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The EU-Wide Individual Farm Model for Common Agricultural Policy Analysis (IFM-CAP v.1)

Economic Impacts of CAP Greening

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The development of the Individual Farm Model for Common Agricultural Policy (IFM-CAP) was initiated by the workshop on 'Development and Prospects of Farm Level Modelling for Post-2013 CAP 2013 Impact Analysis' organised jointly by the Joint Research Centre (JRC) and the Directorate General for Agriculture and Rural Development (DG AGRI) in Brussels on 6–7 June 2012. Model development started with a simplified prototype that was finalised in December 2015 (Louhichi et al., 2015) and now the first model version (v.1) is available and being used for policy assessment. The work has been carried out by Kamel Louhichi, Maria Espinosa, Pavel Ciaian, Angel Perni, Bouda Vosough Ahmadi, Liesbeth Colen and Sergio Gomez y Paloma, who are based at the Economics of Agriculture Unit (EoA) of the JRC. We would like to gratefully acknowledge Pierluigi Londero, Sophie Helaine, Koen Mondelaers and Koen Dillen from DG AGRI (Directorate C.2) for their support in the development of the IFM-CAP model and their valuable comments on this report, as well as Emmanuel Jacquin, Aurora Ierugan and Ana Torres Fraile from DG AGRI (Directorate C.3) for allowing us access to the Farm Accountancy Data Network (FADN) and for helping us to have a better understanding of the database.

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Abstract

This report presents the first EU-wide individual farm level model (IFM-CAP) aiming to assess the impacts of CAP towards 2020 on farm economics and environmental effects. The rationale for such a farm-level model is based on the increasing demand for a micro simulation tool capable to model farm-specific policies and to capture farm heterogeneity across the EU in terms of policy representation and impacts. Based on Positive Mathematical Programming, IFM-CAP seeks to improve the quality of policy assessment upon existing aggregate and aggregated farm-group models and to provide assessment of distributional effects over the EU farm population. To guarantee the highest representativeness of the EU agricultural sector, the model is applied to every EU-FADN (Farm Accountancy Data Network) individual farm (83292 farms).

The report provides a detailed description of the first IFM-CAP model version (IFM-CAP V.1) in terms of design, mathematical structure, data preparation, modelling livestock activities, allocation of input costs, modelling of the CAP post-2013 and calibration process. The theoretical background, the technical specification and the outputs that can be generated from this model are also briefly presented and discussed. Model capability is illustrated in this study with an analysis of the EU farmers' responses to the greening requirements introduced by the 2013 CAP reform.

1 Introduction

Over the last two decades, the Common Agricultural Policy (CAP) has shown a gradual change from market intervention instruments (e.g. price support) towards decoupled farm-specific measures attempting to enhance the environmental performance of the European Union's (EU) agricultural sector. This was evident with the introduction of the Single Payment Scheme (SPS) in 2005. The 2013 CAP reform goes further in this direction by proposing a mandatory component to direct payments, the 'greening' component, with the aim of supporting agricultural practices beneficial to the climate and environment. Other farm-specific measures introduced by the recent CAP reforms include, among others, the capping of direct payments and young farmer and small farmer schemes. The uptake and economic effects of these farm-specific measures differ significantly between farms depending, among others, on their size, specialisation, resource endowment, location and socio-economic characteristics.

A wide range of applied agricultural models available in the literature attempt to investigate the impact of the CAP, spanning from farm-type optimisation models to general equilibrium models (de Muro and Salvatici, 2001; Offermann et al., 2005; Gohin, 2006; OECD, 2006; Buysse et al., 2007; Helming et al., 2010; Louhichi et al., 2010; Gocht and Britz, 2011; Britz and Witzke, 2014; Gocht et al., 2013; Gomez y Paloma et al., 2013; Louhichi et al., 2013). However, most of the available models are implemented at an aggregate level (i.e. regions, countries, group of countries) and are not able to fully capture the impacts of these new policy measures at a disaggregated (farm) level. Although farm-type models can assess these farm-specific policy measures to some extent, they are subject to aggregation bias, reduce farm heterogeneity considerably and cannot model a number of CAP policies for which eligibility depends on individual farm characteristics and location. For example, in the case of crop diversification measures, certain farms have to produce a minimum of two crops, with the main crop representing a maximum of 75 % of arable area. In this case, the cropping pattern is much more diversified for a representative farm than for the actual individual farms on which the representative farm was based. As a result, the crop diversification requirement will usually be respected (although it is not binding) at the level of the representative farm, even though, in reality, the restriction is binding at the level of individual farms. Moreover, aggregated farm group models can only represent average effects for the set of predetermined farm types, while an individual farm-level model calculates the distributional effects over the farm population and allows the aggregation of results to different levels (NUTS2, Member State (MS) or EU) or by farm type (farm size, specialisation, etc.), depending on the specific policy question to be answered.

Another drawback of existing farm models is that most of them were developed for a specific purpose and/or location and, consequently, are not easily adaptable or reusable for in other applications or other contexts (Louhichi et al., 2010). Of a large number of EU-based representative farm models, only two have full EU coverage: Farm type module within Common Agricultural Policy Impact Modelling System (CAPRI-FT; Gocht and Britz, 2011; Gocht et al., 2013) and Agriculture, Recomposition de l'Offre et Politique Agricole (AROPAj; De Cara and Jayet, 2011). The other models cover either a specific MS (Forest and Agricultural Optimisation Model (FAMOS; Schmid, 2004)) or a selected set of MSs/regions (Farm Modelling Information System (FARMIS; Offermann et al., 2005); Farming System Simulator (FSSIM; Louhichi et al., 2010); Agricultural Policy Simulator (AGRIPOLIS; Kellermann et al., 2008); and Stylised Agri-Environmental Policy Impact Model (SAPIM; OECD, 2010)).

Given the shortcomings of the available agricultural policy modelling tools, the Joint Research Centre (JRC) started developing an individual farm-level simulation model, named IFM-CAP (Individual Farm Model for Common Agricultural Policy Analysis), for the ex-ante assessment of medium-term adaptation of individual farmers to policy and market changes. The main expectations of this micro-simulation tool are as follows: (i) it allows a more flexible and comprehensive assessment of a wide range of farm-specific policy measures that cannot be achieved with other models; (ii) it can be applied at EU-wide scale; (iii) it reflects the full heterogeneity ([1]) of the EU commercial farm in terms of policy representation and impacts; (iv) it covers all the main agricultural production activities in the EU; (v) it permits a detailed analysis of different farming systems; and (vi) it enables the distributional impacts across the farm population to be estimated. Some examples of the typical questions that we attempt to answer with IFM-CAP are the following: How is farm income affected by policy reforms? Which farms would gain and which would lose? Where are the affected farms located? What is their production specialisation? Are the impacts equitably distributed? Are small farms more severely affected than large ones?

The IFM-CAP model is a static positive mathematical programming (PMP) model, which builds on the FADN (Farm Accountancy Data Network) data, complemented by other relevant EU-wide data sources such as Eurostat (regional statistics and the Farm Safety Survey (FSS)), the Common Agricultural Policy Impact Modelling System (CAPRI) database, etc. It solves, at given prices and subsidies, a general maximisation problem in terms of input choice and land decisions, subject to a set of constraints representing production technology and policy restrictions. To achieve the best levels of representation and capture the full heterogeneity of the EU farm population, the whole FADN sample (83292 farms in 2012) is individually modelled.

The IFM-CAP model started with a simplified prototype, which is already finalised (Louhichi et al., 2015). This report presents the first version (v.1) of IFM-CAP model. The main features of this first model version are summarised in Table 1.

([1]) The FADN survey (and, therefore, the IFM-CAP model) does not cover all the agricultural farms in the European Union but only those which, because their size, could be considered commercial (the specific threshold varies in each MS). A project aiming to incorporate non-commercial farms (e.g. small farms) in IFM-CAP and assess their responses to policy and market changes is under development.

Table 1. Main features of the IFM-CAP v.1

Model name	Individual Farm Model for Common Agricultural Policy Analysis (IFM-CAP)
Institution responsible for development and maintenance	The Economics of Agriculture (EoA) Unit of the JRC (in-house model development and maintenance) and Directorate-General for Agriculture and Rural Development (DG AGRI) (Directorate C user feedback)
Type of model	Individual farm model running for the whole FADN sample (and therefore all the EU regions and sectors)
Methodology	Comparative static and non-linear programming model
Model calibration	Calibrated to 2012 using PMP
Objective function	Farm utility maximisation (revenues – accounting costs + subsidies – PMP terms – risk component)
Revenues	Production value by activity: price × yield × activity level (ha or head)
Accounting costs	Operating costs per unit of each production activity
Subsidies	First pillar policies: coupling and decoupling (Single Payment Scheme (SPS), Single Area Payments Scheme (SAPS), Basic Payment Scheme (BPS))
Risk component	Constant absolute risk aversion (CARA) coefficient times the variance of revenues (and hence income) due to price and yield variations
Constraints	
Land constraint	Sum of area by activity less than or equal to total farm land endowment defined by type of use (arable and grassland)
Labour, capital	Captured by PMP terms
Policy constraints	Quotas, greening, capping, modulation, regional ceiling for premiums, etc.
Livestock	Animal demography and livestock constraint, balancing feed demand and feed supply
Other considerations	
Expected prices and yields	Exogenous variables derived at farm level assuming adaptive expectations (based on past 3 years with declining weights)
Subsidies	Exogenous variables derived at farm level from FADN for the base year 2012
Expected input costs by activity	Input costs by activity are estimated per year using econometric estimation (highest posterior density (HPD) estimation) and expected input costs for the base year 2012 are estimated assuming adaptive expectations (based on last 3 years with declining weights)
Total farm land endowment	Fixed at base year 2012 level
Technological progress	Yes, using an exogenous yield trend
Structural change	No
Changes in management practices	No
Environmental indicators	Crop diversity, soil erosion, input use proxies, nutrient balance (nitrogen and phosphorus) and greenhouse gas emission (ongoing)
Input and output market interactions	No
Time horizon	2020 (extensive use of results from Aglink/CAPRI baseline work)
Potential scenarios	CAP (i.e. redistributive payments, BPS, greening measures); price change; input cost change

Model results	
Type of model results	Production, land use, land allocation among activities, farm income, variable costs, subsidies, environmental impact, distribution of income and CAP benefit among farmers for each scenario (base year, baseline and policy scenarios)
Farm level	Single farm units
Farm group aggregation	By farm typology, farm size or other relevant dimension by using farm weighting factors from FADN
Regional aggregation	FADN regions, Nomenclature of Territorial Units for Statistics (NUTS), MS, EU
Data needs and other considerations	
FADN data	2007–2012 individual farm data
Other supporting data	Official statistical sources (e.g. Eurostat (regional statistics, FSS)), scientific literature and other model databases (e.g. CAPRI)
Programming language	General Algebraic Modelling System (GAMS)
Visualisation and data analysis	Graphical user interface (GUI) and Qlik (http://www.qlik.com/us/)

The main changes/improvements included in the first model version in comparison with the prototype are shown in Table 2.

Table 2. IFM-CAP v.1: main changes/improvements compared with the prototype

	IFM-CAP prototype	**IFM-CAP v.1**
Base year	Three-year averages around 2008 conditions	2012
FADN sample	2007–2009 FADN constant sample (60 500 farms)	2012 FADN sample (83 292 farms)
Modelling livestock activities	Only adult animals are endogenously determined by the model	All livestock activities are endogenously determined by the model
Model calibration	– Only crops – Feed allocation	– Crops and livestock activities – Feed allocation
Model's objective function	Profit maximisation	Expected utility maximisation
Prices, yields and intermediate input costs	Contemporaneous expectations	Adaptive expectations (based on past 3 observations with declining weights)
Feed module	Feed availability/requirements based on CAPRI	Updated nutrient requirements/feed contents, animal productivity parameters, feed prices
Modelling CAP	– CAP health check – Crop diversification (full compliance)	– 2013 CAP reform – Three greening measures
Environmental indicators	Environmental indicators were not included	Implemented environmental indicators (validation ongoing)

This report provides a detailed description of the IFM-CAP v.1 in terms of design, mathematical structure, data preparation, modelling livestock activities, allocation of input costs, calibration process, baseline construction and modelling of the 2013 CAP reform. The theoretical background, technical specification and outputs that can be generated from this model are also presented and discussed. We also provide an application of the model for analysing the economic impact of CAP greening ([2]).

([2]) Several parts of this report are based on Louhichi et al. (2017a,b).

2 IFM-CAP: model design and specification

The IFM-CAP model is designed for the economic and environmental analysis of the European agricultural systems at the farm level. Rather than providing forecasts or projections, the model aims to generate scenarios – or 'what if' – analyses. It simulates how a given scenario, for example a change in prices, farm resource or environmental and agricultural policies, might affect a set of performance indicators important to decision makers and stakeholders. Performance indicators include changes in crop allocation, input use, crop and animal production, farm income, livestock density and CAP expenditures. In contrast to representative farm models, which provide only average policy impacts, IFM-CAP can provide both average and distributional effects of policies and offer a more in-depth analysis.

IFM-CAP is a constrained optimisation model that maximises an objective function subject to a set of constraints. It assumes that farmers maximise their expected utility at given yields, product prices and production subsidies, subject to resource (arable land, grassland and feed requirements) and policy constraints such as greening restrictions. Land constraints are used to match the available land that can be used in a production operation and the possible uses made of it by the different agricultural activities. Constraints relating feed availability to feed requirements are used to ensure that the total energy, protein and fibre requirements of livestock are met by own-produced or/and purchased feed. For certain animal categories, additional minimum or maximum requirements by type of feeding regarding animals' diet are introduced.

