Henderson, B. and J. Lankoski (2019-05-13), "Evaluating the environmental impact of agricultural policies", *OECD Food, Agriculture and Fisheries Papers*, No. 130, OECD Publishing, Paris.
<http://dx.doi.org/10.1787/add0f27c-en>

OECD Food, Agriculture and Fisheries
Papers No. 130

Evaluating the environmental impact of agricultural policies

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OECD FOOD, AGRICULTURE AND FISHERIES PAPERS

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The publication of this document has been authorised by Ken Ash, Director of the Trade and Agriculture Directorate.

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EVALUATING THE ENVIRONMENTAL IMPACT OF AGRICULTURAL POLICIES

Ben Henderson and Jussi Lankoski (OECD)

The relationship between agricultural support policies (adapted from the OECD Producer Support Estimate (PSE) classification) and a selection of environmental impacts are analysed in a range of country settings, using a farm-level and a market-level model. Based on the methods and environmental indicators used, market price support and payments based on unconstrained variable input use were the most environmentally harmful among the various PSE measures. Decoupled support payments based on non-current crop area were the least harmful, even when considering their impacts on the behaviour of risk averse farmers. The impacts of support policies that clearly change the competitiveness of one production activity in relation to another, such as payments based on current crop area or on animal numbers, were more equivocal. Support payments subject to environmental constraints can improve environmental outcomes compared to coupled support without restrictions, however, they can also have unintended environmental impacts.

Key words: Producer support, GHG, nitrogen runoff, nutrient balance, biodiversity

JEL codes: Q12, Q15, Q18

Acknowledgements

The authors would like to acknowledge the valuable feedback provided by OECD delegations. They also wish to thank Franck Jésus, Martin Von Lampe, Shingo Kimura and Guillaume Gruère for their comments and inputs on successive versions of the paper.

Table of contents

Executive summary	5
1. Introduction	8
2. Categorisation of agricultural policies used in this report.....	9
3. Farm-level assessment of the environmental impacts of agricultural policies	13
4. Market-level analysis using the Policy Evaluation Model	27
5. Conclusions	34
References	40
Annex A. Key parametric equations of the bio-economic model	43
Annex B. List of parameter values	49
Annex C. Changes in PEM variables linked to environmental indicators and the relative contributions of different sectors to these indicators	52

Tables

Table 2.1.	Four types of support represent 82% of the total value of OECD Producer Support Estimate (average 2013-15)	10
Table 2.2.	Policy instruments analysed in the paper as classified by PSE categories and labels	11
Table 3.1.	Baseline situations of the representative farm types	18
Table 3.2.	Impact of policies on input use and land use (% change relative to baseline except for new land allocation levels, ha)	20
Table 3.3.	Environmental impact of policy instruments (% change relative to baseline)	22
Table 3.4.	Risk-averse farmers: Impact of selected policies on land use, dairy herd size, and environment	26
Table 4.1.	Changes in GHG emissions.....	31
Table 4.2.	Changes in N balances	33
Table 4.3.	Changes in P balances	34
Table 5.1.	Environmental impacts of selected policy instruments	36
Table C.1.	Percentage changes in the PEM input and output variables, from the simulated increase in market price support.....	52
Table C.2.	Percentage changes in the PEM input and output variables, from the simulated increase in payments based on input use.....	53
Table C.3.	Percentage changes in the PEM input and output variables, from the simulated increase in payments based on crop area	53
Table C.4.	Percentage changes in the PEM input and output variables, from the simulated increase in payments based on animal numbers.....	54
Table C.5.	Percentage contributions of each PEM sector to country level baseline nutrient balances and GHGs.....	55

Figures

Figure 3.1.	Main interactions in bio-economic modelling framework	15
Figure 3.2.	Percentage changes in GHG emissions, nitrogen runoff, and habitat quality from 10% increases in agricultural support, grouped by category of support.....	24
Figure 4.1.	Framework for assessing environmental impacts with PEM	29
Figure 4.2.	Percentage changes in GHG emissions and nutrient balances from 10% increases in agricultural support, grouped by category of support	30

Executive summary

This report attempts to respond to the following questions: What are the relationships between agricultural support policies and environmental impacts? What conditions may alter the strength and direction of these relationships? It focuses on the main categories of agricultural support policies, and explores the environmental impact of each. The categorisation is adapted from the OECD Producer Support Estimate (PSE) classification. While this report does not provide definitive quantitative measures, it does make illustrative use of models to shed light on the production and market conditions under which agricultural support policies might affect the environment.

More specifically, this report draws on results from *ex-ante* modelling frameworks on the marginal environmental impacts of agricultural policies at market and farm levels, and a review of relevant studies in the literature. The two analytical frameworks are applied to several cases, first in the farm-level framework which is applied to twelve different country and farm situations in the European Union (EU), and then in the market-level framework representing eight countries or regions (Canada, the People's Republic of China (hereafter "China"), Japan, Korea, Mexico, the United States, Switzerland, and EU27¹).

The analyses also gauge the strength of the relationships between agricultural support policies and environmental impacts by the degree of convergence in these relationships across the various country situations and analytical frameworks. In the case of the farm-level framework, the analysis focused on the environmental impacts of greenhouse gas (GHG) emissions, water quality, and biodiversity; while in the case of the market-level framework, it analysed environmental impacts of nitrogen (N) and phosphorus (P) balances, and GHG emissions. These latter environmental indicators were considered to be appropriate for the aggregate scale of the market level framework.

Applied to a number of country situations, both frameworks show the negative environmental impacts of some of the most coupled forms of support policies (market price support and payments based on input use), indicating a strong relationship between increases in these particular support policies and higher GHG emissions and nitrogen pollution. Thus, on the basis of these analytical frameworks, the selected environmental indicators, and the data used, the findings suggest that market price support and payments based on output or unconstrained variable input use are the most environmentally harmful among the various PSE measures.

Findings from the market-level assessment indicate that these support policies can lower phosphorus balances when countries increase support for crops that have negative phosphorus balances. Thus, one key condition for support measures to reduce instead of increase the negative environmental impact is the presence of crops with negative nutrient balances. An important caveat is that the policy evaluation model (PEM) used in the market-level assessment assumes that total agricultural land is fixed and therefore does not consider the possibility that support policies can cause total agricultural land to expand. Since these policies will cause some expansion of agricultural land at the expense of land that either has stronger environmental benefits or lower negative environmental impacts, this framework is likely to underestimate the total environmental impacts of agricultural support. It is possible that even in situations where a support policy reduces a specific environmental impact, relaxation of the fixed agricultural area assumption could cause the environmental impact to change from positive to negative for a particular indicator.

¹ The EU27 here includes all current EU Member States except for Croatia.

By contrast, the modelling frameworks diverge to some extent with respect to the impact of payments based on animal numbers, mainly because cattle production adjustments in the market-level framework are generally larger and represent changes over a longer timeframe. In the market-level assessment, payments based on animal numbers induce cattle stocks to increase by an average of 6%. Given this and the cattle sectors' large share of agricultural GHGs in the assessed countries, the increases in cattle GHGs exceed the reductions in crop GHGs, raising total agricultural GHGs in all of the assessed countries. On the other hand, most cases in the farm-level assessment showed much smaller increases in cattle numbers, where GHG emissions decreased because of livestock diet change from concentrates to silage, which decreases methane and nitrous oxide emissions. At the market level, payments based on animal numbers caused similarly consistent increases in nitrogen balances, with the exception of one country in which cattle contributed very little to its nitrogen balance. The main conditions for this support policy to reverse the negative impact that such payments may have on nitrogen balance are thus the responsiveness of cattle stocks to payments, and their relative contributions to each environmental indicator.

The results of current crop area payments on environmental impacts led to mixed directional impacts in both frameworks for almost all environmental indicators, though the impacts were generally smaller than from other coupled support policies. Because crop area payments increase the competitiveness of crops relative to cattle, and of some crops relative to others, this policy caused cattle production and GHG emissions to fall in most countries, and total agricultural GHG emissions to fall in countries where cattle contributed a large share of agricultural GHGs (>80%). However, where crops accounted for the dominant share of GHGs (>60%), payments based on crop area induced an increase in GHG emissions. For this policy to reduce environmental impacts, conditions must include either relatively high contributions of cattle to baseline environmental impacts, or the presence of some crops with both large environmental impact contributions and relatively high per-hectare values.

The consistency of the relationship between environmental impacts and agricultural support is also a function of commodity coverage in the modelled scenarios. The policies that provided support to all commodities, such as market price support and payments based on input use, tended to generate consistently negative environmental impacts. Conversely, the policies that supported particular groups of commodities, such as those based on crop area or animal numbers, induced trade-offs between commodity groups, which resulted in less consistent outcomes. If the market price support and payments based on input use policies were confined to particular commodity groups, the consistency of their environmental impacts could also decline.

The report also found that farmers risk preferences can alter the direction of the environmental impact of some support measures. For example, the environmental impact of non-current crop area payments (decoupled payments) changes from neutral when assuming that farmers are risk-neutral, to negative when assuming that farmers are risk-averse (though the environmental impacts were relatively small). For non-current crop area payments, broadening the risk behaviour assumptions beyond risk neutrality does not significantly change the conclusion that current fully decoupled payments are among the least environmentally harmful support policies. On the other hand, a revenue insurance subsidy for crops has a relatively strong impact on production choices and the environment by favouring crop production over dairy production.

Analyses of agri-environmental payments for complying with fertiliser use restrictions, and of payments based on non-commodity output (environmental good and services), revealed that both of these policies can create unintended adverse environmental impacts in mixed dairy and crop production systems if they favour crop production and result in land use changes from pasture to cereals. Despite the environmentally positive intentions of these policy measures, policy makers need to be aware of how farms respond in order to avoid unintended environmental consequences.

It is also worth noting that there are limitations related to various modelling assumptions that affect the magnitude of production responses to the support policies and that environmental indicators used in this assessment provide approximations of the environmental impacts from agriculture. As such, insights from this analysis are limited to the farming systems and regions considered in this study. The analysis of other farming systems, such as more specialised farms in other OECD countries with different economic and agronomic conditions, could generate different analytical findings.

1. Introduction

Many factors drive how agricultural production affects environmental outcomes. These include market developments, structural change, technological developments, environmental regulations and agricultural policies. The first step in assessing the environmental effect of agricultural policies is linking a change in farmers' behaviour to the policy being considered. Agricultural policies influence production patterns, farming practices and input use mainly by changing the relative costs and returns of using resources in agriculture, or by imposing direct restrictions on output and input use. Since many other factors influence farmers' choices, it is critical to determine the extent to which a given policy incentive stimulates farmers to do something that they would not otherwise have done. A second step is to assess how the changes in farmer behaviour that can be linked back to a policy incentive affect environmental quality, considering that other factors also affect the environment.

While the conceptual relationships are relatively well-established for some agricultural policy instruments (e.g. market price support and payments based on variable input use, such as fertiliser, water and pesticides), the quantitative assessment of policy performance is often complicated for at least the following reasons:

- Biophysical processes are complex and the relationship between a given agricultural policy instrument, farm management practices and their environmental outcomes is not always deterministic.
- Many of the environmental effects are site specific, reflecting heterogeneous agricultural and environmental conditions, and thus similar agricultural practices may produce different bundles of environmental externalities in different areas.
- There are complex interactions between agricultural commodities that are related in demand, but also in supply through shared input markets.
- There are, in practice, a mix of agricultural policy instruments applied and multiple environmental effects, which make quantitative assessment particularly difficult.

Notwithstanding these challenges, the environmental effects of agricultural support policies must be better understood. With public awareness about the environmental impacts of industries including agriculture increasing, along with willingness by governments to find cost-effective solutions to address these effects, it would be remiss to ignore the environmental impacts of agricultural support policies. For instance, from both government-budgetary and economic welfare perspectives, the reform or removal of policies that negatively affect the environment could provide a very low-cost alternative to establishing new environmental policies for agriculture.

This report characterises the environmental effects of agricultural policy instruments according to the Producer Support Estimate (PSE) classification of agricultural policies (OECD, 2016). It also identifies relationships between policies and their environmental impacts, and identifies the conditions under which these relationships may not hold. The OECD PSE database provides the highest quality of consistent cross-country data on agricultural policies and levels of agricultural support available. The policy instruments to be analysed are selected on the basis of PSE sub-categories and labels in order to distinguish payments that are likely to have very different environmental impacts. For example, payments based on variable input use (such as fertiliser and fuel) are likely to have very different environmental impacts than payments based on on-farm services although both are classified in the same broad PSE category as payments based on input use. Thus, this paper uses the detailed sub-categories and labels available in the PSE classification that offer a sound basis for analysis of environmental impacts of policy instruments. The PSE

classification of agricultural policies dissociates the payments from their intended objectives and therefore allows a more robust comparison of policy instruments that are categorised within the same support type in different countries. Hence, the transfer basis (whether output, input, area, etc.) and associated labels (e.g. input constraints) are core to the pathways by which agricultural support policies affect the environment.

The analysis of the environmental effects of agricultural policies is presented as follows:

- a. Identification of policy instruments for environmental impact analysis using the PSE classification of agricultural support policies (Section 2);
- b. Micro-level framework for assessing the environmental effects of agricultural policies at the farm-level (Section 3);
- c. Market equilibrium framework for assessing the environmental effects of agricultural policies at the market level (Section 4);
- d. Summary table listing policy instruments with positive environmental effects, those with negative environmental effects and those where the direction of change in environmental impacts is dependent on the risk preferences of farmers, market structure and interactions (Section 5);
- e. Discussion of the results in relation to existing literature:
 - Policy instruments for which the results are robust and confirm the existing literature
 - Policy instruments for which the results may differ from those in the existing literature
 - Policy instruments for which new results were developed
 - Policy instruments for which the environmental effect depends on certain conditions
- f. Detailed and robust conclusions from the quantitative assessment regarding policies for which the direction and magnitude of environmental effects are context-specific and depend on certain conditions (biophysical, producer, policy and market).

2. Categorisation of agricultural policies used in this report

This report analyses the environmental impacts of agricultural policies using the Producer Support Estimate (PSE) sub-categories and labels to categorise the different types of policy instruments to be considered (Table 2.1). Following OECD (2010), policy measures included in the PSE are classified according to specific implementation criteria. These identify the economic features of policy measures, which are important for the subsequent analyses of the potential impacts of policies on production, income, consumption, trade, and the environment. Within the PSE classification, policy measures are classified into seven categories, which identify the transfer basis for the policy, whether the basis is current or non-current, and whether production is required or not.² The categories identify:

- The transfer basis for support: output (category A), input (category B), area/animal numbers/receipts/incomes (A/An/R/I) (categories C, D and E), non-commodity criteria (category F);
- Whether the support is based on a current (categories A, B, C, F) or non-current (historical or fixed) basis (categories D and E);

² The seventh category, G (Miscellaneous payments), is not relevant for the analysis in this paper.

- Whether production is required (categories C and D) or not (category E).

Policy measures in each category are further distinguished through labelling: payment limits (limit/no limit), payment rates (fixed/variable), input constraints (with mandatory/with voluntary/without constraint), payment eligibility (based on area, animal number, receipts, income), commodities covered (single, group, all), and production exceptions (with or without).

Policy measures may be classified by category by label, or by both, according to intended use (OECD, 2010).

The PSE data shows that four types of agricultural support represent 82% of total OECD PSE (OECD, 2016): market price support (45%), payments based on non-current area, animal number, revenue or income, production not required and with fixed payment rates (21%), payments based on current area planted or animal numbers with production required (12%), and payments based on variable input use (5%).

Table 2.1. Four types of support represent 82% of the total value of OECD Producer Support Estimate (average 2013-15)

	Million USD	% of total PSE
Producer Support Estimate	237 527	100.0
Support based on commodity output	110 715	46.6
Market price support ¹	106 198	44.7
Payments based on output	4 516	1.9
Payments based on input use	30 604	12.9
Based on variable input use	11 399	4.8
With input constraints	710	0.3
Based on fixed capital formation	11 986	5.0
With input constraints	2 088	0.9
Based on on-farm services	7 219	3.0
With input constraints	1 247	0.5
Payments based on current A/An/R/I, production required	31 859	13.4
Based on Receipts / Income	4 592	1.9
Based on Area planted / Animal numbers	27 267	11.5
With input constraints	20 560	8.7
Payments based on non-current A/An/R/I, production not required	56 020	23.6
With variable payment rates	5 124	2.2
With commodity exceptions	5 066	2.1
With fixed payment rates	50 896	21.4
With commodity exceptions	17 188	7.2
Payments based on non-commodity criteria	5 232	2.2
Payments based on non-current A/An/R/I, production required	2 530	1.1
Miscellaneous payments	568	0.2

Note: A/An/R/I: Area planted/Animal numbers/Receipts/Income.

1. Market price support net of producer levies and excess feed cost.

2.1. Summary of policy instruments analysed in this report

Table 2.2 summarises the categories of agricultural support policies quantitatively assessed in this study using PSE sub-categories and labels.

Sections 2.2 to 2.5, below, provide additional details about the measures that comprise each broad category of PSE agricultural support and how they are specified in the analyses.

