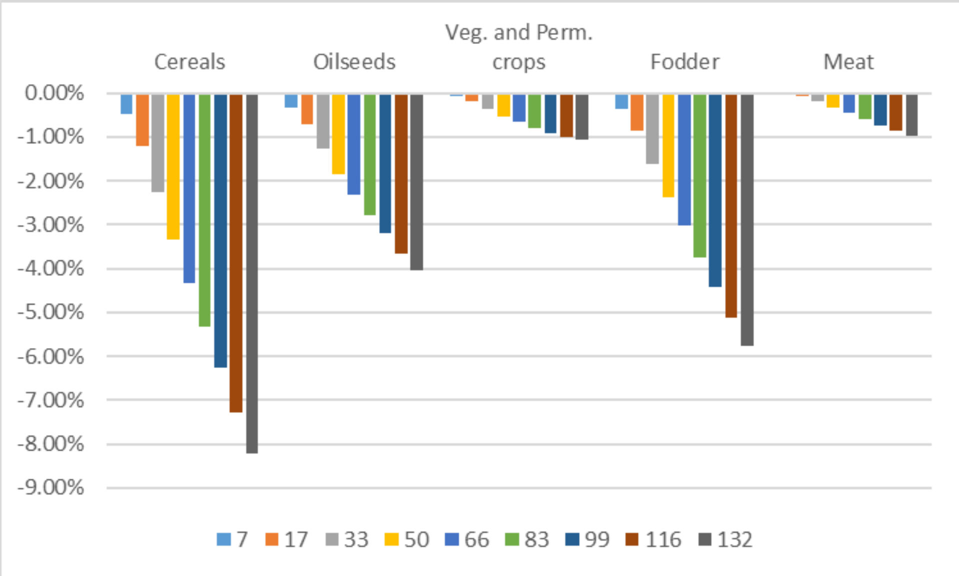


*Figure 27 Percentage changes in the EU supply in response to increased taxation on mineral N fertilizer in the EU, with mitigation technologies*

*Table 16 Income changes in response to increased taxation on mineral N fertilizer in the EU with and without redistribution of tax revenues*

| N-fertilizer tax rate, based on application and production emissions [%] | No Income redistribution | Income redistribution |
|---|---|---|
| **7** | -1.00% | -0.19% |
| **17** | -2.29% | -0.42% |
| **33** | -4.29% | -0.95% |
| **50** | -6.17% | -1.39% |
| **66** | -7.74% | -1.65% |
| **83** | -9.32% | -1.85% |
| **99** | -10.78% | -2.05% |
| **116** | -12.26% | -2.25% |
| **132** | -13.68% | -2.51% |

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## 5.4.3. GLOBIOM

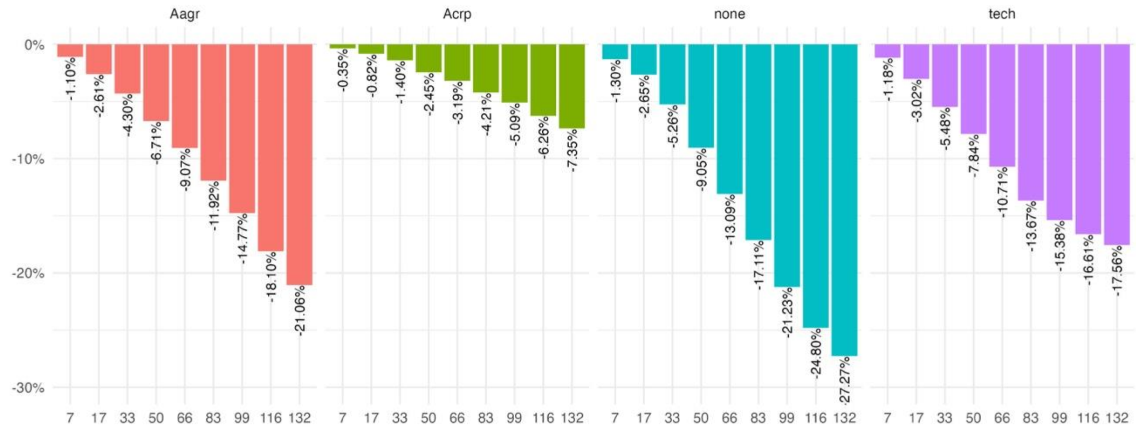


*Figure 28 EU wide reduced fertilizer application in 2030 in response to increased $CO_2$eq taxation on mineral N fertilizer in the EU as percentage of the baseline without taxation.*

*Note: The tax take is either not redistributed ('none') or subsidizes agricultural area ('Aagr'), cropland area ('Acrp'), or agricultural area where mitigation technologies are applied ('tech').*

The above Figure 28 illustrates the impact of nitrogen (N) fertilizer price taxation on fertilizer application within the EU by the year 2030. The x-axis represents the percent of N fertilizer price taxation, ranging from lower percentages to higher, across different policy variants. The y-axis shows the percent reduction in fertilizer application compared to a baseline with no taxation. The categories on the x-axis likely correspond to different taxation rates applied to the price of N fertilizer.

The blue bars represent variants where the tax revenue is not redistributed ("none"), red bars where the tax revenue subsidizes agricultural areas ("Aagr"), green bars where the tax revenue subsidizes cropland areas ("Acrp"), and purple bars where the revenue is used for agricultural areas implementing mitigation technologies ("tech"). The reduction in fertilizer application is inversely related to the tax rate: as the tax rate increases, the use of fertilizers decreases. This suggests that higher taxes on N fertilizer lead to more significant reductions in its use.

The graph indicates that without redistribution of tax revenue ("none"), there's a consistent decrease in fertilizer application as the tax rate increases. When the revenue subsidizes agriculture ("Aagr"), the reduction is less pronounced, suggesting that subsidies may dampen the effect of the tax. In contrast, applying revenue towards technological mitigation ("tech") results in a steeper decline in fertilizer use, implying that investing in technology can effectively reduce fertilizer application, potentially promoting more sustainable agricultural practices.

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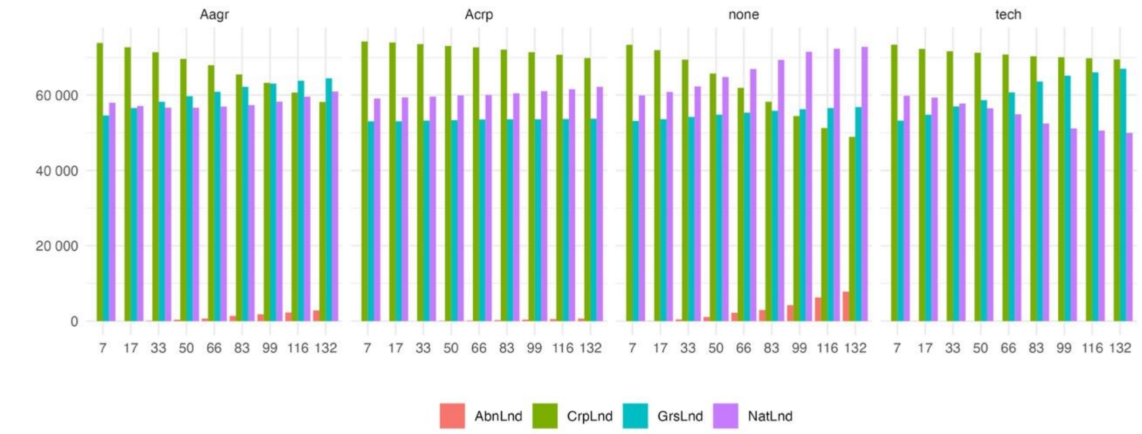


*Figure 29 Changes in EU land cover in response to increased CO2eq taxation on mineral N fertilizer in 1000 ha.*

*Note: Y axis is percent of N mineral fertiliser price increase. With taxation: Abandoned land ('AbnLnd') increases, cropland ('CrpLnd') decreases, grassland (GrsLnd) increases, and other natural land (NatLnd) increases or decreases dependent on the redistribution scheme. Other land covers are constant and not shown (forests, settlements).*

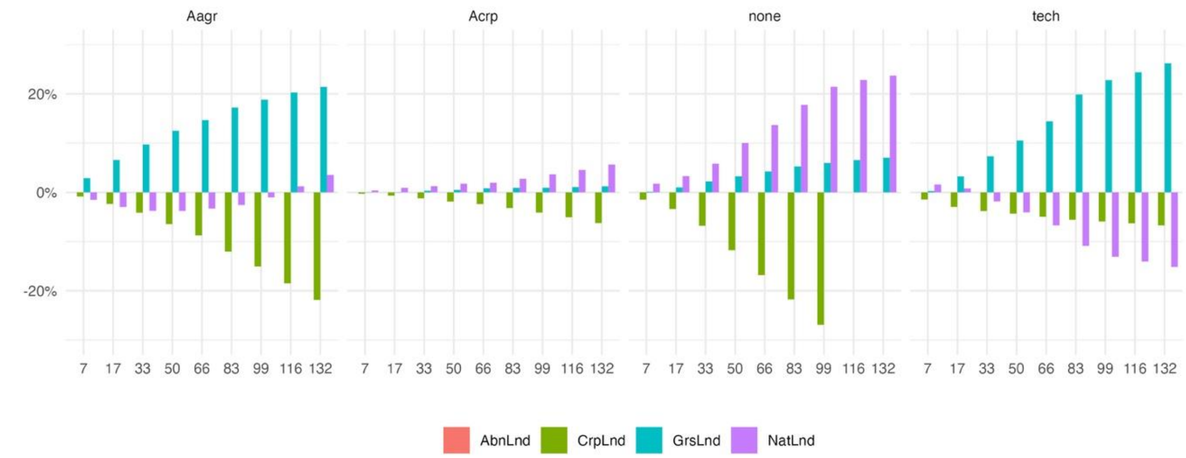


*Figure 30 Changes in EU land cover in response to increased CO2eq taxation on mineral N fertilizer in percent of the baseline. Land covers not depicted stay constant.*

*Note: Y axis is percent of N mineral fertiliser price increase. With taxation: Abandoned land ('AbnLnd') increases, cropland ('CrpLnd') decreases, grassland (GrsLnd) increases, and other natural land (NatLnd) increases or decreases dependent on the redistribution scheme. Other land covers are constant and not shown (forests, settlements).*

Despite the implementation of the most robust policy, characterized by the imposition of a substantial tax of 132% on nitrogen fertilizer prices starting in 2020, there are observable reductions in the global cropland area. This reduction amounts to a decrement of 6 million hectares, accounting for a decrease of 0.5% overall.

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Remarkably, this decline in global cropland area occurs in the face of simultaneous increases in cropland area across the rest of the world (RoW) by 12 million hectares, marking a rise of 1.2% in that specific geographical category.

The decline in global cropland area, despite increases observed in the RoW, underscores the complexity and interconnectedness of agricultural policies and their effects on land use. This outcome suggests that the stringent policy implemented in the variant with a tax of 132% on mineral nitrogen fertilizer prices has substantial repercussions that transcend regional boundaries. Factors such as altered production dynamics, changes in land-use patterns, and potential shifts in agricultural practices due to the imposed policy likely contribute to this global reduction in cropland area.

Such findings emphasize the importance of considering not only local or regional impacts but also the broader global implications of agricultural policies to comprehend their potential effects on land use, agricultural production, and global food security. Additionally, these observations underscore the necessity of comprehensive evaluations when designing policies to address agricultural sustainability without inadvertently impacting global cropland availability.

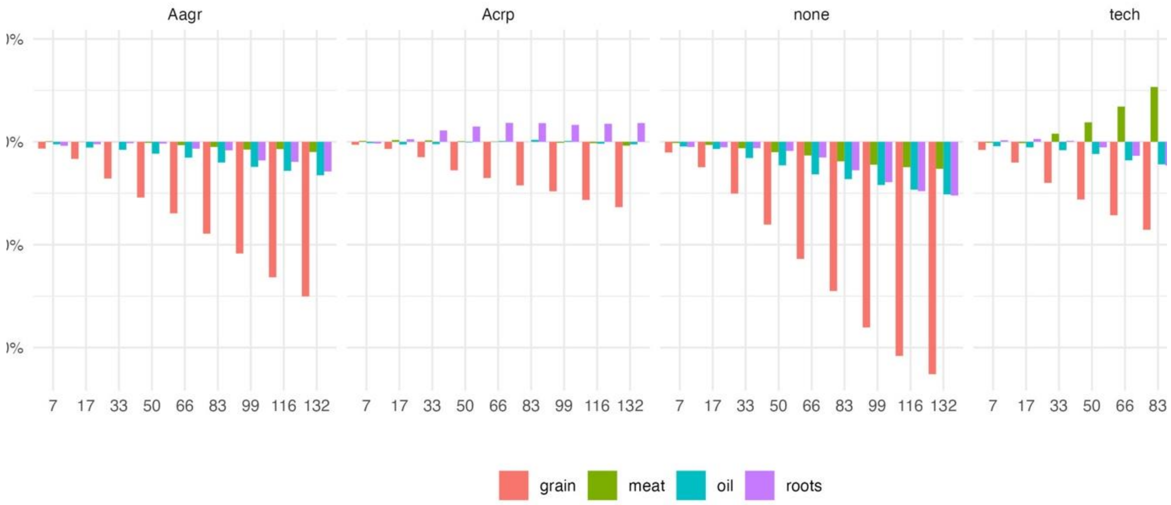


*Figure 31 Changes in EU agricultural net-exports in response to increased $CO_2$eq taxation on mineral N fertilizer in percent of the baseline.*

The implementation of the most impactful policy, which involves levying a substantial tax of 132% on nitrogen fertilizer prices starting in 2020, leads to notable consequences, particularly marked increases in the importation of barley, wheat, and rapeseed. Specifically, the imports of these agricultural commodities surge significantly, showing a substantial uptick of 505% for barley, 258% for wheat, and 206% for rapeseed.

This outcome can be attributed to the influence of the imposed policy on the agricultural sector. The substantial taxation on nitrogen fertilizer production and application appears to have a pronounced effect on the domestic production levels of these crops. Consequently, the substantial rise in imports of barley, wheat, and rapeseed may signify a compensatory measure to fulfil the domestic demand that is no longer being met adequately due to reduced production resulting from the taxation policy.

Such a substantial increase in imports emphasizes the interconnectedness of policies targeting specific sectors of agricultural production and their subsequent impacts on the broader agricultural trade landscape. This variant underscores the n*ecessity of carefully assessing and anticipating the potential*

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*repercussions of stringent policies on specific agricultural commodities to ensure the stability and sufficiency of domestic production and international trade dynamics.*

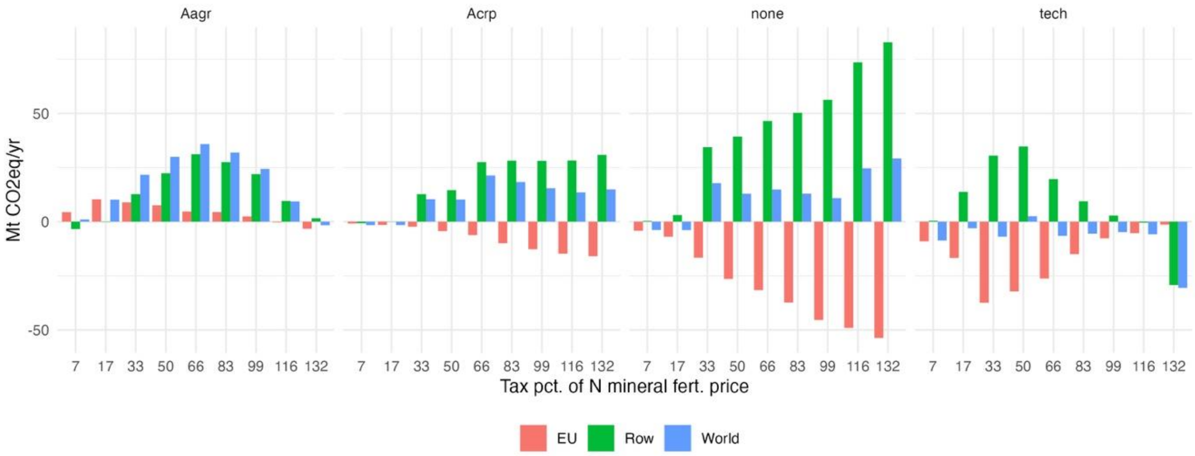


*Figure 32 World total, EU and rest of the world (Row) emissions in Mt CO2eq/yr in 2030 in response to increased CO2eq taxation on mineral N fertilizer in the EU.*

*Note: The tax take is either not redistributed ('none') or subsidizes agricultural area ('Aagr'), cropland area ('Acrp'), or agricultural area where mitigation technologies are applied ('tech').*

Despite the enactment of the most stringent policy, which involves the simultaneous taxation of nitrogen fertilizer production and application starting in 2020 at a rate of 132% on nitrogen fertilizer prices starting in 2020, there are reductions observed in crop emissions on a global scale. This reduction amounts to a decrease of 12 million tons of CO2 equivalent per year, constituting a decline of 0.7% overall.