Farmers' expected utility is defined following the mean–variance (E-V) approach (Markowitz, 1952) with a CARA specification (Pratt, 1964; Arribas et al., 2017) ([3]). According to this approach, expected utility is defined as expected income and the associated income variance. Effectively, it is assumed that farmers select a production plan that minimises the variance of income caused by a set of stochastic variables for a given expected income level (Hazell and Norton, 1986):

$$E[\mathrm{U(Z)}] = E[\mathrm{Z}] - \frac{\varphi}{2}\mathrm{V(Z)} \qquad (1)$$

where U(·) is the utility function on income (*Z*) following an exponential form (Freund, 1956), *E*[U(*Z*)] is the expected utility, *E*[*Z*] is the expected income, φ is the absolute risk aversion coefficient according to CARA specification and V(·) is the variance of income (*Z*).

The computational advantage of the selected E-V approach with CARA specification was one of the main reasons for being used in the IFM-CAP framework ([4]). The optimisation problem is still a quadratic programming problem for which the literature provides several solution methods. Utility functions with preferred theoretical properties often have expected values that are difficult to evaluate numerically and higher-order

([3]) Arribas et al. (2017) conducted a critical review of the studies dealing with the modelling of farmers' risk behaviour in agricultural farm-level models, discussing the advantages and drawbacks offered by the different methodologies. They also attempted to identify the most suitable methodology to incorporate risk within the IFM-CAP framework by testing different model specifications in a set of 10 NUTS-2 regions in Spain. Their findings can be summarised as follows: (i) the mean–variance approach seems to be the most suitable for modelling risk within the IFM-CAP framework; (ii) the highest posterior density estimator performed better than the least squares approach; (iii) both specifications, accounting or not for risk, yield very similar estimates, although the inclusion of risk triples the computational time required, which could be a limitation for a large-scale model; (iv) the explicit consideration of risk is mainly relevant for further assessments of risk management tools.

([4]) CARA is a more restrictive model, but is widely employed in empirical agricultural research because it implies that the farm's utility function is almost quadratic in the parameters, which simplifies the resolution of the optimisation programming problem. More sophisticated specifications may consider constant relative risk aversion (CRRA) or decreasing absolute risk aversion (DARA) (for more details see, for example, Coyle (1999) and Sckokai and Moro (2006)).

polynomials that might lead to non-convex programming problems (Hazell and Norton, 1986).

Farmers' expected income $E[Z]$ is defined as the sum of expected gross margins minus a non-linear (quadratic) activity-specific function. The gross margin is the total revenue including sales from agricultural products and compensation payments (coupled and decoupled payments) minus the accounting variable costs of production activities. Total revenue is calculated using expected prices and yields assuming adaptive expectations (based on the past three observations with declining weights). The accounting costs include the costs of seeds, fertilisers, crop protection, feeding and other specific costs. The quadratic activity-specific function is a behavioural function introduced to calibrate the farm model to an observed base year situation ([5]), as is usually done in positive programming models. This function intends to capture the effects of factors that are not explicitly included in the model (Heckelei, 2002), in this case labour requirements and capital constraints.

The FADN database provides only total accounting costs per variable input category (e.g. seeds, fertiliser, pesticide, feed, etc.), without indicating the unit input costs of each (crop and animal) output which is needed to capture policy impacts and to represent technologies in an explicit way. For crop activities, we overcome this lack of information by using a Bayesian econometric estimation of unit input costs based on the farm-level input costs per category reported in FADN, assuming a Leontief technology, as explained in detail in section 4. Unit input costs are estimated for the whole period 2007–2012 using cross-sectional data (see section 6). The resulting estimated costs are then used to calculate the expected unit input costs for 2012 assuming adaptive expectations (based on the past three observations with declining weights). For livestock activities, we use the farm-level feeding costs reported in FADN and various external sources to estimate animal feed (nutrient) requirements and to balance feed requirements and feed availability at farm level as described in section 7.

The separation of the Leontief production function (i.e. accounting variable costs) from the quadratic behavioural function was motivated by the fact that the primal technology representation through the Leontief production function (i) provides an explicit link between production activities and the total physical input use; (ii) eases the link to environmental indicators calculation; and (iii) allows the simulation of policy measures linked to specific farm management. According to Heckelei and Wolff (2003), the main disadvantage of this approach is the lack of rationalisation, since intermediate input uses are assumed to be independent of the unknown marginal costs captured by the quadratic behavioural function.

Regarding the income variance $V[Z]$, most of the literature incorporates uncertainty in the gross margin per unit of activity (see Cortignani and Severini, 2012; Jansson et al., 2014) or in the revenues per unit of activity (see Coyle, 1999; Paris and Arfini, 2000; Sckokai and Moro, 2006; Arata et al., 2013; Petsakos and Rozakis, 2015). In the former case, the authors assume that prices, yields and costs are stochastic. In the latter case, the authors argue that costs are non-random variables because, in static decision models, all costs are known when decisions are made (Antle, 1983; Petsakos and Rozakis, 2015) or because costs are less stochastic than revenues from the farmer's perspective, so that the variance in the gross margin can be approximated by the variance in revenues (Jansson et al., 2014). In the IFM-CAP framework, we opted for the second approach by considering that uncertainty applies only to prices and yields (i.e. revenues) but without differentiating between sources of uncertainty. Effectively, for each farm and activity, the revenue per hectare or per head given is calculated by the product of the expected yield and price. Then, for each farm type within each NUTS2 region, the covariance matrix of activity revenues per hectare or per head is computed using data from the five most recent available years, that is, 2007 to 2011. This

([5]) In principle, any non-linear convex function with the required properties can reproduce the base year solution. For simplicity and lacking strong arguments for other type of functions, a quadratic function is usually employed.

covariance matrix is then used as prior information to estimate the 'true' covariance matrix that allows replicating the observed crop and livestock activities as well as the observed feed allocation during the base year 2012.

An identical model structure was applied for all modelled FADN farms to ensure a uniform handling of all the individual farm models and their results. In other words, individual FADN farms are represented by individual farm models that have identical equations and variables to the generic format of IFM-CAP, although their model parameters are farm specific. No cross-farm constraints or relationships are assumed in the current version of the model. An exception is in the estimation phase of the behavioural function parameters (see section 8.1), in which all the individual farms in each region are used to simultaneously estimate these parameters.

The general mathematical formulation of the expected utility maximisation problem of farm *f* (= 1,2,…, *F*) is as follows:

$$\underset{\mathbf{x}_{f,i}\geq\mathbf{0}}{\mathbf{Max}} E(U)_f = \sum_i E\left[gm_{f,i}\right]x_{f,i} + e_f t_f - \sum_i d_{f,i}x_{f,i} - 0.5\sum_{i,i'} x_{f,i}Q_{f,i,i'}x_{f,i'} - 0.5\varphi_f \sum_{ft,i,i'} x_{f,i}\Sigma_{ft,i,i'}x_{f,i'} \quad (2)$$

subject to

$$\sum_i A_{f,i,m}x_{f,i} \leq b_{f,m} \quad \left[\rho_{f,m}\right] \quad (3)$$

where indices i,i' = 1,2,…, I denote the agricultural (crop and livestock) activities and products ([6]), and m = 1,2,…, M the resource and policy constraints (e.g. agricultural land, quotas and animal feeding). $E(U)_f$ is the expected utility of farm *f* to be maximised, $x_{f,i}$ is the non-negative level (i.e. hectares and head) of activity, i, $E\,[gm_{f,i}]$ is the expected gross margin for activity i (EUR/ha) (with $gm_{f,i} = p_{f,i}y_{f,i} + s_{f,i} - \sum_k C_{f,i,k}$, $p_{f,i}$ denotes expected product prices (including for feed and young animals), $y_{f,i}$ are expected yields, $s_{f,i}$ are coupled payments, k = 1,2,…, K *are* the intermediate inputs (i.e. fertiliser, seeds, crop protection, etc.) and $C_{f,i,k}$ are accounting variable costs for intermediate input k and activity i), e_f are the decoupled payments, t_f is the eligible area for decoupled payments ([7]), $d_{f,i}$ is the linear part of the behavioural activity function, $Q_{f,i,i'}$ is the quadratic part of the behavioural activity function, φ_f is the farmer's CARA coefficient and $\Sigma_{f,i,i'}$ is the farm-type symmetrical, positive (semi) definite matrix of the covariance activity revenues per hectare or per head. $A_{f,i,m}$ are coefficients for resource and policy constraints (land, obligation set-aside, quotas and animal feeding), $b_{f,m}$ are available resource levels and upper bounds to the policy constraints, and $\rho_{f,m}$ are their corresponding shadow prices. Note that equation (2) assumes no uncertainty around ***s, d*** and ***Q***, and assumes that all variance on income ***Z*** relates to ***p*** and ***y***.

Expected prices, yields, accounting unit cost, subsidies, matrix of coefficients, quotas (sugar beet and milk) and land availability are derived from FADN or calculated in the data preparation step (see sections 3.3 and 3.4 and sections 4 and 5). The unknown parameters ***d, Q,*** $\boldsymbol{\rho}$, $\boldsymbol{\varphi}$ and Σ are estimated simultaneously in each NUTS2 region using the HPD estimator (Heckelei et al., 2008) so that the first-order conditions (FOCs) of the considered farm model (equations (2) and (3)) are exactly satisfied at the observed activity levels ($\mathbf{X_0}$), taking into account the exogenous information (i.e. regional supply elasticities, dual values of resources and farm-type covariance matrix of activity revenues) and all the available observations during the base year period (see section 8).

([6]) To simplify the mathematical notation, we assume one product per activity so that the indices for activity and product are identical.

([7]) The eligible area in MS implementing the SPS is equal to the amount of the farm's entitlements, whereas, in MS that implement the SAPS, it is equal to the total agricultural area.

As usual in mathematical programming models that combine risk and PMP approaches, some parameters are farm independent while others are farm specific. In this IFM-CAP model specification, all the parameters are farm specific, except ***B*** and Σ matrix, which are farm type specific (***Q=sBs'***).

3 The IFM-CAP database

This section provides a brief description of the data used and data treatment procedures applied in IFM-CAP. As mentioned above, the base year of the IFM-CAP model is 2012. This means that all farms represented in the FADN sample in 2012, that is 83 292 farms, are included in the model. However, to parameterise the model, past observations (2007–2012) for these farms are also used, at least when they are available in the FADN database. The observed crop and animal activity levels and the subsidies are based on 2012 data, while a time series (2007–2012) is used to construct the expected yields, prices and input costs, as explained in section 3.

Before using the FADN data, several steps were performed to screen the data and to convert them to a format that is compatible with the IFM-CAP modelling framework. This activity included, in particular, data adjustment to IFM-CAP model needs, identification and correction of out-of-range values and outliers, handling missing values and addressing the issue of variables that are not available in FADN.

The FADN database assigns each individual farm to one of 14 types according to its farm specialisation ([8]). In certain cases, for example when individual farm-level data are missing from the FADN database or when outliers are detected, we use the aggregated FADN data at the level of the farm type to replace missing values or outliers. Whenever in the remainder of the report we mention farm type, we refer to the grouping of farms according to their specialisations.

3.1 Data requirements

Three types of data are required for running the IFM-CAP model: fixed inputs and production rights, output and variable input data for production activities, and calibration data.

(i) **Fixed inputs and production rights**: involves available farmland (i.e. total utilised agricultural area (UAA), arable land and grassland) and sugar beet and milk quota rights. These data are used for setting lower and upper bounds for resource and policy constraints in the model. Farmland and milk quota data are directly available in FADN. Sugar beet quotas are estimated using the national quota share because, for most of the MSs, these data are not reported in the FADN database (see section 5). Data on labour, energy, water and capital resources are not included, since they are not explicitly modelled but are captured by the behavioural function (i.e. PMP terms).

(ii) **Output and variable input data for production activities**: consist of yields, product prices, production subsidies and accounting unit costs for all crop and animal activities in each farm. These data are used for the calculation of the expected gross margin per hectare or per head of each production activity to be embedded in the model objective function, as well as for the definition of input coefficients for resource and policy constraints. The data on yields, prices and subsidies are derived from FADN. Data on accounting unit costs for crops (i.e. specific costs related to seeds, fertilisers, crop protection and other crop-specific costs) are estimated using a Bayesian approach with prior information on input–output coefficients from the DG AGRI input allocation module (see section 4). The feeding costs are also estimated using a Bayesian approach with prior information on animal feed requirements from CAPRI and data on farm-level feed costs, feed prices and feed nutrient contents and fodder yields from FADN, CAPRI and Eurostat, respectively (see section 7). Based on the time-series data for price, yields and input cost, expected values are generated, to obtain the expected gross margin. The list of crop activities defined in the IFM-CAP model and the extraction rules for each activity

([8]) We consider the TF14 grouping, as defined in FADN, which considers 14 distinct farm types specialised in (1) cereals, oilseeds and protein crops (COP); (2) other field crops; (3) horticulture; (4) wine; (5) fruit orchards; (6) olives; (7) various permanent crops combined; (8) milk; (9) sheep and goats; (10) cattle; (11) granivores; (12) mixed crops; (13) mixed livestock; and (14) mixed crops and livestock (FADN, 2015).