To analyse the potential environment impacts of each support policy, both the farm-level and market-level analyses simulate increased payments or market price support equivalent to 10% of

the value of each commodity affected by the payment, and apply these to all of the commodities simultaneously. For example, the increases in market price support and payments based on input used are valued at 10% of the value or revenue of all outputs produced. Whereas the payments based on current crop area and on animal numbers, are valued at 10% of the value of the crop output and 10% of the value of livestock output, respectively. The outcomes are compared to a baseline situation. The usual Policy Evaluation Model (PEM) baseline is used in the case of the market-level analyses. For the farm-level analysis, the baseline is specified as a scenario where all land receives EUR 190 per hectare of decoupled support payments (similar to what exists in the first pillar of the European Union Common Agriculture Policy).

Table 2.2. Policy instruments analysed in the paper as classified by PSE categories and labels

PSE categories	PSE Labels				Farm-level and market-level analysis	
	Current commodity production and payment limits: limit or no limit	Payments rates: fixed or variable	Input constraints: with (mandatory) with (voluntary) without	Payment eligibility based on: A, An, R, I	Included in farm-level analysis: Yes or No	Included in market-level analysis: Yes or No
A. Support based on commodity outputs						
A1. Market price support	No limit	Variable	Without	na	Yes	Yes
B. Payments based on input use						
B1. Variable input use	No limit	Variable	Without	na	Yes	Yes
C. Payments based on current A/An/R/I, production required						
C2. Based on current area or animal numbers						
C2. a) Based on current area	No limit	Fixed	Without	A	Yes	Yes
C2. b) Based on current animal numbers	No limit	Fixed	Without	An	Yes	Yes
C2. c) Based on current area: Agri-environmental payment ¹	No limit	Fixed	With (voluntary)	A	Yes	No
C2. d) Based on current area: Premium subsidy for revenue insurance ²	No limit	Variable	Without	A	Yes	No
E. Payments based on non-current A/An/R/I, production not required						
E2. Fixed rates	No limit	Fixed	Without	A	Yes	Yes
F. Payments based on non-commodity criteria						
F2. A specific non-commodity output	na	na	With (voluntary)	na	Yes	No

Note: na refers to non-applicable, A: Area planted; An: Animal numbers

1. Agri-environmental payment is working lands type of payment, that is, based on current area, and compensates income forgone for complying with voluntary input constraints.

2. Premium subsidy for revenue insurance is only analysed in farm-level analysis under consideration of risk-averse farmers. Premium subsidy for revenue insurance is based on current insured area.

2.2. Market price support

Market price support constitutes close to half of the total producer support estimate (Table 2.1). Market price support arises from policy measures that support agriculture by creating a gap between domestic farm gate prices and border prices of specific agricultural commodities (OECD, 2016). A variety of government policy measures may induce market price support. These include measures imposed at the border, such as tariffs and export subsidisation, as well as quotas on imports or exports. Non-tariff barriers to trade can also result in market price differences between domestic and border price. Domestic market interventions may include direct price administration, quantitative restrictions on production and public stockholding. Market price support is selected for environmental impact analysis as it represents a large share of total PSE (44.7%) and creates strong incentives for increasing production through both the intensive and extensive margins.

2.3. Payments based on input use

Within the PSE classification, payments based on input use include a wide array of input payments. The PSE classification distinguishes three sub-categories of payments based on input use: payments based on variable input use, payments based on fixed capital formation and payments based on on-farm services. In this analysis the focus is on payments based on variable inputs. Payments based on variable input use reduce the on-farm cost of a specific variable input or a mix of variable inputs. These include policies supporting the use of inputs like fuel, water, fertiliser and pesticides. Payments based on variable inputs are selected for environmental impact analysis as they create strong incentives for increasing input use intensity, such as chemical fertiliser. Payments based on fixed capital formation and payments based on on-farm services are not considered in this report. The category "Payments based on input use" also includes some agri-environmental measures, but these are not considered in this report.³

For both the farm-level and market-level analyses, payments based on variable input use are represented as payments for all variable production inputs (excluding land, labour, and capital) and without constraints on variable input use.

2.4. Payments based on current A/An/R/I, with production required

This category of payments is based on current area, animal numbers, receipts, or income, and hence requires production. The category includes, for example, arable crop area payments and per head livestock payments. It also includes some agri-environmental measures. Payments based on current production are selected for environmental impact analysis as they represent a relatively large share of total PSE (11.5%) and have strong impact on extensive margin of production (land allocation and the number of livestock).

Four types of policies are analysed in this category.⁴ The farm-level and the market-level analyses consider payments based on the area of all crops and payments based on the number of animals. In addition, it considers one form of agri-environmental payment falling into this PSE category: a per hectare compensation payment for complying with fertiliser application constraint for eligible crops. Hence, the transfer basis for it is current area and the label is a voluntary input constraint. In

³ Other types of agri-environmental measures are included in the next two PSE categories. The report includes a representation of one of these.

⁴ It should be noted that analysis considers these payments without e.g. limits on livestock density (livestock units per hectare) or limits on area planted (e.g. max share of farmland).

addition, the farm-level analysis considers government premium subsidy for revenue insurance under analysis of risk-averse farmers.

2.5. Payments based on non-current A/An/R/I, with production not required

Payments based on non-current area, animal numbers, receipts or income, not requiring production, are an important part of public support to agriculture in some OECD countries as they attempt to move away from more distortive forms of support, such as linking support to output and input prices. These payments are largely decoupled from production, allowing farmers to follow market signals in their production decisions, including the choice not to produce at all. Payments based on non-current area, not requiring production are selected for environmental impact analysis as they represent a relatively large share of total PSE (21.4%).

For this analysis payments based on non-current area, animal numbers, revenue, or income, not requiring production are specified as payments based on non-current (historical) area in both the farm-level and market-level analyses.

2.6. Payments based on non-commodity criteria

Payments based on non-commodity criteria include, for example, payments for a specific non-commodity output, such as environmental goods and services. Payments for long-term retirement of agricultural land for environmental and conservation purposes are included in this category.

For this analysis, payments based on non-commodity criteria are specified as category F2, payments for a specific non-commodity output, and are represented in the farm-level analysis by an area-based payment for the establishment and management of green set-aside, which provides non-commodity outputs in terms of environmental goods and services (climate change mitigation, water quality improvement and biodiversity enhancement).

3. Farm-level assessment of the environmental impacts of agricultural policies

3.1. Scope of the analysis

The farm-level assessment analyses the environmental effects of agricultural policies under different farming situations, considering both crop and livestock production. To do this, a farm level bio-economic model has been developed which covers a number of arable crops and dairy production. The model is applied to farms representing a diversity of regions and conditions in Europe. The modelling illustrates cause-effect linkages between agricultural policies and their environmental impacts by analysing a farmer's decision-making at the field parcel level, a level of detail that captures complex, site-specific, economic and biophysical interactions. The model framework was designed to be flexible and general enough to incorporate a wide range of agro-ecological conditions and practices for a defined set of environmental impacts in order to best inform policy makers.

The potential environmental effects of agricultural policies will be explored by analysing policy instruments' impact on:

- The *intensive* margin of crop and milk production – the selection of inputs and the intensity with which inputs are used;

- The *extensive* margin of crop and milk production – the allocation of land and other inputs between different outputs (feed crops and milk)
- The *entry-exit* margin for crop and milk production – the allocation of land between cultivated agricultural land (crops, silage and pasture) and other land uses, such as, idled land, forestry or conservation areas.

Some of the agricultural policy instruments may generate environmental effects through all three margins (e.g. market price support) while others may affect only a subset or none of the margins.

3.2. Main features of the bio-economic farm model

This section provides a brief description of the bio-economic farm model developed for the analysis. Annexes A and B provide model documentation detailing all equations and parameters.

The bio-economic farm model accounts for the interactions between decisions on livestock (milk production) and crop choices associated with: (i) on-farm fodder production; (ii) manure use as a source of nutrients; and (iii) competition for quasi-fixed resources such as land and labour between crop and dairy production. The baseline case of the model depicts interrelated profit maximal choices of the herd size, milk and crop yields, diet, fertilisation and land allocation between grass silage and crop production under current market and policy conditions. Under different agricultural policy instruments, the farmer adjusts decision variables to reach new profit-maximising levels.

For dairy production, the impact of the diet composition on milk yield, manure excretion and manure composition is modelled. Increased intake of concentrates increases milk yield per cow, at decreasing rate up to a maximal yield level, while in parallel, the intake of fodder decreases. Fodder sources include grass silage produced on farm and grazing. The replacement of animals for the milk herd is based on heifers raised on the farm. The number of lactations is modelled as a function of the milk yield. All other revenues and costs are expressed as per dairy cow.

Fodder and other crops compete for arable land; their yields depend on the applied fertiliser. Mineral fertiliser and manure – reflecting plant-available nutrients – are assumed to be perfect substitutes in the relevant simulation range. The marginal crop yield response decreases with increasing fertiliser application rates, up to a maximal crop yield. All activities compete for farm labour, which can alternatively be employed off-farm at a given reservation wage. As grass silage is not marketed, its costs reflect, besides production costs, the opportunity costs of labour and land on the one hand and the substitution value against feed concentrates on the other. Similarly, the value of manure reflects differences in application costs relative to mineral fertiliser and the content of plant-available nutrients.

A non-linear programming approach is used to implement the bio-economic processes depicted above. It simulates optimal decision making of a farmer (Figure 3.1) under different endowments and technology, as well as market and policy environments. The farmer manages three fixed production factors, indicated by the black-outlined boxes: grasslands, arable lands and family labour, the latter used on- or off-farm. The interdependent and simultaneously determined decision variables in the comparative-static framework are the cow herd and acreages, crop and milk yields, mineral and organic fertilisation levels, and the feed mix. The costs of mineral fertiliser and concentrates are explicitly considered as well as other production costs. Revenues stem from selling milk and arable crops, costs for animal replacement, and revenues from selling old cows are accounted for as well. Besides grassland and grass silage, the model considers the arable crops wheat, barley and rape. Input and output prices are exogenous.

Figure 3.1. Main interactions in bio-economic modelling framework

Crop yields are endogenously depicted by nitrogen dependent yield functions of either the Mitcherlich or quadratic functional form. The different crops, including grass silage, compete for arable land, while pasture land per cow is fixed. The model maximises either profits or utility when production risks for crops are considered. Compared to other bio-economic models, this model differentiates itself by employing non-linear crop and milk yield functions and by its endogenous use of IPCC Tier 3 emission accounting.

The following GHG emissions are accounted for: 1) methane emissions from enteric fermentation and from manure storage, 2) direct N₂O emissions from manure storage, 3) indirect N₂O emissions from manure storage and spreading (NH₃ emissions from manure storage and spreading cause indirect N₂O emissions), 4) GHG emissions from cultivated land, including nitrogen fertiliser use and autonomous soil emissions, and 5) emissions from cultivation practices, crop yield transportation and grain drying. Furthermore, soil carbon sequestration is taken into account when arable land is put under green set-aside.

Methane emissions from enteric fermentation per cow reflect milk yields and the digestibility of the cow's diet. Methane and nitrous oxide emissions from manure storage depend on feeding and manure storage technologies (e.g. not covered manure storage and manure storage with floating cover). Feeding practices only impact emissions from uncovered manure storage, while a floating manure storage cover decreases emissions by about 30%, independent of concentrate feeding levels.

Water quality impacts of agricultural policies are assessed through nitrogen and phosphorus runoff from field parcels to watercourses. Nitrogen runoff mainly depends on nitrogen application rates (both chemical fertiliser and manure) and land cover type, so that cultivated cropland has higher propensity to runoff than grass silage or pasture land. Dissolved phosphorus runoff mainly depends on phosphorus application rates, level of soil phosphorus, runoff volume and land cover type. The runoff of particulate phosphorus is dependent on phosphorus application, soil erosion, amount of potentially bioavailable phosphorus in eroded soil material and land cover type.

The biodiversity quality of arable farmland habitats (cereals, rapeseed, silage, pasture, and green set-aside) is measured by employing habitat quality indices based on observed species number of butterflies in different kinds of arable farmland habitats (Lehtonen et al., 2007). These show that oilseeds (rapeseed) are two times, and green set-aside 5.3 times more valuable than cereal fields as habitats for butterflies. Intensive silage production is only slightly better (1.2 times) a habitat than cereal fields, while extensive pasture is 7.9 times more valuable a habitat than cereal fields. The highest quality habitat is natural meadow, which is 8.1 times more valuable a habitat than cereal fields. These relative weights are used when calculating a biodiversity index value on the basis of land allocation under different policy instruments. The habitat quality index is scaled so that the index value would be 100 if total land area modelled (100 hectares) was allocated as natural meadows.

3.3. Data and model calibration

The model application draws on the database of the Common Agricultural Policy Regional Impact (CAPRI) model,⁵ which is an agricultural sector model.⁶

To derive stylised regional cases for the bio-economic model, this report draws on the CAPRI database for the year 2012, which considers 23 European countries. Data relate to, for example, regional crop acreage and dairy cow numbers, crop and milk yields, application of nitrogen and phosphorus in chemical fertiliser and manure, value of outputs and production inputs, various GHG emissions, and total global-warming potential of crop and milk production, ammonia emissions and feed inputs.

For the application of the model, four representative farms combining dairy and crop production illustrate the impacts of productivity differences in both crop and milk production. These four farms represent a diversity of EU countries' situations regarding productivity and profitability of dairy and crop production. The following data from the CAPRI database are used to calibrate these four representative farms: crop yields, milk yields, crop-specific production costs, milk-specific production costs, mineral and organic nitrogen application, dairy cow diet (the amount of feed cereals and protein), and output value for crops and milk. On the basis of this data, crop and milk yield functions for each farm case were calibrated so that yield levels correspond to input levels given in the CAPRI database. Also production costs were calibrated on the basis of the CAPRI database for each farm.

Farm A represents a high milk and low crop yields situation. Farm B has both low milk and crop yields. Farm C represents a low milk and high crop yields situation. Finally, Farm D features both high milk and crop yields. The yields, production costs, and profitability of crop and dairy production for the four cases relate to four regions from the CAPRI database, selected to illustrate

⁵ http://www.capri-model.org/docs/capri_documentation.pdf.

⁶ As an agricultural sector model, CAPRI combines a global partial-equilibrium model for agri-food products (employing the Armington assumption to depict bi-lateral trade) with non-linear programming models for 280 NUTS2 regions, or about 3000 farm group models, to detail agricultural production decisions in the European Union, EU candidate countries and Norway. EUROSTAT is the key data source for the European part of the model providing, for instance, crop and animal production statistics, land use statistics, market balances and Economic Accounts for Agriculture (EAA). The CAPRI database at national level integrates the EAA (valued output and input use) with, for example, market balances, and trade and production statistics. The country data are subsequently used to derive a regionalized database at NUTS2 level that depicts the allocation of inputs across activities and regions as well as acreages, herd sizes and yields. The regional data are subsequently further disaggregated to farm-type level mainly based on farm structural data.

how productivity and profitability differences affect the environmental effects of agricultural policies.

All four cases are represented through the same standard farm layout: a mixed dairy and crop production farm with 60 hectares of arable land and up to 40 hectares of pastureland, reflecting the EU-15 average of about 60 dairy cows.

Investment costs have a key role in farms' adjustment and production response to different agricultural support policy instruments and can lead to substantially different reactions in the short and long run. This is especially the case in dairy farming, which is characterised by long-lasting investments in stables and milking parlours, which account for a large share of overall production cost. The following analysis assumes that farms consider 50% of their fixed costs of investments in dairy production in order to simulate farms' medium-term responses to support policies. This simulates a situation where farms have to invest over the medium-term and are likely to adjust dairy production (herd size) as a response to agricultural support policies.

3.4. Results for risk-neutral farmers

Results in this section assume that farmers are risk-neutral. Given that risk behaviour may affect farmers' optimal choices, and consequently the environmental impacts of some types of agricultural support, Section 3.5 presents results for such policy instruments assuming that farmers are risk-averse.

This section presents and explains the quantitative impacts of the assessed policy instruments on input use, land use, crop and milk yields, GHG emissions, nutrient runoff and biodiversity. Section 5 then articulates the key policy messages and policy implications together with the results of the market-level analysis.

Baseline scenario

Table 3.1 presents the baseline situation for the four representative farms illustrating different conditions regarding crop and milk yields, production costs and profitability across four regions.

Farm A represents high milk and low crop yields, and devotes most of the land area for silage and pasture for dairy production purposes.

The majority of GHG emissions stem from enteric fermentation (58% of total CO₂-eq emissions, accounting for 90% of livestock-related emissions), followed by nitrogen fertilisation (22% of total CO₂-eq emissions). These numbers are similar to findings in other studies for intensive dairy systems in the temperate zone. Due to relatively low productivity of wheat production in Farm A, the GHG emission intensity of wheat is high relative to the value of output, while GHG emission intensity is low for milk production owing to high milk yields. Total nitrogen and phosphorus runoff are lowest among the analysed farms as the optimal fertiliser application (including chemical fertiliser and manure) is the lowest, and the highest share of land is allocated to silage and pasture that have smaller nutrient runoff propensity than cereal crops and oilseeds. The habitat quality index value is highest among analysed farms as the share of cereal crops is low and the share of pasture high.