Interestingly, this decline in global crop emissions occurs despite observed increases in emissions leakage from the rest of the world (Row), which amounts to 11 million tons of CO2 equivalent per year, marking a rise of 0.7% in emissions leakage within that specific geographical category.

The reduction in global crop emissions in the face of leakage increases from the RoW indicates that the implemented policy exerts a significant influence on the emission dynamics of crop production worldwide. This suggests that while leakage occurs in certain regions due to the policy's effects, the overall impact results in a net decrease in global crop emissions. Factors such as alterations in fertilizer use, changes in agricultural practices, and shifts in production methods likely contribute to these observed changes in emissions.

These findings underscore the intricate and interconnected nature of policies targeting agricultural emissions and their effects on global emission trends. It highlights the necessity of comprehensive evaluations when formulating and implementing policies aimed at mitigating agricultural emissions to ensure a holistic understanding of their impacts on global emission reductions while considering potential leakage effects from differing regional responses.

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### 5.4.4. FarmDyn

**Arable farms:**

Just like in section 4.4.4, farms were aggregated to NUTS2 level using their weights. This time they were arable farms with farm typologies 15 (Specialist cereals, oilseed and protein crops), 16 (General field cropping) and 20 (Specialist horticulture). From these farms, only those were selected that had at least 80 % of their land cultivated with maize, summer cereals (oats, rye, others), summer beans (peas), winter barley, winter wheat, winter rape, and/or potatoes. Under this sample of in total 9640 farms, the data can be extrapolated to represent 429536 farms in the European Union.[6] Table 17 shows the resulting structure of the data with selected variables aggregated to NUTS0 level.

Similar to the implementation in the other models, the mineral fertilizer tax implemented in FarmDyn is based on the taxation of the CO2 emission equivalents arising from the application of fertilizer (namely N2O) and the production of fertilizer (CO2), as outlined in Table 11. To ensure a wide range of tax rates that would permit to see also extreme changes in models results in a tractable number of variants, FarmDyn was shocked with the equivalents of 25 to 200 Euro/tCO2eq with application emissions as tax base and, as extreme variant, with the equivalent of 200 Euro/tCO2eq using application and production emissions as tax base (Table 18). This resulted in 5 variants for mineral fertilizer taxation amounting to 8 %, 15 %, 30 %, 61 % and 132 % for the evaluation of the response of average arable and dairy farms to the tax at these different levels. These tax levels were introduced with and without variant specific input (other than mineral fertilizer) and output prices based on the CAPRI results. This illustrates the impact of including market prices. Additionally, the manure application was capped not to exceed the base scenario level under the restriction that manure market are not well established in most EU countries, while in other regions animal manure is applied to maximum levels given manure legislation.

On arable farms, fertilizer use will decline in response to taxes, but to a lesser extent than indicated by CAPRI. This is because mitigation technologies like e.g. variable rate application or precision farming are not included.  Also substitutability of mineral fertilizer at farm level with organic fertilizer is not taken into account. Figure 33 shows the results of the runs for the changes in price of land and income per AWU, while Figure 34 shows changes in applied mineral nitrogen fertilizer and GWP, in both cases with and without market price adjustments. At lower tax levels (8 and 15 %) the tax only has a negligible effect on the reduction of applied fertilizer, but quickly gaining pace at higher levels. At the highest tax rate of 132% of the fertiliser price and without market price changes from CAPRI, the decrease in mineral N fertilizer applied equals around 16% on the average arable farm (Figure 34). With price changes from CAPRI this equals 14%. Figure 34 shows that impacts on mineral N fertilizer applied can be quite different per region in the EU.

[6] The sample of arable farms was based on a very specific selection of crops included in the FarmDyn model.

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*Table 17 Descriptive statistics of the national average arable farm.*

| NUTS0 | Land [ha] | Share of Cereals [%] | Annual Work Units | kg N per ha | Farm Net Value Added [EUR] | FNVA per AWU | n |
|---|---|---|---|---|---|---|---|
| AT | 45.2 | 58.1 | 1.0 | 115.2 | 32103 | 33603 | 91 |
| BE | 56.3 | 57.2 | 1.1 | 153.7 | 44493 | 38827 | 44 |
| BG | 92.8 | 61.8 | 2.3 | 119.2 | 28272 | 12070 | 114 |
| CZ | 195.2 | 61.9 | 3.5 | 150.2 | 41414 | 11795 | 294 |
| DE | 120.8 | 61.4 | 1.6 | 129.7 | 33231 | 21026 | 1466 |
| DK | 99.9 | 82.4 | 1.2 | 108.6 | -6554 | -5253 | 343 |
| EE | 212.9 | 70.6 | 1.8 | 106.3 | 7308 | 4101 | 114 |
| EL | 10.2 | 53.6 | 0.7 | 125.1 | 6910 | 9772 | 58 |
| ES | 65.4 | 81.2 | 1.1 | 92.4 | 24912 | 23221 | 473 |
| FI | 51.6 | 85.4 | 0.6 | 84.7 | 13589 | 22681 | 68 |
| FR | 117.0 | 60.0 | 1.4 | 167.5 | 39067 | 27485 | 779 |
| HR | 21.1 | 36.1 | 1.3 | 135.1 | 10922 | 8603 | 82 |
| HU | 34.3 | 48.2 | 0.8 | 109.8 | 18029 | 21472 | 257 |
| IE | 131.1 | 85.7 | 1.1 | 189.4 | 117014 | 102510 | 17 |
| IT | 18.9 | 55.6 | 1.1 | 130.0 | 22630 | 20345 | 270 |
| LT | 91.6 | 71.7 | 1.7 | 159.4 | 13818 | 8311 | 381 |
| LV | 141.5 | 76.1 | 2.1 | 119.9 | 9954 | 4801 | 245 |
| NL | 55.5 | 41.0 | 1.4 | 123.2 | 58847 | 42849 | 114 |
| PL | 26.1 | 64.5 | 1.3 | 137.6 | 9010 | 6749 | 3238 |
| PT | 15.4 | 58.5 | 1.3 | 142.4 | 18055 | 13756 | 25 |
| RO | 69.6 | 50.1 | 1.5 | 211.0 | 29679 | 19811 | 906 |
| SE | 116.6 | 80.3 | 1.4 | 120.2 | 9381 | 6709 | 114 |
| SI | 11.7 | 46.2 | 0.6 | 135.3 | 3572 | 5644 | 31 |
| SK | 243.5 | 52.3 | 4.8 | 129.4 | 46989 | 9832 | 116 |
| EU27 | 56.1 | 62.8 | 1.4 | 139.9 | 18544 | 14012 | 9640 |

*Source: own calculations from FADN, bookkeeping year 2018.*

*Note: (weighted mean, % cereal after weighted mean of the area of each cereal divided by the weighted mean of Land, not weighted mean of percentages)*

*Table 18 CO2 Taxation levels and N-Tax multipliers used in FarmDyn*

| CO2 Tax (Euro/tCO2eq) | N-Tax Multiplier | N-Tax base |
|---|---|---|
| 25 | **1.08** | Application |
| 50 | **1.15** | Application |
| 100 | **1.30** | Application |
| 200 | **1.61** | Application |
| 200 | **2.32** | Combined |

At all tax levels there is a reduction in income per AWU, which scales with the tax rate. Without market price changes from CAPRI, the highest tax rate provokes a decrease in income of around 2772 euro

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per AWU or about 20% reduction in income per AWU on the average arable farm in the EU (Figure 33). Including market price changes, the highest tax rate provokes a decrease in income of around 1599 euro per AWU or about 11% reduction in income per AWU on the average arable farm in the EU.

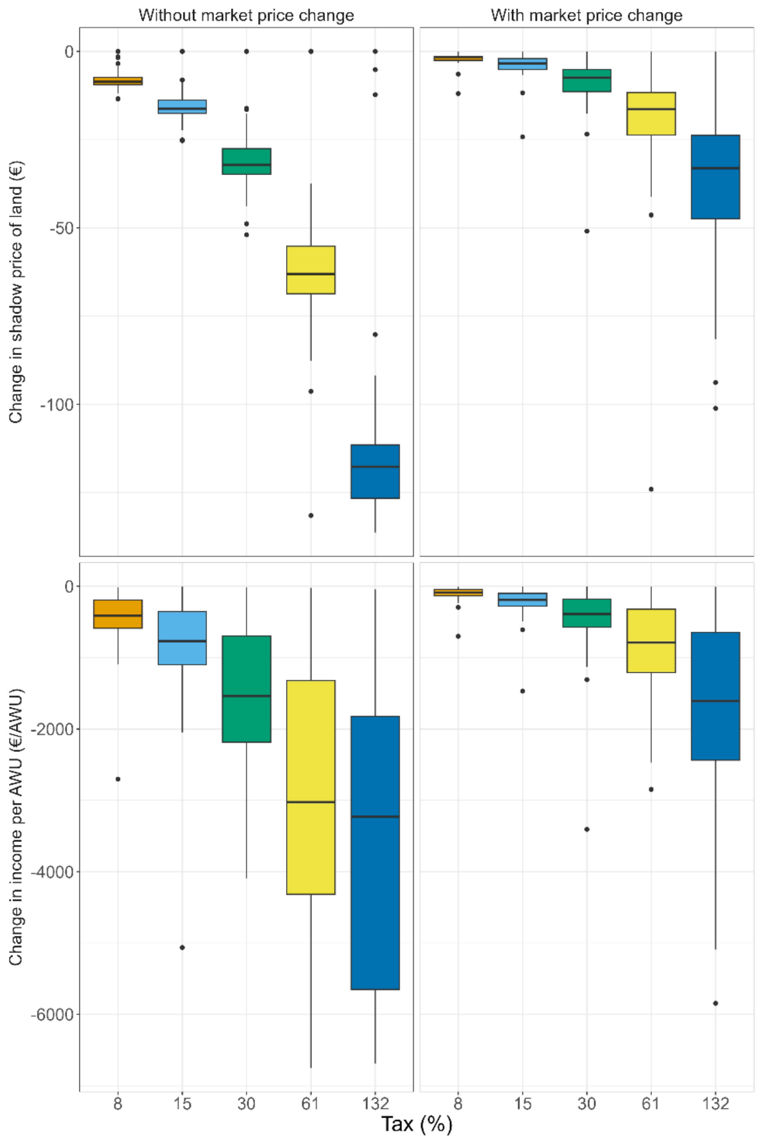


*Figure 33 Change in income per AWU and changes in shadow price of land at different taxation levels and including or excluding market price changes for inputs and outputs - arable farms*

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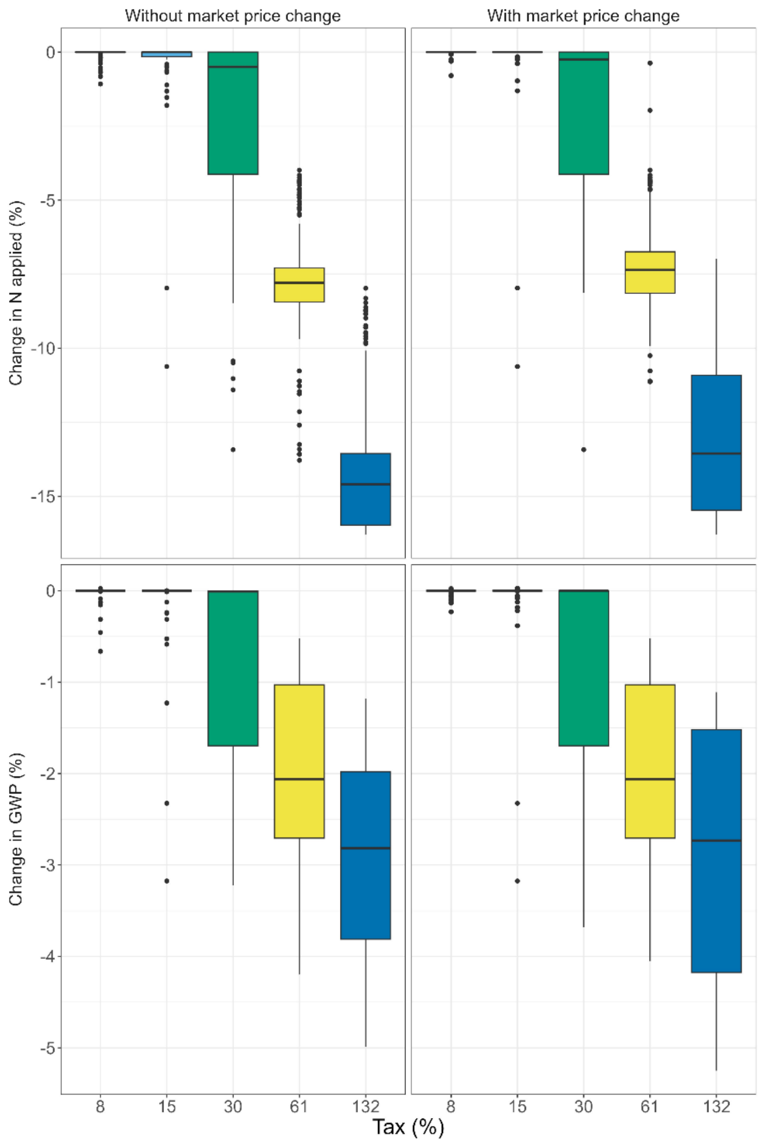


*Figure 34 Change in N from mineral fertilizer applied and change in GWP at different tax rates on mineral N fertilizer and with or without output price changes – arable farms*

As can be seen in

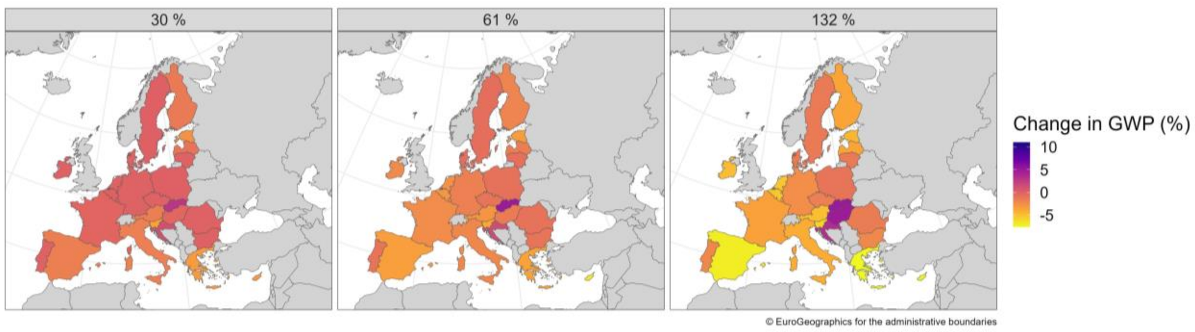


Figure 36, the impact of the tax on GHG emissions is limited, reaching an average of less than 3 % on arable farms and 1.2% on dairy farms at the highest tax level of 132%. At the 8% and 15% tax levels there is almost no difference compared to the baseline scenario. The decrease in the N surplus on the

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average arable farm in the EU is highly sensitive to the use of animal manure on the farm and the assumptions regarding initial nutrient use efficiency. Sensitivity analysis show that decrease in the N surplus on the average arable farm in the EU at the highest tax level of 132% could range between - 30% and - 60%.