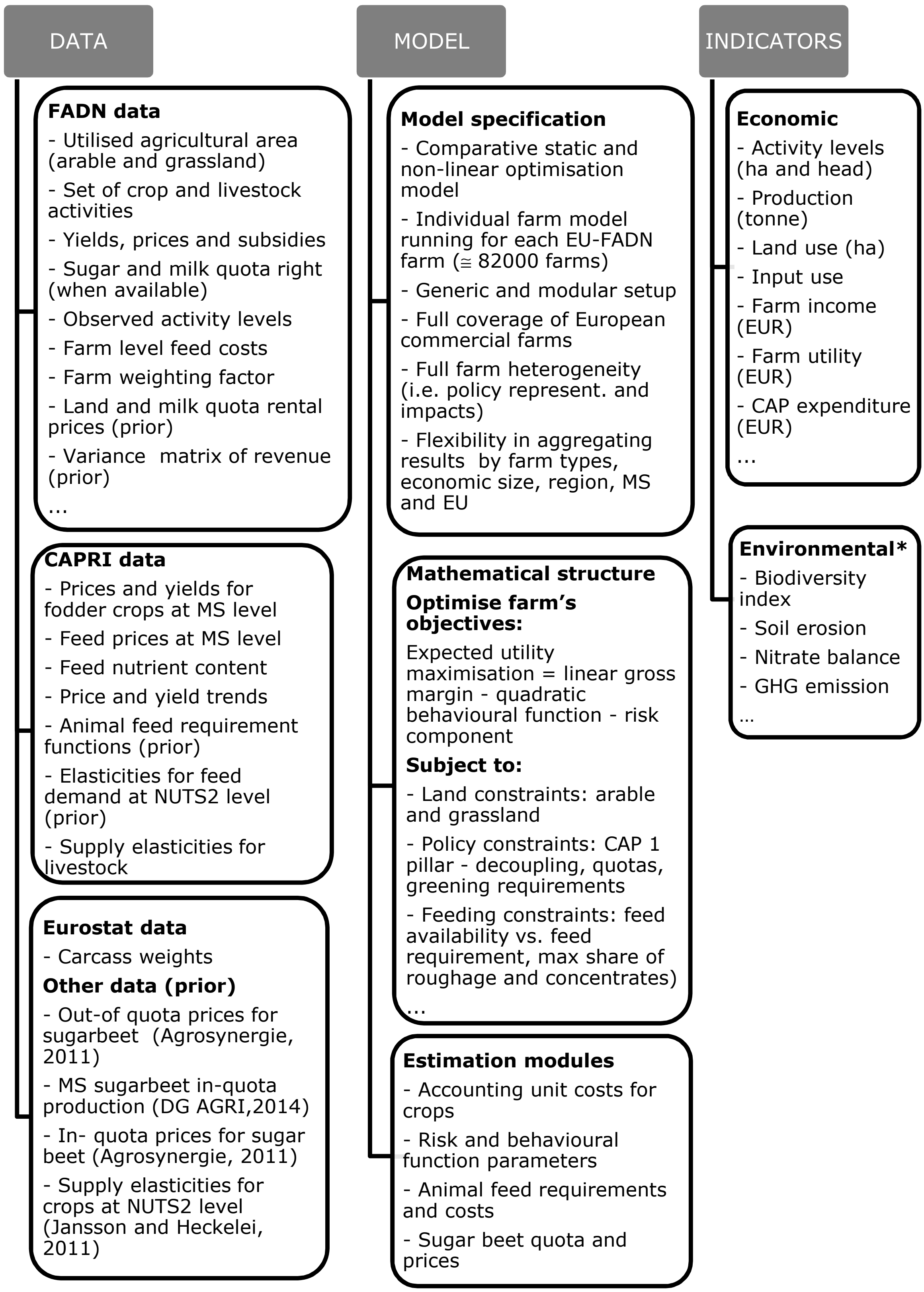
are provided in Table A 1 in Annex A. The extraction rules for the livestock activities are explained in section 6.3, as they are more complex owing to the livestock herd demography.

(iii) **Calibration data** consist of observed activity levels (i.e. hectares or heads), land and milk quota rental prices, the gross margin differential between sugar beet and the next best alternative crop, supply elasticities at NUTS2 level and the farm-type covariance matrix of activity revenues per hectare or per head. The observed activity level (x0) is used to calibrate the model, assuming that it is the optimal level in the base year. The rest of the data (i.e. land and milk quota rental prices, supply elasticities, farm-type covariance matrix of activity revenues and the gross margin differential between sugar beet and the next best alternative crop) are used as prior information. Section 8 describes in detail how these data are used in the calibration process.

Overall, most of the required data for the IFM-CAP model come directly or indirectly from FADN, with the exception of some data linked to feed crops and animal activities (see section 6) or those used as prior information for model calibration (see section 8) or for the estimation of sugar beet quota and prices (see section 5). For example, the majority of calibration and farm resource data are recorded in the FADN database and, therefore, are used in the modelling exercise directly. However, some other data, such as prices and yields, are not directly reported in FADN and, therefore, are derived from the original FADN variables using simple assumptions. For example, prices are approximated by dividing production value (TP) by the production quantity (QQ). Production value (TP) is reported in FADN as the sum of sales, own consumption and change of stocks, which may result in negative, very small or very large positive (i.e. out-of-range) values for the derived prices in a given year. In fact, a high carryover of stock and a subsequent drop in prices may lead to a negative total production value and ultimately generate a negative output price. Out-of-range (i.e. negative, outliers) or zero values for prices and yields are not suitable for use in the modelling exercise, because they are key factors determining farmers’ decisions. Section 3.2 describes in detail the identification of outliers, while section 3.3 explains the calculation of expectations.

The left panel of Figure 1 summarises the data needs of IFM-CAP and their sources. As shown in this figure, some data are not directly used in the optimisation process but only as prior information to estimate certain input coefficients.

Figure 1. IFM-CAP v.1 description



* Environmental indicators are not yet fully operational

3.2 Data screening and treatment

The purpose of the FADN data screening is to remove aberrations and to check the extent to which these data need to be adjusted to meet the IFM-CAP modelling requirements. The key data that have been screened are yields and product prices. Prices and yield data are not directly available in FADN, but are calculated as follows:

$$p = TP / QQ$$

$$y = QQ / AA$$

$$TP = SA + FC + FV - (BV - CV)$$

where *p* is price, *y* is yield, *TP* is production value (euros), *QQ* is production quantity (tonnes), *AA* is production area (ha) or livestock head, *SA* is sales, *FC* is farm consumption, *FV* is farm use, *BV* is opening stock and *CV* is closing stock.

Outliers

The IFM-CAP model is calibrated to 2012, but the observations of earlier years (2007–2011) are used to generate expected prices and yields for 2012. Therefore, the detection of outliers in the price and yield data was applied by year to the time series 2007–2012.

Outliers are observations that are numerically distant from the assumed distribution of the data. In our case, they concern mainly prices and yields and may arise for various reasons:

- Prices and yields are derived from other FADN data (based on total production value, production quantity and areas), so their values in some farms may deviate significantly from the rest of the sample if underlying data do not contain sufficient information to identify their true value (e.g. because of high carryover stock combined with high price) ([9]).
- Yields of, and prices achieved for, specific activities included in a given aggregated activity group (e.g. flowers, other cereals, other vegetables), as well as for crops whose yields are strongly dependent on climatic conditions or variety cultivated (e.g. tobacco, potatoes, olive trees), are highly heterogeneous.
- It is possible that a farmer may have entered incorrect information, in particular for output quantity and/or output value, in the FADN farm returns.

For prices and yields, we carried out normality tests and, for consistency reasons, we used the interquartile range (IQR), a non-parametric method, to determine the outliers. The IQR is a measure of statistical dispersion, being equal to the difference between the upper and lower quartiles:

$$IQR = Q3 - Q1$$

This data treatment was conducted at NUTS2 level and by year for the time series 2007–2012. The outlier calculation is based on all the values that are greater than zero and therefore was not applied to missing values and negative values. More precisely, it is a trimmed estimator, defined as the 25 % trimmed mid-range, and is the most significant basic robust measure of scale. It is the third quartile of a box and whisker plot minus the first quartile. An outlier is defined as any value that lies more than 1.5 times the length of the IQR from the first quartile (lower outlier) or from the third quartile (upper outlier); therefore:

$$if\ Xi < (\ Q1 - 1.5 \times IQR\ ) > Lower\ outlier$$

([9]) The opening valuation is the value of the stocks at the start of the accounting year based on farm gate prices prevailing at that time.

$$if\ Xi > (\ Q3 + 1.5 \times IQR\ ) > Upper\ outlier$$

The values that are not considered outliers are used in the expectations module described in the next section. Farms with outliers are not discarded from the sample but, instead, the outliers are replaced with average values at farm type level.

3.3 Expectations

As defined in equation (2), farmers are assumed to maximise their *expected* utility, that is, farmers' decision making is based on *expected* prices, yields and unit costs. The formulation of expectations for the calibration of the IFM-CAP model is based on the theory of adaptive expectations, which results in expectations being a weighted average of past observations. Expected prices, yields and unit costs are constructed at the level of the farm type or NUTS2 region. Subsequently, the individual farm-level expectation is constructed to account for farm-specific factors. In the current version of the model, the same form of expectations is used for all products. In addition, the same procedure is applied for the construction of expectations for yield and (estimated) input costs for each for the farm activities.

The adaptive expectations theory assumes that expectations are revised based on past forecasting error. This corresponds to expected prices being equal to the weighted average of past prices with geometrically declining weights (Nerlove, 1958). Alternative formulations, such as naive expectations, where expected values are set equal to the last observed prices, or future prices were considered. However, based on the available empirical literature, a statistical test based on FADN data and data limitations ([10]), a simplified version of the adaptive expectation approach was considered. This approach (i.e. covering only three periods in the past) can be applied to all products and is believed to provide the best solution for the IFM-CAP model.

Ideally, the model would generate expected prices at the individual farm level to account for farm-specific transaction costs and quality differences across farms. However, since not all activities and products are observed at all farms or in each of the past 3 years, an approach for generating farm-specific expected prices for every product is proposed. In the first step, average expected prices are generated for each farm type in each NUTS2 region, consisting of the weighted average over the past 3 years of prices at farm type level. The weights approximate geometrically declining weights, that is, recent observations get a higher weight than observations made in the past ([11]).

([10]) The empirical literature on different models of price expectations is inconclusive, without a clear preference for either backward-looking prices (naive or adaptive expectations), (quasi-)rational expectations, future prices or monthly prices (Shideed and White, 1989; Chavas, 2000; Kenyon, 2001; Nerlove and Bessler, 2001; Haile et al., 2016). Chavas et al. (1983) find that future prices may correspond better to the price formation process for some crops, but future price information is not available for all activities and farmers in all countries (Chavas, 2000), which complicates its implementation in the IFM-CAP model. In contrast, backward-looking expectations can be homogeneously constructed for all IFM-CAP farms using FADN data. We performed a simple econometric test (comparing R^2 and the root mean square error) to compare the use of different types of backward-looking expectations on the supply response of wheat and maize in the Netherlands and France. There were no significant differences in the results obtained using expectations based on past prices at the individual, farm type or regional level, naive expectations or a (weighted) combination of past prices (adaptive expectations). Therefore, our choice of the use of a simplified formula of adaptive expectations is driven mainly by pragmatic arguments related to data error and availability; using a weighted combination of farm type or regional-level prices for the last 3 years prior to the base year of 2012 allows smoothing of some potential errors in the data compared with the use of naive prices. In the current version of the model, policy-related price changes (e.g. sugar reform) that could have influenced price expectations for specific crops over the period examined are not considered.

([11]) The weights used correspond to those used in the CAPRI expectations module. They correspond to an adaptive expectations model with a correction factor of 0.55. To make sure that the sum of the weights equals 1, the weights on observations in (t–2) and (t–3) are slightly higher than would be the case if prices further back in time were included as well. This results in weights of 0.55, 0.30 and 0.15 for observations 1, 2 or 3 years ago, respectively. If only two observations of the past 3 years are available, these weights are adjusted in an ad hoc way, that is 0.67 for the more recent and 0.33 for the later observation.

In the second step, the average farm-specific deviation from the average price for that farm type is calculated for each product based on the actual farm-specific prices observed in the past (i.e. over the period 2007–2012). This deviation is then added or subtracted from the average for the farm type to obtain an individual farm-specific expected price. Note that this farm-specific deviation is assumed to remain constant over time. As such, it will not influence the expected prices in the baseline or other scenarios (i.e. each farm within the same farm level and region will experience the same absolute price change in the scenarios). Below, the different steps of the construction of the expected prices and, accordingly, yields and unit costs are described in detail.

Generation of adaptive expected prices at the farm-type level

After the exclusion of outliers in the price data, for each product the expected price at farm type level is constructed as the weighted average of prices in the past 3 years prior to the base year of 2012 (i.e. 2009, 2010, 2011). If expected prices for a farm type cannot be constructed, the expected price is calculated at NUTS2 level instead. If regional-level prices are also missing, expected prices are generated at MS level, or at EU level if needed.

For fodder crops, if information is missing form FADN or if the difference between FADN and CAPRI values is bigger than ±25 % at MS level, we use annual prices and yields at national level from the CAPRI database.

More specifically, the following forms of adaptive expectations are constructed at the farm type level for each MS, going back three periods in the past:

- o $p^e_{FTit} = \sum_{n=1}^{3} w_{t-n}\ p_{FT,i,t-n}$ with $w_{t-1} = 0.55$, $w_{t-2} = 0.30$, $w_{t-3} = 0.15$
- – where *FT* is farm type, *i* is product *t* is year and *p* is the average price for the farm type if data exist in the three successive years;
- o $p^e_{FTit} = \sum_{n=1}^{2} w_{t-n}\ p_{FT,i,t-n}$ with $w_{t-1} = 0.67$, $w_{t-2} = 0.33$
- – if data exist in only two of the three successive years, all the combinations are implemented;
- o $p^e_{FTit} = \sum_{t=2007}^{2012} p_{FT,i,t}\,/N$
- – if data exist in only one of the three years 2009, 2010 or 2012 (which occurs in only a few cases). In these cases we include as well prices from the earlier years 2007 and 2008 if available. *N* is the number of years (between 2007 and 2012) with available data.

The regional-level expected prices for each MS are calculated following a similar formula, with the index *FT* (standing for farm type) being replaced by the index *r* (standing for NUTS2 region).

Generation of farm-specific deviation from the farm-type or regional average

For each individual farm and for each product, we then calculate the farm-specific deviation from the weighted average price by year for that farm type and take the average over the all years between 2007 and 2012 for which price data are available(dev_FT_{fi}). If the farm was observed only in the 2012 sample, the deviation is based on 2012 only.

$$dev\_FT_{fi} = \frac{1}{N} \sum_{t=2007 \text{ to } 2012} (p_{fit} - p_{FTit})$$

In the same way, for each product, the average farm-specific deviation from the regional (NUTS2) average price is calculated (dev_R_{fi}). For products not produced at the farm in 2007–2012, the farm-specific deviation is set to zero.