Table 3.1. Baseline situations of the representative farm types

	Farm A High milk and low crop yields	Farm B Low milk and low crop yields	Farm C Low milk and high crop yields	Farm D High milk and high crop yields
Herd size, dairy cows	57	42	63	57
Land allocation, ha: CO:Si:P:Se:GSe ¹	18-42-40-0-0	31-29-32-0-8	37-23-21-0-19	40-20-37-0-3
Wheat yield, kg/ha	4 371	4 866	6 406	6 760
Nitrogen fertiliser application, kg/ha ²	151	159	181	184
Milk, kg/dairy cow /year	9 098	8 074	8 070	9 130
Concentrates, kg DM/dairy cow/day	10.3	7.1	6.0	14.0
Grass silage, kg DM/dairy cow/day ³	5.3	6.9	7.3	3.0
Total GHG emissions, kg CO ₂ - eq./year	642 600	515 504	649 996	671 539
GHG emission shares: Cultivation: Fertiliser: Soil: Livestock	7-22-13-58	11-26-15-48	9-22-10-58	11-22-13-55
GHG Emission intensity for wheat (kg CO ₂ -eq per value of output)	4.3	3.9	3.1	2.9
GHG Emission intensity for milk (kg CO ₂ -eq per value of output)	1.1	1.2	1.2	1.1
Nitrogen runoff, kg/year	1 351	1 466	1 971	1 862
Phosphorus runoff, kg/year	54	68	81	72
Habitat quality index value	43.7	41.0	37.6	42.3
Profit, €/year	125 606	99 234	159 140	146 159

1. Cereals and oilseeds (CO), Grass silage (Si), Pasture (P), Set-aside (Se) and Green set-aside (GSe).

2. Nitrogen fertiliser application combines chemical fertiliser and manure nitrogen inputs.

3. DM stands for dry matter.

Due to lower milk yields in Farm B, dairy cow feeding is less intensive than in Farm A and thus requires higher grass silage areas per cow, while at the same time marginal returns per unit of grass silage produced are lower. Combined with moderate crop yields, this leads to the smallest herd of the four cases as land is allocated to cereal crops. The smaller dairy herd size reduces methane emissions from enteric fermentation as the main emission source such that the total GHG emissions are smaller than in Farm A. However, the emission intensity of milk production is higher as emissions linked to the energy maintenance needs of the herd are distributed over a smaller output quantity. The GHG emission intensity for wheat is lower than in Farm A, reflecting slightly higher yields. Nitrogen and phosphorus runoff are higher than in Farm A since optimal nitrogen fertiliser intensity (and phosphorus application intensity) is higher for wheat in Farm B and more land is allocated to wheat production, which has higher propensity to nutrient runoff than acreage under grass silage and pasture. Despite the allocation of land to green set-aside (8 hectares), the habitat quality index is lower than for Farm A as a relatively large share of land is allocated to cereals (31%).

Although milk yields are relatively low in Farm C, higher crop yields (and in particular grass silage production) helps to push the optimal herd size of dairy cows to 63. High productivity silage production allows less land to be allocated to silage and more land to be allocated to wheat production. Although total GHG emissions are higher than in Farms A or B, the GHG emission intensity for wheat in Farm C is lower due to high wheat yields. Due to high fertiliser intensity and more land allocated to cereals production, both nitrogen and phosphorus runoff are higher than in Farm A or B. The high share of green set-aside does not offset the impact of intensive production and high share of land allocated to cereals for either nutrient runoff or habitat quality.

Farm D represents the case of both high milk and crop yields. This leads to a high fertiliser intensity in wheat production and high concentrate feeding for dairy cows. Due to intensive production, total GHG emissions at farm level are high, but the emission intensities for wheat and milk are relatively low. Nutrient runoff is large due to intensive production and high share of land allocated to cereals. The habitat quality index is better than in Farm B or C due to the high share of pasture land (40%), which provides higher habitat value than, for example, a combination of 32 hectares of pasture and 8 hectares of green set-aside in the case of Farm B, since biodiversity weight for pasture is 7.9 and that of green set-aside is 5.3.

Environmental impact of policy instruments

As Section 2.1 describes, the assessment includes the following support policies: 1) Market price support; 2) Payments based on input use; 3) Payments based on current area of all crops; 4) Payments based on animal numbers; 5) Payments based on non-current crop area; 6) Agri-environmental payments for complying with nitrogen fertiliser application constraints for eligible crops (oilseeds and cereals); and 7) Payments based on specific non-commodity outputs (establishment and management of green set-aside to provide environmental services). The impact of each policy instrument is assessed by simulating an increase in support equivalent to 10% of the value of each commodity at market prices and applied to all of the affected market commodities simultaneously. For example, the increases in market price support and payments based on input are valued at 10% of the value of all outputs produced. In turn, payments based on current crop area and on animal numbers are valued at 10% of the value of crop output and 10% of the value of livestock output, respectively. Similarly, agri-environmental payments and payments for specific non-commodity outputs are valued at 10% of the value of the crop output.

Table 3.2 presents the impact of the analysed policy instruments on input use intensity and land allocation relative to the baseline situation in Table 3.1.

Market price support and payments based on input use consistently increase the optimal level of nitrogen application in all farm cases for both wheat and silage. The impact of these support instruments on the relative profitability of dairy and crop production differs among farm cases, although the impact on the number of dairy cows is relatively small (except for Farm B). The changes in relative profitability are reflected in land allocation between cereals and oilseeds and grasslands (silage and pasture). Farm B responds strongly to these support instruments and increases dairy herd size and land allocation to silage and pasture and away from cereals and oilseeds. Strong adjustments for this farm are driven by the close relative profitability of dairy and crop production, which leads to strong adjustments whenever support instruments favour one subsector over the other one. For the other farms, adjustments regarding herd size and land allocation are much smaller.

Payments based on current area of crops (cereals and oilseeds) shift land use allocation from silage and pasture to cereals and oilseeds, and reduce the optimal dairy herd size in three out of four cases. Again, Farm B responds strongly as regards dairy herd size and land allocation. Payment based on animal numbers increases optimal dairy herd size in all farms, but does not have an impact on optimal nitrogen application for wheat or silage. Payments based on non-current area (decoupled area payments) consistently have zero impact on both input use and land use, since farmers are assumed to be risk-neutral. Thus, decoupled payments appear to have no impact on production decisions on the intensive or extensive margins of production.

Table 3.2. Impact of policies on input use and land use
 (% change relative to baseline except for new land allocation levels, ha)

	Farm A High milk and low crop yields	Farm B Low milk and low crop yields	Farm C Low milk and high crop yields	Farm D High milk and high crop yields
Market price support				
Land allocation, ha: CO:Si:P:Se:GSe	26-34-40-0-0	21-39-40-0-0	38-22-19-0-21	40-20-33-0-7
Dairy cows	-0.9	+47.0	-1.1	+0.4
Nitrogen fertiliser application for wheat, kg/ha	+5.5	+5.2	+4.6	+4.4
Nitrogen fertiliser application for grass silage, kg/ha	+8.6	+6.8	+1.0	+4.2
Payments based on input use				
Land allocation, ha: CO:Si:P:Se:GSe	32-28-40-0-0	22-38-40-0-0	39-21-19-0-21	41-19-34-0-6
Dairy cows	-0.8	+46.5	-1.8	+0.3
Nitrogen fertiliser application for wheat, kg/ha	+6.6	+6.3	+5.5	+5.3
Nitrogen fertiliser application for grass silage, kg/ha	+10.2	+7.4	+1.2	+4.7
Payments based on current area of crops				
Land allocation, ha: CO:Si:P:Se:GSe	29-31-40-0-0	60-0-0-0-40	38-22-21-0-19	41-19-37-0-3
Dairy cows	-9.0	-100.0	-0.6	0.0
Nitrogen fertiliser application for wheat, kg/ha	0.0	0.0	0.0	0.0
Nitrogen fertiliser application for grass silage, kg/ha	+9.2	0.0	0.0	+4.6
Payments based on animal numbers				
Land allocation, ha: CO:Si:P:Se:GSe	14-46-40-0-0	14-46-40-0-0	36-24-19-0-21	37-23-33-0-7
Dairy cows	+1.5	+55.8	+2.4	+0.4
Nitrogen fertiliser application for wheat, kg/ha	0.0	0.0	0.0	0.0
Nitrogen fertiliser application for grass silage, kg/ha	0.0	0.0	0.0	0.0
Payments based on non-current area				
Land allocation, ha: CO:Si:P:Se:GSe	18-42-40-0-0	31-29-32-0-8	37-23-21-0-19	40-20-37-0-3
Dairy cows	0.0	0.0	0.0	0.0
Nitrogen fertiliser application for wheat, kg/ha	0.0	0.0	0.0	0.0
Nitrogen fertiliser application for grass silage, kg/ha	0.0	0.0	0.0	0.0
Agri-environmental payments				
Land allocation, ha: CO:Si:P:Se:GSe	19-41-40-0-0	46-14-12-0-28	37-24-18-0-22	40-20-37-0-3
Dairy cows	-10.7	-58.7	-0.8	0.0
Nitrogen fertiliser application for wheat, kg/ha	-36.6	-39.8	-7.9	-9.7
Nitrogen fertiliser application for grass silage, kg/ha	-12.8	-26.7	-9.7	-1.6
Payments based on non-commodity output				
Land allocation, ha: CO:Si:P:Se:GSe	22-38-35-0-5	39-21-20-0-20	37-23-15-0-25	37-23-34-0-6
Dairy cows	-11.0	-27.2	+0.4	+0.3
Nitrogen fertiliser application for wheat, kg/ha	0.0	0.0	0.0	0.0
Nitrogen fertiliser application for grass silage, kg/ha	0.0	0.0	0.0	0.0

Note: Cereals and oilseeds (CO), Grass silage (Si), Pasture (P), Set-aside (Se) and Green set-aside (GSe). Nitrogen fertiliser application intensity combines chemical fertiliser and manure nitrogen inputs.

Agri-environmental payments for complying with fertiliser application constraints for cereals and oilseeds consistently decrease the optimal level of nitrogen application. These payments also shift land allocation to cereals and oilseeds from silage and pasture in Farms A and B, while Farm C reallocates land from pasture to green set-aside. In all these cases, the optimal dairy herd size decreases, although the reduction is relatively small in Farm C.

Payments based on non-commodity output (through establishment and management of green set-aside) shifts land allocation from silage and pasture to green set-aside. In Farms A and B, the optimal dairy herd size decreases, pastureland is allocated to green set-aside, and reduced silage area is allocated to cereals and oilseeds. In Farms C and D the optimal dairy herd size increases slightly (less than 1%). In Farm D, more land is allocated to silage (from cereals and oilseeds) and

green set-aside (from pastureland). Payments based on non-commodity output do not have any impact on optimal nitrogen fertiliser application for cereals and silage.

Overall, production-coupled support instruments have the strongest impact on dairy cow numbers, input use and land allocation in Farm B, which is the least profitable of the four farms analysed, and in which the relative profitability of dairy and crop production are close to each other. In the more profitable farm types (A, C and D), changes in dairy cow numbers and land use due to different policy instruments are significantly smaller than is the case of Farm B.

Table 3.3 presents the environmental impacts of the policy instruments analysed. These are driven by the impact of policy instruments on input use intensity, number of dairy cows and land allocation between cereals and oilseeds, silage, pasture and green set-aside.

Market price support increases nitrogen runoff in all farms mainly due to increased intensity of fertiliser application in all farms, and due to land allocation change from silage to cereals in Farm A, from green-set aside to pasture and silage in Farm B, and from silage to cereals in Farm C. In Farm D, optimal fertiliser and manure application intensity for silage and pasture increases. As a result, silage and pasture yields increase and less land is required for fodder production, since dairy cow numbers increase only slightly (0.4%). Increased allocation of land to green-set aside, however, does not offset increased nitrogen runoff due to fertiliser intensity increase in cereals, silage and pasture.

In all farms except B, market price support also increases total phosphorus runoff (including both dissolved and particulate runoffs). This is driven by increased phosphorus application in chemical fertiliser (nitrogen and phosphorus are in fixed proportions in composite chemical fertiliser) and manure. Phosphorus runoff decreases significantly in Farm B due to land allocation away from cereals to silage and pasture, which have much lower propensity for particulate phosphorus runoff. Relative to baseline, particulate phosphorus runoff decreases by over 22% and dissolved phosphorus runoff by 5% despite increased intensity of input use.

Market price support decreases the index value of wildlife habitat quality in all farms except B. Land allocation between alternative uses drives this index value, with the most valuable habitat being pastureland, followed by green set-aside. Intensive silage production is only slightly more valuable as a habitat than cereal fields, which are the least valuable habitats. Due to increased allocation of land from cereals to silage and from green set-aside to pasture, habitat value increases in Farm B relative to baseline. In other farms, habitat value decreases relative to baseline as land allocation either shifts to cereals (Farm A), to cereals and away from pasture (Farm C) or away from pasture (Farm D).

Market price support consistently increases total GHG emissions in all analysed farms by increasing nitrogen fertiliser application for both cereals and silage. In Farms A and C, total GHG emissions increase despite a small decrease of dairy cow numbers (-0.9% and -1.1%, respectively). The largest increase of dairy cow numbers under market price support takes place in Farm B and increases GHG emissions over one fourth relative to baseline when combined with increased nitrogen application through chemical fertiliser and manure, and reduced allocation of land to green-set aside.

Payments based on input use yield results similar to market price support regarding environmental impacts (in both direction and magnitude of change). They have a similar impact as market price support on dairy cow numbers and provide slightly stronger incentives for increased intensity of nitrogen fertiliser application in all farms. They also shift land allocation slightly towards cereals and away from silage. Thus, total GHG emissions and nitrogen runoff increase relative to baseline.

Table 3.3. Environmental impact of policy instruments (% change relative to baseline)

	Farm A High milk and low crop yields	Farm B Low milk and low crop yields	Farm C Low milk and high crop yields	Farm D High milk and high crop yields
Market price support				
Total GHG emissions, kg CO ₂ -eq./year	+1.7	+26.3	+0.3	+0.3
Nitrogen runoff, kg/year	+10.7	+5.9	+5.3	+7.3
Phosphorus runoff, kg/year	+11.5	-18.2	+3.0	+4.6
Habitat quality index value	-0.4	+6.3	-1.6	-2.8
Payments based on input use				
Total GHG emissions, kg CO ₂ -eq./year	+2.3	+26.5	+0.4	+0.5
Nitrogen runoff, kg/year	+16.0	+7.4	+5.5	+7.6
Phosphorus runoff, kg/year	+19.4	-16.3	+3.7	+3.2
Habitat quality index value	-0.7	+6.3	-1.7	-2.2
Payments based on current area of crops				
Total GHG emissions, kg CO ₂ -eq./year	-3.2	-54.0	0.0	+0.3
Nitrogen runoff, kg/year	+6.5	+13.0	-0.2	+1.6
Phosphorus runoff, kg/year	+62.0	+59.4	+0.3	+0.1
Habitat quality index value	-0.6	-24.7	-1.7	-0.1
Payments based on animal numbers				
Total GHG emissions, kg CO ₂ -eq./year	-0.5	+27.4	-0.1	-0.3
Nitrogen runoff, kg/year	-2.2	-2.5	+2.0	+2.2
Phosphorus runoff, kg/year	-5.8	-26.8	-0.1	+3.2
Habitat quality index value	+0.2	+6.7	-1.5	-2.6
Payments based on non-current area				
Total GHG emissions, kg CO ₂ -eq./year	0.0	0.0	0.0	0.0
Nitrogen runoff, kg/year	0.0	0.0	0.0	0.0
Phosphorus runoff, kg/year	0.0	0.0	0.0	0.0
Habitat quality index value	0.0	0.0	0.0	0.0
Agri-environmental payments				
Total GHG emissions, kg CO ₂ -eq./year	-9.4	-37.7	-1.6	-0.9
Nitrogen runoff, kg/year	-19.1	-22.3	-7.7	-7.4
Phosphorus runoff, kg/year	-1.3	+28.7	+0.1	-1.5
Habitat quality index value	-0.1	-15.3	-2.0	0.0
Payments based on non-commodity output				
Total GHG emissions, kg CO ₂ -eq./year	-7.1	-14.8	-0.3	-0.3
Nitrogen runoff, kg/year	+3.1	+4.9	+7.8	+1.8
Phosphorus runoff, kg/year	+12.6	+17.3	+5.0	+2.5
Habitat quality index value	-3.6	-9.1	-4.7	-1.9

Phosphorus runoff is higher in all farms except D. The reason for this is an over 20% reduction of particulate phosphorus runoff due to land reallocation from cereals to silage and pasture. The habitat quality index value decreases in Farms A, C and D relative to baseline, driven by land allocation to cereals (Farms A and C) and to cereals and away from pasture (Farm D). They increase in Farm B due to increased allocation of land from cereals to silage and from green set-aside to pasture.

Payments based on current area of crops change the relative profitability of crop and dairy production, and shift land allocation from silage to cereals. Due to the decrease in dairy cow numbers in three out of four farms, total GHG emissions decrease relative to baseline except in Farm D, where emissions increase slightly as dairy cow number are the same as baseline and slightly more land is allocated to cereals and away from silage. Nitrogen fertiliser application increases for silage and this increases nitrous oxide emissions from the farm. Due to land allocation towards cereals, nitrogen runoff increases in all farms except C. In Farm C, a small reduction relative to baseline is due to reduced fertiliser intensity for pasture, which slightly decreases total

nitrogen runoff. Phosphorus runoff increases significantly in Farms A and B due to land allocation towards cereals, while Farms C and D show only a slight increase in phosphorus runoff as land reallocation changes little from baseline. The habitat quality index value decreases in all farms relative to baseline as more land is allocated to cereals.