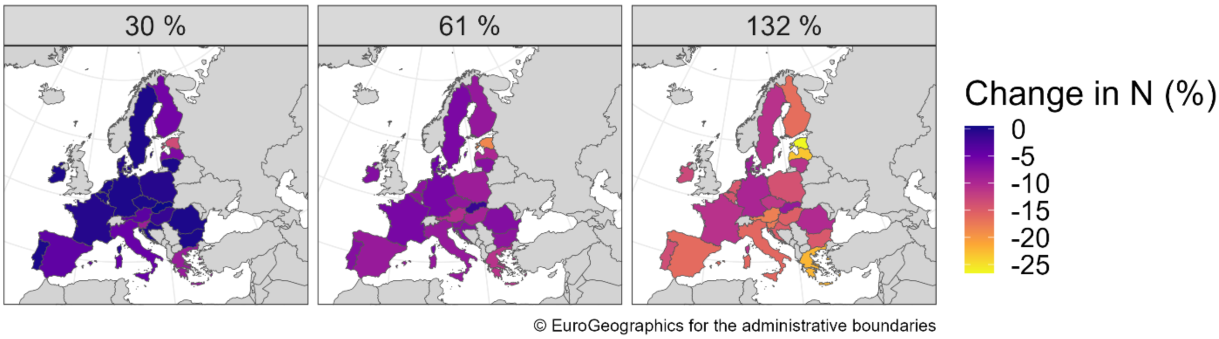


*Figure 35 Change in N in applied mineral fertilizer in Europe at the tax rates of 30, 61 and 132 % on mineral N fertilizer with output price changes- arable farms*

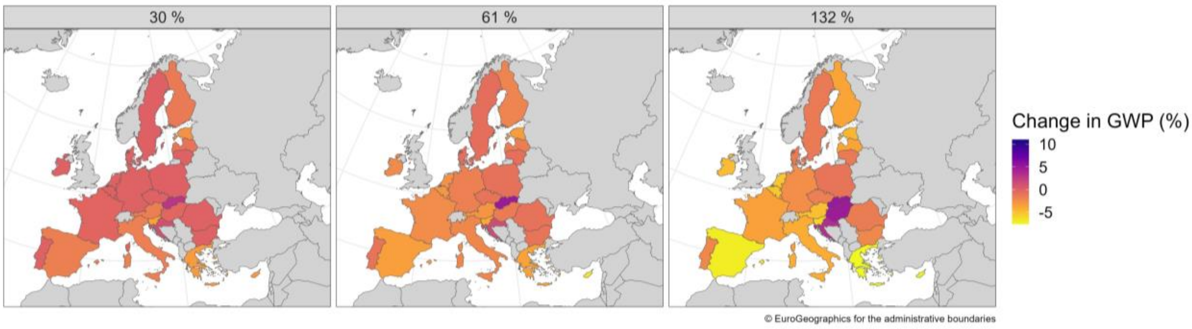


*Figure 36 Change in GWP at tax rates of 30, 61 and 132 % on mineral N fertilizer in Europe. Darker colours indicate an increase and lighter colours indicate a decrease.*

**Land use and N response curves**

On crop farms, there is no substantial change of land allocation, but intensity levels are adjusted, but this does not result in substantial reduction of total production due to flat N-response curves, see Figure 37 and Figure 38.

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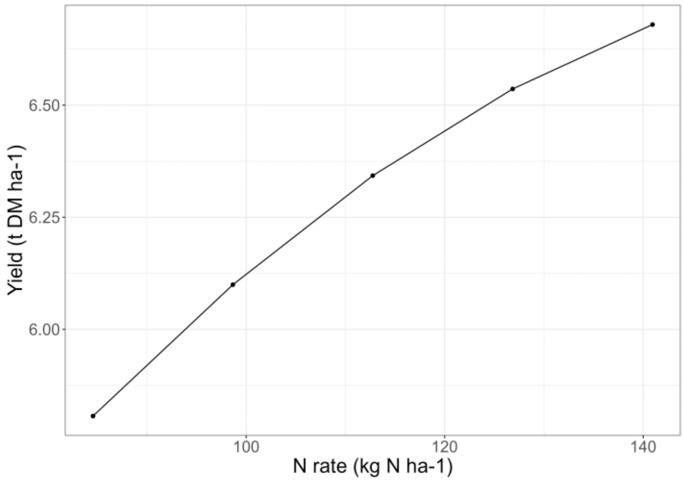


*Figure 37 N response curve of Winter Wheat*

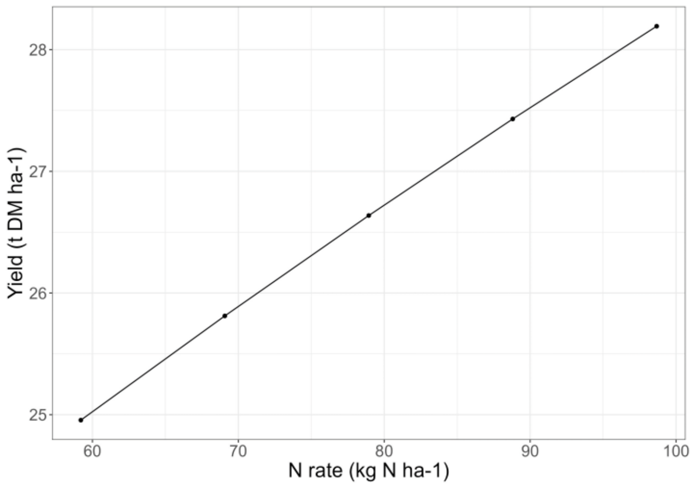


*Figure 38 N response curve of Potatoes*

**Dairy farms:**

As in the case of arable farms above, the FarmDyn model was applied to average NUTS2 dairy farms to test the impact of the different tax rates on mineral fertilizer (Table 18). Again, the model was executed including and excluding market price changes for inputs and outputs as projected by the CAPRI model. Figure 39 summarizes the main findings for the highest (132%) tax variant. Without market price adjustments, EU-average income per AWU declines substantially by around 1353 Euro/AWU (or 4% for the EU average dairy farm). The decrease in income is caused by increased costs of mineral fertiliser due to the imposed tax. As an optimization model, FarmDyn attempts to compensate these higher prices for one input by reducing other cost, especially by lowering the machinery use for grass cultivation (less cuts, lower frequency of mineral N application), see also Figure 41. Including the price adjustments from CAPRI, farm income on the average continuing dairy farm tend to go up by around 675 Euro/AWU (or 2%).

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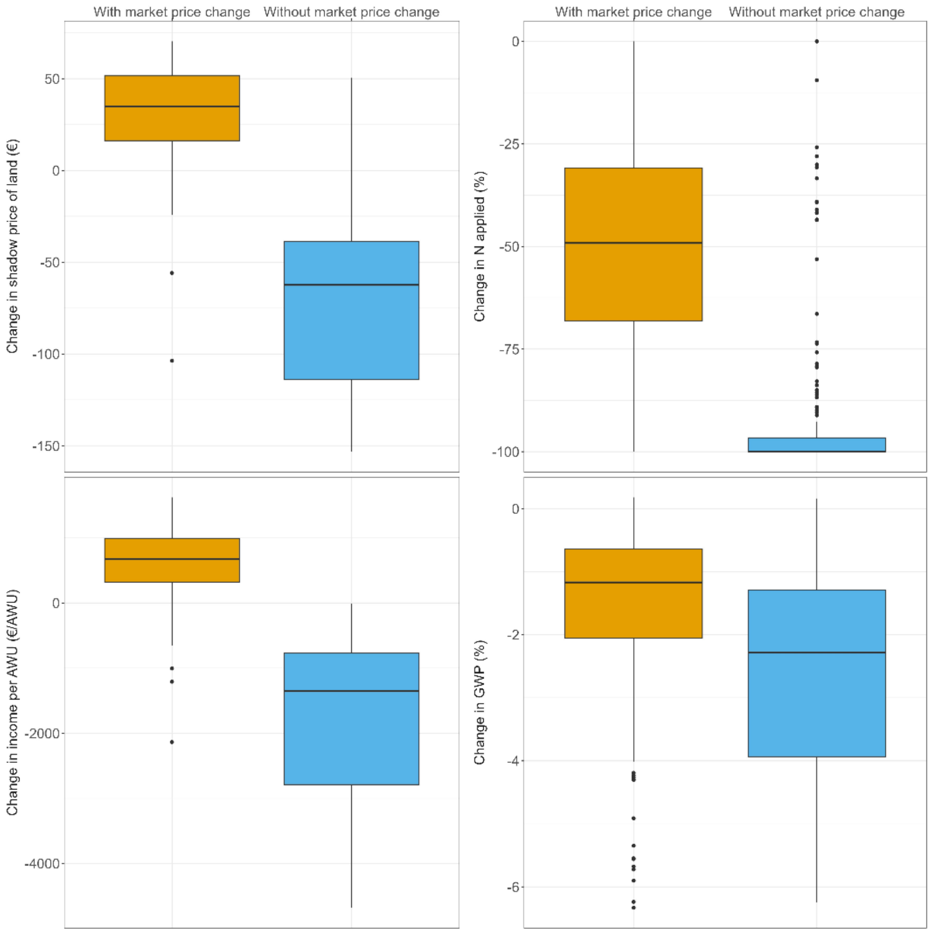


*Figure 39 Change in income per AWU, in shadow price of land, N applied, and change in GWP at 132% taxation level and including or excluding output price changes - dairy farms*

With market price change dairy farms reduce their application of mineral N fertilizer by more than 49% in the highest tax variant (Figure 39), much more than observed on the arable farms. It appears that most dairy farms have a surplus of organic fertilizer on their grassland, while still remaining below 170kgN/ha, largely due to the fact that grassland yields in these regions are comparatively low. Once the price for mineral fertilizer increases, farmers reduce the mineral fertilizer intensity on both, arable and grassland. So the change in intensity and land use is such that overfertilization with organic manure is minimized. In effect, the taxation of mineral nitrogen causes a more efficient use of organic fertilizer and has a substantial impact on the nutrient losses at farm level. Figure 39 shows that especially due to more efficient use of organic fertilizer, at the highest mineral N fertilizer taxation rate the decrease in nitrogen surplus equals around 25% on the average EU dairy farm.

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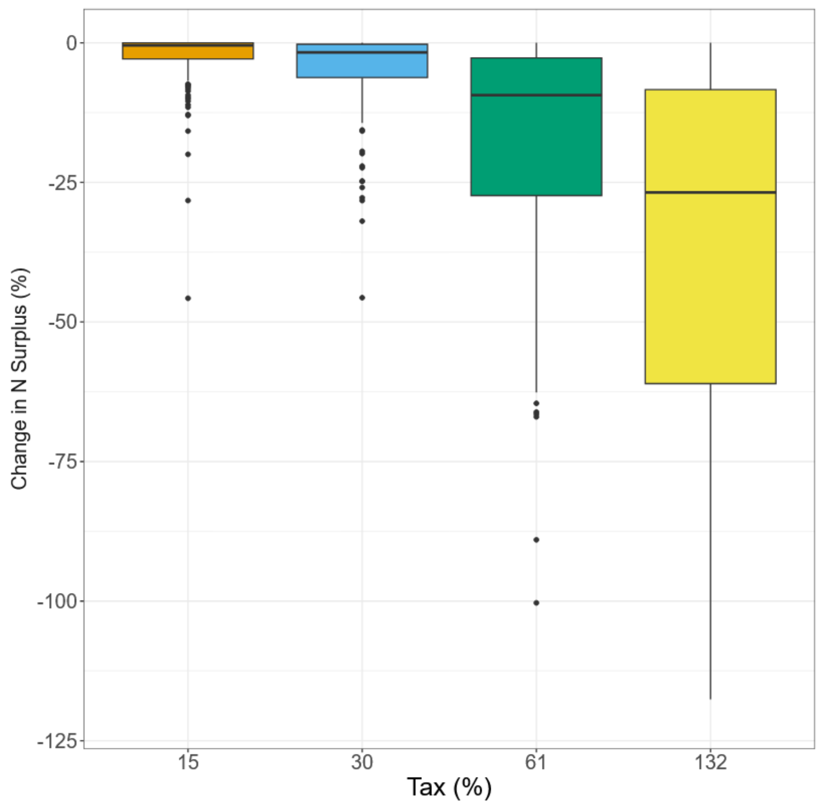


*Figure 40 Change in N surplus in Dairy farms at different tax rates on mineral fertilizer with market price change*

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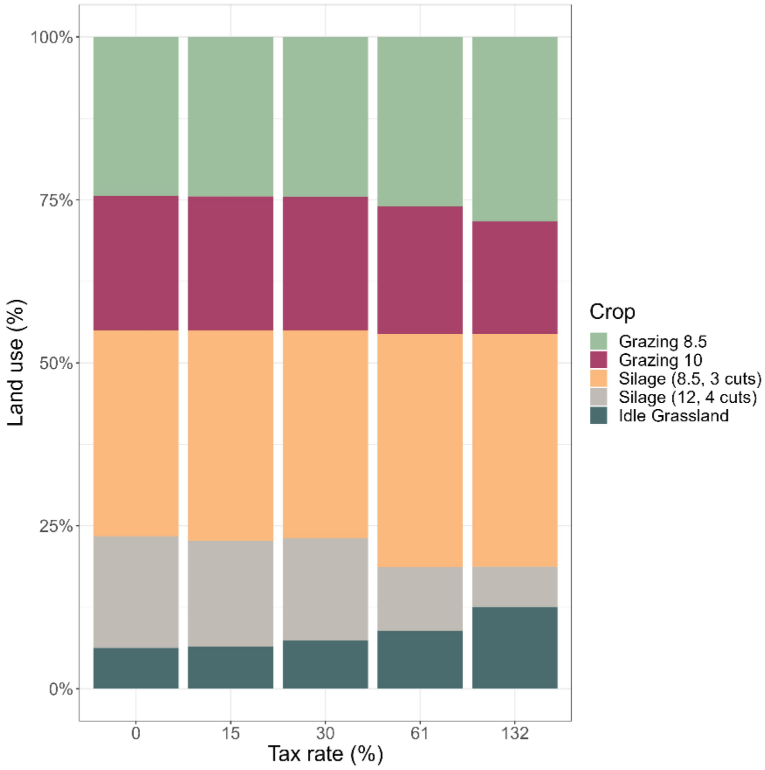


*Figure 41 Changes in grassland use in dairy farms at different tax rates on mineral N fertilizer with market price change*

An important finding for dairy farms is the change of grassland use (Figure 41): While the share of grazing area in total grassland area remains constant, silage area is reduced and kept idle, largely due to the increased fertilizer expenses. As mentioned above the tax on mineral N fertiliser, reduces the use of mineral N fertiliser. This in turn results in more extensive grassland use, decrease in own feed production and increase in use of purchased feeds (to compensate for the lower own feed production).