Generation of farm-specific expectations

Finally, for each product, the farm-specific expected price is constructed as follows:

- o $p_{fit}^{e} = p_{FTit}^{e} + dev\_FT_{fi}$
- – if farm type expectations are available;
- o $p_{fit}^{e} = p_{rit}^{e} + dev\_R_{fi}$
- – if farm type expectations are missing but expectations are available at the NUTS2 level;
- o $p_{fit}^{e} = p_{MSit}^{e}$
- – if both farm type and NUTS2 expectations are missing;
- o $p_{fit}^{e} = p_{EUit}^{e}$
- – if, at MS level, expectations are also missing.

For the baseline and simulation scenarios, the formulation of expectations is based on projected prices and yields, to which the individual farm-specific deviation is applied according to the formulas above.

3.4 Extraction rules for subsidies

The current version of the IFM-CAP model fully relies on subsidy data available in FADN for base year of 2012. The FADN (and therefore also IFM-CAP) covers both coupled and decoupled CAP payments. The *coupled payments* for crops (SUBCRO) include compensatory payments for annual and permanent crops (SUBCRO_COP), set-aside (SUBCRO_SETA), other specific crop payments (SUBCRO_OTHER) and other coupled subsidies (SUBART) ([12]). The *decoupled payments* (SUBDEC) include the SPS ([13]) (DPSFP) and the Single Area Payment Scheme (DPSAP), as well as additional aid (DPAID). The rural development subsidies included in the model are LFA (less favoured area) payments and agri-environmental schemes (AES). In addition, coupled and decoupled Complementary National Direct Payments (CNDP) are also considered (Table 3 and Table 4).

Table 3. Extraction rules for payments from Tables J and M in FADN

Categories of grants and subsidies	GAMS abbreviation for subsidy positions	FADN table	Extraction rule for each category of grants and subsidies
Coupled payments	**SUBCRO**	**J+M**	
Compensatory payments per area	SUBCRO_COP	M	M(602CP...614CP)+ M618CP+M(622CP...629CP)+ M(632CP...634CP)+M638CP+M655CP
Set-aside premiums	SUBCRO_SETA	M	M650CP
Other crop payments	SUBCRO_OTHER	J	JC(120...145)+JC146+JC(147...161)+JC 185+ JC(281...284)+JC(296...301)+ JC(326...357)+JC(360...374)+JC952+JC 924+JC925
Art. 68 subsidies	SUBART	J	JC956
Decoupled payments	**SUBDEC**	**J**	**JC670+JC680+JC955**
Single farm payment	DPSFP	J	JC670
Single area payment	DPSAP	J	JC680
Additional aid	DPAID	J	JC955
Rural development payments	**SUB_RUR**	**J**	
Agri-environmental subsidies	ENV_AEAWP	j	JC800

([12]) The extraction rules for the subsidies have partially followed those implemented in FADNTOOL (Neuenfeldt and Gocht, 2014). Other coupled subsidies include those granted under the Article 68 of Regulation (EC) No 73/2009.

([13]) Often referred to as the Single Farm Payment.

Less favoured area payments	LFA_HANDICAP	j	JC820
Decoupled CNDP	**SUB_DCNDP**	**J**	**JC950**

*Bold indicates an aggregation of subsidies

Coupled crop payments are distributed between eligible crops ([14]). They are calculated per hectare for each eligible activity based on area shares in the total eligible area. This means that, in cases where there is more than one activity benefiting from the payment (e.g. DPCER), subsidies are distributed over all eligible activities using the area shares. In the special case when all eligible activities have 'zero' area in the database, the payment is distributed to all farm activities using the area shares as the distribution key.

In the livestock sector, four types of coupled animal payments are considered: dairy subsidies (SUBLIV_DAIR), other cattle subsidies (SUBLIV_OTCA), sheep and goat subsidies (SUBLIV_SHGO) and other livestock subsidies (SUBLIV_OTHER). Given that these subsidies are distingushed by livestock type (cattle, sheep and goats, etc.) and animal catgeory (cows, heifers, male cattle, etc.), they are calculated per head. As in the arable sector, they are distributed over eligible animal activities based on the share of each eligible activity in the total number of animals benefiting from these payments. Table 4 summarises the rules used for the extraction of animal subsidies from FADN.

For the decoupled payment (i.e. SUBDEC), we calculate the payment value in each farm on the basis of the received decoupled aid and the number of eligible hectares. All the eligible area in each single farm receives a uniform per hectare decoupled payment (Table 3).

([14]) The crop and livestock activities benefiting from each payment (and by year) are specified in Table A-3 in Annex A.

Table 4. Extraction rule for coupled animal payments

Subsidies in FADN	GAMS abbr.	GAMS abbr.	Description	Extraction rule
Dairying	SUBLIV_DAIR	DPDCOW	Direct payments for dairy cows	M770CP
		JCDOW	Other payments for dairy cows	JC30+JC32+JC163
		JCARTDAIR	Art. 68 payments for dairy livestock	JC921
Other cattle	SUBLIV_OTCA	DPBULF	Special premiums for bulls and steers	M710CP
		DPSCOW	Direct payments for suckler cows	M731CP
		DPNE_MEAT	Additional payments for bovine meat cattle	M735CP
		DPSL_ADCT	Slaughter premium for adult cattle	M742CP
		DPSL_CALV	Slaughter premium for calves	M741CP
		DPADDPNA	Additional payments (national envelope)	M760CP
		DPEXTENS	Extensification payments for bulls, steers and suckler cows	M750CP
		JCBULF	Payments for bull fattening	JC25+JC27
		JCSCOW	Payments for suckler cow	JC32
		JCHEIR	Payments for heifers raising	JC26+JC28
		JCHEIF	Payments for heifers fattening	JC29
		JCCAR	Payments for calves raising	JC24
		JCCAF	Payments for calves fattening	JC23
		JCCATT	Payments for cattle	JC52+JC307
		JCOCAT	Other payments for other cattle	JC31
		JCARTOTCA	Art. 68 payments for other cattle	JC922
Sheep and goats	SUBLIV_SHGO	JCSHGO	Payments for sheep and goat fattening	JC54+JC55

		JCSHGM	Payments for sheep and goat milk	JC38+JC40+(JC164….JC168)
		JCARTSHGO	Art. 68 payments for sheep and goats	JC923
Other livestock	SUBLIV_OTHER	JCPIGF	Payments for pig fattening	JC45+JC46
		JCPIGS	Payments for pigs and sows	JC309+JC56
		JCSOWS	Payments for sows	JC44
		JCHENS	Payments for hens	JC48+JC169+JC43
		JCPOUF	Payments for poultry	JC47+JC49+JC310
		JCPOU	Payments for hens and poultry	JC57
		JCOANI	Payments for other animals	JC50+JC58
		JCOTHLI	Other payments for livestock	JC951+JC170+JC171+JC311
		JCARTOTLI	Art. 68 payments for other livestock	JC926

4 Estimation of input unit costs

FADN collects the monetary value of crop inputs, livestock inputs and other farm costs (e.g. overheads, depreciation, hired labour costs and interest costs) at farm level. However, information on how these aggregate costs are distributed over specific farm activities is not recorded. Starting from the reported farm-level aggregate input costs, we therefore estimate activity-specific unit input costs using a Bayesian econometric approach for all crop activities. The resulting estimated accounting unit costs for **K** input categories (seed, fertiliser, plant protection and other specific costs) are directly incorporated in the model's objective function (2).

4.1 Leontief technology specification for intermediate inputs

For the estimation of input costs, we assume a linear Leontief technology for intermediate inputs (i.e. different inputs increase proportionally to each other and increase linearly with production activity levels). This form of input demand equation has been assumed widely in the literature (e.g. Léon et al., 1999; Kleinhanss, 2011). This allows us to link production activities and total physical input use. However, the rigid technology assumption and the non-consideration of, for example, soil quality and crop rotation effects in input use can have serious limitations. One common way to handle these problems and make the technology set more flexible, without departing from the Leontief specification, is to include activities with discretely varying input intensities.

Hence, input allocation is assumed to display the following linear relationship to output:

$$\mathbf{z} = \mathbf{H}\mathbf{v} + \mathbf{u} \tag{4}$$

where **z** is the (K × 1) vector of input costs, **v** is the (N × 1) vector of total value of outputs, **H** is an (N × K) matrix of unknown input–output coefficients and **u** is the (K × 1) vector of random errors.

This relationship can be expressed by farm and input category as follows:

$$z_{f,k} = \sum_i H_{i,k} v_{f,i} + u_{f,k} \tag{5}$$

where $z_{f,k}$ is the total (explicit) cost of variable input k (k = 1,…, K) for farm f (f = 1,…, F) recorded in FADN, $v_{f,i}$ is the total value of output i (i = 1,…, N) for farm f, $H_{i,k}$ is the expenditure on input k required per unit of output value i and $u_{f,k}$ is a random disturbance term that is specific to each input category and to each farm (Errington, 1989). It is assumed that farms within the same NUTS2 region and the same farm type have a common technology and therefore the same input–output coefficients $H_{i,k}$ (i.e. the index for farm types is omitted here).

To ensure that the accounting balance between total revenue and total cost is respected, the following accounting restriction is imposed for each output i:

$$\sum_k H_{i.k} = 1 \tag{6}$$

Following Léon et al. (1999), this is achieved by introducing a residual input category 'value added' with corresponding monetary input coefficients equal to the difference between the total revenue and the sum of all other monetary input coefficients across input categories. Similarly to other input categories, value added is restricted to be positive, assuming that, for each type of output *i* averaged (across all farms), total cost cannot exceed total revenue.

4.2 Highest posterior density estimation

To select the most accurate method for estimating the unknown input–output coefficients $H_{i,k}$, we have tested several alternative estimation approaches for a sample of 565 farms in a region in France for which details on activity-level input costs were recorded. We aggregated the crop-specific input costs at farm level and tested the performance of different methods including seemingly unrelated regressions (SUR), entropy and HPD estimation in recovering the true disaggregated crop-specific input costs (for details on these alternative estimation approaches and their performance, see Colen et al., 2014). As prior information for the entropy and HPD approach, we propose the use of the results of the input allocation key developed by DG AGRI and we compare this to alternative priors that were proposed in earlier studies. The key allocates total accounting costs to individual output activities based on the share of activity output value in total output value (for details see Table A-4 in Annex A). Several accuracy criteria showed that the HPD approach, using the inputs allocated according to the input allocation key as prior information, has the best performance. HPD has also a significantly lower computational demand, which is non-negligible given the large sample of individual farms in the IFM-CAP model.

Hence, we estimate the input–output coefficients **H** by NUTS2 region and farm type, using the HPD approach and prior information $\bar{\mathbf{H}}$ based on the input allocation key developed by DG AGRI. The HPD approach minimises the normalised least square deviation between the estimated input–output coefficients and the prior information. This Bayesian approach was proposed by Heckelei et al. (2005) as an alternative to entropy methods for deriving solutions to underdetermined systems of equations. They argued that the main advantage of this approach is that it allows a more direct and straightforward interpretable formulation of available a priori information and a clearly defined estimation objective. In the HPD estimation, the model parameters are treated as stochastic outcomes. In this context, the method distinguishes between the prior density **p(H)**, which summarises a priori information on parameters, and the likelihood function **L(H|v)**, which represents information obtained from the data in conjunction with the assumed model. The combination of the prior density and the likelihood function results in a posterior density (e.g. Zellner, 1971, p. 14), which can be expressed as:

$$\mathbf{z(H|v)\propto(p(H)L(H|v))} \qquad (7)$$

where **z** denotes posterior density, ∝ is the proportionality, **H** are the parameters to be estimated and **v** is the vector of observations. This approach is extensively discussed in Heckelei et al. (2008). This leads to the following estimation problem:

$$Min\ HPD = [vec(\mathbf{H}-\bar{\mathbf{H}})]' \sum^{-1} [vec(\mathbf{H}-\bar{\mathbf{H}})]$$

Subject to: (8)

$$\mathbf{z} = \mathbf{Hv} + \mathbf{u}$$

$$\mathbf{I'H} = \mathbf{1}$$

where $\bar{\mathbf{H}}$ contains the prior values and HPD is the prior density function of the form vec(H) ~ N(vec($\bar{\mathbf{H}}$),Σ). The prior values $\bar{H}_{i,k}$ are the mean input–output coefficients by NUTS2 region and farm type, obtained through DG AGRI's input allocation key (see Table A-4). The covariance matrix Σ is set equal to a diagonal matrix with, as elements, twice the variance of the input–output coefficients obtained from the input allocation key method, $(2\sigma^H)^2$. For the error term **u**, we use a prior density function of the form N(0,Σ), with prior mean zero and with twice the squared standard deviation of the error $(2\sigma^{u})^2$ as elements of the diagonal covariance matrix. For more details, refer to Annex A.

The solution of this optimisation problem provides estimates for the unknown input–output coefficients $H_{i,k}$ for each region and per farm type and for the error term $\boldsymbol{u}$.

This approach does not ensure that all input costs are fully distributed over all activities. Therefore, for each farm, we allocate the remaining non-distributed costs proportionally across the different activities, leading to a farm-specific corrected input–output coefficient $\widetilde{H}_{f,i,k}$. These corrected input–output coefficients ensure that aggregate input costs are completely distributed and improve the accuracy of input cost estimates further (see Colen et al., 2014). Based on these corrected coefficients, $\widetilde{H}_{f,i,k}$, and the value of production per observed activity level, $\boldsymbol{v_{f,i}/x^0_{f,i}}$, the unit input costs of the matrix **C** (K × N), that is, the input costs per hectare of activity *i*, which can be calculated as follows:

$$\widetilde{H}_{f,i,k} = H_{i,k} \frac{z_{f,k}}{\sum_i H_{i,k} v_{f,i}} \tag{9}$$

$$z_{f,k} = \sum_{i=1}^{n} \widetilde{H}_{f,i,k} v_{f,i} = \sum_{i=1}^{n} C_{f,i,k} x^0_{f,i} \tag{10}$$

Hence,

$$C_{f,i,k} = \widetilde{H}_{f,i,k} \frac{v_{f,i}}{x^0_{f,i}} \tag{11}$$

This HPD approach is used to obtain estimated input unit costs per activity for each farm and for each year from 2007 to 2011. Based on the resulting estimated input costs, the expected inputs costs for 2012 is constructed using the same procedure as for calculating expected prices and yields (i.e. adaptive expectations with declining weights) that is described above (section 3.3).