Payments based on animal numbers slightly decrease total GHG emissions (0.1-0.5%) in Farms A, C, and D because of weak impact on dairy cow numbers in these farms (increase of 0.4-2.4%), while land allocation shifts from cereals to silage. Increased silage use reduces concentrates feeding, and the nitrogen content of manure decreases. The change in diet reduces both methane and nitrous oxide emissions per cow. In Farm B, dairy cow numbers increase significantly, and the change in diet from concentrates to silage does not offset GHG emissions from the increased number of livestock. Nitrogen runoff decreases in Farms A and B due to significant reallocation of land from cereals to silage, while optimal application of fertiliser for cereals and silage does not change from baseline. In Farms C and D, nitrogen runoff increases slightly due to increased application of nitrogen fertiliser to pasture. Particulate phosphorus runoff decreases in Farms A, B, and C due to land reallocation from cereals to silage. The habitat quality index value increases in Farms A and B due to land reallocation from cereals to silage and pasture. In Farms C and D, the reduction of pasture area decreases the habitat index value relative to baseline.

Payments based on non-current area (decoupled area payment) have zero impact on all environmental effects as they have no impact on farmers' production decisions at the intensive or extensive margin (assuming farmers are risk-neutral).

Agri-environmental payments for complying with constraints on nitrogen fertiliser application for cereals and oilseeds decreases nitrogen fertiliser use and the number of dairy cows, which decreases total GHG emissions in all farms. Despite increased allocation of land to cereals, nitrogen runoff also decreases in all farms due to reduced nitrogen application. Phosphorus runoff decreases in Farms A and D as nitrogen application constraints also reduce applied phosphorus in manure and chemical fertiliser (nitrogen and phosphorus are in fixed proportions in composite chemical fertiliser). In Farm B, phosphorus runoff increases significantly due to strong allocation of land to cereals. In Farm D, a small increase of phosphorus runoff is explained by the slightly increased amount of fertiliser in pastureland. The habitat index value decreases in most farms due to increased allocation of land to cereals and a decreased amount of pastureland.

Payments based on non-commodity output (through establishment and management of green set-aside) decreases total GHG emissions in all farms due to land reallocation from silage and pasture to green set-aside. In Farms A and B, the reduction of optimal dairy herd size further decreases emissions. In Farms C and D, the optimal dairy herd size increases slightly (less than 1%), but increased allocation of land to green set-aside offsets the resulting emissions increase. Nitrogen and phosphorus runoff increase in all farms despite increased area under green set-aside. This is explained by increased cereals acreage (Farms A and B) or increased application of nitrogen and phosphorus fertiliser (in manure and chemical fertiliser) in pastureland, which is driven by reduced allocation of land to pasture in favour of green set-aside. The habitat quality index value decreases in all farms due to reduced pasture area and increased allocation of land to cereals, which is not offset by increased area under green set-aside.

Market price support and payments based on input use consistently increase GHG emissions and nitrogen runoff in all analysed farm cases, while agri-environmental payments with fertiliser application constraints consistently decrease them. Most of the policy instruments have negative impact on habitat quality due to decreased land area allocated to pasture or green set-aside, which have the highest habitat quality values of the land uses modelled. Even payments based on non-commodity output lead to negative impact on habitat quality in all farms due to reduced pastureland, which is the most valuable habitat.

Environmental effects vary between farms for payments based on current area of crops and payments based on animal numbers, mainly because of land allocation changes induced by the support instruments. An increase of payments based on current area of crops will tend to shift land use in favour of crops, and an increase of payments based on animal numbers will tend to shift land use away from crops. Adjustments of dairy herd size and land allocation strongly affect GHG emissions, nutrient runoff, and habitat quality. Since Farms A and B are most responsive to support policies with regard to dairy herd size and land allocation, the most significant changes in environmental effects take place in these farms.

Overall, these results show that for some of the instruments, the environmental impact is consistent across farm cases. This is the case for market price support, payments based on input use, payments based on non-current area of crops, agri-environmental payments and payments based on non-commodity output. For others, including payments based on current area of crops and on animal numbers, they differ somewhat due to differential conditions of these farms regarding milk and crop productivity, and thus their response to these policy instruments may differ.

Figure 3.2. provides a visual representation of the main results presented in Table 3.3. They exclude the results for payments based on non-current area, which were all zero under the assumption of risk-neutral farmers, and impacts on phosphorus runoff, because nitrogen runoff represents water quality impacts of the policy instruments. In this figure, each farm is represented as a small dot, with the exception of the median farm in each environmental impact and policy combination, represented by a large dot.

Figure 3.2. Percentage changes in GHG emissions, nitrogen runoff, and habitat quality from 10% increases in agricultural support, grouped by category of support

Note: Animal refers to payments based on animal number, agri env refers to agri-environmental payment, crop area refers payments based on current area of crops, inputs refers to payments based on input use, mps refers to market price support, and non comm refers to payments based on non-commodity outputs.

3.5. Results for risk-averse farmers

The analysis so far assumed that farmers are risk-neutral. This section briefly investigates how risk-aversion affects farmers' optimal choices and, through them, the environmental impacts of agricultural policy instruments. A feature associated with risk-averse behaviour is that the size of profits (wealth) matters. An increase in an exogenous lump sum income (such as decoupled area payments) may impact optimal choices regarding input use and land allocation. When a farmer exhibits decreasing absolute risk-aversion, an increase in the lump sum income payment makes the farmer better off and decreases risk aversion. Thus, the farmer increases use of risk-increasing inputs (e.g. nitrogen fertiliser) and allocates more land to crops with higher production risk.⁷

The investigation of this section focuses on two agricultural policy instruments for which risk aversion, and thus the choices of risk-averse farmers, are expected to be different from those of risk-neutral farmers: 1) payments based on non-current area of crops (decoupled area payments) and 2) a premium subsidy for revenue insurance. Decoupled area payments are selected because of their wealth effect (explained above), while a premium subsidy for revenue insurance is selected because of the dampening effect of insurance on variability of revenues. Payments based on non-current area of crops (decoupled payments) are implemented in the same way as in the case of risk-neutral farmers. Premium subsidy for revenue insurance is implemented here as a government premium subsidy for revenue insurance covering cereals (wheat and barley) and oilseeds (rapeseed), and is based on area of insured crops. As in other policy scenarios, the level of premium subsidy reflects 10% of the value of the crop output (see Annex A for a more detailed description of revenue insurance modelling).

In comparison to Table 3.1, which reports the baseline for risk-neutral farmers, results presented in Table 3.4 show that risk-averse farmers tend to increase dairy herd size and allocate more land to silage and pasture than risk-neutral farmers. This is because production risk, and thus income variability, is considered by this model to be higher for crop production than dairy production. In all cases, except total GHG emissions for Farm B, the negative environmental impacts are lower for risk-averse farmers than for risk-neutral farmers under their respective baseline scenarios. In addition, the habitat quality index value is higher for all cases under the risk-averse scenario than under risk-neutral scenario. These results are mainly driven by land use differences between risk-neutral and risk-averse farmers, as risk-averse farmers allocate more land to silage and pasture instead of oilseeds and cereals.

While payments based on non-current area (decoupled payments) did not show any impact on the environment in the case of risk-neutral farmers, this is not true in the case of risk-averse farmers. However, these impacts are small. For example, optimal nitrogen fertiliser application increases for wheat and silage less than 1%. Moreover, the wealth effect is not strong enough to have an impact on land allocation or dairy cow numbers in Farms B and C relative to baseline. In Farm A, the one-unit reduction of dairy herd size does not change optimal land allocation but reduces GHG emissions, and nutrient runoff slightly increases due to slightly increased fertiliser use for wheat and silage. Farm D adjusts more strongly with regard to dairy cow numbers and land allocation. The dairy cow number is reduced by four heads (6.6%), and land allocation changes from silage and set-aside to wheat production. Thus, due to the wealth effect of decoupled payment, Farm D shifts land allocation from a set-aside, which provides non-stochastic income (CAP basic payment), to greater-risk wheat cultivation. Reflecting reduced dairy herd size, the area for silage production

⁷ When variance is taken as the sole measure of risk, nitrogen application usually increases the variance of yields. However, empirical evidence is mixed regarding whether nitrogen fertiliser is risk-increasing or risk-reducing input. In this analysis nitrogen is considered as risk increasing input.

is reduced and allocated to wheat. Although the dairy herd size decreases somewhat, total GHG emissions increase due to a large increase in cereals acreage and the reduction of set-aside. An increase in nutrient runoff and decrease in the habitat quality index also reflect a land allocation shift to cereals from silage and set-aside.

Table 3.4. Risk-averse farmers: impact of selected policies on land use, dairy herd size, and environment

	Farm A High milk and low crop yields	Farm B Low milk and low crop yields	Farm C Low milk and high crop yields	Farm D High milk and high crop yields
Baseline				
Land allocation, ha: CO:Si:P:Se:GSe	14-46-40-0-0	0-60-40-0-0	1-31-22-28-18	1-50-37-9-3
Dairy cows	58	64	69	62
Total GHG emissions, kg CO ₂ -eq./year	633 309	599 787	522 682	577 415
Nitrogen runoff, kg/year	1 261	1 005	1 158	976
Phosphorus runoff, kg/year	50	40	54	48
Habitat quality index value	43.8	44.1	51.7	47.4
Payments based on non-current area (decoupled payment)				
Land allocation, ha: CO:Si:P:Se:GSe	14-46-40-0-0	0-60-40-0-0	1-31-22-28-18	31-29-37-0-3
Dairy cows	57	64	69	58
Total GHG emissions, kg CO ₂ -eq./year	-0.1%	0.0%	0.0%	+14.7
Nitrogen runoff, kg/year	+0.1%	+0.1%	0.0%	+73.1
Phosphorus runoff, kg/year	+0.2	0.0%	0.0%	+37.1
Habitat quality index value	0.0%	0.0%	0.0%	-10.3%
Payments based on current area of crops (revenue insurance)				
Land allocation, ha: CO:Si:P:Se:GSe	17-43-40-0-0	23-37-37-0-3	37-23-21-0-19	23-37-37-0-3
Dairy cows	55	49	64	49
Total GHG emissions, kg CO ₂ -eq./year	-3.0%	-9.2	+24.1	-5.7%
Nitrogen runoff, kg/year	-4.5%	+20.2	+66.4	+3.3%
Phosphorus runoff, kg/year	+4.0%	+44.9	+16.5	+21.3%
Habitat quality index value	-0.2%	-7.3%	-27.3%	-9.9%

Note: Cereals and oilseeds (CO), Grass silage (Si), Pasture (P), Set-aside (Se) and Green set-aside (GSe). Due to risk-aversion, the baseline for risk-averse farmers differs from risk-neutral farmers presented in Table 3.1. For policy instruments, land allocation and dairy herd size are absolute numbers while environmental impacts are presented as % change relative to baseline for risk-averse farmers.

Revenue insurance has a relatively strong impact on production choices by favouring crop production over dairy production. The resulting environmental impacts depend on changes with respect to land allocation and dairy herd size. The dairy herd size decreases in all farms as a result of the policy. This reduces total GHG emissions in all farms except C, where a significant land allocation towards cereals more than offsets the GHG emissions reduction induced by reducing the number of dairy cows. Nutrient runoffs increase in all cases except Farm A. The reason is that Farm A switches from wheat cultivation in the baseline scenario to barley cultivation under the revenue insurance policy, and barley has a much lower optimal nitrogen application level than wheat. As a result, the total nitrogen runoff decreases despite an increased allocation of land to cereals. The habitat quality index value decreases in all farm cases as a result of the insurance subsidy, as the dairy herd size decreases and less land is allocated to pasture, which has high habitat quality value.

Overall, payments based on non-current area (decoupled payments) are relatively neutral (except in case of Farm D, which set-asides 12% of land area in baseline and shifts 75% of it to crop cultivation under policy instruments) with respect to environmental impacts, while revenue insurance has strong environmental impacts. In most cases, the revenue insurance subsidy decreases GHG emissions, increases nutrient runoffs and decreases habitat quality.

4. Market-level analysis using the Policy Evaluation Model

4.1. Scope of the analysis

This section presents *ex ante* findings from the market-level analysis, which include multiple production inputs and commodities for a selection of major national-level agricultural markets. The Policy Evaluation Model (PEM) was selected for this purpose. PEM is a partial equilibrium, agricultural sector model designed to assess agriculture producer support policies and incorporate support data from the Producer Support Estimates (PSE) database. PEM is an equilibrium displacement model, currently set up to assess four crop commodities (wheat, coarse grains, oil seeds, and rice) and two livestock commodities (milk and beef) for seven OECD countries and regions (Canada, China, Japan, Korea, Mexico, Switzerland, the United States and EU27), with the rest of the world specified as an aggregate region. PEM contains a number of commodity markets and inputs markets, including land, fertiliser, chemicals and cattle, which can be related to certain environmental impacts. PEM provides a direct link between agricultural support policies and the levels of these commodities and inputs. Given that PEM already contains a representation of agricultural support policies and provides a detailed treatment of land and other input markets, it is considered a suitable tool for assessing the environmental impacts of these policies. Further, PEM was already used to assess the impacts of changes in agricultural support policies on a selection of environmental impacts for Switzerland (OECD, 2015).

The analysis presented in this section assesses the potential impacts of increasing the same non agri-environmental support payments as analysed in Section 3 and outlined in Section 2 on a selection of environmental indicators: greenhouse gas (GHG) emissions, and nitrogen (N) and phosphorous (P) balances. Surpluses in the balance of N and P nutrients can lead to N and P runoff and associated problems of water quality. Methane (CH₄) from livestock and rice production contribute substantially to agricultural GHGs. N from fertiliser use, manure, crop and pasture residues are also linked to higher emissions of nitrous oxide (N₂O), which is a powerful GHG. The decision to choose this set of environmental indicators was motivated by two considerations: first, these indicators are the most straightforward to assess in this national-scale analysis; and second, these indicators are well aligned with the national-level indicators available in the OECD Agri-Environmental Indicators (AEI) database.⁸ An important factor governing environmental impacts is the mixture of different commodities produced, given that in each country each commodity has a different environmental impact profile. In the presence of competition for production resources, some types of support may, for instance, increase the production of some crops at the expense of other crops and livestock commodities. This can introduce trade-offs, with environmental impacts increasing among the supported commodities but falling elsewhere. The net environmental impacts could be negative or positive depending on where in the food market system the support policies aim. Because PEM considers total agricultural land to be fixed in any given production year, this analysis does not consider the environmental impacts associated with its possible expansion.

4.2. Data and methods for PEM and the modelled agri-environmental indicators

PEM is a global comparative-static, partial equilibrium, net-trade model for key agricultural sectors. Its behavioural functions derive from cost minimisation under an explicit constant elasticity of substitution (CES) production function and regional input markets for intermediate and primary factors used in the production of these commodities (Martini, 2011; Britz, 2015). The market elasticity parameters in the model are intended to represent medium-term adjustments of

⁸ <http://www.oecd.org/agriculture/sustainable-agriculture/agri-environmentalindicators.htm>

approximately five years. The structure and main features of PEM, including a detailed description of the model parameters and equations, are outlined in Annex 2 of Martini (2011). Activity data in the model corresponds to 2014, which this analysis uses as the reference production year because it is the most recent year of global fertiliser use data available from the International Fertiliser Association (IFA). As shown below, this is a critical data source required for each of the environmental indicators.

As described in Section 2.1, the assessment includes the following support policies: 1) Market price support; 2) Payments based on variable input use; 3) Payments based on current area of all crops; 4) Payments based on animal numbers; 5) Payments based on non-current crop area.⁹

The impact of each instrument is assessed by simulating an increase in support equivalent to 10% of the value of each commodity at domestic market prices (inclusive of baseline price support), and applied to all of the affected commodities simultaneously. For example, the increases in market price support and payments based on input used are valued at 10% of the value of all outputs produced. The payments based on current crop area and on animal numbers, are valued at 10% of the value of the crop output and 10% of the value of livestock output, respectively. It should also be noted that the payments based on input use affect multiple production inputs, including fertiliser, chemicals, energy, machinery and equipment. The increases in support are simulated and reported independently for each country, so that the impacts of policy changes in one country do not influence the assessment results of any other countries. This approach allows for much greater tractability of the policy impacts in each country, compared with the simultaneous application of each policy across all countries.

PEM has four crop sectors and two cattle sectors. The policy simulation results from the model include changes in commodity production and changes in the production inputs used by these sectors, with the most relevant for this study being fertiliser use, cattle stocks and land use, differentiated by sector. Environmental indicator coefficients are used to convert changes in these inputs and commodity production levels into GHG emissions, N balance and P balance impacts, as illustrated in Figure 4.1.