### 5.4.5. Micro-Econometric Multi-Crop modelling (INRAE-MC)

The simulation results obtained on the Italian FADN arable crop farms are summarised in Figure 42 to Figure 46. Figure 42 reports the impact of the various tax variants on the acreage shares of the main crops. The impact on land allocation decisions is rather limited: the increase in the share of alfa-alfa, barley and corn is compensated by the decrease in soft wheat and soybean, but all changes are in the order of magnitude of one percentage point. The impact on yields (Figure 43) is negative and, under the highest tax rate, it can reach -6% on average for winter cereals (soft wheat, durum wheat and barley) and -4/5% for corn and soybean. The impact on N fertiliser use (Figure 44 and Figure 45) is the most direct effect of the taxation, but in order to reach the Farm-to Fork target of 20% reduction, the mineral fertiliser tax rate must be above 100%. The N use reduction tends to be higher for all cereals (soft and durum wheat, barley and corn), which are driving the farm level impact, since N use on alfa-alfa and soybean is very limited. Finally, the impact on crop returns (i.e. the difference between revenues (excluding direct payments!!!) and costs (including machinery and labor costs that can be attributed to the crops) for the crops considered in the model) is quite substantial (Figure 46): under the highest tax rate (132%), farm returns may decrease up to 36%, as results of the decrease in yields and of the increase in fertiliser costs.

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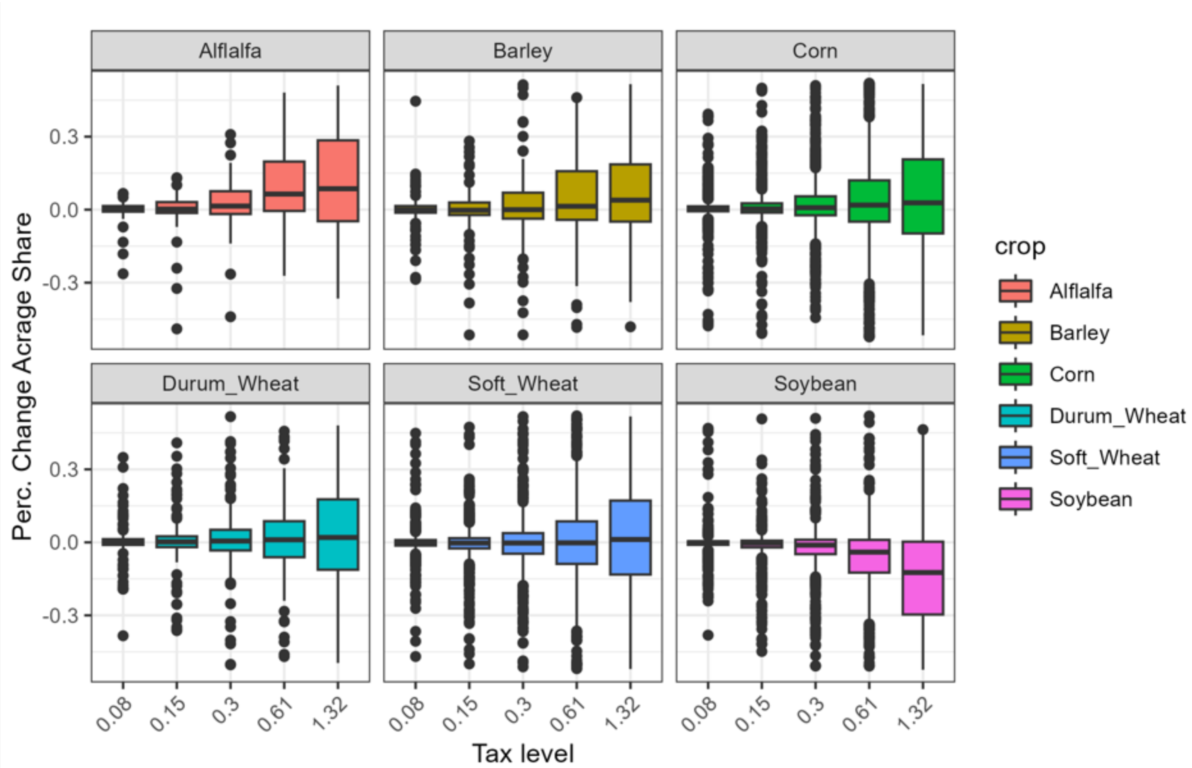


*Figure 42 Changes in acreage crop shares under different mineral fertiliser tax rates (INRAE Model - Italian arable crop farms)*

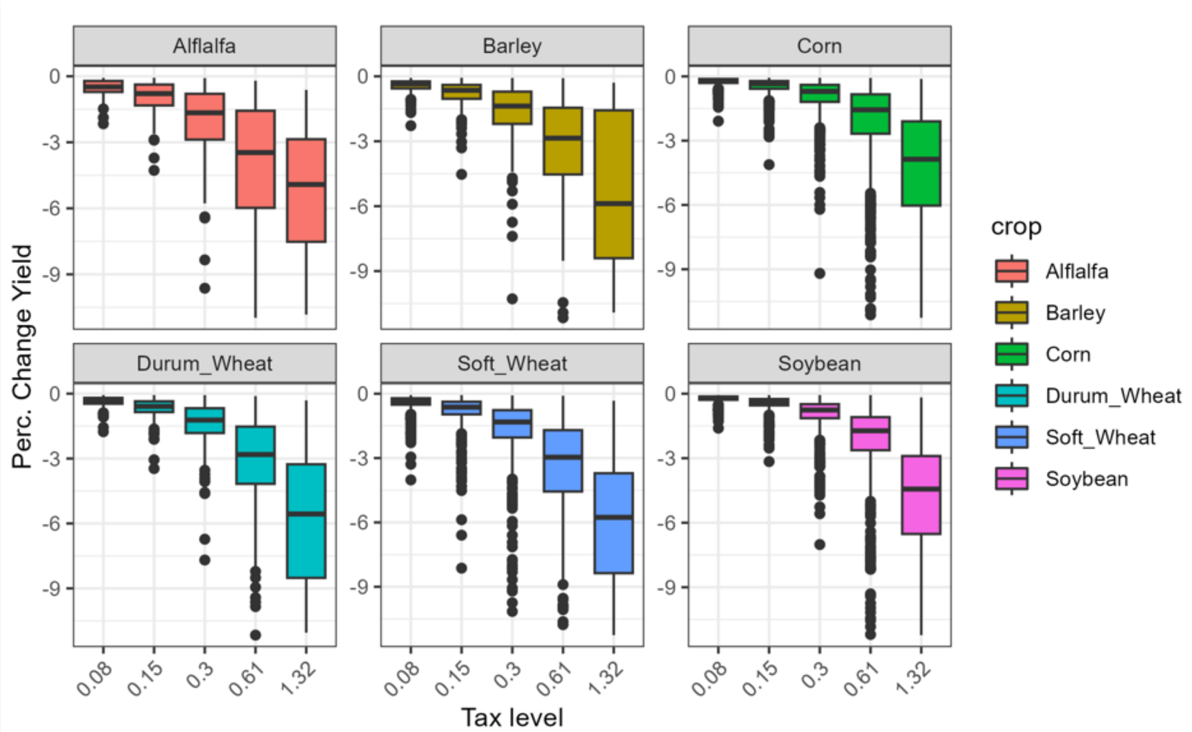


*Figure 43 Changes in crop yields under different mineral fertiliser tax rates (INRAE Model - Italian arable crop farms)*

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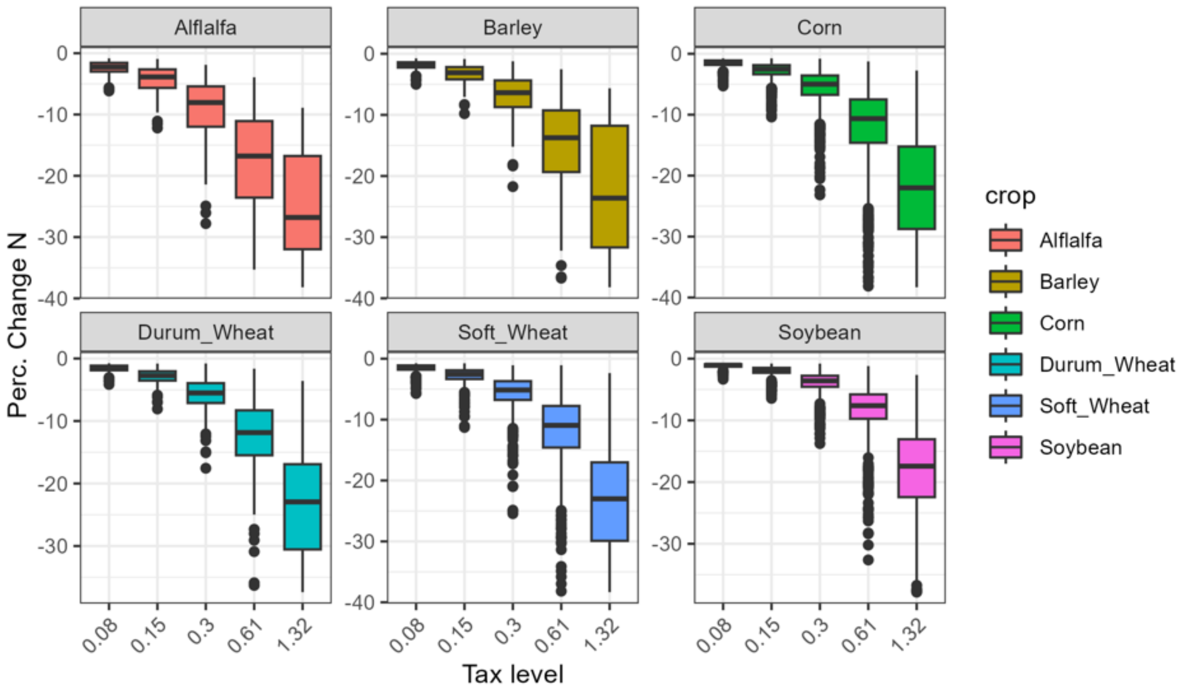


*Figure 44 Changes in Nitrogen application by crop under different mineral fertiliser tax rates (INRAE Model - Italian arable crop farms)*

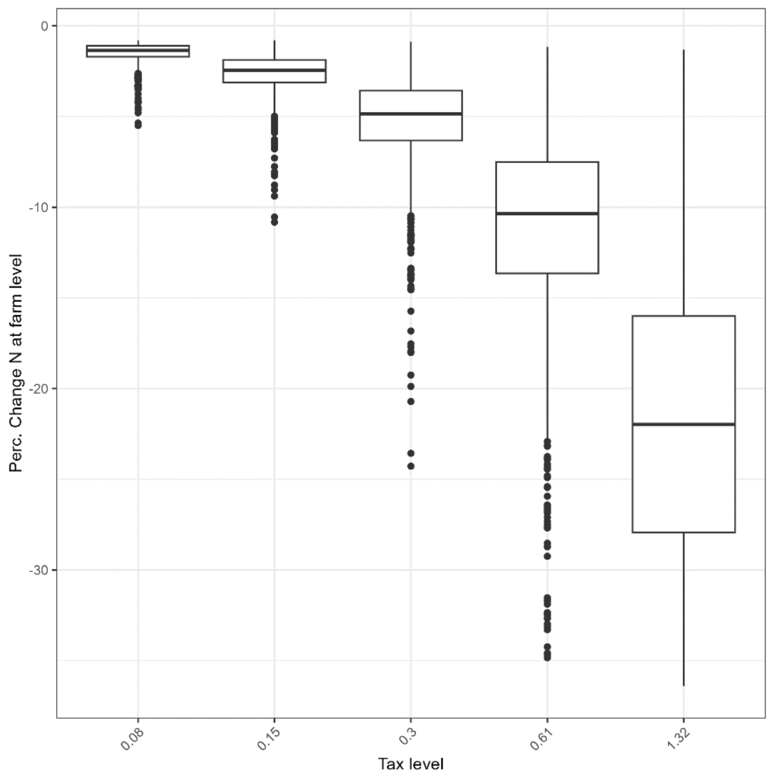


*Figure 45 Change in Nitrogen application at farm level under different mineral fertiliser tax rates (INRAE Model - Italian arable crop farms)*

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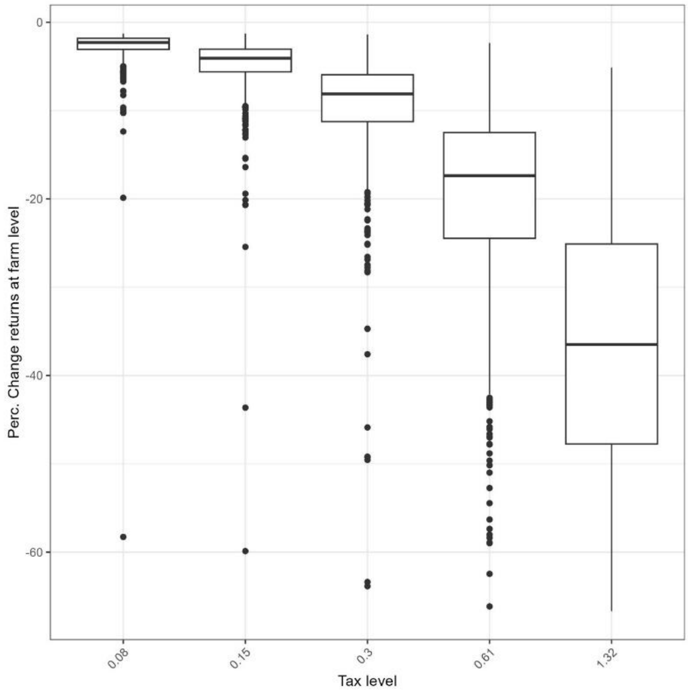


*Figure 46 Change in crop returns at farm level under different mineral fertiliser tax rates (INRAE Model - Italian arable crop farms)*

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### 5.4.6. IFM-CAP

**Effects of tax on production**

- Production changes are driven by changes in allocated area
- Production decreases for major cash crops and increases for soya and other fodder crops (includes leguminous crops for animal feed)
- The decrease is lower in the case of the N fertilizer tax of 30%; -1% for soft wheat, -2% for grain maize and rapeseed
- The decrease is higher in the case of the N fertilizer tax of 132%; -5% for soft wheat, -7.5% for grain maize, -11% for sugar beet and fodder maize
- There is also an increase in the fallow land

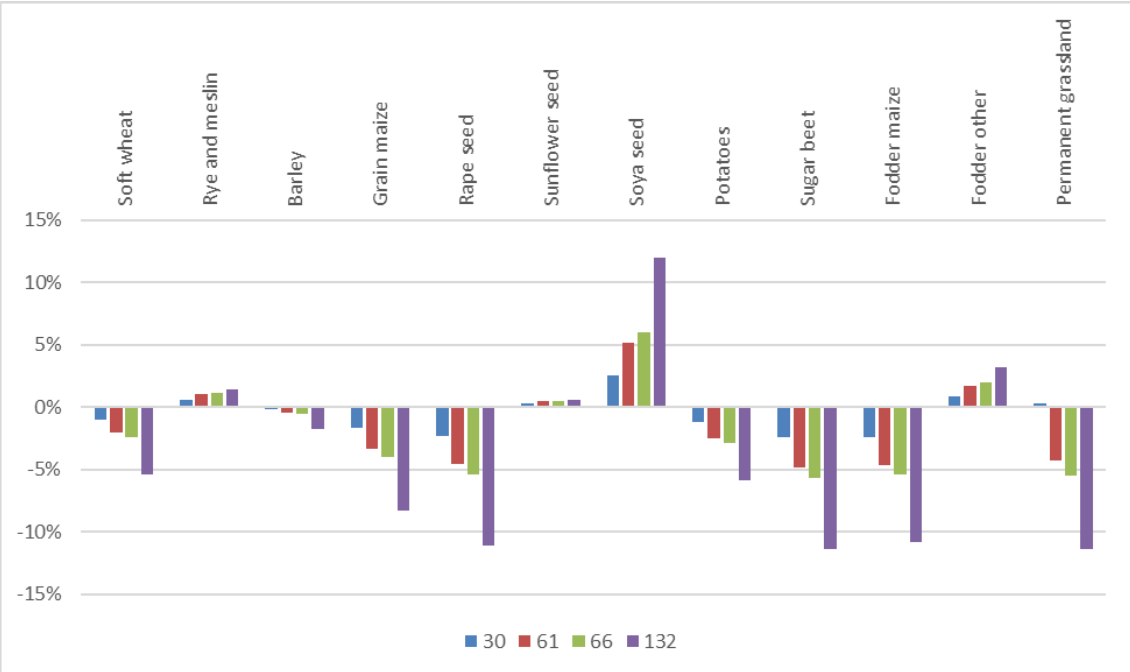


*Figure 47. Change in the production volume of main crops for different taxation rates on mineral N fertilizer variants [%]*