5 Estimation of sugar beet quota

The common market organisation for sugar was subject to production controls implemented by a system of supply quotas before 2017. The sugar quotas were defined for each MS, which allocated the quota to sugar refineries, which in turn allocated 'delivery rights' to individual farms. The quota specified the amount of 'quota beet' (in-quota sugar beet) that farms could deliver at supported prices. Any quantities sold beyond the quota (out-of-quota sugar beet) had to be sold at international prices and thus received a lower price than the in-quota beet production (Agrosynergie, 2011; European Commission, 2013; Burrell et al., 2014).

To model the sugar quota system in IFM-CAP and capture its effects on farm behaviour, we need information on in- and out-of-quota sugar beet production and prices at farm level. The FADN provides data on sugar beet area (K131AA), total sugar beet production (K131QQ) ([15]), average sugar beet price (p) (K131TP/K131QQ) and sugar beet in-quota quantity (L421I). Although data on sugar beet quota (L421I) are available for several MS in the time series 2007–2012 (i.e. Austria, Belgium, Germany, Greece, Lithuania, Netherlands, Poland, Romania, Spain, Sweden and the UK), their quality needs to be considered carefully. In only two MSs, namely Belgium and Germany, is the ratio between the reported MS sugar quota (DG AGRI, 2014) and the quota in FADN (aggregated at MS level using the farm weights for the average year) within the reasonable range, that is, between 0.5 and 1.5 for the whole time series, as shown in Table 5. This implies that the data for in-quota prices, sugar beet quota, and out-of-quota prices, which are indispensable for the modelling of quota regime in IFM-CAP, cannot be fully recovered from FADN and need to be estimated and/or extracted from other data sources. Other potential data sources available for the entire EU that can supplement the FADN data include FSS and DG AGRI (see Table A-6 in Annex A).

Table 5. Ratio between DG AGRI reported sugar quota and that reported in FADN

MS	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
AT	1.14	1.54	132.13	159.99	175.70	160.29
BL	1.02	1.20	1.28	1.14	1.21	1.18
DE	0.89	1.07	1.25	1.19	1.40	1.21
EL	0.00	0.00	n.a	n.a	n.a	n.a
ES	0.78	0.84	0.92	0.05	0.05	0.04
LT	1.29	0.76	1.66	1.51	1.48	1.37
NL	0.13	0.14	0.16	0.17	0.17	0.18
PL	0.17	0.34	0.97	0.87	0.93	0.93
RO	0.01	0.00	n.a	n.a	n.a	n.a
SE	0.16	0.23	0.36	0.18	0.19	0.15
UK	0.91	1.11	1.08	1.11	1.25	1.59

Table A-7 (in Annex A) provides a comparison of the (weighted) FADN data with the FSS data for the production of sugar beet in 2007–2012. On average, FADN reports higher values than FSS by around 4 %, implying that sugar beet is over-represented in the FADN sample compared with the total population. There are some MSs in which this difference is very large. For example, in Spain and Romania, the sugar beet area in FADN is 83 % and 175 % higher, respectively, than in FSS. Other MSs with a large deviation are Finland, Latvia, Sweden and the UK ([16]).

([15]) The reported quantity is net of sugar beet tops.

([16]) The sugar beet area reported in the balance sheet of sugar production by DG AGRI (DG AGRI, 2014) is lower than the area reported in FSS and FADN. For example, the total area in MSs (for those with quota) reported by DG AGRI for the marketing year 2010/2011 is 1 519 thousand hectares, while in FSS and FADN the total area is 1 631 and 1 950 thousand hectares, respectively. The difference between the FSS

Owing to this data limitation, we attempted to estimate the farm-level sugar beet quota production using time-series data from 2007 to 2012. Following Adenäuer (2005), we employ the HPD estimation approach to estimate the in- and out-of-quota sugar beet production and prices, as well as the farm-specific sugar quota in each single FADN farm producing sugar beet ([17]).

The HPD approach minimises the weighted sum of normalised squared deviations between the estimated key variables and their respective priors, subject to a set of data consistency constraints. The estimated key variables are the in-quota sugar production and prices at farm level and the in-quota and out-of-quota sugar prices at MS level. All the farm-specific components are weighted with the proportion of the sugar farm in the sugar farm population to obtain a weighted average normalised squared deviation at MS level, $\omega_f = w_f / \sum_f w_f$, where w_f is the farm weighting factor reflecting the number of sugar farms in the MS sugar farm population that is represented by farm *f*.

The prior information for the unknown parameters is defined as follows: for the share of farm in-quota production in total sugar production, we set the prior mean equal to the national share of in-quota sugar production reported by DG AGRI in the total sugar production derived from Eurostat (q_{ms}). The standard deviation is assumed to be 20 % of the mean. For MS in-quota and out-of-quota sugar beet prices ($\overline{p^q}$ *and* $\overline{p^w}$), we set the prior mean equal to EU average prices, which are, respectively, EUR 30 and EUR 20/tonne ([18]). These prices are derived from Agrosynergie (2011) ([19]). The same ratio between in-quota and out-of-quota sugar beet prices as that given in Agrosynergie (2011) was assumed (i.e. the in-quota sugar prices are, on average, higher than out-of-quota prices by a factor of 1.5) ([20]). The standard deviation (σ^{p^q}) is assumed to be 20 % of the mean for both prices (i.e. EUR 6 and EUR 5/tonne for in-quota and out-of-quota sugar beet prices, respectively). For the price correction factors ($\overline{c^q}$ and $\overline{c^w}$), we set the prior mean equal to zero, since the aim was to obtain farm prices close to the MS prices and a standard deviation equal to EUR 5/tonne following Adenäuer's (2005) assumption.

Table 6. Design of the higher posterior density approach

Prior	$N(\overline{s^q}, (\sigma^{s^q})^2)$	$N(\overline{p^q}, (\sigma^{p^q})^2)$	$N(\overline{p^w}, (\sigma^{p^w})^2)$	$N(\overline{c^q}, (\sigma^{c^q})^2)$	$N(\overline{c^w}, (\sigma^{c^w})^2)$
Design	$N(\frac{q^q_{ms}}{q_{ms}}, (0.2\frac{q^q_{ms}}{q_{ms}})^2)$	*N*(30, 6)	*N*(20, 5)	*N*(0, 5)	*N*(0, 5)

The general formulation of the HPD approach is presented as follows ([21]):

and DG AGRI data arises because the former data include only sugar (or the sugar equivalent of sugar beet) produced under the quota system (i.e. in-quota and out-of-quota sugar), whereas the latter includes also other types of sugar (e.g. the sugar equivalent of sugar beet used for feeding livestock). The reason why the sugar beet data differ between FSS and FADN is that, by construction, FADN is not representative of sugar beet production, but its representativeness is based on the number of farms in a specific farm typology (specialisation and economic size) and FADN region. Moreover, the FADN sample covers only commercial farms.

([17]) Note that only farms with yields and prices that are within the bounds of the interquartile range (after excluding outliers and negative and missing values) are used in HPD estimations.

([18]) Results on prices are presented for sugar beet, while production relates to sugar (unless otherwise stated in the text). The sugar content per beet (in %) per year and MS is used for converting results from sugar to sugar beet.

([19]) The effective in-quota sugar beet EU prices reported by Agrosynergie (2011) for the years 2007, 2008 and 2009 are EUR 30.1, EUR 30.6 and EUR 33.7 per tonne, respectively. As there is no information for the following years, EUR 3 per tonne has been assumed for the whole time series.

([20]) The in-quota sugar prices were EUR 606, EUR 565, EUR 483 and EUR 496 per tonne for the years 2007, 2008, 2009 and 2010, respectively. The out-of-quota sugar prices can be approximated with the 'industrial sugar' prices, which were EUR 271, EUR 298, EUR 324 and EUR 332 per tonne for the years 2007, 2008, 2009 and 2010, respectively. These prices are lower than the world prices, which were equal to EUR 211, EUR 285, EUR 399 and EUR 463 per tonne for the corresponding years (Agrosynergie, 2011).

([21]) For simplicity, indices for time (years) are omitted.

$$\mathbf{Min}\sum_{MS}\left[\omega_f\frac{\left(\mathrm{s}_{\mathrm{f}}^{\mathrm{q}}-\overline{s^q}\right)^2}{\left(\sigma^{s^q}\right)^2}+\frac{\left(p_{ms}^q-\overline{p^q}\right)^2}{\left(\sigma^{p^q}\right)^2}+\frac{\left(p_{ms}^w-\overline{p^w}\right)^2}{\left(\sigma^{p^w}\right)^2}+\omega_f\frac{\left(\mathrm{c}_{\mathrm{f}}^q-\overline{c^q}\right)^2}{\left(\sigma^{c^q}\right)^2}+\omega_f\frac{\left(\mathrm{c}_{\mathrm{f}}^w-\overline{c^w}\right)^2}{\left(\sigma^{c^w}\right)^2}\right]$$

$$q_f = q_f^q + q_f^w \quad (12)$$

$$p_f q_f = p_f^q q_f^q + p_f^w q_f^w \quad (13)$$

$$s_f^q = q_f^q / q_f \quad (14)$$

$$Q_f = q_f^q + u_f^q \quad (15)$$

$$p_f^q = p_{ms}^q + c_f^q \quad (16)$$

$$p_f^w = p_{ms}^w + c_f^w \quad (17)$$

$$p_f^q \geq 26.29 \quad (18)$$

$$p_f^q \geq p_f^w \quad (19)$$

$$u_f^q q_{f=0}^w \quad (20)$$

$$u_f^q < q_f^q \quad (21)$$

where $\boldsymbol{f}$ indexes farm, $\boldsymbol{ms}$ indexes MS, $\boldsymbol{q_f}$ is the farm sugar production, $\boldsymbol{q_f^q}$ and $\mathbf{q_f^w}$ are, the farm in-quota and out-of-quota sugar production (in tonnes), respectively, $\boldsymbol{Q_f}$ is the farm sugar quota, u_f^q is the underdelivery of sugar quota, $\boldsymbol{s_f^q}$ is the share of farm in-quota production in total sugar production, $\boldsymbol{p_f}$is the average farm sugar price (derived from the FADN), $\boldsymbol{p_{ms}^q}$ and $\boldsymbol{p_{ms}^w}$ are the MS in-quota and out-of-quota sugar prices, respectively, which are adjusted at farm level by the correction factors $\boldsymbol{c_f^q}$and $\boldsymbol{c_f^w}$to obtain the farm-level in-quota and out-of-quota sugar prices $\boldsymbol{p_f^q}$ and $\boldsymbol{p_f^w}$, respectively, and $\boldsymbol{w_f}$ and $\boldsymbol{\omega_f}$ represent the number and the proportion of farms in the overall population, respectively.

Equation (12) ensures that the sum of farm-specific in-quota and out-of-quota sugar production is equal to the observed farm sugar beet production. Equation (13) is used to balance the observed sugar beet revenue reported values in FADN and the estimated value. Equation (14) calculates the share of in-quota production, while equation (17) sets the relation between sugar quota endowment and quota production (due to the underdelivery of sugar quota). Equations (12) and (17) set the farm-specific sugar prices equal to the MS's average price adjusted by a farm-specific correction term for both in-quota and out-of-quota sugar beet ([22]). Equation (18) constrains the in-quota sugar beet price to be higher than the minimum farm gate price set in the EU regulation (i.e. EUR 26.29/tonne) ([23]), while equation (19) sets the constraint that the out-of-quota sugar price cannot be higher than the in-quota price. Equations (20) and (21) ensure that the out-of-quota sugar price cannot be higher than the in-quota sugar price and that the underdelivery of quota is lower than the farm sugar quota.

The variables to be estimated at farm level per year are $\boldsymbol{Q_f^q}$, $\boldsymbol{q_f^q}$, $\boldsymbol{q_f^w}$, $\boldsymbol{p_f^q}$, $\boldsymbol{p_f^w}$, $\boldsymbol{c_f^w}$, $\boldsymbol{c_f^q}$, and $\boldsymbol{u_f^q}$, while the variables $\boldsymbol{p_{ms}^w}$ and $\boldsymbol{p_{ms}^q}$ are estimated at MS level.

Note that sugar beet prices received by farms might be affected by other sugar-sector-related factors such as the price of sugar substitutes (e.g. isoglucose), the downstream supply chain (bioethanol, sugar processing) and sugar trade policies (e.g. tariff rate quotas) (Burrell et al., 2014). All these factors are omitted in this estimation because of data limitation. However, they may be captured indirectly through the price wedge that they may cause between the in-quota and the out-of-quota sugar beet.

Table 7 provides an accuracy test for the HPD estimated results for Belgium/Luxembourg (BL) and Germany (DE) − the two MSs for which the FADN quota data appear to be reasonable (i.e. the ratio between the FADN and the reported and DG AGRI quota is between 0.5 and 1.5) − using ordinary least squares (OLS) regression. The table provides the slope and the R^2 for the estimated linear model between the FADN reported in-quota production and the estimated in-quota production by year and for the pooled years.

Table 7. Estimated IFM-CAP in-quota sugar beet production versus FADN reported quota

Year	Slope		R-squared	
	BL	DE	BL	DE
2007	0.951	0.791	0.908	0.678
2008	0.962	0.862	0.953	0.789
2009	1.063	0.922	0.961	0.759
2010	0.962	0.934	0.965	0.423
2011	1.003	1.072	0.963	0.440
2012	1.028	0.933	0.936	0.637
Overall	0.993	0.923	0.943	0.548

Note: OLS regression results for the linear model, where *FADN reported quota = slope*IFM-CAP estimated in-quota production + error.*

The R-squared value indicates the goodness-of-fit of the OLS regression. A value of the slope or R-squared value close to 1 indicates a close similarity between the actual and estimated in-quota production, whereas a value close to zero suggests the reverse. The overall R-squared value is very similar to that for Belgium, indicating that the variance in sugar beet in-quota production is explained largely by the linear regression model. In Germany, the R-squared value is only 0.55 owing to the low level of correlation between total production and in-quota production in FADN (i.e. R-squared of the estimated linear

([22]) The sugar industry is very concentrated, and seven of the biggest alliances control nearly 90 % of the production quota (Benešová et al., 2015). Therefore, it is assumed that in-quota prices are similar across MSs.