The input data used to construct the assessed environmental indicators were gathered and constructed using data from the OECD AEI database along with additional calculations to disaggregate the environmental indicators to match each commodity covered by PEM. The N and P balance indicators were constructed following OECD and EUROSTAT guidelines (OECD/EUROSTAT, 2012a, 2012b). The GHG emission calculations were based on the national GHG inventory methods outlined in IPCC (2006), with the Tier 1 approach used to calculate N₂O emissions from crops, and the Tier 2 approach used to calculate all other GHG emission sources. The N₂O and CH₄ emissions from crop and livestock production are expressed in CO₂-equivalent terms, based on global-warming potentials from IPCC (2006). The nutrient contributions from fertiliser, obtained from the International Fertiliser Association (IFA) and other literature sources (OECD, 2015), are used to convert the percentage changes in the PEM fertiliser input into N and P balance, and GHG impacts. Manure production and forage withdrawal coefficients were used to convert the changes in the beef and dairy cattle population variables into changes in N and P quantities, and GHG emissions. Coefficients for nutrient inputs from atmospheric deposition and biological fixation were used to convert the percentage changes in land area of each sector into changes in N and P quantities. Similarly, coefficients for seeds and planting materials and non-cattle manure use were combined and used to convert PEM-derived changes in crop production into changes in N and P. The coefficients for N₂O from residues and non-cattle manure use were combined with changes in crop production from PEM, and CH₄ from rice paddy production was

⁹ The results on the impact of this policy are not reported as all impacts were not significant (below 1.01%).

combined with rice land area from PEM, to calculate changes in agricultural GHG emissions. Finally, nutrient removal coefficients are used to convert the output from PEM to calculate changes in N and P removed in harvested grains.

Figure 4.1. Framework for assessing environmental impacts with PEM

4.3. Results

The findings in this section are based on simulations for seven countries (Canada, China, Japan, Korea, Mexico, Switzerland, United States) and the EU27 region. For ease of description, all of these will be referred to as countries for the remainder of the report. The results of this assessment are presented as aggregate ranges including all of these countries, and they are summarised by environmental indicator and support policy in Figure 4.2. In this figure, each country is represented as a small dot, with the exception of the median country in each indicator and policy combination, which is represented by a large dot.

There are clear differences in the median impacts between the support policies reported in Figure 4.2, with market price support, payments based on animal numbers, and input use all increasing GHG emissions, N balances and P balances. In contrast, payments based on crop area are the most neutral in terms of median-level impacts for each environmental indicator. There are also clear differences in the impacts grouped by indicator. Considering the range of effects among all eight countries, the impacts on GHG emissions are the most straightforward, with emission increases in all countries for all instruments except for the payments based on current crop area, for which there are a mixture of negative and positive changes. Mixed directional changes are more apparent in both of the nutrient balance indicators and P balances in particular. Market interactions between the different sectors as well as the presence of both positive and negative baseline nutrient

balances contribute to these mixed outcomes, creating complex pathways of net environmental impact, explored in more detail in sections 4.3.1 to 4.3.3. The wide variation in impacts between countries for P balances occurs because P balances tend to be closer to zero, especially on a per hectare basis. Therefore, small changes in P balances result in much more pronounced percentage changes in either direction, compared to the other indicators. The sections below provide more detailed explanations about the conditions underpinning the relationships between support policies and environmental impacts.

Figure 4.2. Percentage changes in GHG emissions and nutrient balances from 10% increases in agricultural support, grouped by category of support

Note: To improve the readability of the figure, the vertical axis range is cropped between -20% and +30%. Larger changes are therefore not visible in the graph, which are only relevant for P-balance impacts of three support policies.

The impact of agricultural support on GHG emissions

As discussed, the impacts of agricultural support on GHG emissions are straightforward for all instruments with the exception of payments based on current crop area in certain countries. The input payments, market price support and payments based on animal numbers had median impacts of 5%, 3% and 5%, and caused emissions to increase in every country. The rise in total agricultural emissions from the former two policies was driven by simultaneous increases in emissions from both crop and livestock sources. Whereas the more sector-specific payments based on either crop area or animal numbers introduced clear trade-offs between crop and livestock sector emissions. A breakdown of the contribution of each sector to the changes in total crop, livestock and agricultural emissions is provided for these two support policies in Table 4.1. The animal-based payments unsurprisingly improve the competitiveness of cattle relative to crop production, which raises cattle production and emissions in all countries, while causing crop production and emissions to fall. This results in a net increase in total agricultural emissions in all countries. The crop area payments have a much more negligible impact, with very small reductions in total GHG emissions in five countries.

In countries 1, 6 and 7, trade-offs between the crop and livestock sectors, cause crop and livestock emissions to move in opposite directions, with overall crop emissions increasing as a consequence of the payments based on crop area in countries 1 and 6, and livestock emissions falling as a consequence of competitive interactions between these two aggregate sectors. For country 6, where cattle account for the majority of emissions, total agricultural emissions fall, and country 1, where crop emissions dominate, total agricultural emissions increase (Annex Table C.5). In country 7, the emission shares between the crop and cattle sectors are more similar, and the very small increase in cattle emissions is dominated by the fall in emissions from rice production. In all other countries, crop and cattle emissions move in unison. The reductions in cattle emissions can be easily explained by the fall in cattle numbers that ensues from the crop sector's increase in capacity to compete for agricultural production resources. The fall in aggregate crop emissions stem from competitive interactions between crops. For four of the five countries in which total crop emissions fall, rice production falls relative to other crops. For two, wheat production falls. Given the higher emissions associated with the production of these crops in these countries, total crop emissions decrease as well. The relative fall in the production of these crops can be explained by the fact that the current area crop payment is applied uniformly so that high value crops, with relatively high per hectare land values, such as rice, receive a smaller relative reduction in their cost of land and, consequently, a smaller increase in net revenue from this payment, compared to lower valued crops.

Table 4.1. Changes in GHG emissions

	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6	Country 7	Country 8
Crop area payment								
Wheat	0.8%	-0.1%	0.0%	0.0%	-0.1%	0.6%	0.0%	-0.1%
Coarse grains	1.4%	0.0%	-0.2%	0.0%	0.8%	-0.1%	0.0%	0.2%
Oil seeds	0.5%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
Rice	-0.3%	0.0%	0.0%	-0.4%	-2.2%	-0.2%	-5.2%	-0.8%
All crops	2.4%	-0.1%	0.2%	-0.4%	-1.5%	0.3%	-5.2%	-0.8%
Milk	0.0%	0.0%	-0.6%	0.0%	-0.3%	-0.2%	0.0%	0.0%
Beef	0.0%	-0.1%	1.4%	-0.2%	-0.1%	-0.1%	0.0%	-0.1%
All cattle	-0.05%	-0.1%	0.8%	-0.2%	-0.3%	-0.3%	0.1%	-0.2%
All agriculture	1.5%	-0.1%	0.6%	-0.3%	-0.4%	-0.2%	-2.1%	-0.2%
Animal payment								
Wheat	-1.0%	-0.5%	-0.2%	0.0%	-0.1%	-0.3%	0.0%	0.6%
Coarse grains	-1.5%	-0.2%	-0.2%	0.0%	-0.5%	-1.1%	0.0%	-0.3%
Oil seeds	-0.6%	0.0%	-0.4%	0.0%	0.0%	-0.1%	0.0%	-0.3%
Rice	-0.6%	0.0%	0.0%	-0.2%	-8.3%	-0.5%	-0.1%	-0.6%
All crops	-3.7%	-0.8%	-0.7%	-0.2%	-8.9%	-2.1%	-0.1%	-0.6%
Milk	1.9%	0.9%	4.1%	1.1%	1.4%	4.4%	3.5%	1.4%
Beef	6.5%	7.3%	4.6%	6.7%	5.0%	2.1%	4.7%	6.3%
All cattle	8.3%	8.2%	8.6%	7.7%	6.4%	6.5%	8.2%	7.8%
All agriculture	0.7%	8.1%	5.9%	3.4%	4.9%	5.1%	4.8%	6.7%

The impact of agricultural support on N balances

The impact of market price support is straightforward, causing N balances to rise for all countries. The results from the other instruments are more mixed and in some cases opposite their impacts on GHG emissions. Table 4.2 shows the percentage changes in the crop and cattle N balance contributions for the three support policies that induce a mixture of directional changes. Aside from the market price support policy, the payments based on animal numbers and input use are the next most consistent policies in terms of their impact on N balances. They cause N balances to rise in seven of the eight countries, although the input support policy generates much larger increases in some countries. This policy generally causes the production and the N balances of both crop and

livestock commodities to increase. However, for one country (country 6), the input support policy increases the production of a crop that has a large negative N balance (Annex Tables C.2 and C.5), causing its overall crop and agricultural N balance to fall. Thus, we can conclude that input support payments should increase N balance unless the country has at least one major crop with a negative N balance. In this case the crop was the oilseed aggregate, mainly comprised of soybean. The presence of negative N balances in soybean enterprises is not uncommon, as N removed in the soybean grain exceed the amount of N fixed by the crop in some years and locations (Christianson et al., 2012; Salvagiotti et al., 2008; Barry et al., 1993; Goolsby et al., 1999; Di Ciocco et al., 2011). Close examination of this outcome reveals a few underpinning conditions: a) N-fixing crops should assume a relatively important share of the overall crop sector (the soybean crop in the above country accounted for 36% of the area of the four aggregate PEM crop sectors, compared to between 0% and 8% for all other countries); b) the contribution of N from fertilisation, N fixation, seeds and planting materials, and atmospheric deposition should be exceeded by the amount of N removed from harvesting the crop (for the above country, this condition caused a negative N balance of 0.07 t N ha⁻¹ for the oilseed crop sector); c) the size of increase in production of the crop with the negative balance needs to be large enough for its change in negative N balance to exceed the increases in the N surpluses of all other commodities. For country 6, the combination of a) and b) led to the absolute value of its total baseline N balance exceeding the positive N balances summed over all other crops, representing a large share relative to the cattle sector's N surplus (64%). Given this high baseline N deficit, only an average sized percentage increase in production compared to other crops (Annex Table C.2) was needed for the negative net N contributions from this crop sector to exceed the positive N contributions of all other crop and cattle sectors. The increases in the crop sector as a whole were also larger than for cattle as a whole because the share of subsidised inputs compared to total inputs for the crops (47%-60%) is larger than for the cattle sectors (30%-31%) in this country.

The increase in crop area payments produces the most mixed set of impacts, causing the N balances to rise in half of the countries and fall in the other half. However, with the exception of two countries, these changes are very small. In contrast to the input payments, this policy consistently increases the competitiveness of crop production relative to livestock production, introducing trade-offs between these aggregate sectors. This can be seen in Table 4.2, where the percentage changes in the N surpluses of total crops increases in the majority of cases, while the N surpluses of cattle falls in all but one country. The increasing N surplus contributions from crops exceed the reductions from cattle in each of the countries for which the total N surplus change is positive. This is due to the combination of crops accounting for relatively dominant shares of baseline N balances in most of these countries (countries 1, 3 and 5 in Annex Table C.5), and because the percentage increases in crop production induced by the policy exceeds the percentage reductions in cattle production (e.g. country 6 in Annex Table C.3). By contrast, in all countries where the N balance falls, crops contribute minority shares to their N balances (Annex Table C.5). In most cases, however, the changes in N balances are so small that the value of deriving conditions to explain these changes is questionable. For the two countries that experience larger changes in their N balances (countries 1 and 7) some further explanation is warranted. The large positive change in the N balance (11.5%) for country 1 is due to its crop sector contributing an overwhelming share (94%) of its N balance, combined with the high own price elasticity of demand for its crops relative to those in other countries. For country 7, interactions between crop sectors following the crop area payment increase leads to a fall in rice production, which is one of the main contributors to its agricultural N balance. As explained earlier, this occurs because crops such as rice, with relatively high per hectare values, obtain a smaller relative reduction in their cost of production from the payments based on crop area, which are applied at the same rate to all crops. This causes the competitiveness of these crops with high per unit land values to fall relative to others.

The animal payments cause N balances to rise in all countries but one, and the causes for these increases mirror the crop area payments. The increases in the N balances in this case are associated with increases in cattle production, with the contribution from crops decreasing in all countries, as the payment induces an expansion in cattle production at the expense of the crop sector. In the single country in which the N balance falls (country 1), its crop sector contributes the largest baseline share (94%) of its N balance (Annex Table C.5). In all other countries, the contribution from the crop sector is not sufficient to offset the increases from cattle.

Table 4.2. Changes in N balances

	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6	Country 7	Country 8
Input payment								
Wheat	9.6%	18.6%	3.8%	1.6%	3.0%	8.7%	0.0%	13.9%
Coarse grains	11.5%	11.3%	4.6%	0.3%	21.1%	10.7%	0.9%	25.7%
Oil seeds	2.0%	2.4%	1.2%	-0.4%	-0.9%	-35.0%	-0.8%	13.6%
Rice	9.0%	0.0%	0.0%	8.8%	-0.1%	2.3%	19.2%	0.4%
All crops	32.1%	32.4%	9.6%	10.3%	23.1%	-13.2%	19.3%	53.6%
Milk	0.0%	1.6%	1.4%	0.8%	0.1%	1.0%	1.0%	1.3%
Beef	-0.5%	0.8%	2.4%	1.0%	-0.3%	2.0%	1.7%	1.5%
All cattle	-0.5%	2.3%	3.8%	1.8%	-0.1%	3.0%	2.7%	2.8%
All agriculture	30.1%	3.9%	7.4%	5.0%	13.6%	-2.6%	10.4%	16.4%
Crop area payment								
Wheat	3.5%	-0.1%	0.1%	-0.1%	-0.1%	3.3%	0.0%	-0.3%
Coarse grains	7.3%	0.0%	-0.3%	0.0%	1.4%	-0.3%	-0.1%	0.6%
Oil seeds	2.3%	0.3%	0.6%	0.0%	0.0%	0.1%	0.5%	-0.1%
Rice	-0.8%	0.0%	0.0%	-0.4%	0.0%	-0.1%	-6.5%	-0.1%
All crops	12.3%	0.2%	0.4%	-0.4%	1.3%	3.1%	-6.1%	0.1%
Milk	-0.3%	-0.1%	0.8%	-0.1%	0.0%	-0.1%	0.0%	-0.2%
Beef	-0.7%	0.0%	-1.0%	0.0%	-0.4%	-0.3%	0.1%	-0.2%
All cattle	-1.1%	-0.1%	-0.2%	-0.1%	-0.4%	-0.4%	0.1%	-0.4%
All agriculture	11.5%	-0.1%	0.2%	-0.2%	0.6%	0.8%	-2.8%	-0.3%
Animal payment								
Wheat	-4.0%	-1.1%	-0.3%	0.0%	-0.1%	-1.7%	0.0%	1.1%
Coarse grains	-7.3%	-0.4%	-0.2%	0.0%	-1.1%	-3.4%	0.0%	-1.7%
Oil seeds	-2.1%	-0.3%	-0.5%	0.0%	0.0%	0.3%	0.0%	-1.2%
Rice	0.6%	0.0%	0.0%	-0.2%	-0.2%	-0.2%	-0.2%	-0.1%
All crops	-12.8%	-1.8%	-1.0%	-0.2%	-1.3%	-4.9%	-0.2%	-1.8%
Milk	3.2%	2.8%	2.6%	3.6%	2.4%	1.7%	2.2%	3.4%
Beef	3.4%	1.5%	4.5%	3.0%	-0.5%	4.0%	3.3%	2.3%
All cattle	6.5%	4.3%	7.1%	6.6%	2.0%	5.7%	5.5%	5.8%
All agriculture	-11.6%	4.0%	2.1%	4.0%	0.0%	2.0%	2.9%	3.7%

The impact of agricultural support on P balances

As mentioned, the percentage changes in the agricultural P balances, following increases in the various support measures, are notable for their relatively large range of impacts. As shown in Table 4.3, the market price support and input payment policies cause P balances to fall in three countries.¹⁰

¹⁰ Note once again, that large percentage changes in P balances in some countries, particularly following the increases in payments based on input, are a result of base P balances being close to zero, particularly on a per hectare basis.