*Table 19 . Increase in the fallow area under different taxation rates on mineral N fertilizer variants*

| N-tax rate [%] | 30 | 61 | 66 | 132 |
|---|---|---|---|---|
| Fallow land | 5.7% | 25.6% | 31.5% | 74.5% |

**Environmental effects**

In the EU level the decrease of nitrogen fertilizer for each variant is as follows

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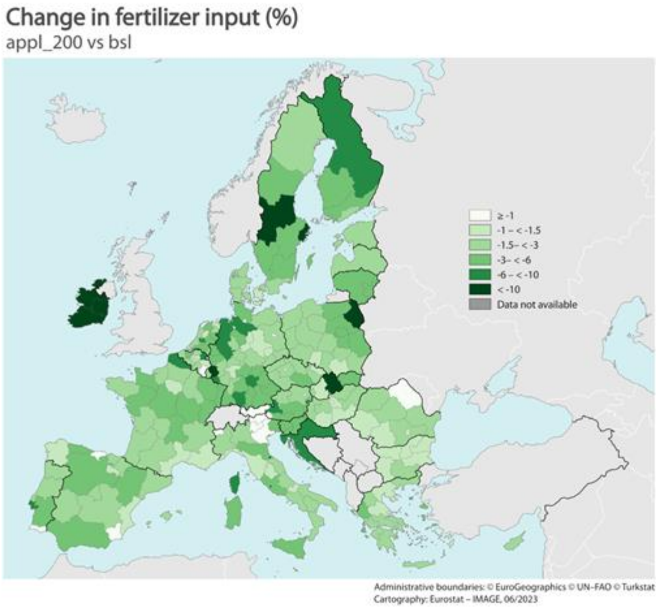
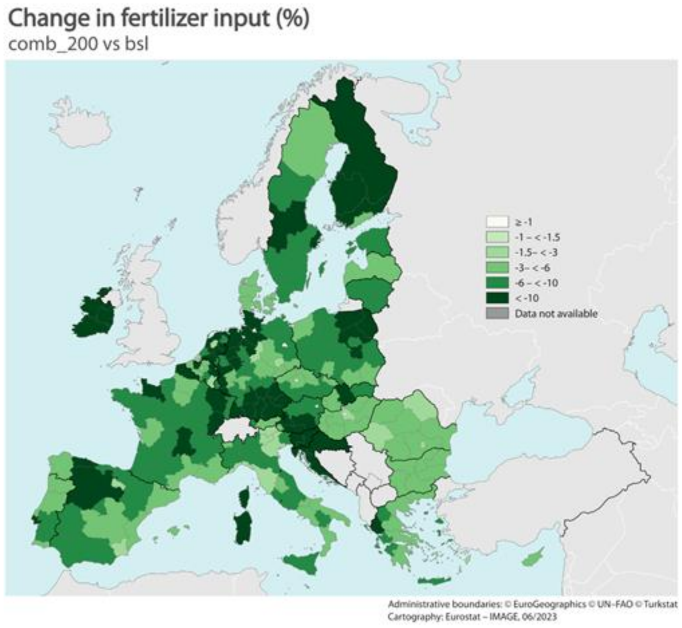
*Table* 20. Decrease of mineral nitrogen fertilizer input *under different $CO_2$eq taxation on mineral N fertilizer variants*

| N-tax rate [%] | 30 | 61 | 66 | 132 |
|---|---|---|---|---|
| Decrease in mineral fertilizer | -1.7% | -4.5% | -5.4% | -10.8% |

We have assumed that the relative decrease in the nitrogen fertilizer use is the same as the relative decrease in the expenditure of nitrogen fertilizer. This decrease is distributed across EU NUTS2 regions as shown in Figure 48




61% N-Tax rate




132% N-Tax rate

*Figure 48. Change in fertilizer input per NUTS2 across EU for 61% and 132% taxation on mineral N fertilizer [%].*

The decrease in the CO2 emission is as follows:

*Table 21 % decrease in greenhouse gas emissions under different $CO_2$eq taxation on mineral N fertilizer variants*

| N-tax rate [%] | 30 | 61 | 66 | 132 |
|---|---|---|---|---|
| Decrease in emissions | -0.20% | -0.67% | -0.80% | -1.67% |

This decrease is distributed across EU regions as follows:

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| | |
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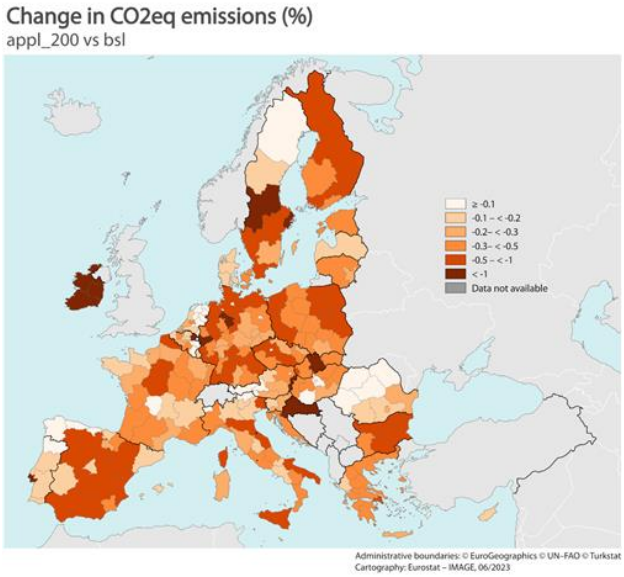
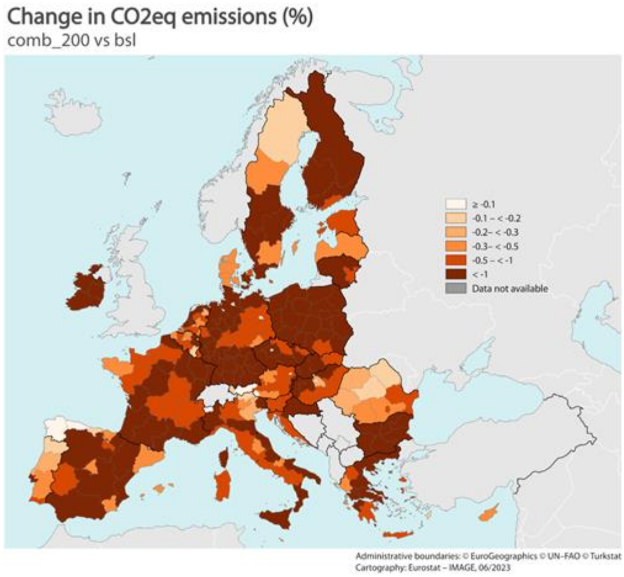
|  |  |
| 61% N-Tax rate | 132% N-Tax rate |





*Figure 49. Change in GHG emissions (CO2 equivalent) per NUTS2 across EU under a 61% and 132% taxation on mineral N fertilizer.*

**Redistribution strategies**

We have simulated the redistribution of the tax collected back to the farms. We assume an equal per hectare payment to farms in the NUTS2 level. That means that we give back the tax collected in a NUTS2 region as a flat rate payment per hectare to all farms of that NUTS2 region.

In the following table, we show the tax collected from different farm types. Note the following:

- The tax collected in the 132% tax variant is more than 25% of the annual CAP budget. For 2021 the CAP budget was about 40,000 million euro and for eco-schemes (~25% of CAP) was 10,000 million euro. The tax collected is 11,414 million.
- The majority of the tax is collected from the arable crop farms, the milk farms and the mixed crops/livestock farms. That means that the redistribution scheme will draw income from these farm types and redistribute it to the rest of the farm types.

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*Table 22 Tax collected for different variants of taxation on mineral N fertilizer (mil euro)*

| N-tax rate [%] | 30 | 61 | 66 | 132 |
|---|---|---|---|---|
| Specialist COP (15) | 892.6 | 1,758.7 | 2,040.7 | 3,904.7 |
| **Specialist other fieldcrops (16)** | **388.5** | **765.9** | **889.1** | **1,713.2** |
| Specialist horticulture (20) | 178.1 | 353.6 | 411.4 | 807.4 |
| Specialist wine (35) | 86.7 | 172.7 | 201.1 | 397.7 |
| Specialist orchards - fruits (36) | 105.7 | 208.8 | 242.7 | 470.6 |
| Specialist olives (37) | 44.8 | 87.6 | 101.5 | 192.2 |
| Permanent crops combined (38) | 24.7 | 49.0 | 56.9 | 111.2 |
| Specialist milk (45) | 321.7 | 583.8 | 663.0 | 1,128.1 |
| Specialist cattle (49) | 139.3 | 255.3 | 290.5 | 504.9 |
| Specialist sheep and goats (48) | 37.7 | 71.7 | 82.3 | 151.3 |
| Specialist granivores (50) | 76.9 | 150.3 | 174.0 | 327.7 |
| Mixed crops (60) | 79.5 | 157.2 | 182.7 | 355.3 |
| Mixed livestock (70) | 36.9 | 72.0 | 83.4 | 156.2 |
| Mixed crops and livestock (80) | 279.8 | 548.0 | 634.5 | 1,193.9 |
| Total | 2,692.9 | 5,234.7 | 6,053.9 | 11,414.4 |

In the following table, you can see the effect of the redistribution on the farm income:

- With the redistribution, the income decrease is comparatively smaller than the no redistribution case.
- In some cases the redistribution increases the income of some farm types

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*Table 23 Effects on gross income under different taxation of mineral N fertilizer variants, with and without redistribution of the tax. Percentage change compared to the base*

| N-tax rate [%] | 61 | | 132 | |
|---|---|---|---|---|
| | Without | With | Without | With |
| **Specialist COP (15)** | **-4.40%** | **-1.10%** | **-10.30%** | **-2.90%** |
| **Specialist other fieldcrops (16)** | **-3.20%** | **-1.20%** | **-7.50%** | **-3.00%** |
| **Specialist horticulture (20)** | -1.40% | -1.20% | -3.20% | -2.80% |
| **Specialist wine (35)** | -1.10% | -0.40% | -2.50% | -1.10% |
| **Specialist orchards - fruits (36)** | -2.30% | -1.30% | -5.40% | -3.00% |
| **Specialist olives (37)** | -1.60% | -0.70% | -3.70% | -1.60% |
| **Permanent crops combined (38)** | -1.20% | -0.50% | -2.80% | -1.10% |
| **Specialist milk (45)** | -0.70% | 0.10% | -1.50% | 0.20% |
| **Specialist sheep and goats (48)** | -0.50% | 1.30% | -1.10% | 2.60% |
| **Specialist cattle (49)** | -0.80% | 0.80% | -1.70% | 1.60% |
| **Specialist granivores (50)** | -0.50% | 0.00% | -1.20% | -0.10% |
| **Mixed crops (60)** | -1.90% | -0.70% | -4.50% | -1.70% |
| **Mixed livestock (70)** | -0.90% | 0.30% | -2.10% | 0.50% |
| **Mixed crops and livestock (80)** | -2.20% | -0.20% | -5.00% | -0.60% |
| **All farms** | -1.70% | -0.20% | -3.80% | -0.80% |

**The economic cost of the Tax for the farming sector**

A reasonable assumption is that this GHG reduction will be linked to an income loss due to decrease in production. In the following table we estimate the ratio of "income loss" (column 2) to "reduction of GHG" (column 1) that provides us the income loss for one tone of CO2 reduction (column 3). Overall, the economic cost per ton is very diversified, starting from income gains (the negative numbers) to a cost of around 7,000 euro per CO2 ton.

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*Table 24 Income loss for reducing one ton of GHG emissions under a 132% taxation on mineral N fertilizer.*

| | Reduction of GHG equivalent (MtN) | Change in gross income (mil. euro) | Income loss per for reducing one ton of CO2 equivalent |
|---|---|---|---|
| Specialist COP (15) | -1.494 | -1308 | 876 |
| Specialist other fieldcrops (16) | -0.530 | -894 | 1,687 |
| Specialist horticulture (20) | -0.118 | -900 | 7,654 |
| Specialist wine (35) | -0.030 | -226 | 7,438 |
| Specialist orchards - fruits (36) | -0.096 | -367 | 3,808 |
| Specialist olives (37) | -0.081 | -158 | 1,939 |
| Permanent crops combined (38) | -0.020 | -66 | 3,363 |
| Specialist milk (45) | -2.923 | 183 | -63 |
| Specialist sheep and goats (48) | -0.269 | 389 | -1,445 |
| Specialist cattle (49) | -1.498 | 545 | -364 |
| Specialist granivores (50) | -0.216 | -32 | 150 |
| Mixed crops (60) | -0.082 | -181 | 2,212 |
| Mixed livestock (70) | -0.101 | 41 | -409 |
| Mixed crops and livestock (80) | -0.613 | -187 | 305 |

If we plot the above table we can also get an idea of the efficiency of the redistributive payment. In principle, the redistribution measure targets to level the income loss between farms/farm types. Although a negative aggregate income loss may not be possible, the redistribution should correct for extreme cases of income loss, making the distribution of the income loss more uniform.

In the figure below, an efficient redistribution measure would make all farm types to have similar losses that would appear as a quasi-horizontal line. On the contrary, the redistribution measure applied in our variants seems to resemble more to a vertical line, meaning that it does not make the income loss uniform.

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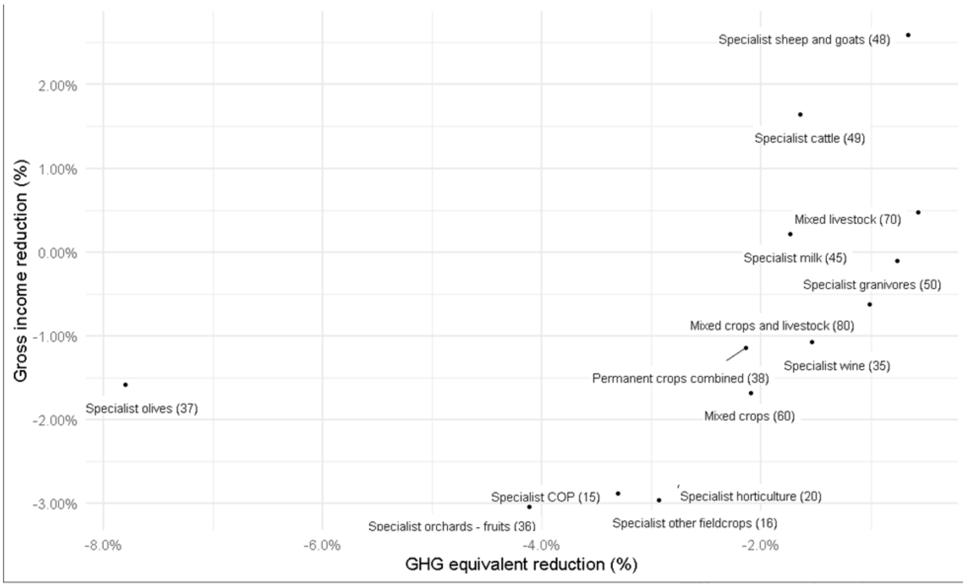


*Figure 50 Relationship between income reduction and GH emission reduction*

**Integration with the structural change module**

In MIND STEP, we have linked IFM-CAP with a structural change module and estimations from MIND STEP WP4 (Krisztin et al. 2023). In short, the linkage is as follows.