([23]) This price for the campaign years 2007/08 and 2008/09 was EUR 27.78 and EUR 27.83 per tonne, respectively.

model between the total FADN production and the in-quota FADN production is 0.49 for Germany, while, in the case of Belgium, it is 0.94; not shown in Table 7).

6 Modelling livestock activities

6.1 Literature review on modelling livestock activities at farm level

Livestock production systems are complex systems composed of biological, economic, environmental, social and behavioural elements. The main components of livestock production systems can be grouped under four main categories: (i) biological processes; (ii) herd demography/dynamic; (iii) livestock–crop interactions that consists of (a) feeding, grazing and nutritional demand and supply, and (b) manure production and application; and (iv) economic behaviour of the farmers or farm managers. Incorporating these four elements in models along with their interactions is crucial in accurately capturing the behaviour of the whole livestock system.

Among these elements, inclusion of herd demography in models, particularly in static optimisation models, is challenging. An important reason for this is that characteristics of the livestock life cycles make the production activities highly interlinked and dynamic processes; changes in one component can affect the other components of the livestock production systems. Moreover, explicit modelling of herd demography and its dynamic requires detailed data and information on various technical and biological parameters of livestock systems that are often not accessible for a broad range of farming systems. Two main types of models that are used in mathematical programming literature and have attempted to incorporate livestock activities and their demography/dynamic are biophysical models and economic models. These model types are briefly introduced and discussed below.

Biophysical models

Biophysical models usually attempt to identify optimal farm practices by endogenously defining biological parameters such as animal replacement rate, lactation length, slaughter weight, milk yield, etc. Herd dynamic is featured in many biophysical models (e.g. Gartner, 1982; Kristensen, 1992; Koots and Gibson, 1998; Nielsen et al., 2005; Cabrera, 2012; Kalantari et al., 2014). At the core of biophysical models are specific livestock categories for which herd dynamic and optimal management choices are analysed. For example, key parameters determining herd dynamic in dairy cow models are replacement decisions and reproductive performance of the herd. Both parameters are key drivers of how the herd evolves over time and have a significant impact on the productivity and profitability of dairy farming.

The typical and most widely used biophysical models are single-component models that consider only one animal category, such as dairy cows, suckler cows, breeding sows or breeding sheep, whereas other on-farm livestock categories are treated in a simplified way, for example by assuming unlimited supply of replacement heifers and sale of calves after calving in dairy cow models (Nielsen et al., 2005; Cabrera, 2012; Kalantari et al., 2014). Extensions of the single-component models consider multiple livestock categories that are regarded as multiple-component models (Gartner, 1982; Kristensen, 1992; Koots and Gibson 1998). The structure of the herd is endogenous in biophysical models and the model parameters determine the optimal herd demography. Livestock categories are defined by a set of characteristics (e.g. lactation period, milk production level, calving period, weight, etc.) and often define management practices used to identify optimal choices in a particular production system.

Economic models

In contrast to biophysical models, in economic models all or the majority of the parameters (e.g. lactation period, milk production level, calving period, weight, etc.) are exogenously determined and therefore productivities of different animal categories are exogenously defined. Explicit modelling of herd dynamic of individual farms in economic models also poses challenges, as it requires detailed information on various technical parameters of livestock systems. The central element in many economic models that incorporate livestock dynamic is animals' reproductive characteristics. For example, replacement rate is the key parameter that determines the herd dynamic of dairy and breeding suckler cow systems. A common assumption in many economic models is that cows are replaced by heifers raised on the farm (e.g. Lelyon et al., 2010). Some models also allow for purchase of replacement heifers alongside their own raised heifers (Veysset et al., 2005). Other livestock categories are derived from the number of cows based on reproductive performances of the herd. This is defined either exogenously by parameters such as calves per cow (i.e. shares) or cow replacement rate or endogenously by management practices. Another important management decision determining the herd dynamic is the choice of sales and purchases of different livestock categories.

This modelling approach implies that the demography of reproductive animals (e.g. dairy or breeding suckler cows) is fully endogenous, whereas the rest of the livestock activities can vary from being fully exogenous to fully endogenous. The herd composition and size are co-determined by the herd reproductive performance (e.g. cow replacement rate, calf per cow, etc.) and animal sale and purchase decisions. One possible extreme situation is when sale and purchase activities are not modelled, implying that all non-cow livestock categories (i.e. demography) are exogenous and are determined exclusively by the number of adult cows observed by the herd reproductive performance (Thorne et al., 2009). The other extreme situation is when sale and purchase activities are allowed for all livestock categories. In this case, the herd composition is fully endogenous and depends on the relative return of various livestock activities. Between these two extreme situations, there are many possibilities for partially endogenous herd dynamics. In fact, most of the applied economic models consider partially endogenous herd dynamics. The type of livestock farm modelled largely defines the behaviour of herd dynamic and possible livestock activities. The static characteristics of many economic models reflect the steady-state equilibrium of the modelled farms. The equilibrium solutions reflect the full adjustments of herd demography to the simulated economic and policy shocks.

Economic models can be categorised under normative and positive approaches. Our literature review showed that the normative approach is the dominant approach used in farm-level economic modelling. Examples of these two approaches are presented below.

Normative models

Normative models usually refer to linear programming models typically result in a wide divergence between the simulated results of considered activities, including livestock numbers and the on-farm observed values. The inclusion of a risk term may improve the model performance, but still may not fully reproduce the actually observed activity level. Despite this weakness, there are many applications of normative models, including livestock modelling. The main focus of these models is on analysing the difference between the simulated scenarios rather than on the accuracy of reproducing the observed livestock activities in the baseline simulations.

From the methodological point of view of incorporating livestock herd dynamic in mathematical programming models, normative models tend to explicitly represent the herd dynamic. They often explicitly represent intergenerational dependences or links and the flows between different livestock categories as well as herd reproduction parameters, such as cow replacement rate, that are key drivers of livestock herd dynamism (e.g. Nicholson et al., 1994; Ramsden et al., 1999; Visagie and Ghebretsadik, 2005; Ducros et al., 2005; Veysset et al., 2005; Havlík et al., 2006; Crosson et al., 2006; Acs et al., 2010; Lelyon et al., 2011; Jones and Salter, 2013). The main characteristics of the normative models used in the cited studies are summarised In Annex B.

Positive models

PMP has been the preferred method of many scientists and policy makers in calibrating models that generate precisely the actually observed activities and outcomes for farmers. In other words, PMP assumes that farmers' choice of combination of activities is optimal. This provides a reliable tool to simulate policy scenarios and predict future changes. Although the PMP approach does not require an explicit representation of the herd dynamic or management practices regarding the sale and purchase activities for different animal categories, the use PMP for livestock activities may not be as straightforward as for other activities, such as crops. An important reason for this is the intergenerational dependences or the linkages between adult animals and their youngstock, which may be retained to replace the breeding animals or may be sold in the market. As stated earlier, most of the livestock systems and related herd demography follow a cyclical pattern that implies the importance of dynamism in these systems. Incorporating this dynamism into static PMP models such as IFM-CAP, therefore, requires certain considerations and assumptions. The main characteristics of the positive models reviewed for the purpose of further development of IFM-CAP model are summarised Annex B.

6.2 Modelled livestock activities in IFM-CAP

In the current version of the IFM-CAP, as in the approach used in modelling crop activities, PMP terms have been estimated for each livestock category, that is, adult animals and their youngstock separately, without explicitly modelling intergenerational dependences. All livestock activities, therefore, are endogenously determined by the model. The advantage of this approach, compared with the earlier version of the IFM-CAP (where the numbers of young animals were determined by shares of adult animals), is that the number of youngstock is not fully dependent on the number adult animals; this can, therefore, represent real farm management practices. A potential disadvantage, however, may be that the simulated effects for the livestock sector will depend mainly on the sale and purchase prices of animal outputs and this may not reflect the livestock management systems actually practised by farmers. As a result, it may be possible for the model to react differently from the patterns observed in reali, for example drastically reducing the number of young animals. We envisage that this is not likely to be the case, but, if this behaviour were observed, then an additional constraint linking adult and young animals will be added and their levels (i.e. shares of youngstock) will be introduced exogenously to adults. In the current version of the model, sale and purchase activities of various livestock categories are not explicitly modelled and therefore these are implicitly captured by PMP terms for each activity (i.e. only animal products can be sold).

6.3 Definition of livestock activities and outputs

Four categories of livestock activities are modelled in IFM-CAP: cattle (dairy and beef), pigs, small ruminants (sheep and goats) and other animals. For certain categories (e.g. cattle and small ruminants) two different systems can be considered: raising and fattening systems.

FADN data are used to identify the predominant livestock activities across regions of the EU. Table 8 describes the set of livestock activities included in IFM-CAP and the rules used for extracting their numbers (i.e. activity level) by animal category from FADN (Table D) for the base year period. The set of livestock outputs modelled in IFM-CAP are the following: beef, cow milk (for feeding and sales), milk from sheep and goats (for feeding and sales), meat from sheep and goats, poultry meat, pork and young animals (male and female calves and piglets). Table 9 presents the list of livestock outputs and the rules used to define their coefficients. For some outputs, such as cow milk and beef, the coefficients are derived by dividing production by activity levels, and for some other outputs these coefficients are computed using animal numbers, such as numbers of young animals.

Table 8. Extraction rules for herd sizes for livestock activities from Table D in FADN

Production activity	IFM-CAP acronym	FADN Table	Extraction rule
Cattle	**ACAT**		
Dairy cows	DCOW	D	30AV
Heifers breeding	HEIR	D	28AV + MIN(26AV,28AV)
Raising male calves	CAMR	D	MAX(0,(24AV-28AV))
Raising female calves	CAFR	D	MIN(28AV,24AV)
Other cows	SCOW	D	32AV
Heifers fattening	HEIF	D	29AV + MAX (0,26AV-28AV)
Male adult cattle	BULF	D	25AV + 27AV
Fattening male calves	CAMF	D	0.5*23AV
Fattening female calves	CAFF	D	0.5*23AV
Pigs	**APIG**		
Pig fattening	PIGF	D	45AV + 46AV
Pig breeding	SOWS	D	44AV
Goats and sheep	**ASAG**		
Milk ewes and goats	SHGM	D	38AV + 40AV
Sheep and goat fattening	SHGF	D	39AV + 41AV
Other animals	**AOAN**		
Laying hens	HENS	D	48AV/1 000
Poultry fattening	POUF	D	(47AV + 49AV)/1 000
Other animals	OANI	D	50AV+ 22AV

Source: own elaboration based on FADNTOOL (Neuenfeldt and Gocht, 2014).

Table 9. Definition of output coefficients for livestock activities

Output (animal product, young animal)/adult livestock activity	**GAMS abbreviation for animal activity**	**Adult livestock output abbreviation**	**Extraction rule**
Female calves produced/dairy cow	DCOW	YCAF	0.5*N24SN*(DCOW/(DCOW+SCOW))/DCOW
Male calves produced/dairy cow	DCOW	YCAM	0.5*N24SN*(DCOW/(DCOW+SCOW))/DCOW
Female calves produced/suckler cow	SCOW	YCAF	0.5*N24SN*(SCOW/(DCOW+SCOW))/SCOW
Male calves produced/suckler cow	SCOW	YCAM	0.5*N24SN*(SCOW/(DCOW+SCOW))/SCOW
Piglets produced/sow	SOWS	YPIG	(D43AV/D44AV)
Beef produced/dairy cow	DCOW	BEEF	(N30SN/D30AV)*CW
Beef produced/suckler cow	SCOW	BEEF	(N32SN/D32AV)*CW
Beef produced/bull	BULF	BEEF	(N25SN+N27SN)/(D25AV+D27AV)*CW
Beef produced/heifer fattening	HEIF	BEEF	((N29SN/D29AV)+MAX(0,N26SN-N28SN)/MAX(0,D26AV-D28AV)*CW
Beef produced/calf fattening	CAMF/CAFF	BEEF	0.5*(N23SN)/(D23AV)*CW
Milk for sale produced/dairy cow	DCOW	COMI	(K162QQ)/(D30AV)
Milk for feeding produced/dairy cow	DCOW	COMF	(K162QQ/D30AV)*MC
Milk for feeding produced/suckler cow	SCOW	COMF	(K162QQ)/(D32AV)*MC*5
Pork produced/sow	SOWS	PORK	(44SN/D44AV)*CW
Pork produced/pig fattening	PIGF	PORK	(N45SN+N46SN)/(D45AV+D46AV)*CW
Meat produced/sheep and goats for milk production	SHGM	SGMT	(N38SN+N40SN)/(D38AV+D40AV)*CW
Meat produced/sheep and goats for fattening	SHGF	SGMT	(N39SN+N41SN)/(D39AV+D41AV)*CW
Milk for sale produced/sheep and goats for milk production	SHGM	SGMI	(K164QQ+K165QQ)/(D38AV+D40AV)
Milk for feeding produced/sheep and goats	SHGM	SGMF	(K164QQ+K165QQ)/(D38AV+D40AV)*MC
Poultry meat produced/poultry fattening	POUF	POUM	(N47SN+N49SN)/(D47AV+D49AV)*CW

Notes: CW: carcass weight at MS level derived from ESTAT; MC: share COMF/COMI and SGMF/SGMI at NUTS2 level from CAPRI. In FADN, the value of milk suckled by calves is reported (however, it is reported in value and therefore should be assumed a price). We have preferred at this stage to use the share COMF/COMI derived from CAPRI.