Table 4.3. Changes in P balances

	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6	Country 7	Country 8
Input payment								
Wheat	12.7%	34.9%	-8.3%	3.0%	-20.3%	3.8%	0.0%	-10.3%
Coarse grains	11.5%	-5.0%	2.7%	0.9%	54.4%	-4.5%	0.6%	-1.2%
Oil seeds	5.0%	-1.2%	-13.9%	1.2%	11.7%	-8.8%	2.2%	-1.3%
Rice	10.2%	0.0%	0.0%	15.4%	-0.5%	0.1%	14.1%	0.2%
All crops	39.4%	28.6%	-19.6%	20.4%	45.4%	-9.4%	16.9%	-12.5%
Milk	0.2%	1.2%	3.8%	0.8%	1.4%	2.6%	-1.5%	5.5%
Beef	0.0%	1.5%	1.2%	1.1%	-0.4%	0.7%	6.7%	-4.1%
All cattle	0.2%	2.7%	5.0%	1.8%	1.0%	3.3%	5.2%	1.3%
All agriculture	35.9%	25.7%	-98.8%	15.0%	169.8%	-15.7%	16.6%	-13.8%
Crop area payment								
Wheat	4.1%	-0.2%	0.0%	-0.1%	0.7%	1.3%	0.0%	0.1%
Coarse grains	6.7%	0.0%	-0.3%	0.1%	2.6%	0.1%	-0.1%	-0.2%
Oil seeds	4.0%	0.0%	-0.2%	0.1%	0.1%	-0.2%	0.4%	-0.1%
Rice	-0.8%	0.0%	0.0%	-0.2%	-0.6%	0.0%	-4.8%	0.0%
All crops	14.0%	-0.2%	-0.4%	-0.1%	2.8%	1.2%	-4.5%	-0.2%
Milk	0.0%	-0.1%	2.1%	-0.1%	-0.3%	-0.3%	0.0%	-0.6%
Beef	-0.1%	-0.1%	-0.7%	0.0%	0.1%	-0.1%	0.1%	-0.3%
All cattle	-0.1%	-0.1%	1.4%	-0.1%	-0.2%	-0.5%	0.1%	-0.9%
All agriculture	12.7%	-0.4%	4.8%	-0.1%	9.8%	1.9%	-4.4%	-0.3%
Animal payment								
Wheat	-5.0%	-1.2%	0.2%	-0.1%	0.4%	-0.6%	0.0%	-0.5%
Coarse grains	-6.6%	0.1%	-0.2%	0.0%	-1.9%	0.6%	0.0%	-0.6%
Oil seeds	-3.5%	0.0%	0.4%	0.0%	-0.1%	1.0%	0.0%	-0.3%
Rice	0.7%	0.0%	0.0%	-0.1%	-2.4%	0.0%	-0.2%	0.0%
All crops	-14.4%	-1.2%	0.4%	-0.2%	-4.0%	0.9%	-0.1%	-1.4%
Milk	3.6%	2.0%	7.1%	3.4%	24.2%	4.6%	-2.9%	14.7%
Beef	3.7%	2.7%	2.4%	3.4%	-1.6%	1.4%	14.8%	-5.7%
All cattle	7.3%	4.6%	9.5%	6.8%	22.6%	6.0%	11.8%	9.0%
All agriculture	-12.5%	7.2%	54.0%	1.9%	46.0%	8.0%	0.1%	-0.6%
Market price support								
Wheat	1.7%	17.3%	-3.4%	0.3%	-4.5%	2.5%	0.0%	-0.3%
Coarse grains	1.2%	-0.7%	2.4%	0.1%	15.7%	-3.4%	0.2%	-0.7%
Oil seeds	-0.4%	0.3%	-6.1%	0.3%	1.4%	-3.7%	1.1%	-0.2%
Rice	1.9%	0.0%	0.0%	7.0%	-2.6%	0.1%	5.6%	0.1%
All crops	4.5%	16.9%	-7.0%	7.8%	10.0%	-4.6%	6.9%	-1.2%
Milk	1.8%	0.2%	4.5%	1.8%	5.2%	3.3%	-1.6%	4.1%
Beef	2.4%	1.6%	1.7%	2.9%	-0.6%	1.1%	5.6%	-3.6%
All cattle	4.2%	1.8%	6.2%	4.7%	4.6%	4.4%	4.0%	0.5%
All agriculture	4.4%	15.6%	-11.8%	6.9%	49.2%	-4.8%	6.8%	-1.2%

The crop area payments generate similarly mixed impacts, however with smaller percentage changes. The differences in the direction of change in the overall P balances are strongly driven by the presence of crops with negative P balances. According to the spatial assessment of P balances by MacDonald et al. (2011), around 30% of global cropland had a negative P balance in the year 2000. All three of the countries that experience reductions in their P balance from higher market price support and input payments, have negative aggregate P balances for their baseline crop production (Annex Table C.5). This reinforces the point made in relation to the N balance results, that a necessary condition for market price and input support policies to reduce nutrient balances is the presence of at least one major crop with a negative nutrient balance in the baseline. With regard to explaining the directional impacts of crop area payments on P balances, additional factors also

come into play, as this policy causes P balances to fall in two countries that did not have negative baseline balances for any of their crops (countries 4 and 7). In these countries, the fall in P balance can mainly be explained by a fall in rice production (Annex Table C.3), which contributes a dominant share of these country's positive crop P balances (Annex Table C.5). As was found with the other indicators, the crop area payments cause cattle production and its associated environmental impacts to fall slightly in the majority of cases.

Competition effects come into play with the animal-based payments, but this time raising cattle production and its associated positive contributions to the P balance in every country. This increase in the contributions of cattle causes total agricultural P balances to increase in all countries except countries 1 and 8. As was the case for the N balance changes, the large positive change in the P balance (12.7%) for country 1 is due to its crop sector contributing an overwhelming share (91%) of its P balance, and its large changes in crop production, which are a consequence of the relatively low share of land to crop production costs and relatively high own price elasticities of demand for its crops, compared to other countries. In country 1 the crop sector contributes the overwhelming share of its positive baseline agricultural P balance (Annex Table C.5) and the reductions in the production of three of its crops are relatively large (Annex Table C.4). In country 8, on the other hand, each of its crop and cattle commodities (wheat and beef) that contribute the largest negative contributions to its total P balance increase.

To summarise, the payments based on crop area generate the most mixed directional outcomes, although the size of the changes tends to be smaller than for the other instruments. As with payments based on variable inputs, the presence of crops with negative baseline P balances plays a role in these reductions, but so do competitive interactions between crops, which tend to favour crops with lower contributions to agricultural P balances, for which the value of land is lower. For payments based on animal numbers, the results are more consistently positive, as they cause relatively large contributions to P balances from cattle to override savings for lower crop contributions, with the only large exception being one case in which the crop sector contributes an overwhelming share of the country's agricultural P balance.

5. Conclusions

This section summarises and compares results from both model frameworks in order to identify which policy-impact relationships converge the most across both frameworks and the literature, and which depend more on the biophysical, producer and market conditions within each country. Table 5.1 presents a summary of the results in terms of the direction of impact that each support policy was assessed to have on each indicator, from both the farm-level and market-level analyses. The farm-level analysis presents the impact of the policy instruments on water quality (on the basis of nitrogen runoff), GHG emissions and biodiversity, while the market level analysis presents changes in national level GHG emissions, nitrogen (N) and phosphorus (P) balances. These directional changes are shown relative to the baseline scenario for the farm-level analysis that includes decoupled area payment (CAP basic payment), and relative to a baseline that includes current policies for the market-level analysis. These results are for risk-neutral farmers in both analyses.

Table 5.1. Environmental impacts of selected policy instruments

Environmental impact	GHG emissions		Water quality (N runoff)	N balance		P balance	Changes to biodiversity
	Farm-level	Market-level		Farm-level	Market-level		
Market price support	↑↑↑↑	↑↑↑↑	↑↑↑↑	↑↑↑↑	↑↑↓↑	↑↓↑↑	↑↓↑↑
Payment based on variable input use	↑↑↑↑	↑↑↑↑	↑↑↑↑	↑↑↑↑	↑↓↑↓	↑↓↑↓	↑↓↑↑
Payment based on current area of all crops	↓↓0↑	↑↓↑↓	↑↑↓↑	↑↓↑↓	↑↓↑↓	↑↑↑↑	↑↑↑↑
Payment based on animal numbers	↓↑↓↓	↑↑↑↑	↓↓↑↑	↓↑↑↑	↓↑↑↑	↓↓↑↑	↓↓↑↑
Payment based on non-current area of all crops	0000	0000	0000	0000	0000	0000	0000
Agri-environmental payment with fertiliser constraint	↓↓↓↓		↓↓↓↓				↑↑↑0
Payment based on non-commodity output (green set-aside)	↓↓↓↓		↑↑↑↑				↑↑↑↑
Risk-averse farmer: Payment based on non-current area of all crops	↓00↑		↑↑0↑				000↑
Risk-averse farmer: Premium subsidy for revenue insurance	↓↑↓↓		↓↑↑↑				↑↑↑↑

Note: Each arrow and zero presented represents the result for each one of the assessed representative farms and countries. Upward arrows (↑) indicate increasing environmental problems from negative impacts, and downward arrows (↓) indicate environmental benefits from lessening those impacts. Zeroes (0) indicates no impact, while larger arrows represent changes greater than 5%.

There is strong agreement between the models for the negative impacts on GHG emissions for two of the most coupled forms of support policies (market price support and payments based on input use), with emissions increasing in every single situation for each of these policies in both model frameworks. There is a similarly strong convergence with respect to the impacts of these policies on the N-related impacts in both frameworks. This suggests that for these two models there is a stronger positive relationship between these particular support policies and increasing GHG emissions and N pollution, than there is for the other policies. However, the payments based on variable input use caused a reduction in the N balance for one country, in which the policy supported an increase in the output of a crop (soybean) with a negative N balance. Negative P balances are much more common among crops and, as a consequence, market price support and payments based on variable input use, can cause these balances to fall by increasing these commodities. Thus, for crops with negative nutrient balances, support policies that encourage their production can reduce environmental impacts that are driven by nutrient surpluses (such as, GHG emissions and water quality). An important caveat is that the PEM assumes that total agricultural land is fixed and therefore does not consider the possibility that support policies can cause total agricultural land to expand. Since these policies will cause some expansion of agricultural land at the expense of land that either has stronger environmental benefits or lower negative environmental impacts, this framework is likely to underestimate the total environmental impacts of agricultural

support. It is possible that even in situations where a support policy reduces a specific environmental impact, relaxation of the fixed agricultural area assumption could cause the environmental impact, for a particular indicator, to change from positive to negative.

In contrast, the model frameworks diverge noticeably with respect to the impact of payments based on animal numbers, particularly for GHG emissions. This divergence can be explained by differences between the models with respect to the responsiveness of cattle production and cattle numbers.¹¹

The farm-level model reflects short to medium-term responses where farmers need to re-invest in dairy production in the near future. How policy instruments affect the relative profitability of crop and milk production determines the medium-term response regarding dairy production. In three of the four cases, however, the adjustments of dairy herd size to the animal payments are lower than 1%.

In the market-level analysis, the market elasticity parameters in PEM also conform to a slightly longer medium-term timeframe, and cattle stocks in this model are generally more responsive to the animal payments, with a mean annual response in cattle stocks of 6%. Thus, for the market-level analysis in all of the assessed countries, this level of responsiveness, combined with the sizeable contributions of cattle to baseline agricultural GHG emissions (37%-91%), cause cattle emissions to outweigh the reductions in crop emissions following an increase in payments based on animal numbers. This policy caused similarly consistent increases in N balances in this framework for the seven countries in which cattle made large contributions to their total N balances (38%-95%), but not for the one country in which cattle contributed little to its N balance (6%). Similarly, payments based on animal numbers increased P balances in all countries where cattle contributed the dominant share of total P balance. Therefore, the responsiveness of cattle stocks to payments, and their relative contribution to each environmental indicator are key conditions for countries to consider for this support policy.

Conclusions about the environmental impacts of the crop area payments are the most equivocal, as this policy led to mixed directional impacts in both model frameworks. However, the impacts were generally smaller compared to those of the other coupled support policies. Close examination of the reasons behind these mixed outcomes can help identify a set of conditions to determine the direction of environmental impacts from this and other support policies. These conditions relate to: 1) the relative baseline contribution of different commodities to environmental impacts, 2) changes to the relative competitive positions of different sectors, conferred by the support policies, and 3) the adjustments in the relative production levels of each sector or enterprise as a consequence of these changes.

For the market-level analysis, the crop area payments increased the competitiveness of crops relative to cattle production, causing cattle production and GHG emissions to fall in most cases. In all of the countries where cattle contributed a very large share of emissions (84-99%), total agricultural emissions also fell.

On the other hand, where crop contribution was the most dominant (63%), increasing emissions from crops were sufficient to increase total agricultural emissions. For the cases in between, the competitive interactions between crops lead to reductions in agricultural GHG emissions, as the crop area payments lower the competitiveness of crops with high land values and high GHG emissions, such as rice, relative to other crops.

¹¹ Note that the payment based on animal number does not have a constraint, or upper limit, on the number of animals.

The competitive interactions this policy induced between cattle and crops also plays a big role in the N balance outcomes. In every country for which this policy increased N balances, the positive contributions from crops exceeded the reductions from livestock. In most of these countries, crops contributed the largest shares (59-94%) of the agricultural N balance. As was the case with GHG emissions, falling N contributions from crops with high land values and large N balances caused the total agricultural N balances to fall in two countries. The same process also causes P balances to fall as consequence of this policy in two countries.

In summary, the conditions required for this policy to reduce environmental impacts are high relative contributions of cattle to baseline environmental impacts (e.g. 84-99% for GHG emissions) or the presence of crops with both large environmental impact contributions and relatively high land values.

Similarly, in the farm-level analysis, environmental effects vary between farms for payments based on current area of crops and payments based on animal numbers, mainly driven by land reallocation induced by the support instruments. An increase of payments based on current area of crops will tend to shift land use towards crops and away from silage and pasture, and an increase of payments based on animal numbers will tend to shift land use the opposite way. Adjustments to dairy herd size and land allocation strongly affect GHG emissions, nutrient runoff, and habitat quality. Environmental impacts (both positive and negative) are most significant in farms that are the most responsive to policy incentives. Usually this is the case when profitability of crop or dairy production is relatively close. Moreover, farm-level analysis assumes a medium-term perspective, which allows farms to respond and adjust policy incentives favouring one of the production lines.

In contrast, under deterministic settings, payments based on the non-current area of all crops (fully decoupled payment) consistently had zero environmental impacts in both frameworks, as economic theory dictates for risk-neutral producers. In the farm-level analysis, the fully decoupled payment was also investigated under the assumption of farmer risk-aversion. Results show that it has impacts on farmers' production choices and subsequently on the environment. However, for three out of four farms, these impacts were relatively small. Therefore, for non-current crop area payments, broadening the risk behaviour assumptions beyond risk neutrality does not strongly change the conclusion that fully decoupled payments are the least environmentally harmful support policies.

Agri-environmental payments for complying with fertiliser use restrictions are consistent in improving environmental outcomes for water quality and GHG emissions, but have small negative or zero impacts in the case of biodiversity, due to land reallocation from pasture and silage towards cereals. Similarly, payments based on non-commodity outputs (payments for establishment and management of green set-aside) has consistently positive impact on GHG emissions while it has consistently negative impact on water quality and biodiversity. Nitrogen and phosphorus runoff increase in all farms despite increased area under green set-aside. This is explained by an increase in cereals acreage or increased application of nitrogen and phosphorus fertiliser in pastureland, when pasture area is reallocated to green set-aside. The habitat quality index value decreases in all farms due to reduced pasture area and increased allocation of land to cereals, which is not offset by increased area under green set-aside. Thus, despite the environmentally positive intentions of these agri-environmental measures, policy makers need to be aware of how different farm types respond to these measures and consider a wide range of environmental impacts.

A careful review of the literature on the environmental impacts of agricultural support policies, revealed a notable absence of studies that isolate the impacts of individual categories of support. On one hand, this clearly points to the added value of this assessment, but on other hand makes it very difficult to find direct comparisons between the results of this assessment and existing studies. For example, Fares and Minviel (2017), Lewandrowski et al. (1997) and Porter (2002) found that coupled support measures were associated with increased fertiliser and chemical use, but they did

not report the impacts of individual types of coupled support. These studies may confirm our findings if they include market price support and input payments, but again it is difficult to judge because the influence of these specific policies is not identified. Koundouri et al. (2009), on the other hand, assesses the impact of payments based specifically on current crop area in Finland, with mixed results including a small reduction in fertiliser use and a relatively large increase in pesticide use. This further confirms the influence of specific production contexts on the environmental performance of this policy. One other study by OECD (2001) also used PEM to examine the efforts of different crop support measures on production and crop input and output markets. They calculated similar impacts of support policies on production as the present study, but did not assess the environmental impacts of these policies.

It is worth emphasising that, as with any other modelling exercise, there are limitations related to various modelling assumptions, which affect both the magnitude of production responses to the support policies, and the market interactions that influence the way different sectors and enterprises compete for resources. For example, data and the calibration of the farm-level model focus on four regions in Europe drawing on the database of the CAPRI model. These four cases represent regional differences in crop and milk yields, crop-specific costs, milk-specific costs, mineral and organic fertiliser use, and dairy cow feeding practices. However, calibration of farm-level model also requires a relatively large amount of detailed bio-physical data and considering that these data were not available for certain regions, the analysis rather aims to illustrate the performance of policy instruments under heterogeneous productivity and profitability of production. Thus, results cannot be considered representative of neither Europe nor OECD countries in general.

It is also worth noting that the consistency of the relationship between environmental impacts and support is also a function of commodity coverage in the modelled scenarios. The policies that provided support to all commodities, such as market price support and payments based on input use, tended to generate consistently negative environmental impacts. Conversely, the policies that supported particular groups of commodities, such as those based on crop area or animal numbers, induced trade-offs between commodity groups that resulted in less consistent outcomes. If the market price support and payments based on input use policies were confined to particular commodity groups, the consistency of their environmental impacts could also decline.

Further, the calculated environmental indicators provide approximations of the environmental impacts from agriculture. Consequently, this report does not provide definitive quantitative measures of the environmental impacts of agricultural support policies, but instead identifies relationships between support policies and environmental impacts and, on the basis of the selected models, it sheds light on some of the conditions that can affect the strength of this relationship. This should help policy makers develop a more economically optimal configuration of policies that can better address the environmental externalities of agricultural production.

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Annex A. Key parametric equations of the bio-economic model

This annex provides a brief description of the key parametric equations of the model.

Total intake function of dairy cows, kg DM/animal/year

$$intake(v) = (v - 0.163v - 0.0188v^2 + 13.4) * 365$$

In the intake function v denotes concentrate feed intake, and silage intake is given by $intake(v) - v$. Intake function is from Huhtanen et al. (2008).

Milk production function, kg/animal/year

$$g(v) = (20.09 + 1.252 v - 0.04 v^2) * 300$$

The quadratic milk production function is based on Lehtonen (2001). By assumption each cow has 300 milking days and the rest of the year cows are dry. Milk production peaks roughly at 16-17 kg of the concentrate feeding.