First, a logit model is used to represent the binary decision of the farmer to exit the sector. The German Farm Structure Survey (FSS) survey is used and the included information on the farms that exited agricultural activity between 2010 and 2020.

Given a set of explanatory parameters (Xi), the effect on the probability to exit is estimated (vector of coefficients β):

$$\log\left(\frac{P(exit_i = 1|x_i, \beta)}{1 - P(exit_i = 1|x_i, \beta)}\right) = x_i'\beta + \epsilon_i$$

For an IFM-CAP simulation, we use the characteristics of the IFM-CAP farms (categorical variables) and the estimated coefficients (β) to estimate the marginal effect on the probability to exit. In this step, given a policy scenario and the effects on the farm income, we get the probability of each IFM-CAP farm to exit.

Then, we set an exit probability threshold, so that farms with a higher probability to exit will abandon the agricultural activity and release their land. The released land will be traded in the land market, so that some farms will grow. This provides insights on the impact of policy on the land concentration (structural change).

In Figure 51, we show the effect of the tax and the redistribution on the land concentration using the changes in the Gini index of land ownership (a positive number signifies an increase in the concentration of land, so less farms). The column 'no redistribution', show the change in Gini index when the tax is applied but no redistribution is in effect. This column gives the effect of the tax per se to the land concentration. The column ' with redistribution' considers also the effect of the redistribution (i.e. the tax and the redistribution). The results show that neither the tax nor the redistribution have a clear effect (accelerating or stopping) on the concentration of land and the number of farms. Either way the taxation on mineral N fertilizer variants have limited impact on land concentration and number of farms.

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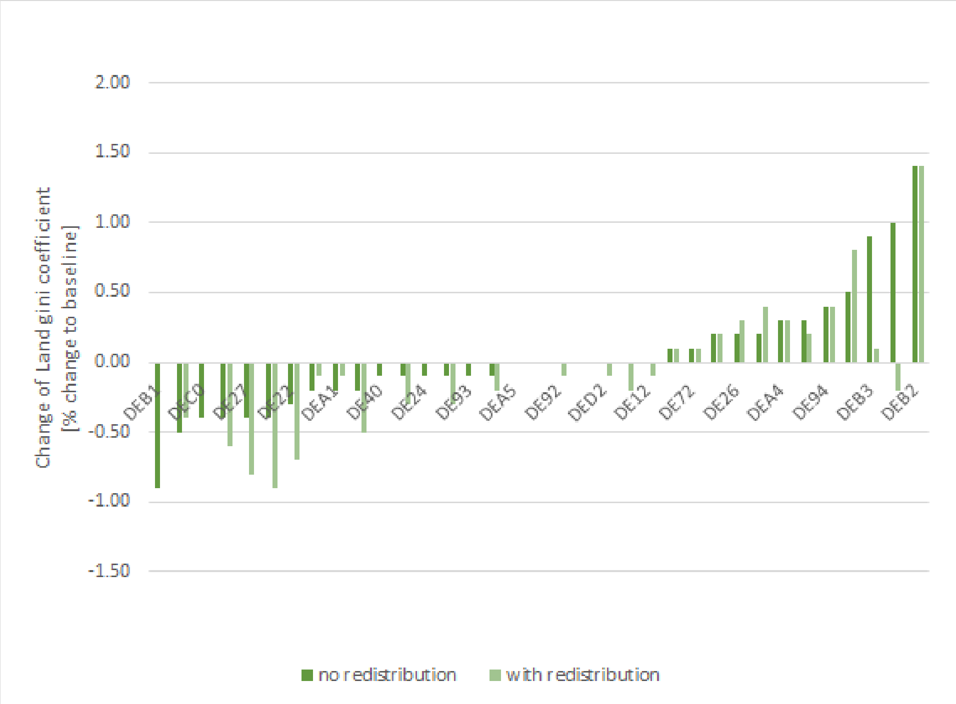


*Figure 51 Effect of redistribution under a 132% taxation on mineral N fertilizer, combined on the Gini index of the land concentration*

The IFM-CAP model exhibits limitations in its ability to encompass certain critical considerations. Specifically, it falls short in addressing variants such as whether the escalation in producer prices adequately offsets the rise in input prices, thereby resulting in no alteration in the quantity of nitrogen utilized. Additionally, the model overlooks the prospect of substituting mineral fertilizers with manure, which holds significance in agricultural practices.

To enhance the model's comprehensiveness, it would be beneficial to incorporate and contemplate various aspects. For instance, integrating price feedback mechanisms could offer a more realistic depiction of shocks within the livestock sector. Furthermore, understanding the potential shifts in the utilization of manure and how such alterations might influence agricultural dynamics represents a pivotal area for inclusion and consideration within the IFM-CAP model.

## 5.5. Discussion of model results

This chapter summarizes and combines the most prominent findings from the ensemble model application, focussing on the impact of the different tax implementation strategies on the reduction of mineral fertilizer use, the associated losses of farm income, and the changes in agricultural production (Table 25).

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*Table 25 Key model results for the taxation strategy and highest variant (200Euro/tCO2eq, combined application and production emissions, equivalent to 132% tax rate on mineral N fertilizer)*

| Name of model | Tax implementation strategy and scale | Mineral fertilizer application change | Income change | Production change |
|---|---|---|---|---|
| 1 GLOBIOM | No redistribution, EU agricultural sector | -27% | | -35% (cropland) |
| | With redistribution, total area based, EU agricultural sector | -21% | | -21% (cropland) |
| | With redistribution, subsidy to mitigation technologies, EU agricultural sector | -18% | | -7% (cropland) |
| 2 CAPRI | No redistribution, EU agricultural sector | -30% | -14% | -8% (cereals) |
| | With redistribution, EU agricultural sector | | -3% | |
| 4 IFM-CAP | Arable, w/o price change, no redistribution | | -10% | |
| | Dairy, no redistribution | | -2% | |
| | All farms, no redistribution | -11% | -4% | -5% (wheat) |
| 5 FarmDyn | No redistribution, average arable farm, with (w/o) price change | -14% (-16%) | -11% (-20%) | |
| | No redistribution, average Dairy farm, with (w/o) price change | -49% (-100%) | +2% (-4%) | |
| 6 INRAE | No redistribution, Italian arable crop farm, w/o price change | -22% | -36% (expected crop return) | -6% (winter cereals) |

Concerning the use of mineral fertilisers, it is noteworthy that under the highest variant of the taxation strategy, reduction in use of mineral N fertilizer in IFM-CAP equals about 11%, the reduction in FarmDyn equals around 49% for dairy farms and around 14% for arable farms, the total reduction in EU agriculture in GLOBIOM and CAPRI equals around 30%. In IFM-CAP and GLOBIOM increases in fallow or abandoned land play an important role. In CAPRI the decrease in N from mineral fertilizer is especially explained by adoption of mitigation options, while changes in land use are more limited. Mitigation options are also missing in FarmDyn. On the other hand, FarmDyn includes the existing overfertilization with animal manure on dairy farms. This overfertilization with organic manure is minimized under the tax on N from mineral fertilizers variants, at the expense of lower yield and extra feed costs.

With regard to farm income, it appears that under the highest variant of the taxation strategy, total farm income in EU agriculture in CAPRI and IFM-CAP decrease with about 14% and 4% respectively. The difficulty is that the comparison base (income definition) can be quite different. In FarmDyn, farm Net Value Added decreases with about 12% on the average arable farm, if market price changes as in the CAPRI model are taken into account. On dairy farms, this may even cause an increase of income on dairy farm by 2% at the highest considered level of taxation. In IFM-CAP gross income decreases

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with about 10% on the average Specialist COP farm and about 1.5% on the average Specialist milk farm. Besides differences in the definition of income (Net Value Added versus gross income), cost structures in FarmDyn and IFM-CAP are also quite differently defined.

Changes of land use and agricultural production are fairly heterogeneous across the models. Although results from CAPRI and GLOBIOM for reduction in the use of N from mineral fertilizers look similar, the mechanism is quite different. In GLOBIOM it seems that mitigation technologies are quite expensive and reduction in N from mineral fertilizers is especially achieved via decrease in crop area and increase in fallow or abandoned land, grassland and other natural land. Compared to this, CAPRI projects a reduction in the production of cereals and oilseeds of around 8% and 4% respectively under the highest variant of the taxation strategy. If the tax is redistributed via a subsidy on agricultural area where mitigation technologies are applied, the decrease in crop area is much less in GLOBIOM – only 7%. In this case the decrease in N from mineral fertilizer equals around 18%.

The model results presented above exhibit a rather wide range of possible outcomes for fertilizer use reduction, farm incomes, and production changes (Table 25) in the taxation variants. This wide range can be attributed to several fundamental differences between the models in the MIND STEP toolbox: Base year of the model database and baseline projections (see chapter **Error! Reference source not found.**), representation of market effects, included mitigation technologies, definition of result indicators like income, and many more. In particular differences in baseline and technology representation, namely the cost of nitrogen fertilizer application, effects on crop yields, the cost of alternative technologies, and reporting indicators are areas where further alignment is desirable. Still, the juxtaposition of purely supply-side models like FarmDyn and IFM-CAP with market models like CAPRI and GLOBIOM, supplemented by econometric models, permits the identification of plausible intervals in which the outcomes of the policy intervention may materialize. It is therefore possible to draw a number of policy recommendation from the application of the MIND STEP toolbox to the fertilizer taxation variants:

- Mitigation technologies play a key role in reaching input reduction targets; re-investing the levied tax as additional subsidies has beneficial effects. A combination of taxations along with subsidies on mitigation technologies may be a suitable approach to mitigate extreme agricultural income and price effects, although environmental improvements will be dampened as well.
- Results suggest that N input reduction by 20% can be reached through tax rates between 25% and 65%
- Target of reducing N surplus by 2030 is out of reach at max. considered taxation of 132%
- Redistribution of levied taxation reduces heterogeneous impact on different farm types
- Specialized crop farm types are much more affected by the taxation. Smaller farms on average are affected more by taxation but there is no clear pattern of farm size and negative income by taxation.
- Re-investing tax revenues as subsidy on mitigation technologies reduces net global emissions and has the least impact on European production
- Dairy farms appear to have a higher potential to reduce mineral fertilizer use because of the availability of organic fertilizer. Facilitation of exchange of organic fertilizer between dairy and specialized arable farms may also reduce the mineral fertilizer application on arable farms.

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# 6. CONCLUSIONS

While each of the two scenarios offers unique insights into specific policy aspects, their shared exploration of policy implications, model variations, environmental and economic impacts, structural changes in agriculture, and the need for alignment presents avenues for interlinking and synthesizing findings to provide a more comprehensive understanding of policy impacts on agriculture. Integrating insights from both scenarios contribute to more robust policy recommendations and modelling approaches within the MIND STEP toolbox.

## 6.1. Synthesis of main outcomes from the two scenarios

In the GHG Mitigation scenario, the TAXATION strategy (130CO2eq_TAX) led to varied outcomes across models. GLOBIOM exhibited higher GHG emission reductions (around 33-34%) compared to MAGNET (27%), attributed to GLOBIOM's broader consideration of GHG mitigation technologies. Production changes also differed: GLOBIOM and MAGNET showcased varying decreases in beef, primary milk production, and cereals production. Market price developments diverged significantly, notably with MAGNET projecting a much higher beef price increase (around 60%) compared to GLOBIOM's 15%. Structural changes, particularly in the dairy sector, were expected, influencing trends in milk production and farm numbers. Notably, the exclusion of CO2eq emissions from imported feed in FarmDyn impacted feed production decisions in dairy farms.

Moving to mineral N fertilizer use reduction scenario, the impact of tax strategies on mineral fertilizer use, farm income, and agricultural production varied significantly across models. Reductions in mineral N fertilizer usage showed diverse percentages: IFM-CAP and GLOBIOM revealed reductions around 11-30%, while FarmDyn showcased around 50% reduction for dairy farms and around 15% for arable farms. CAPRI also shows that without tax revenue redistribution change in N surplus in EU27 equals around 20% at sector level. So, while the Green Deal policy target of 20% mineral N fertiliser reduction is reached, the targeted reduction of N losses of 50% is not reached with the tax on mineral N fertilizer only. This is confirmed by FarmDyn results for the average EU dairy and arable farm. Changes in land use and agricultural production diverged between models; CAPRI suggested decreases in cereal and oilseed production, while GLOBIOM emphasized reductions in crop area and increased fallow or abandoned land. In CAPRI production effects of the tax on mineral N fertilizers are dampened by adoption of mitigation technologies. In GLOBIOM the costs and potentials of mitigation technologies to reduce mineral N fertilizer are more restrictive. Differences in income definitions and cost structures across models influenced the reported farm income changes.

## 6.2. ROADMAP

### 6.2.1. Limitations of Scenarios

The scenarios present several constraints that warrant attention. Measuring CO2eq emissions at the farm level remains a challenge, impacting the precision of estimations within the models. Further investigation into the potential political and administrative challenges of implementing fertilizer or GHG taxes is imperative. Taxation policies, although effective, demand national-level implementation, which poses logistical and administrative complexities.

Moreover, the scenarios include a selected number of GHG mitigation measures, potentially limiting the breadth of the analysis. A more comprehensive understanding could be achieved by delving deeper into refining mitigation technologies to better represent expected advancements. Additionally,

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data quality regarding emission reductions and the costs of mitigation technologies requires enhancement to bolster the accuracy of model predictions.

### 6.2.2. Limitations of the MIND STEP toolbox

The toolbox itself encounters several limitations that impede its comprehensive application. Variability in models' time horizons introduces disparities; for instance, models like MAGNET focus on the long term, while FarmDyn operates within short to medium-term frameworks. This variation causes discrepancies in reflecting the time-lagged effects of GHG mitigation measures, affecting the accuracy of predictions.

Inconsistencies in representing mitigation technologies hinder the toolbox's efficiency. While the toolbox excels in explicitly modeling the adoption and investments in new technologies, alignment issues exist among models. MAGNET measures indicators in monetary terms, contrasting with other models that use physical terms, complicating comparisons.

The potential for structural change in the agricultural sector remains underexplored. Achieving consistency between impacts per farm, alterations in farm size and number of farms, and impacts per sector per region would provide a clearer picture of the full potential impacts. In this deliverable the problem is solved by referring to farm level impacts as impacts on the continuing farms, without information on number of farms leaving the sector. MIND STEP Deliverable report 4.5 presents an approach to couple the technology rich, bio-economic farm model FarmDyn to the Agent Based Model (ABM) AgriPoliS, including farm exit modelling, using surrogate models.

Assumptions regarding risk preferences and behavior across all farms are uniform, which may not accurately reflect real-world agricultural practices, see also MIND STEP Deliverable report 3.5. Addressing the potential role of structural change and risk behaviour within the models of the MIND STEP toolbox, remains a challenge.

Despite these limitations, the MIND STEP toolbox holds strengths in explicitly considering the uptake of new technologies for impact assessment. Its integrated approach across different scales stands as a notable advantage. However, there's acknowledgment of the necessity for greater transparency regarding the assumptions and limitations of the models, as highlighted in discussions from MIND STEP Deliverable Report 6.3. The toolbox's linkage between models is recognized as a major benefit, but improvements in transparency and alignment among models are crucial for enhancing its utility and reliability.