7 Feed module

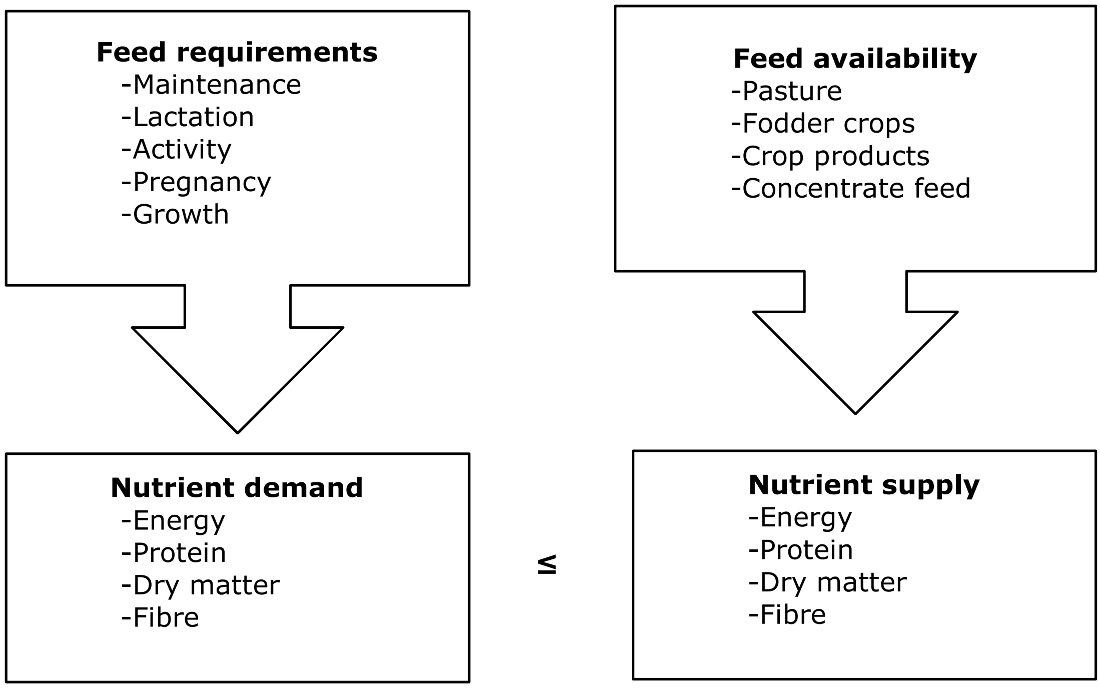
7.1 Aims and methodology

Most of the mathematical programming models applied in the literature represent the interactions between crop and animal activities through feed supply and demand balances. The feed balances guarantee that animal-specific nutrient demands (requirements) are met from internally produced or purchased feed (e.g. forage, grains, concentrates). Balancing feed supply (availability) and demand (requirements) is done through nutrient values. The physical quantities of feed, as well as the animal feed requirements, are expressed in nutrient values such as energy, dry matter, protein, fibre and essential amino acids such as lysine. The feed demand depends on the feed requirement per animal and the number of animals; the feed supply depends on the nutrient content of each feed component and its available (on-farm produced and/or purchased) quantity (e.g. De Cara and Jayet, 2000; Alford et al., 2004; De Cara et al., 2005; Crosson et al., 2006; Britz and Witzke, 2014; Heckelei et al., 2012; Arata et al., 2013).

Following the literature, we have developed a specific module within IFM-CAP to endogenously match feed availability and feed requirements for the livestock in each farm. The structure of this feed module is depicted in Figure 2. It consists of two main components: feed availability and feed requirements. Feed availability represents the supply of different types of feed, such as grass, fodder, cereals and concentrates. The list of individual feed products considered in IFM-CAP, as well as their corresponding feed category, is reported in Table 10. Feed requirements depend on livestock type (species and purpose) and are determined by, among other things, animal productivity (e.g. weight, milk production), duration of animal raising and keeping activities and farm herd size.

Feed availability and feed requirements are then converted into nutrient values and balanced by animal category at farm level. Table 11 lists the set of nutrients considered in IFM-CAP. Feed availability has to meet the protein (CRPR) and energy (ENNE) needs of each animal category (i.e. supply equals demand for CRPR and ENNE). In addition, for certain animal categories, additional minimum and/or maximum intake constraints are introduced. Maximum intake constraints concern dry matter (DRMX) and fibre (FIDI, FICO, FICT, FISM, FISF, FILG), while the minimum constraints are set for dry matter (DRMN) and lysine (LISI).

Figure 2. Feed module in IFM-CAP



Moreover, minimum and maximum thresholds of feed groups (e.g. cereals, fodder) in animal diets expressed in dry matter intake are defined for each animal category. These thresholds are reported in Table A-5 in Annex A. The thresholds ensure that the allocation of feed does not result in overuse or underuse of certain feed groups and matches animals' physiological requirements.

Table 10. List of feed products in IFM-CAP

Feed (GAMS acronym)	Aggregated feed grouping (GAMS acronym)	Name	Feed category			
			Fodder crops	Concent rate feed*	On-farm produced feed	Purchas ed feed
SOYC	FPRO	Soya cake		X		X
RAPC	FPRO	Olive cake		X		X
SUNC	FPRO	Sunflower cake		X		X
FRMI	FMIL	Fresh milk products		X		X
SMIP	FMIL	Skimmed milk powder		X		X
WMIO	FMIL	Whole milk powder		X		X
WHEP	FMIL	Whey powder		X		X
CASE	FMIL	Caseine		X		X
RAPO	FPRO	Rape seed oil		X		X
SOYO	FPRO	Soya oil		X		X
SUNO	FPRO	Sunflower oil		X		X
SUGA	FOTH	Sugar		X		X
DDGS	FRPO	Distillers dried grains with solubles		X		X
COMF	FCOM	Milk for feeding			X	X
STRA	FSTR	Straw	X		X	X
ROOF	FROO	Fodder root crops	X		X	X
OFAR	FOFA	Fodder other on arable land	X		X	X
MAIF	FMAI	Fodder maize	X		X	X
GRAS	FGRA	Pasture	X		X	X
POTA	FOTH	Potato			X	
SUNF	FOTH	Sunflower			X	X
SOYA	FOTH	Soya			X	X
RAPE	FOTH	Rapeseed			X	X
SWHE	FCER	Soft wheat			X	X
DWHE	FCER	Durum wheat			X	
RYEM	FCER	Rye and meslin			X	X
BARL	FCER	Barley			X	X
OATS	FCER	Oats			X	X
MAIZ	FCER	Grain maize			X	X
RICE	FCER	Rice			X	
OCER	FCER	Other cereals			X	

Note: *Concentrate feed refers to all the feed that cannot be produced on-farm because it needs to undergo some transformation by the feed-producing industry (e.g. soycake is the by-product of the extraction of soybean oil).

FADN data do not contain all the information needed to parameterise the feed module in IFM-CAP. FADN contains farm aggregated economic data on feed availability and costs. However, disaggregated feed data by activity (e.g. feed use by animal category), prices and yields of certain feed crops, nutrient content of feed and animal requirements are not available in FADN. To fill this gap, we supplement FADN data with external sources such as other official statistical sources (e.g. Eurostat, FSS), scientific literature or other models (e.g. CAPRI). The external sources utilised in the current version of the model are documented below. The disadvantage of using external data is that they may be inconsistent with FADN data and may provide unreliable information, in particular when MS or regional data are used at farm level. To reduce this problem, we employ the HPD approach to estimate farm-level data and external data are used only as prior information in the estimation approach. The estimation approach combines these different data sources by taking into consideration the minimisation of deviation of estimated data values from the available prior information, the minimisation of feed costs (this component was included in the HPD objective function), balancing between feed requirements and availability, and data constraints to ensure that the sum of activity feed costs is as close as possible to the aggregated cost values reported in FADN (see section 7).

Feed availability is represented by the physical quantity of feed, as well as its nutrient content and costs (i.e. prices, time, quantity). Farms can use feed produced on-farm or purchased on the market. The on-farm production of feed during the base year is reported as a monetary value in FADN. We have divided this monetary value by the price reported in FADN (described in section 3.2) to obtain the quantity of feed in tonnes ([24]). For straw, we use the residue-to-crop ratio (RCR) as a function of grain yield (SWHE, DWHE, RYEM, BARL and OATS) to obtain straw production (see Annex D). The data on yields of fodder crops (OFAR, GRAS, ROOF and MAIF) are not fully reported in FADN. We give priority to FADN data when available. We use CAPRI data only if information is not available in FADN or if the yield difference between FADN and CAPRI data is greater than 25 %.

Feed prices are derived from FADN, except for fodder and concentrates, for which data come from the CAPRI and Aglink databases, respectively.

Table 11. List of nutrients in IFM-CAP

Nutrient	Description (unit)
ENNE	Net energy (MJ/kg)
ENMR	Metabolisable energy ruminants (MJ/kg)
ENMC	Metabolisable energy chicken (MJ/kg)
ENMH	Metabolisable energy horses (MJ/kg)
ENMP	Metabolisable energy pigs (MJ/kg)
DRMN	Minimum dry matter (kg/kg)
DRMX	Maximum dry matter (kg/kg)
CRPR	Crude protein (kg/kg)
LISI	Lysine (kg/kg)
FIDI	Fibre (kg/100 kg)
FICO	Fibre dairy cows (fill unit system)
FICT	Fibre cattle (fill unit system)
FISM	Fibre sheep and goat milk (fill unit system)
FISF	Fibre sheep and goat fattening (fill unit system)
FILG	Fibre long

For the *nutrient content of feed*, we rely exclusively on external sources, as this type of data is not available in FADN. In the literature, nutrient values (e.g. regional averages) are most often taken from technical books and/or are based on expert knowledge. For example, in their FADN-based farm model for Emilia-Romagna in Italy, Arata et al. (2013) collected nutrient content data from regional rule books and from personal communications from a local animal nutritionist. Similarly, De Cara et al. (2005) and De Cara and Jayet (2000) extracted nutrient data from the literature (Jarrige, 1988; Jarrige, 1989) and combined this with expert knowledge for their FADN-based representative EU farm model. The CAPRI model relies on nutrient contents from the Institut National de la Recherche Agronomique (INRA) and the SPEL/EU-Base Model (Wolf, 1995). In the current version of the IFM-CAP model, we use the nutrient content of feed at MS level from CAPRI.

The *feed requirements* are critical for an accurate representation of crop–animal interactions. They describe how much nutrients (i.e. energy, crude protein, fibre and dry matter) each animal activity requires for its main biological functions. The full set of underlying data needed to calculate feed requirements including nutrients and physical

([24]) Note that FADN reports, for crop activities, the total production value and the value of production used on-farm. The total production value was used to derive crop prices as described in section 3.3. These derived prices are used in the feed module to calculate the proportion of feed used on-farm by dividing the value of production used on-farm by its price.

quantities is not available in FADN. To overcome this lack of data, we use the requirement functions combined with FADN and external data, as is usual in the literature (e.g. De Cara and Jayet, 2000; De Cara et al., 2005; Arata et al., 2013). More precisely, we used the requirement functions as implemented in CAPRI (Nasuelli et al., 1997; IPCC, 2006; Britz and Witzke, 2014) and from other sources (e.g. GfE, 2006; LfL, 2014, NRC, 1994) to calculate an approximate value of animal requirements. These values are then used as prior information to estimate the final nutrient requirements by animal category, which guarantees that feed availability equals feed requirement at farm level in both physical and nutrient terms (see section 7).

A detailed calculation of prior information for requirement functions is provided in the next subsection. The prior values of animal requirements are determined by predefined coefficients and animal productivity parameters. The predefined coefficients are extracted from FADN data or other sources (e.g. CAPRI; Eurostat), or are calculated based on the combination of both sources. However, the predefined coefficients and animal productivity parameters may depart significantly from the actual values observed at farm level. To account for this uncertainty, we consider variation of these coefficients and parameters (e.g. by using the standard deviation) to derive lower and upper bounds of animal requirements. The lower and upper bounds demarcate the most likely interval within which the actual values of animal requirements lie.

The main productivity parameters that determine the nutrient requirements include live weight of animal, raising/fattening period, milk and/or meat production, daily animal growth rate; fat content of milk, and start and end date of animal raising/fattening process. These values are obtained from FADN, calculated based on the combination of FADN data and other sources (e.g. CAPRI; Eurostat) or are assumed to be in CAPRI. For example, the fat content of milk is extracted from Eurostat, whereas the live animal weight of dairy cows is obtained by dividing the selling value of cows available from FADN by the cows' live weight price obtained from Eurostat.

7.2 Estimation of feed requirements and allocation of feed resources

The feed module aims to balance feed requirements and feed availability at farm level as described in section 7. It describes how many kilograms of certain feed categories (cereals, rich protein, rich energy, feed based on dairy products, other feed) or single feeding stuff (fodder maize, grass, fodder from arable land, straw, milk for feeding) are used per animal activity level (cows, heifers, calves, etc.). It also ensures that the total energy, protein, dry matter and fibre requirements of animals are met by the own-produced and purchased quantities of feed. The feed requirements can be covered by roughage produced on-farm or purchased (hay, straw, silage, etc.) and own-produced or purchased concentrates.

Assuming that the feed contents are accurately known, the objective is to estimate, at given animal herd sizes and prices, the quantity of feeding stuffs needed to meet animal requirements, in physical units and nutrient values, at the minimum feed costs. In addition, the minimum relative squared deviation between estimated animal requirements and prior information (including the deviation from lower/upper bounds) is assured, as is the minimum relative squared deviation between estimated on-farm produced feed, purchased/sold feed, other feed uses and feed costs and their observed values in FADN data. This is performed with the HPD approach using information on feeding costs and on-farm produced feed reported in the FADN database, feed content from CAPRI, feed prices from FADN, CAPRI or Aglink ([25]), prior information on animal requirements functions reported in Annex C, and a set of constraints for balancing feed requirement and feed availability (energy, crude protein, fibre, dry matter).

([25]) CAPRI feed prices are used for fodder crops and Aglink prices are used for concentrated feeds.