Manure excretion to cowshed, m³/animal/year

To determine the manure excretion, one needs to define the following shares of animals in the farm. The notion of *production animal* refers to the steady-state process needed to maintain one lactating cow and is technically a composition of one lactating cow, 1/3 calf and 1/3 heifer. Thus,

$$shareD = 1, shareH = \frac{1}{slaught}, shareC = \frac{1}{slaught}$$

where *slaught* is the number of milking seasons before a dairy cow is slaughtered, and the ending D stands for dairy cows, H for heifers and C for calves. Using this notation, the manure excretion to cowshed and pasture, respectively, can be defined as follows (Nennich et al., 2005):

Manure excretion to cowshed, m³/production animal/year

$$w(v) = \frac{[(intake(v)*w1+w0) shareD+wC*shareC+wH*shareH](1-wp)365 scale}{1000} + h2o$$

Manure excretion to pasture, m³/ production animal/year

$$wpa(v) = \frac{[(intake(v)*w1+w0) shareD+wC*shareC+wH*shareH]wp 365 scale}{1000}$$

Manure N content

To determine the manure N content, one needs to account for the share of manure N evaporated as $\text{NH}_3\text{-N}$. This evaporation is affected by manure storage and spreading technologies and defined as $\text{ammonia}^{ij} = \text{emstor}^i * \text{emsperad}^j$, where $i = \{1,2\} = \{\text{no cover}, \text{floating cover}\}$ and $j = \{1,2\} = \{\text{broadcast}, \text{injection}\}$. Manure N content, kg N/m³ manure/year (ThetaN) and total N excretion in manure, kg N/animal/year (Nexcr), respectively, are based on Nennich et al. (2005) and given by

$$\text{ThetaN}(v) = \frac{(1 - \text{ammonia}^{ij}) \text{scale} \left(\text{intake}(v) \left(\frac{v}{\text{intake}(v)} * vcp + \left(1 - \frac{v}{\text{intake}(v)} \right) scp \right) N1 + BWD * N2 \right)^{365}}{(w(v) + wpa(v)) 1000}$$

$$\text{Nexcr}(v) = \frac{(1 - \text{ammonia}^{ij}) \text{scale} \left(\text{intake}(v) \left(\frac{v}{\text{intake}(v)} * vcp + \left(1 - \frac{v}{\text{intake}(v)} \right) scp \right) N1 + BWD * N2 \right)^{365}}{1000}$$

Manure transport and application cost

Costs for manure spreading and transportation are determined based on the distance, amount of manure, spreading technology, gear capacity and contractor charge as follows.

$$\text{em}(r, m) = \frac{m}{\text{spcap}} \left(\frac{2 * r}{\text{crsp}} + \text{load} * \text{spcap} + \frac{\text{spread}^i}{60} * \text{spcap} \right) * \text{spp}^i + \text{ctran} * r * m$$

where $i = \{1,2\} = \{\text{broadcast}, \text{injection}\}$, m is m³/manure and r is distance in km.

CH₄ emissions from enteric fermentation

Methane emissions are calculated applying a procedure from GHG inventory calculations that follow IPCC's recommendations. Calculation is based on the following set of equations, which account also for the possible abatement through fat supplementation. Equations are based on the inventory reporting of the Statistics Finland (2016). When estimating CH₄ emissions from enteric fermentation, the diet's gross energy digestibility is calculated only for dairy cows, and the same value is used for calves and heifers for simplification. The same set of equations are thus used for calculating the emissions for dairy cows, heifers and calves. Dry cows are not accounted for separately.

$$\text{EFem}(v) = \frac{(\text{GED}(v) * \text{shareD} + \text{GEH}(v) * \text{shareH} + \text{GEC}(v) * \text{shareC}) * Ym * 365}{55.65} * \frac{(100 - \text{fatinc} * 4)}{100}, \text{ where}$$

$$\text{GEX}(v) = \frac{\frac{\text{NEmX} + \text{NEaX} + \text{NE1}(v) + \text{NEpX}}{\text{REM}(v)} + \frac{\text{NEgX}}{\text{REG}(v)}}{\text{DE}(v) / 100}$$

$$\text{REM}(v) = 1.123 - (4.092 * 10^{-3} * \text{DE}(v)) + (1.126 * 10^{-5} * \text{DE}(v)^2) - \frac{25.4}{\text{DE}(v)}$$

$$\text{REV}(v) = 1.164 - (5.160 * 10^{-3} * \text{DE}(v)) + (1.308 * 10^{-5} * \text{DE}(v)^2) - \frac{37.4}{\text{DE}(v)}$$

$$\text{NEgX} = 22.02 * \frac{\text{BW}X}{(\text{CoX} * \text{MW})^{0.75}} * \text{WGX}^{1.097}$$

$$\text{NEpD} = \text{CpD} * \text{NEmD} \text{ (only for dairy cows)}$$

$$\text{NE1}(v) = \frac{g(v)}{300} * (1.47 + 0.40 * \text{fat}) \text{ (only for dairy cows)}$$

$$NEaX = \left(cap * \frac{tpX}{365} + cao * \left(1 - \frac{tpX}{365} \right) \right) * NEmX$$

$$NEmX = CfiX * BWX^{0.75}$$

$DE(V) = -11.3 + 0.977 * \frac{seosoas(v)}{10}$, where $seosoas(v)$ is the share of digestible organic matter of the total organic matter as g/kg DM

$$X = \{D, H, C\}$$

GHG emissions from manure storage

Manure storage is a source of both methane and nitrous dioxide emissions. They are defined using the following equations.

CH₄ emissions from storage, kg CH₄/animal/year (based on Statistics Finland 2016)

$$EFmm(v) = \left(GED(v) * \left(1 - \frac{DE(v)}{100} \right) + 0.04 \right) * \left(\frac{1-ash}{18.45} \right) * 365 * chmax * 0.67 * mcf^i$$

where mcf^1 is storage without cover and mcf^2 is storage with floating cover

Direct N₂O emissions from storage, kg N₂O/animal/year (based on Statistics Finland 2016)

$$EFmn(v) = \frac{Nexcr(v)*wp}{(1-ammonia^{ij})} * ef^i * \frac{44}{28}$$

where ef^1 is storage without cover and ef^2 is storage with floating cover

GHG emissions from manure management

Manure storage and spreading cause NH₃ emissions and based on those indirectly N₂O emissions. Drawing on Statistics Finland (2016) and Grönroos (2014) they can be expressed using the following equations.

NH₃ emissions from manure management, kg NH₃-N/m³ manure/year

$$ThetaNvol(v) = \frac{ThetaN(v)}{(1-ammonia^{ij})} * ammonia^{ij}$$

Indirect N₂O emissions from manure managements, kg N₂O/m³ manure/year

$$EFmni(v) = ThetaNvol(v) * 0.01 * \frac{44}{28} + ThetaN(v) * 0.01 * \frac{44}{28}$$

Emissions from fertiliser use, machinery and soil (kg CO₂-eq./ha) from cultivated land

The GHG emissions from cultivated land comprise autonomous soil emissions (soil N₂O emissions due to fertilisation are assumed to be included here, i.e. they are not accounted for separately) and emissions from cultivation practices, yield transportation to processing, crop drying and manufacturing mineral fertilisers.

$$ghgX(N) = autoX + cultX + emtrans + emdry * y^X(N) + emprod * N$$

where X is {s, c}={silage, barley}

Emissions from fertiliser use, machinery and soil (kg CO₂-eq./ha) from pasture land

The GHG emissions from pasture land are calculated based on Statistics Finland (2016) with additional terms for autonomous soil emissions, cultivation practices and mineral fertiliser manufacture.

$$empas(v, H) = \left(H * wpa(v) * \frac{\frac{Nexcr(v)}{wpa(v)}}{\frac{1000}{(1-ammonia^{ij})}} \right) * 0.02 * \frac{44}{28} * N2O + (autop + cultp + emprod * lp)Ap(H)$$

Crop yield response functions

The crop nitrogen response function for rapeseed and silage (kg DM yield/ha) is given by quadratic response function

$$y(N) = a + bN + cN^2$$

where a , b and c are parameters of a quadratic nitrogen response function. And for wheat and barley by Mitscherlich nitrogen response function

$$y^c(N) = \varphi(1 - \sigma \exp(-\rho N))$$

where φ , σ and ρ are parameters of a Mitscherlich response function. The parameters of the quadratic crop yield functions are taken from Lehtonen (2001) and those of the Mitscherlich yield function have been estimated by Bäckman et al. (1997) on the basis of Finnish field experiments.

Nitrogen and phosphorus runoff functions

Both nitrogen and phosphorus runoff are included and in the case of phosphorus both dissolved reactive phosphorus (DRP) and particulate phosphorus (PP) runoff is estimated. Because in compound fertiliser (NPK) the three main nutrients are in fixed proportions, nitrogen fertiliser intensity determines also the amount of phosphorus used. Part of this phosphorus is taken up by the crop, while the rest accumulates and builds up soil P. Drawing on Finnish field experiment studies it is assumed that 1 kg increase in soil phosphorus reserve increases the soil P status (i.e. ammonium acetate-extractable P) by 0.01 mg/l soil. Uusitalo and Jansson (2002) estimated the following linear equation between soil P and the concentration of dissolved phosphorus (DRP) in runoff: *water soluble P in runoff (mg/l) = 0.021*soil_P (mg/l soil) – 0.015 (mg/l)*. The surface runoff of potentially bioavailable particulate phosphorus is approximated from the rate of soil loss and the concentration of potentially bioavailable phosphorus in eroded soil material as follows: *potentially bioavailable particulate phosphorus PP (mg/kg eroded soil) = 250 * ln [soil_P (mg/l soil)] - 150* (Uusitalo, 2004). Thus, the parametric description of surface phosphorus runoff is given by

$$Z_{PP}^i = \alpha^i \left[\zeta^i \left\{ \frac{250 \ln(\theta + 0.01P_i) - 150}{1000000} \right\} \right]$$

For particulate phosphorus PP runoff function, ζ^i is erosion rate (kg/ha), θ the amount of soil phosphorus (mg/l). *Soil_P* is fixed at 10.6 mg/l, which is the average for Finnish FADN farms situated in southern and south-western Finland.

$$Z_{DRP}^i = \beta^i \left[\frac{\psi(0.021(\theta + 0.01P_i)) - 0.015}{100} \right]$$

For DRP runoff function ψ is the amount of surface runoff (mm/ha). P_i is in both equations the phosphorus application rate (kg/ha). Runoff and erosion differ between different tillage methods (no-till versus conventional tillage) or land cover types (grasslands versus cereals) and technology specific factors, α^i and β^i describe the distinctive characters of the different tillage methods and land cover types.

Nitrogen runoff assessment employs the following runoff function, estimated by Simmelsgaard (1991):

$$Z_l^i = \varpi * \exp \left[b_0 + b_1 * \frac{l_i}{100} \right]$$

where Z_l^i = nitrogen runoff at fertiliser intensity level l_i , kg/ha, ϖ = nitrogen runoff at average nitrogen application, $b_0 < 0$ and $b_1 > 0$ are constants and l_i = nitrogen fertilisation in relation to the normal fertiliser intensity for the crop, $0.5 \leq N \leq 1.5$. This runoff function represents nitrogen runoff generated by a nitrogen application rate of l_i per hectare and the parameter ϖ reflects differences in tillage methods and land cover types.

Biodiversity

The potential impact of policy instruments on biodiversity is assessed through the wildlife habitat quality index. In this index quality of arable habitats (cereals, rapeseed, silage, pasture, and green-set aside) is measured by employing habitat quality indices based on observed species number of butterflies in different kinds of arable farmland habitats (Kuussaari and Heliölä, 2004). Habitat quality indices show that oilseeds (rapeseed) are two time, and green set-aside five to six times more valuable habitat for butterflies than cereal fields. Intensive silage production is only slightly better (1.2 times) wildlife habitat than cereal field while extensive pasture is 7.9 times more valuable habitat than cereal field. The highest quality habitat would be a natural meadow, which is 8.1 times more valuable habitat than cereal fields. These relative weights are used when calculating a biodiversity index value on the basis of land allocation under different policy instruments. Habitat quality index is scaled so that the index value would be 100 if total land area modelled (100 hectares) were allocated as natural meadows.

Revenue insurance

Regarding farmers' risk preferences, the flexible utility function developed by Saha (1997) is employed:

$$U(\pi, \sigma) = \pi^\theta - \sigma^\gamma$$

where $\theta > 0$ and γ are parameters. The risk attitude measure is given by the marginal utility ratio of the utility function, $U(\pi, \sigma) = (\frac{\gamma}{\theta})\pi^{1-\theta} - \sigma^{\gamma-1}$. Risk aversion corresponds to $\theta > 0$ and risk-neutrality to $\theta = 0$. Decreasing absolute risk aversion is presented by $\theta > 0$.

In insurance systems, a farmer has to pay some net costs (premium) for the reduced income variability avoided by a given insurance system. The utility function in the empirical model explicitly works in this way – there is a trade-off between reduced risk and increased cost due to insurance adoption, and a farmer has the option of non-adoption of yield or revenue insurance. Yield and revenue insurance affect the utility function directly by increasing the value of the utility associated with reduced revenue volatility and increasing the average revenue net of the annual premium (net of government premium subsidy) for the insurance. The model solves the optimal insurance coverage level endogenously and simultaneously with other variables including input use and land allocation.

The effect of crop yield and revenue insurance are modelled through four parameters: 1) increased expected revenue of each crop in % revenue, REVENUE; 2) increased expected yield of each crop in %, YLD; 3) net payment for the insurance per area unit of each crop, NETPAY; and 4) reduced volatility of revenues due to the insurance in %, REDREVVOL.

The parameter for REVENUE is very close to zero. This is because insurance loading is expected to be 1.5, which indicates that the insurance company would be including its administrative and operating cost as part of the premiums by multiplying the actuarially fair premium by the factor 1.5. Simultaneously, the government is offering 65% premium subsidy for insurance. Thus, loading and premium subsidy will override each other. NETPAY is the fair price for the insurance that will be effective for farmer. Parameters YLD and REDREVVOL are subject to fairly priced yield insurance.

Annex B. List of parameter values

Parameter	Symbol	Value	Reference
Market price, €/kg			
Milk	p^M	0.4455	OSF (2014)
Concentrate, domestic	p^v	0.183	Tuottopehtori (2014)
Concentrate, soybean meal	p^{soy}	0.3507	IndexMundi (2014)
Mineral fertiliser, YaraMila Y2	p^l	0.45	Tuottopehtori (2014)
Meat	p^{meat}	2.1	Tuottopehtori (2014)
Calf (selling), €/animal	p^{calf}	115	Tuottopehtori (2014)
Mineral fertiliser, YaraMila Y2			
N-content	ε^N	0.24	Tuottopehtori (2014)
P-content	ε^P	0.04	Tuottopehtori (2014)
Variable cost in barley production, €/kg	h^C	0.056	Tuottopehtori (2011)
Variable costs in silage production			
€/kg yield	$h0$	0.0918	Tuottopehtori (2014)
Silage dry matter %	$dmpc$	25	
Silage density, kg/m ³	$dens$	250	
Loading capacity, m ³	$trcap$	20	
Transport speed, km/h	$trsp$	15	
Transport price, €/h	trp	63.1	Palva (2015)
Cost of floating storage cover, €/m ² /year	$float$	2	
Capacity of manure spreader, m ³	$spcap$	16	Palva (2015)
Contractor charge for spreading, €/h			
Broadcast spreading	spp^1	77.9	Palva (2015)
Injection	spp^2	102.5	Palva (2015)
Time for loading, h/m ³	$load$	0.004	
Time for spreading, min/m ³			
Broadcast spreading	$spread^1$	0.5	
Injection	$spread^2$	1.5	
Transport cost interrelated to spreading, €/m ³ /km	$ctran$	0.4	Palva (2015)
Damage from GHG emissions, €/kg CO ₂ -eq.	ζ^G	0.05	
Animal body weight, kg			
Dairy cow	BWD	600	
Heifer	BWH	400	
Calf	BWC	150	
Number of milking seasons	$slaught$	3	
Number of dairy cows	H	60	chosen
Share of animals per dairy cow			
Dairy cow	$shareD$	1	
Heifer	$shareH$	1/3	
Calf	$shareC$	1/3	
Total intake, kg DM/animal/day			
Heifer	inH	5	
Calf	inC	10	
Share of concentrates in H and C diet, %		50	
Manure excretion, m ³ /animal/year			
Heifer	wH	8.5	Finlex 1250/2014
Calf	wC	6.25	Finlex 1250/2014
Water in liquid manure, m ³ /animal/year	$h2o$	10	
Manure density, kg/m ³	$kgm3$	1000	
Share of manure excreted on pasture	wp	0.15	
Scaling factor to match Finnish statistics	$scale$	0.65	chosen
Parameter for manure excretion	$w0$	9.4	Nennich et al. (2005)
Parameter for manure excretion	$w1$	2.63	Nennich et al. (2005)