### 6.2.3. Input from third stakeholder workshop

The stakeholder workshop from October 2022 raised several crucial points, shedding light on various aspects of the first and early results of the Greenhouse gas mitigation scenario and the mineral N fertilizer use reduction scenario and the MIND STEP toolbox.

**Scenario Assumptions and Results:** The workshop highlighted the representation of exogenous prices, the number of branches, and farm types in farm models. It emphasized the disparity in farm-level results among different scenarios. The GHG emission reduction scenario primarily focused on dairy farms in the Netherlands using FarmDyn. This resulted in a lack of farm-level results for other farm types and regions. The mineral N fertilizer use reduction scenario included all farm types using IFM-CAP, albeit N-response curves are not included.  Market price feedback in farm models can be obtained from the market models in the MIND STEP toolbox, as shown in this deliverable. Also in this

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deliverable FarmDyn has been applied to the NUTS2 average dairy and arable farm in the EU using EU FADN. This should be seen as first applications and more work is needed for finetuning and to include more farm specific data.

**Structural Change and Transferability:** The potential for structural change in the agricultural sector was a key concern, particularly its limited incorporation into the chemical input reduction scenario within this deliverable. Recognizing the importance of structural change, MIND STEP's Deliverable 4.5 combines FarmDyn and the ABM AgriPolis to model such shifts. Furthermore, the workshop delved into the transferability of farm-level results to regions beyond the case study area, highlighting examples from Deliverable 6.2 that applied the FarmDyn model in Germany and the Netherlands. As mentioned above in this deliverable this is extended to the NUTS2 average dairy and arable farm in the EU using EU FADN. Also the INRAE-MC model has been translated to also apply to farms in the EU FADN. In this deliverable results of the INRAE-MC model for Italian arable crop farms in the EU FADN are presented.

**Management, Technology, and Policy Design:** Discussions revolved around the uptake of new technologies and the nuanced selection and adoption of GHG mitigation measures. The need for improved data quality in analyzing emission reduction potential and associated costs was underscored. In this deliverable scenario results are presented including improved and enhanced mitigation and costs parameters of the large scale policy models, taking results from farm models as input. The policy design discussion emphasized the potential enhancement of scenarios through a combination of voluntary measures, eco-schemes, taxations and subsidies. This has resulted in refinement of strategies including combined taxation and redistribution strategies and assessing performance based agricultural policy strategies like the budget neutral subsidy on CO2eq emission technologies to be financed via an adjustment of the EU CAP direct payments. Additionally, trade-offs with other objectives like social dimensions and food security were highlighted in policy considerations.

**Energy Representation and Model Collaboration:** Although energy markets weren't a primary focus within MIND STEP scenarios, the workshop identified the need to model energy input use and energy price risk in more detail. Collaboration among models was stressed as pivotal, recognizing its importance in strengthening the overall modeling approach.

In essence, the workshop discussions highlighted various intricacies and opportunities for refinement within the scenarios and the MIND STEP toolbox. They underscored the need for a more comprehensive representation of structural changes, improved data quality, nuanced policy designs, and enhanced collaboration among models to achieve a more robust and holistic modeling framework. Only a limited number of the recommendations could be included in this deliverable.

## 6.3. Policy recommendations

### 6.3.1. Reflection on market based policies

The simulations vividly illustrate the contrasting outcomes of tax versus subsidy policies in tackling agricultural emissions. Taxation models showcase significant reductions in nitrogen use and GHG emissions at both sector and farm levels, albeit accompanied by pronounced economic and leakage effects. Subsidy strategies and strategies to reinvest tax revenues as subsidies in (expensive)

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mitigation technologies temper economic impacts but also dampens emission reductions, posing a conundrum for policy effectiveness.

Subsidies on CO2eq emission reductions reveal notable shifts in farm dynamics, altering farm exit trends and enhancing farm incomes due to possible overcompensation as e.g. appeared for dairy farms in the Greenhouse gas mitigation scenario. Subsidies bear the challenge of fairness, potentially disadvantaging farmers who've previously invested in mitigation or exposing disparities across farm types, reflecting inconsistencies with the "polluter pays" principle.

Proposals to balance these disparities through targeted tax-finance subsidies encounter challenges in defining farm groups and risk overcompensation within these groups. Cap-and-trade schemes offer efficiency gains (Lankoski et al., 2019), but the argument above that the policy might be unfair to farmers who've previously invested in mitigation measures remain. Actually this accounts for all measures putting a physical constraint on GHG emission, including command-and-control schemes and cap-and-trade schemes. Compensating the farmers in retrospect could overcome this problem, if possible.

The preferential approach seems to lean towards emissions taxation, despite its non-inclusion in EU policies, given its potential to mitigate emissions, albeit at initial economic costs. However, the long-term outlook suggests a dampening of income effects at farm level as prices increase and new mitigation techniques emerge and farm productivity escalates. Yet, fundamental challenges remain, including measurement accuracy and validation, posing persistent hurdles in effectively implementing market-driven emission policies within the agricultural sector.

### 6.3.2. Policy recommendations towards a more sustainable CAP

Our policy recommendations stress gradual implementation, adaptive support mechanisms, and flexible phase-out strategies, all acknowledging the crucial role of evolving technology in achieving sustainable agricultural practices.

The preferential approach seems to lean towards emissions taxation. A gradual implementation allowing farmers and markets the necessary time to adjust and invest in emission-reducing technologies is recommended. Tax revenues could be channelled to support farms adopting these technologies, lessening potential income impacts while acknowledging possible rises in food prices.

A careful roll-out of a subsidy on CO2eq emission reduction strategy could also be further investigated. In this case, gradual implementation is also recommended, especially to prevent overcompensation. Periodic assessments of farm-specific emission benchmarks would facilitate a phased policy withdrawal once emission reduction goals are met, considering technological advancements like improved breeding methods.

Regarding  mineral N fertilizer use reduction, emphasizing mitigation technologies remains critical. Redirecting tax revenues to supplement subsidies could help mitigate extreme income and price fluctuations, even though environmental benefits might be somewhat compromised.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

# 7. ACKNOWLEDGEMENTS

This Deliverable 6.4 was developed as part of the H2020 MIND STEP project, which received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

# 9. ANNEX 1: SAMPLE FARMS FOR THE FARMDYN MODEL

## 9.1. Background

The bio-economic single farm model FarmDyn (Britz et al. 2016) allows simulating optimal farm management and investment decision under changes in boundary conditions such as prices, technology or policy instruments, for a wide range of farming branches (arable, pig fattening, sows, dairy, beef cattle including mother cow systems, biogas). It is based on a model template for a fully dynamic or comparative-static bio-economic simulation building on Mixed-Integer Programming. The fully dynamic version can be extended to a stochastic dynamic model, combined with different risk behavioural models. Farm branches and other elements such as e.g. fertilization and manure policy restriction can be added in a modular fashion to the core model, as well as a module for large-scale sensitivity analysis. Originally developed for applications to German farming systems, the model's default data and parameterization comprise detailed engineering data for Germany which cover field operations, a crop calendar for over hundred crops, detailed by tillage system, conventional versus organic farming and by plot size and farm-plot distance. The same data provider also offers matching data on yields, prices, direct costs for crop and animal processes and on machinery and stable costs. A bi-level estimation approach allows for automated calibration of the model against observed crop choices and animal herds (Britz 2020).

The farming branches for dairy and cattle farming differentiate raising and fattening processes by month, grazing share and weight gains, and, in case of dairy cows, by month of calving and lactation period, and account for the possibility to consider cross-breeding and sexing (Pahmeyer and Britz 2020). These options interact with multiple, seasonally differentiated grass land management options. FarmDyn further differentiates manure, related storage and application chains.

Investments into a detailed machinery park, stables and other structures are depicted by integer variables, the same holds for the possibility to work off-farm. The model distinguishes on-farm labour needs for field operations, stable work and management/maintenance. Management and maintenance work as well as differently sized investments in machinery and stables provoke increasing returns-to-scale in branch sizes and depict different labour-capital intensities endogenously.

FarmDyn was stepwise developed based on funds provided by research projects. It is currently maintained by a research unit at Bonn University and used, as well as extended, by several international partners. It is hosted on a revision control system; its coding follows guidelines and quality management measures include automated testing of the model on a larger set of test cases with reporting of differences in key results against previous revisions. Recent developments by the main developing team in Bonn involved the improved separation of code from data, which greatly facilitated the application of FarmDyn for the Netherlands and other regions in the EU using FADN data. Some details regarding the required data-files and the available options are discussed in the next chapter.

## 9.2. Constructing Sample Farms

### 9.2.1. FarmDyn Data Requirements

The parameterization of FarmDyn requires an extensive set of data for input- and output coefficients for the farm technologies, farm endowments, cost structures, and prices. The major source of information for the EU-wide version of FarmDyn is the Farm Accountancy Data Network (FADN), which contains data on the economic results of farmers from a sample covering all member states of the European Union (EU).

A distinction has to be made between default data specific per country or region, that permits executing all modules of FarmDyn for typical farms, and farm-specific data if available. The generation of default data (specific per country or region) and farm-specific data are distinct workflows that enter the model in different places.

**Default data**

FarmDyn is a model with a very detailed representation of farming activities and requires therefore a large amount of data, which is in general not available at farm level. Typical examples are nutrient contents of animal feeds, labour and machinery requirements for field operations, or emissions factors for crops and animal production. Such information is taken from various sources, including KTBL as well as handbooks and other publications on animal feedings or fertilizer application and yield responses. Part of the default data for FarmDyn are also some variables, which are in principle available at farm level, like crop yields, rotational shares, nutrient contents, milk yield, and certain variable cost items. They have to be provided to the model to permit the execution of the different modules even if farm-specific data are not available. The data has to be provided in the form of GAMS programs that connect the model parameters to the underlying databases. These default data-files are listed in Table 26.

*Table 26 GAMS files containing data for FarmDyn*

| | |
|---|---|
| mach_*.gms | defines the list of machines and their attributes (such as price, lifetime) |
| buildings_*.gms | defines bunker-silos used to store silage and other buildings, current potato stores, and their attributes (investment sum, capacity, lifetime, yearly variable costs) |
| silos_*.gms | Define the list of manure silos, their capacity, prices and cost of different silo coverage types |
| stables_*.gms | Defines the list stables, their capacity, prices, additional labour need per animal compared to most efficient stable type, their lifetime. Prices and labour needs are automatically interpolated between size classes for which data are given |
| feeds_*.gms | Defines the list of feeds and contains their nutrient contents |
| cropop_*.gms | Define the list of field operations, their link to field working requirement levels, their attributes (labour time, diesel, fix and variable costs, # of persons, amount), operations per crop and each lab period by tillage type, link to machinery |

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| | |
|---|---|
| crops_*.gms | Variable costs of crops not linked to field operations, |
| cattle_*.gms | Variable costs for dairy cows (otherwise from GUI), stocking rate factors, labour per animal and year, tractor hours for animal |

**Farm-specific data**

Farm-specific data can be added in the form of farm-sample files, which replace default values if available. The flexible generation of these files for livestock farms based on FADN data was developed over the last years at Wageningen Economic Research (WEcR). The generation takes place in a separate workflow, which generates a GDX file that has to start with "farmData_*" to be recognized by the GUI. The major work is to read and re-arrange parameters from the FADN files and to perform aggregations to typical or average farms by certain groups. For this, it is important to have a complete list of farm identifiers and their correspondences to regions or farm types over the years for which data is available. The farmData_*.gdx file has to contain at least the list of farm identifiers and a parameter named p_farmData with farm-specific settings and data. The screenshot below shows the header of p_farmData for average NUTS2 dairy farms:

p_farmData(*, *, *): R data from GDXRRW

global
maxrot
misc
yields

| | Aks | AllowManureExport | AllowManureImport | farmbranchArable | farmbranchBeef | farmbranchBiogas | farmbranchDairy | farmbranchFattners | farmbranchMotherCows | farmbranchSows | milkPrice | milkYield | nArabLand | nCalves | nCows |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AT11 | 2 | -3 | -4 | -1 | -2 | -2 | -1 | -2 | -2 | -2 | 35 | 79 | 41 | 27 | 51 |
| AT12 | 2 | -3 | -4 | -1 | -2 | -2 | -1 | -2 | -2 | -2 | 37 | 71 | 8 | 14 | 24 |
| AT21 | 2 | -3 | -4 | -1 | -2 | -2 | -1 | -2 | -2 | -2 | 38 | 66 | 4 | 11 | 20 |
| AT22 | 2 | -3 | -4 | -1 | -2 | -2 | -1 | -2 | -2 | -2 | 38 | 69 | 2 | 12 | 19 |
| AT31 | 2 | -3 | -4 | -1 | -2 | -2 | -1 | -2 | -2 | -2 | 38 | 68 | 9 | 15 | 26 |
| AT32 | 2 | -3 | -4 | -1 | -2 | -2 | -1 | -2 | -2 | -2 | 41 | 68 | 1 | 10 | 20 |
| AT33 | 2 | -3 | -4 | -1 | -2 | -2 | -1 | -2 | -2 | -2 | 42 | 56 | | 8 | 14 |
| AT34 | 1 | -3 | -4 | -1 | -2 | -2 | -1 | -2 | -2 | -2 | 42 | 71 | 1 | 11 | 20 |

The block "global" shown here is used for the general set-up for an instance of FarmDyn, including milk yields, milk prices, endowments with arable land and labour force (Aks). In addition, certain global settings switch on or off the respective modules in FarmDyn. These switches are coded as negative numbers for technical reasons. For instance, a "-1" entry in the column farmBranchArable activates the modules relevant for crop farming, which would otherwise not be used. Similarly, a value of "-3" for AllowManureExport permits the farm to export manure, while a "-4" entry would mean the opposite.

The block "yields" are farm-specific crop yields derived from FADN. The block "maxrot" refers to maximal rotational shares of crops on the farm, which determine the degree of specialization the farm might have. The block "misc" contains additional information required for reporting and parameterization of equations.

### 9.2.2. Average NUTS2 Dairy and Arable Farms

Individual arable farms in EU FADN were aggregated to NUTS2 level using their weights. First, arable farms with farm typologies 15 (Specialist cereals, oilseed and protein crops), 16 (General field cropping) and 20 (Specialist horticulture) were selected. From these farms, only those were selected that had at least 80 % of their land cultivated with maize, summer cereals (oats, rye, others), summer beans (peas), winter barley, winter wheat, winter rape, and/or potatoes. This selection corresponds to the current arable crops covered by FarmDyn.