Parameter	Symbol	Value	Reference
Parameter for manure N content	<i>N1</i>	84.1	Nennich et al. (2005)
Parameter for manure N content	<i>N2</i>	0.196	Nennich et al. (2005)
Feed nutrition values			
Concentrate (barley 54-62 kg/hl)	<i>v</i>		
Dry matter, g/kg	<i>cka</i>	860	
Organic matter, g/kg DM	<i>coa</i>	971	
Organic matter digestibility	<i>coas</i>	0.82	
Crude protein content of DM	<i>vcp</i>	0.126	
P content of DM	<i>vp</i>	0.0041	
Concentrate (soybean meal)	<i>v</i>		
Dry matter, g/kg	<i>cka</i>	880	
Organic matter, g/kg DM	<i>coa</i>	821	
Organic matter digestibility	<i>coas</i>	0.88	
Crude protein content of DM	<i>vcp</i>	0.520	
P content of DM	<i>vp</i>	0.007	
Silage feed (grass silage)	<i>s</i>		
Dry matter, g/kg	<i>ska</i>	1000	
Organic matter, g/kg DM	<i>soa</i>	911	
Organic matter digestibility	<i>soas</i>	0.74	
Crude protein content of DM	<i>scp</i>	0.161	
P content of DM	<i>sp</i>	0.0031	
Parameters for nitrogen response functions			
Quadratic response function for silage	<i>a</i>	1182.9	Bäckman et al. (1997) and Lehtonen (2001)
	<i>b</i>	24.24	
	<i>c</i>	-0.0394	
Quadratic response function for rapeseed	<i>a</i>	890.0	
	<i>b</i>	9.95	
	<i>c</i>	-0.0354	
Mitscherlich response function for wheat	φ	4956	
	σ	0.7624	
	ρ	0.011	
Mitscherlich response function for barley	φ	5218	
	σ	0.8280	
	ρ	0.017	
Parameters for GHG emissions			
Conversion factors			
N ₂ O to CO ₂ -eq.	<i>N₂O</i>	298	
CH ₄ to CO ₂ -eq.	<i>CH₄</i>	21	
Enteric fermentation			
Coefficients			
Dairy cow	<i>CfiD</i>	0.379	Statistics Finland (2016)
Heifer	<i>CfiH</i>	0.322	Statistics Finland (2016)
Calf	<i>CfiC</i>	0.322	Statistics Finland (2016)
Pasture	<i>cap</i>	0.17	Statistics Finland (2016)
Stall	<i>cao</i>	0.00	Statistics Finland (2016)
Pregnancy (dairy cows)	<i>CpD</i>	0.10	Statistics Finland (2016)
Growth			
Dairy cow	<i>CoD</i>	0.00	Statistics Finland (2016)
Heifer	<i>CoH</i>	0.80	Statistics Finland (2016)
Calf	<i>CoC</i>	1.00	Statistics Finland (2016)
Average weight gain, kg/day			
Dairy cow	<i>WGD</i>	0.05	Statistics Finland (2016)
Heifer	<i>WGH</i>	0.45	Statistics Finland (2016)
Calf	<i>WGC</i>	0.90	Statistics Finland (2016)

Parameter	Symbol	Value	Reference
Pasture season, days			
Dairy cow	<i>tpD</i>	125	OSF (2010)
Heifer	<i>tpH</i>	135	OSF (2010)
Calf	<i>tpC</i>	115	OSF (2010)
Milk fat content, %	<i>fat</i>	4.3	Statistics Finland (2016)
CH ₄ conversion rate	<i>Ym</i>	0.065	Statistics Finland (2016)
Manure storage			
No cover			
Emission factor N ₂ O	<i>ef1</i>	0	Statistics Finland (2016)
Emission factor CH ₄	<i>mcf1</i>	0.17	Statistics Finland (2016)
Manure N evaporated as NH ₃ , %	<i>emstor1</i>	10	Grönroos (2014)
Floating cover			
Emission factor N ₂ O	<i>ef2</i>	0.005	Statistics Finland (2016)
Emission factor CH ₄	<i>mcf2</i>	0.10	Statistics Finland (2016)
Manure N evaporated as NH ₃ , %	<i>emstor2</i>	6	Grönroos (2014)
Manure ash content	<i>ash</i>	0.08	IPCC (2006)
Max. CH ₄ producing capacity, m ³ /kg vs	<i>chmax</i>	0.24	Statistics Finland (2016)
Manure spreading			
Broadcast spreading			
Manure N evaporated as NH ₃ , %	<i>emspread1</i>	40	Grönroos (2014)
Injection			
Manure N evaporated as NH ₃ , %	<i>emspread2</i>	9	Grönroos (2014)
Autonomous soil emissions, kg CO₂-eq./ha			
Barley	<i>autoc</i>	1535	
Silage	<i>autos</i>	426	
Pasture	<i>autop</i>	1535	
Cultivation practices, kg CO₂-eq./ha			
Barley	<i>cultc</i>	362	
Silage	<i>cults</i>	136.5	
Pasture	<i>cultp</i>	362	
N applied to pasture land, kg N/ha	<i>lp</i>	220	
Other parameters			
Yield transport to processing, kg CO ₂ -eq./ha	<i>emtrans</i>	0.00696	
Crop drying, kg CO ₂ -eq./kg yield	<i>emdry</i>	0.028	
Mineral fertiliser manufacture, kg CO ₂ -eq./kg N	<i>emprod</i>	4.32	
Soybean meal manufacture, kg CO ₂ -eq./kg	<i>emsoy</i>	5.35	Opio et al. (2013)
Parameters for nutrient functions			
Constant	<i>b0</i>	-0.7	Simmelsgaard (1991) Uusitalo and Jansson (2002) Uusitalo (2004)
Constant	<i>b</i>	0.7	
Average runoff from fertilisation	<i>ω</i>	15	
Erosion	<i>ζ</i>	800	
Surface runoff	<i>ψ</i>	234	
Soil phosphorus	<i>θ</i>	10.6	
Phosphorus rate	<i>P</i>	0.143	
Technology factor, PP	<i>α</i>	2.4	
Technology factor, DRP	<i>β</i>	0.77	

Annex C.

Changes in PEM variables linked to environmental indicators and the relative contributions of different sectors to these indicators

**Table C.1. Percentage changes in the PEM input and output variables,
from the simulated increase in market price support**

These variables are used to calculate the changes in the environmental indicators reported in Section 4

Prod	Variable	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6	Country 7	Country 8
Wheat	Fert	3.9%	11.5%	10.2%	1.2%	9.8%	8.8%	0.0%	-0.3%
Coarse grains	Fert	2.2%	13.7%	12.5%	3.1%	7.0%	10.2%	3.4%	-0.6%
Oil seeds	Fert	-1.8%	8.8%	10.2%	3.2%	8.9%	5.7%	12.7%	1.2%
Rice	Fert	3.7%	0.0%	0.0%	8.3%	-33.9%	12.2%	4.9%	-0.4%
Wheat	Land	-4.1%	-0.7%	1.6%	-0.3%	2.2%	-0.1%	0.0%	-0.2%
Coarse grains	Land	-4.2%	-0.7%	2.1%	0.3%	1.1%	1.2%	-1.3%	-0.1%
Oil seeds	Land	-5.6%	-0.1%	2.1%	0.6%	1.8%	-0.5%	2.0%	0.2%
Rice	Land	-1.1%	0.0%	0.0%	0.5%	-44.0%	-1.6%	0.6%	-5.4%
Pasture	Land	1.0%	0.3%	1.4%	0.9%	0.1%	0.7%	0.6%	0.5%
Milk	Cattle	4.8%	4.3%	8.4%	4.1%	4.0%	4.6%	5.2%	2.4%
Beef	Cattle	4.0%	4.4%	4.3%	5.2%	0.5%	5.2%	4.5%	3.4%
Wheat	Output	3.9%	11.5%	10.2%	1.2%	9.8%	8.8%	0.0%	0.2%
Coarse grains	Output	2.2%	13.7%	12.5%	3.1%	7.0%	10.2%	3.5%	0.3%
Oil seeds	Output	-1.8%	8.8%	10.2%	3.2%	8.9%	5.7%	12.7%	1.2%
Rice	Output	3.7%	0.0%	0.0%	8.3%	-33.9%	12.2%	4.9%	-3.5%
Milk	Output	4.9%	4.7%	9.4%	4.3%	4.1%	5.0%	5.7%	2.7%
Beef	Output	4.0%	4.6%	4.8%	5.5%	0.5%	5.6%	4.8%	3.5%

Table C.2. Percentage changes in the PEM input and output variables, from the simulated increase in payments based on input use

These variables are used to calculate the changes in the environmental indicators reported in Section 4

Commodity	Variable	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6	Country 7	Country 8
Wheat	Fert	25.0%	27.2%	17.2%	10.3%	54.9%	13.9%	0.0%	26.6%
Coarse grains	Fert	17.5%	35.6%	21.6%	20.1%	21.0%	8.3%	7.0%	38.4%
Oil seeds	Fert	18.9%	17.3%	17.6%	11.2%	60.0%	12.1%	24.7%	34.7%
Rice	Fert	16.9%	0.0%	0.0%	17.9%	-6.0%	24.3%	11.7%	18.7%
Wheat	Land	14.1%	-0.2%	2.0%	0.4%	16.7%	1.2%	0.0%	0.5%
Coarse grains	Land	11.6%	0.2%	3.2%	3.3%	2.7%	-1.1%	-2.1%	3.3%
Oil seeds	Land	12.4%	0.3%	3.0%	0.9%	18.9%	1.4%	2.6%	1.3%
Rice	Land	1.1%	0.0%	0.0%	0.8%	-28.0%	-0.3%	0.9%	-13.1%
Pasture	Land	-2.6%	0.2%	0.5%	-0.1%	-0.3%	0.4%	-0.1%	-0.2%
Milk	Cattle	0.6%	5.1%	7.0%	1.8%	1.1%	3.6%	7.2%	3.2%
Beef	Cattle	0.0%	2.9%	3.4%	1.9%	0.1%	3.4%	2.5%	3.7%
Wheat	Output	28.1%	32.0%	17.7%	11.9%	54.9%	14.4%	0.0%	26.6%
Coarse grains	Output	19.6%	41.4%	22.1%	22.8%	21.0%	8.8%	9.0%	32.5%
Oil seeds	Output	21.2%	20.7%	18.0%	12.7%	60.0%	12.8%	24.7%	26.0%
Rice	Output	19.9%	0.0%	0.0%	20.2%	-6.0%	24.8%	13.2%	9.7%
Milk	Output	0.8%	7.2%	9.0%	2.5%	1.8%	5.3%	10.4%	5.8%
Beef	Output	0.1%	4.3%	5.1%	2.6%	0.8%	5.1%	3.6%	6.2%

Table C.3. Percentage changes in the PEM input and output variables, from the simulated increase in payments based on crop area

These variables are used to calculate the changes in the environmental indicators reported in Section 4

Commodity	Variable	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6	Country 7	Country 8
Wheat	Fert	9.1%	-0.1%	0.2%	-0.5%	-1.5%	4.3%	0.0%	-0.3%
Coarse grains	Fert	11.4%	0.0%	-1.1%	1.9%	1.1%	-0.2%	-0.8%	0.7%
Oil seeds	Fert	16.6%	0.7%	0.6%	0.9%	0.6%	0.3%	4.4%	-0.1%
Rice	Fert	-1.7%	0.0%	0.0%	-0.2%	-8.3%	-1.1%	-4.3%	-7.2%
Wheat	Land	19.6%	0.0%	0.8%	-0.6%	-1.0%	6.1%	0.0%	-0.7%
Coarse grains	Land	19.3%	0.0%	-1.2%	2.5%	1.6%	0.1%	-1.8%	2.1%
Oil seeds	Land	20.6%	1.1%	1.1%	1.3%	1.0%	0.6%	12.8%	0.8%
Rice	Land	0.0%	0.0%	0.0%	-0.4%	-10.2%	-0.8%	-5.5%	-10.4%
Pasture	Land	-4.0%	-0.1%	-2.4%	-1.2%	-0.4%	-1.0%	0.2%	-1.7%
Milk	Cattle	0.0%	-0.1%	3.9%	-0.3%	-0.2%	-0.4%	0.1%	-0.2%
Beef	Cattle	0.0%	0.0%	-1.1%	0.0%	-0.4%	-0.3%	0.1%	0.0%
Wheat	Output	9.2%	-0.1%	0.2%	-0.5%	-1.5%	4.3%	0.0%	-0.2%
Coarse grains	Output	11.4%	0.0%	-1.1%	1.9%	1.1%	-0.2%	-0.8%	0.8%
Oil seeds	Output	16.6%	0.7%	0.6%	0.9%	0.6%	0.3%	4.4%	0.1%
Rice	Output	-1.7%	0.0%	0.0%	-0.2%	-8.3%	-1.1%	-4.3%	-8.9%
Milk	Output	0.0%	-0.1%	4.4%	-0.3%	-0.2%	-0.5%	0.1%	-0.2%
Beef	Output	0.0%	0.0%	-1.3%	0.0%	-0.4%	-0.3%	0.1%	0.0%

**Table C.4. Percentage changes in the PEM input and output variables,
from the simulated increase in payments based on animal numbers**

These variables are used to calculate the changes in the environmental indicators reported in Section 4.

Commodity	Variable	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6	Country 7	Country 8
Wheat	Fert	-12.0%	-0.8%	-0.8%	-0.2%	-0.9%	-2.2%	0.0%	1.8%
Coarse grains	Fert	-12.5%	-0.7%	-0.8%	-0.2%	-0.8%	-2.0%	0.0%	-1.1%
Oil seeds	Fert	-17.2%	-0.7%	-0.7%	-0.2%	-0.7%	-1.5%	0.1%	-1.4%
Rice	Fert	1.4%	0.0%	0.0%	-0.1%	-31.5%	-1.4%	-0.1%	-5.5%
Wheat	Land	-18.5%	-1.2%	-1.2%	-0.2%	-1.5%	-3.0%	0.0%	-0.5%
Coarse grains	Land	-18.1%	-1.2%	-1.2%	-0.2%	-1.4%	-2.8%	0.0%	-0.8%
Oil seeds	Land	-20.1%	-1.1%	-1.0%	-0.2%	-1.4%	-2.4%	0.0%	-0.8%
Rice	Land	-1.4%	0.0%	0.0%	-0.2%	-37.9%	-2.6%	-0.1%	-7.0%
Pasture	Land	3.7%	0.4%	3.6%	1.4%	0.4%	1.6%	1.7%	1.3%
Milk	Cattle	9.4%	9.0%	13.2%	8.1%	18.6%	6.4%	15.9%	8.1%
Beef	Cattle	6.1%	5.5%	5.9%	6.2%	1.3%	6.6%	4.8%	5.7%
Wheat	Output	-12.0%	-0.8%	-0.8%	-0.2%	-0.9%	-2.2%	0.0%	1.5%
Coarse grains	Output	-12.5%	-0.7%	-0.8%	-0.2%	-0.8%	-2.0%	0.0%	-0.3%
Oil seeds	Output	-17.3%	-0.7%	-0.7%	-0.2%	-0.7%	-1.5%	0.1%	-0.3%
Rice	Output	1.4%	0.0%	0.0%	-0.1%	-31.5%	-1.4%	-0.1%	-6.4%
Milk	Output	8.5%	5.4%	12.6%	4.8%	4.9%	6.0%	6.0%	5.8%
Beef	Output	6.5%	5.8%	6.9%	6.6%	1.4%	7.3%	5.1%	6.6%

Table C.5. Percentage contributions of each PEM sector to country level baseline nutrient balances and GHGs

Commodity	Variable	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6	Country 7	Country 8
Wheat	N bal	20%	3%	18%	5%	2%	22%	0%	12%
Coarse grains	N bal	36%	1%	15%	0%	56%	52%	3%	9%
Oil seeds	N bal	7%	1%	28%	1%	0%	-42%	1%	5%
Rice	N bal	31%	0%	0%	33%	0%	3%	42%	0%
All crops	N bal	94%	5%	62%	38%	59%	35%	46%	27%
Milk	N bal	2%	45%	8%	30%	6%	18%	8%	35%
Beef	N bal	4%	50%	31%	32%	35%	47%	46%	39%
All cattle	N bal	6%	95%	38%	62%	41%	65%	54%	73%
Wheat	P bal	25%	11%	-279%	18%	-248%	44%	0%	-53%
Coarse grains	P bal	28%	-55%	94%	3%	-180%	-93%	6%	-33%
Oil seeds	P bal	11%	-29%	-457%	6%	35%	-153%	6%	-24%
Rice	P bal	27%	0%	0%	44%	25%	0%	87%	0%
All crops	P bal	91%	-74%	-642%	71%	-368%	-202%	98%	-111%
Milk	P bal	3%	58%	292%	13%	352%	73%	-1%	20%
Beef	P bal	5%	115%	250%	17%	-83%	29%	3%	-9%
All cattle	P bal	9%	174%	542%	29%	268%	102%	2%	11%
Wheat	GHG	5%	1%	8%	1%	1%	2%	0.0%	5%
Coarse grains	GHG	8%	0%	6%	0%	7%	9%	0.4%	4%
Oil seeds	GHG	2%	0%	16%	0%	0%	1%	0.0%	3%
Rice	GHG	48%	0%	0%	53%	2%	3%	41%	1%
All crops	GHG	63%	1%	29%	55%	9%	16%	41%	13%
Milk	GHG	25%	81%	24%	38%	24%	27%	17%	65%
Beef	GHG	12%	18%	46%	8%	66%	56%	41%	22%
All cattle	GHG	37%	99%	71%	45%	91%	84%	59%	87%

Note: For the nutrient balances, the percentage calculations are based on changes relative to the absolute value of the total agricultural balances in each country. This maintains the correct sign on the contribution from each sector.