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*Table 27 Descriptive statistics of the national average arable farm. (weighted mean, % cereal after weighted mean of the area of each cereal divided by the weighted mean of Land, not weighted mean of percentages)*

| NUTS0 | Land [ha] | Share of Cereals [%] | Annual Work Units | kg N per ha | Farm Net Value Added [EUR] | FNVA per AWU | n |
|---|---|---|---|---|---|---|---|
| AT | 45.2 | 58.1 | 1.0 | 115.2 | 32103 | 33603 | 91 |
| BE | 56.3 | 57.2 | 1.1 | 153.7 | 44493 | 38827 | 44 |
| BG | 92.8 | 61.8 | 2.3 | 119.2 | 28272 | 12070 | 114 |
| CZ | 195.2 | 61.9 | 3.5 | 150.2 | 41414 | 11795 | 294 |
| DE | 120.8 | 61.4 | 1.6 | 129.7 | 33231 | 21026 | 1466 |
| DK | 99.9 | 82.4 | 1.2 | 108.6 | -6554 | -5253 | 343 |
| EE | 212.9 | 70.6 | 1.8 | 106.3 | 7308 | 4101 | 114 |
| EL | 10.2 | 53.6 | 0.7 | 125.1 | 6910 | 9772 | 58 |
| ES | 65.4 | 81.2 | 1.1 | 92.4 | 24912 | 23221 | 473 |
| FI | 51.6 | 85.4 | 0.6 | 84.7 | 13589 | 22681 | 68 |
| FR | 117.0 | 60.0 | 1.4 | 167.5 | 39067 | 27485 | 779 |
| HR | 21.1 | 36.1 | 1.3 | 135.1 | 10922 | 8603 | 82 |
| HU | 34.3 | 48.2 | 0.8 | 109.8 | 18029 | 21472 | 257 |
| IE | 131.1 | 85.7 | 1.1 | 189.4 | 117014 | 102510 | 17 |
| IT | 18.9 | 55.6 | 1.1 | 130.0 | 22630 | 20345 | 270 |
| LT | 91.6 | 71.7 | 1.7 | 159.4 | 13818 | 8311 | 381 |
| LV | 141.5 | 76.1 | 2.1 | 119.9 | 9954 | 4801 | 245 |
| NL | 55.5 | 41.0 | 1.4 | 123.2 | 58847 | 42849 | 114 |
| PL | 26.1 | 64.5 | 1.3 | 137.6 | 9010 | 6749 | 3238 |
| PT | 15.4 | 58.5 | 1.3 | 142.4 | 18055 | 13756 | 25 |
| RO | 69.6 | 50.1 | 1.5 | 211.0 | 29679 | 19811 | 906 |
| SE | 116.6 | 80.3 | 1.4 | 120.2 | 9381 | 6709 | 114 |
| SI | 11.7 | 46.2 | 0.6 | 135.3 | 3572 | 5644 | 31 |
| SK | 243.5 | 52.3 | 4.8 | 129.4 | 46989 | 9832 | 116 |
| EU27 | 56.1 | 62.8 | 1.4 | 139.9 | 18544 | 14012 | 9640 |

For the construction of the database for the EU-wide version of FarmDyn to generate MAC curves for the MAGNET model, a sub-sample of dairy farms (farm type number "TF45") with at least five dairy cows, and a milk yield over a reasonable range (>0 and <=12000 kg/cow/year, representing the bottom 10% and the top 1 % of milk yields), was selected for the year 2019, resulting in more than 11000 individual farms.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

*Table 28 Descriptive statistics of the national average dairy farm. (weighted mean, % cereal after weighted mean of the area of each cereal divided by the weighted mean of Land, not weighted mean of percentages)*

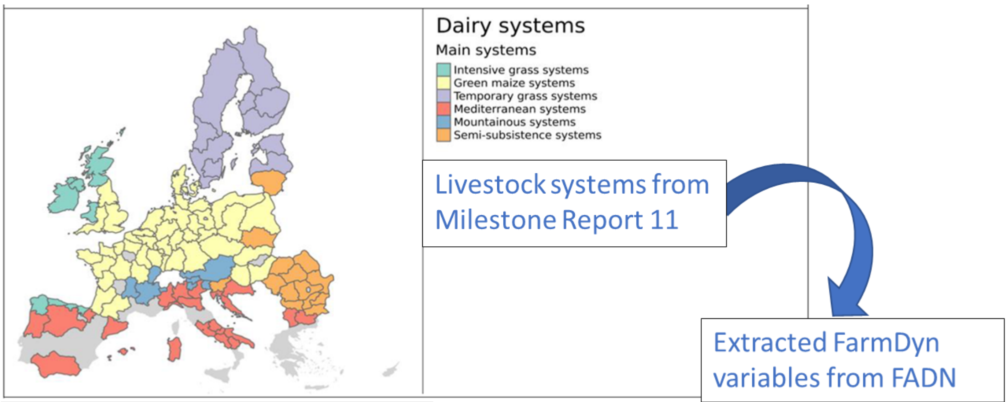
| NUTS0 | Cows [LU] | Arable Land [ha] | Grassland [ha] | Milk yield ['00 kg/cow/year] | Share of Grassland [%] | Farm Net Value Added [EUR] | Annual Work Units | FNVA per AWU | Livestock density [LU/ha] | n |
|---|---|---|---|---|---|---|---|---|---|---|
| AT | 21.4 | 5.4 | 21.3 | 67.3 | 80.7 | 39068 | 1.6 | 23937 | 0.8 | 669 |
| BE | 82.5 | 19.8 | 38.0 | 78.3 | 59.7 | 96993 | 1.9 | 50012 | 1.4 | 205 |
| BG | 33.2 | 8.4 | 12.1 | 45.0 | 34.0 | 37606 | 2.6 | 14676 | 1.6 | 45 |
| CZ | 139.3 | 155.2 | 152.6 | 68.1 | 54.8 | 326741 | 14.0 | 23404 | 0.5 | 110 |
| DE | 72.5 | 34.2 | 40.7 | 72.0 | 60.3 | 96803 | 2.2 | 44991 | 1.0 | 2530 |
| DK | 179.6 | 89.2 | 66.2 | 92.1 | 39.8 | 277524 | 3.3 | 83597 | 1.2 | 391 |
| EE | 116.0 | 106.0 | 181.0 | 73.0 | 81.0 | 128151 | 5.9 | 21558 | 0.4 | 98 |
| ES | 60.2 | 6.5 | 21.4 | 75.8 | 72.3 | 61890 | 1.9 | 33155 | 2.2 | 766 |
| FI | 42.5 | 18.9 | 51.2 | 88.1 | 71.7 | 53923 | 2.1 | 25101 | 0.6 | 229 |
| FR | 65.4 | 38.3 | 57.0 | 67.7 | 60.2 | 62167 | 1.9 | 32012 | 0.7 | 847 |
| HR | 20.5 | 14.1 | 10.3 | 52.0 | 39.3 | 39817 | 2.3 | 17222 | 0.8 | 131 |
| HU | 119.1 | 81.5 | 40.0 | 62.3 | 26.4 | 189153 | 8.2 | 23158 | 1.0 | 67 |
| IE | 84.2 | 1.2 | 63.1 | 57.5 | 98.2 | 77828 | 1.7 | 46350 | 1.3 | 298 |
| IT | 57.6 | 10.1 | 14.3 | 65.8 | 47.2 | 131149 | 2.0 | 64652 | 2.4 | 613 |
| LT | 21.9 | 13.4 | 37.0 | 54.8 | 74.7 | 21872 | 2.0 | 10900 | 0.4 | 219 |
| LU | 82.0 | 35.0 | 67.0 | 76.0 | 64.3 | 100926 | 1.9 | 54193 | 0.8 | 193 |
| LV | 25.0 | 13.0 | 48.0 | 57.0 | 82.0 | 24449 | 2.2 | 11130 | 0.4 | 242 |
| MT | 73.0 | 2.0 | 0.0 | 69.0 | 0.0 | 58273 | 2.5 | 23728 | 36.5 | 71 |
| NL | 101.6 | 9.0 | 49.1 | 85.8 | 84.7 | 123447 | 1.9 | 63924 | 1.7 | 355 |
| PL | 21.9 | 14.1 | 11.2 | 57.0 | 43.7 | 27463 | 1.9 | 14223 | 0.9 | 2082 |
| PT | 36.0 | 6.9 | 9.9 | 68.9 | 36.0 | 35438 | 1.9 | 18872 | 2.1 | 239 |
| RO | 12.0 | 3.4 | 5.9 | 43.9 | 39.5 | 17180 | 1.4 | 12614 | 1.3 | 180 |
| SE | 89.7 | 35.1 | 115.0 | 84.6 | 72.4 | 106317 | 2.8 | 37504 | 0.6 | 320 |
| SI | 20.7 | 4.4 | 14.3 | 53.6 | 74.9 | 19718 | 1.8 | 10952 | 1.1 | 138 |
| SK | 293.0 | 348.5 | 557.1 | 65.3 | 57.8 | 584923 | 33.8 | 17303 | 0.3 | 34 |
| EU27 | 52.5 | 19.6 | 33.5 | 66.1 | 60.7 | 68102 | 2.0 | 33109 | 1.1 | 11072 |

While it is technically possible to execute FarmDyn for all individual farms, this is not always practical for such large samples. Apart from long computation times, the main problem is that FADN provides information on farm endowments and output coefficients but not on input coefficients by production activity. This information can usually be derived from handbooks on standard farming practices or, in some cases, from farm surveys but is generally not available for individual farms in FADN. Therefore, the modelled farms would not differ in their cost structure, resulting in the repeated execution of very similar model instances for farms with comparable endowments and productivity. For this reason, individual farms are often grouped to generate typical or average farms with comparable characteristics, depending on certain projects or research questions.

In the case of this report, average farms for each NUTS2 region in the FADN were created by extracting the relevant variables necessary for running the FarmDyn model and aggregating them at the NUTS2 level using the mean, weighted with the SYS02 weights.

### 9.2.3. Outlook: Expert-driven Farm Typologies

A known disadvantage of using average regional farms is that they mix together rather different farms, resulting in a model farm with characteristics that do not reflect actual farming systems in a region. An alternative is the usage of expert knowledge on dominant or typical farming systems within regions that share certain characteristics, like being located in mountainous regions or in a Mediterranean environment with historical reasons for size-distributions. An example for such an expert-driven farming system, namely for livestock systems , can be found in Bailly-Caumette et al. 2022. In there, a set of livestock production systems for EU Member States at sub-national level was proposed. An important feature of these production systems s that they are not only characterized by farm statistics but also by location within NUTS1 or NUTS2 regions. This permits the straightforward extraction of sample farms from FADN and the construction of input files used by FarmDyn as described above. Figure 52 shows the usage of the dairy production systems characteristics by Bailly-Caumette et al. 2022 for the construction of dairy farm input files for FarmDyn. However, comparison of the average values derived from FADN revealed some deviations from the farm characteristics shown in MS11 (Table 29), which call for a more restrictive sampling approach. But in purely technical terms, the hand-shake between the extraction methods for FADN data used in the FarmDyn workflow and the PATHWAYS production systems could be established.




| System group | System name | SYST_ID | milkYield | nArabLand | nCows | nGrasLand | ShareGras: | sharemaizsil |
|---|---|---|---|---|---|---|---|---|
| Green maize systems | Mix grass and green maize | MXGG | | 50 | 70 | 50 | 0.5 | |
| | High green maize system | HGMZ | 80 | 60 | 75 | 40 | 0.4 | 0.3 |
| | Temporary grasslands system | TGGM | 100 | 129.5 | 225 | 55.5 | 0.3 | 0 |
| | PG grass + green maize system | PGGM | 87 | 12 | 100 | 48 | 0.8 | 0.2 |
| Intensive grass systems | High nitrogen input | IRSH | 56 | 3 | 90 | 57 | 0.95 | 0 |
| | Large herds on large areas | SCOT | 60 | 18 | 400 | 342 | 0.95 | 0 |
| | Semi-extensive system | CANT | | | 55 | 30 | 1 | |
| Mountainous systems | Mountainous systems | MOUN | 60 | 5 | 50 | 95 | 0.95 | 0 |
| Mediterranean systems | Intensive indoor sytems | SPAN | 120 | 25 | 200 | 25 | 0.5 | 0.5 |
| | Small indoor systems | CROA | 70 | 20 | 5 | 30 | 0.6 | 0.3 |

*Figure 52. PATHWAYS Dairy Systems and FarmDyn variables (selection)*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 817566.

*Table 29 Comparison between PATHWAYS farmtypes and average FADN variables*

| SYST_ID | global%milkYield | global%nCows | global%nGrasLand | global%ShareGrassLand |
|---|---|---|---|---|
| CANT | 77.05114379 | 56.93155623 | 21.44977143 | 0.783961207 |
| **CANT** | | 55 | 30 | 1 |
| HGMZ | 72.92248933 | 85.72584829 | 49.62788616 | 0.501036508 |
| **HGMZ** | 80 | 75 | 40 | 0.4 |
| MOUN | 62.89335543 | 52.43231399 | 78.24322738 | 0.837048332 |
| **MOUN** | 60 | 50 | 95 | 0.95 |
| MXGG | 73.16622086 | 74.49949458 | 49.18097325 | 0.502325963 |
| **MXGG** | | 70 | 50 | 0.5 |
| SPAN | 78.1607141 | 92.98992 | 35.54602951 | 0.590234736 |
| **SPAN** | 120 | 200 | 25 | 0.5 |
| TGGM | 81.96086173 | 320.7127698 | 181.0928376 | 0.364824153 |
| **TGGM** | 100 | 225 | 55.5 | 0.3 |

## 9.3. FarmDynR package

Development of the FarmDynR package started with deliverables 7.1 and 7.2, and was subsequently extended to be used in deliverables 5.2 and 6.4. This was used to create the average sample farms from FADN data that can be used to run FarmDyn simulations. In this case, the NUTS2 variable, corresponding to the NUTS2 region in which each farm in the FADN is located, was selected as the variable to which the farms would be aggregated. This means that the resulting farm data will contain the weighted mean of selected variables used in FarmDyn for each NUTS2 region. The aggregation was done for both arable and dairy farms, and for dairy farms using the NUTS2 regions identified with the Pathways dairy system farm types. To do this, FADN data was loaded into R, then running a function (fadn2fd()) available from the FarmDynR package makes the aggregation by providing the variable to which the aggregation should take place (NUTS2) and the farm branch (arable or dairy). The package can include additional conditions or constraints for extraction, such as selecting variables within a certain range, and produces the farmData file in gdx format necessary to run FarmDyn. For more detailed information on this package, please visit https://gitlab.iiasa.ac.at/mind-step/farmdynr . You can also find there the manual and how to install the package. Additionally, the dataset used to run the simulations can be found there.

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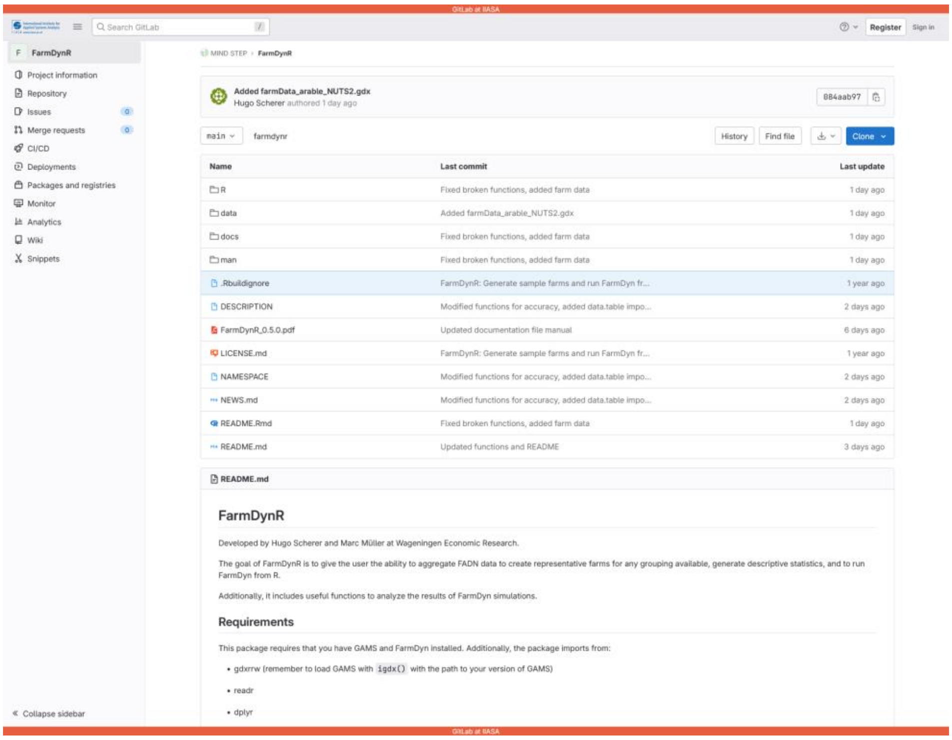


*Figure 53 FarmDynR repository*

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