The model results provide estimates on nutrient requirements and physical quantity of feed for each feed and each animal activity, as well as quantity of purchased, sale and other use of feed.

A simplified formulation of the HPD estimation model can be summarised as follows:

$$\mathbf{Min}\left[\frac{(\mathbf{R}_{\mathbf{f},nut}-\overline{\mathbf{R}}_{f})^2}{\boldsymbol{\sigma}_{\mathrm{f}}^{\mathrm{R}}}+\frac{(\mathrm{d}\mathbf{R}_{\mathbf{f},nut}^{\min})^2}{\boldsymbol{\sigma}_{\mathrm{f}}^{\mathrm{Rmin}}}+\frac{(\mathrm{d}\mathbf{R}_{\mathbf{f},nut}^{\max})^2}{\boldsymbol{\sigma}_{\mathrm{f}}^{\mathrm{Rmax}}}+\frac{(\mathbf{p}_{\mathbf{f}}'\mathbf{u}_{\mathbf{f}})^2}{2}\frac{1}{v_f}\right.$$
$$+\frac{(\mathbf{u}_{\mathbf{f},\mathbf{own}}-\mathbf{u}_{\mathbf{f},\mathbf{own}}^{0})^2}{(\mathbf{u}_{\mathbf{f}})^2}+\frac{(\mathbf{dSH}_{\mathbf{f}}^{\min})^2}{2}+\frac{(\mathbf{dSH}_{\mathbf{f}}^{\max})^2}{2}+\frac{(\mathbf{dSH}_{\mathbf{f},\mathbf{c}}^{\max})^2}{2} \qquad (22)$$
$$\left.+\frac{(\mathbf{dc}_{\mathbf{f}}^{\mathbf{P}})^2}{2}+\frac{(\mathbf{dc}_{\mathbf{f}}^{\mathbf{T}})^2}{2}\right]$$

$\mathbf{R}_{\mathbf{f},\mathbf{nut}}\mathbf{x}_{\mathbf{f}}^{\mathbf{0}}=\mathbf{U}_{\mathbf{f}}\mathbf{g}_{\mathbf{nut}}$ for *nut* = energy and protein (23)

$\mathbf{R}_{\mathbf{f},\mathbf{nut}}\mathbf{x}_{\mathbf{f}}^{\mathbf{0}}\geq\mathbf{U}_{\mathbf{f}}\mathbf{g}_{\mathbf{nut}}$ for *nut* = dry matter and fibre (24)

$\mathbf{R}_{\mathbf{f},\mathbf{nut}}\geq\mathbf{dR}_{\mathbf{f},\mathbf{nut}}^{\min}+\mathbf{R}_{\mathbf{f},\mathbf{nut}}^{\min}$ for all nutrients (25)

$\mathbf{R}_{\mathbf{f},\mathbf{nut}}\leq\mathbf{dR}_{\mathbf{f},\mathbf{nut}}^{\max}+\mathbf{R}_{\mathbf{f},\mathbf{nut}}^{\max}$ for all nutrients (26)

$$\mathbf{dc}_{\mathbf{f}}^{\mathbf{P}}+\mathbf{u}_{\mathbf{f},\mathbf{own}}\mathbf{p}_{\mathbf{f}}=\mathbf{P}_{\mathbf{f}}^{\mathbf{0}} \qquad (27)$$

$$\mathbf{dc}_{\mathbf{f}}^{\mathbf{T}}+\mathbf{t}_{\mathbf{f}}\mathbf{p}_{\mathbf{f}}=\mathbf{T}_{\mathbf{f}}^{\mathbf{0}} \qquad (28)$$

$$\mathbf{q}_{\mathbf{f}}=\mathbf{u}_{\mathbf{f},\mathbf{own}}+\mathbf{e}_{\mathbf{f}} \qquad (29)$$

$$\mathbf{u}_{\mathbf{f}}=\mathbf{u}_{\mathbf{f},\mathbf{own}}+\mathbf{t}_{\mathbf{f}} \qquad (30)$$

$$\mathbf{u}_{\mathbf{f}}'=\mathbf{x}_{\mathbf{f}}^{\mathbf{0}}{}'\mathbf{U}_{\mathbf{f}} \qquad (31)$$

$$\left[\mathbf{dSH}_{\mathbf{f},\mathbf{F_n}}^{\min}+\mathbf{MinShr}_{\mathbf{f},\mathbf{F_n}}\right]\mathbf{R}_{\mathbf{f},\mathbf{DRMA}}\,\mathbf{x}_{\mathbf{f}}^{\mathbf{0}}\leq\mathbf{U}_{\mathbf{f}}\mathbf{F}_{\mathbf{n}}\mathbf{g}_{\mathbf{DRMA}} \qquad (32)$$

$$\left(\mathbf{dSH}_{\mathbf{f},\mathbf{F_n}}^{\max}+\mathbf{MaxShr}_{\mathbf{f},\mathbf{F_n}}\right)\mathbf{R}_{\mathbf{f},\mathbf{DRMA}}\,\mathbf{x}_{\mathbf{f}}^{\mathbf{0}}\geq\mathbf{U}_{\mathbf{f}}\mathbf{F}_{\mathbf{n}}\mathbf{g}_{\mathbf{DRMA}} \qquad (33)$$

$\left(\mathbf{dSH}_{\mathbf{f},\mathbf{c}}^{\max}+\mathbf{MaxShr}_{\mathbf{f},\mathbf{c}}\right)\mathbf{U}_{\mathbf{f},\mathbf{c}}\mathbf{F}_{\mathbf{c}}\geq\mathbf{U}_{\mathbf{f},\mathbf{c}}\,\mathbf{x}_{\mathbf{f}}^{\mathbf{0}}$ for all concentrate feed (34)

where *f* indexes farm; superscript 0 indexes for observed value of a given variable; *F* is the set of feed activities ($F \in N$); $\mathbf{x^0}$ is the ($N \times 1$) vector of non-negative observed activity level (i.e. animal number) for each of *N* animal activities; $\mathbf{R_{nut}}$ is the ($N \times N$) diagonal matrix of animal nutrient (*nut*) requirements for *nut* = energy, protein, dry matter and fibre; $\mathbf{R_{nut}^{min}}$ and $\mathbf{R_{nut}^{max}}$ are the ($N \times N$) diagonal matrixes of the lower and upper bounds of the animal nutrient requirements, respectively; $\mathbf{dR_{nut}^{min}}$ and $\mathbf{dR_{nut}^{max}}$

are the ($N \times N$) diagonal matrixes of the deviations of animal nutrient requirements from their lower and upper bounds, respectively; $\mathbf{R}_{\mathbf{DRMA}}$ is the ($N \times N$) diagonal matrix for dry matter requirements; $\mathbf{g}_{\mathbf{nut}}$ is the ($F \times 1$) vector of nutrient contents of feed for *nut* = energy, protein, dry matter and fibre; $\mathbf{g}_{\mathbf{DRMA}}$ is the ($F \times 1$) vector for dry matter content of feed; **p** is the ($F \times 1$) vector of feed prices; **q** is the ($F \times 1$) vector of produced feed quantities; **t** is the ($F \times 1$) vector of sales/purchases for quantities of feed; $\mathbf{t}_{\mathbf{purc}}$ includes only negative values (feed purchases) of the vector **t**; $\mathbf{t}_{\mathbf{sale}}$ includes only positive values (feed sales) of the vector **t**; **u** is the ($F \times 1$) vector of used quantities for feeding (by feed); **e** is the ($F \times 1$) vector of other uses of feed (e.g. losses, on-farm non-feed use for seeds, sales); $\mathbf{u}_{\mathbf{f},\mathbf{own}}$ is the estimated value of on-farm produced feed, where $\mathbf{u}_{\mathbf{f}} = \mathbf{u}_{\mathbf{f},\mathbf{own}} + \mathbf{t}_{\mathbf{f}}$, $\mathbf{u}^{0}_{\mathrm{f,own}}$ is the observed value of on-farm produced feed in FADN; **U** is the ($N \times F$) matrix of used quantities for feeding by animal activity; $\mathbf{U_c}$ is the ($N \times F$) matrix of used quantities for concentrate feeding by animal activity; $\mathbf{F_n}$ is the ($F \times F$) matrix defining different feed groups ([26]), where $\mathbf{F_1}$, $\mathbf{F_1}$, …, $\mathbf{F_n} \in \mathbf{F}$; and $\mathbf{F_c}$ is the ($F \times 1$) matrix defining concentrate feed group, where $\mathbf{F_c} \in \mathbf{F}$. $\mathbf{P^0}$ and $\mathbf{T^0}$ represent the total value of observed costs in FADN for on-farm produced and purchased feed, respectively; $\mathbf{dc_f^P}$ and $\mathbf{dc_f^T}$ are the error terms for the estimated costs relative to the costs reported in FADN for own-produced and purchased feed, respectively; **MinShr** and **MaxShr** are the ($N \times N$) diagonal matrixes of minimum and maximum shares of feed in total feed consumption (represented in dry matter), respectively; $\mathbf{dSH^{min}}$ and $\mathbf{dSH^{max}}$ are the ($N \times N$) diagonal matrixes of deviations of the feed share from the minimum and maximum share in total feed consumption (represented in dry matter), respectively; $\mathbf{MaxShr_c}$ is the ($N \times N$) diagonal matrix of maximum shares of concentrate feed in total concentrate feed quantity (represented in kg); $\mathbf{dSH_c^{max}}$ is the ($N \times N$) diagonal matrix of deviations of the concentrate feed share from the maximum share in total concentrate feed consumption (represented in kg); and $\mathbf{v_f}$ is the rescaling factor for the feed cost component of the objective function given by the animal production value. Prior information on animal requirements is assumed to be normally distributed with the means $\overline{\mathbf{R}}$ derived in Annex C and the standard deviation $\boldsymbol{\sigma}^{\mathbf{R}}_{f}$ calculated as 30 % of the mean value.

The first component of the objective function (22) is linked to the minimisation of the normalised squared deviation of estimated animal requirements from the prior information; the second and the third components are related to the minimisation of normalised squared deviation estimated animal requirements from lower and upper bounds, respectively. The aim is to impose a higher penalty if requirements are outside the bounds. The fourth component ensures cost minimisation of feed consistent with the IFM-CAP expected utility maximisation function (2); the fifth component minimises the relative squared deviation between the estimated on-farm produced feed and its observed values in FADN; the sixth and seventh components minimise the relative squared error of the feed group share from the minimum and maximum share in the total feed consumption (measured by dry matter), whereas the eighth component does the same for the individual concentrate feed shares in total concentrate consumption but measured in physical quantities instead of dry matter. The final two components minimise the relative squared error of the estimated feed costs from the FADN recorded feed costs. Because all components in the objective function except the cost minimisation element are differences, we scale the function by the livestock production value (v_f).

Equations (23) and (24) balance the feed requirement with the feed availability in nutrient values. Equations (25) and (26) constrain the deviation of animal requirements to be within or around the lower and upper bounds of animal requirements. The bounds

([26]) For example, fodder, concentrates, high-protein feed, etc.

are used to account for the uncertainty in data determining the level of animal requirements. The bounds are obtained by varying animal productivity parameters (e.g. milk fat content, animal live weight, start/end of day of production process) in the requirement function. We use the standard deviation to quantify the amount of variation or dispersion of the animal productivity parameters around their mean value. Equations (27) and (28) constrain the estimated costs of on-farm produced feed and purchased feed, respectively, to equal their observed values in FADN. Equations (29) and (30) ensure that physical quantity of feed is balanced at farm level for own-produced feed (own production equals feed use and other use) and total quantity of feed (total feed equal own plus purchased feed), respectively. Equation (31) sums the feed use over all animal activities. The minimum share constraint (equation (32)) ensures that a given feeding stuff (or group of feed) represents at least a certain amount of total feed consumption (measured in dry matter), whereas the maximum share constraint (equation (33)) ensures that a given feeding stuff (or group of feed) does not exceed a certain limit in the total feed consumption for a given animal activity. These two constraints ensure certain feed management practices and prevent overuse or underuse of certain feeds. The constraint described by equation (34) ensures that a feed concentrate does not exceed a certain maximum limit in the total concentrate feed consumption for a given animal activity (measured in physical quantity). This constraint aims to ensure that the composition of the concentrate feed corresponds as closely as possible to the observed data ([27]).

Figures 3 to 5 compare the estimated IFM-CAP costs with the actual FADN costs for all farms considered in IFM-CAP. The three figures compare the following three categories of costs: costs of purchased feed, costs of own feed and costs of purchased fodder. We also report the slope for the estimated linear model between IFM-CAP costs and the FADN costs ([28]). A slope value equal to 1 implies that, on average, the estimated IFM-CAP costs correspond to the FADN costs across farms in a given MS. A slope lower than 1 implies that estimated costs are on average lower than the FADN costs. The slope between the estimated and FADN costs is highest for the purchased feed (84 %), followed by the own feed (82 %) and cost of purchased fodder (at 35 %) (Figures 7.2 to 7.4). Because the slopes are lower than 1, our model underestimates the FADN costs. The use of external data and regional aggregates for nutrient feed content, feed prices and, to some extent, for fodder yields may have led to differences between the estimated and the observed costs. The discrepancy arises because, in reality, these data will probably vary strongly across farms and thus may depart from the regionally aggregated values. In addition, imposing cost minimisation of feed mix may have led to an underestimate of the feed cost given that, in reality, strict cost minimisation may not always hold, particularly in the presence of market imperfections (e.g. transaction costs, uncertainty). In particular, a low slope is reported for purchased fodder costs. FADN includes fewer data on fodder costs than on other feed activities, and data on the fodder price, nutrient content and, to a certain extent, yield are particularly scarce.

([27]) The maximum limits are available from FEEDMOD.

([28]) Linear model is specified as follows: *IFM-CAP estimated costs = Slope * FADN costs + error*

Figure 3. Estimated FADN purchased feed costs (F64, F66, F67) versus IFM-CAP estimated costs (euros/farm) for all IFM-CAP farms (euros/farm)

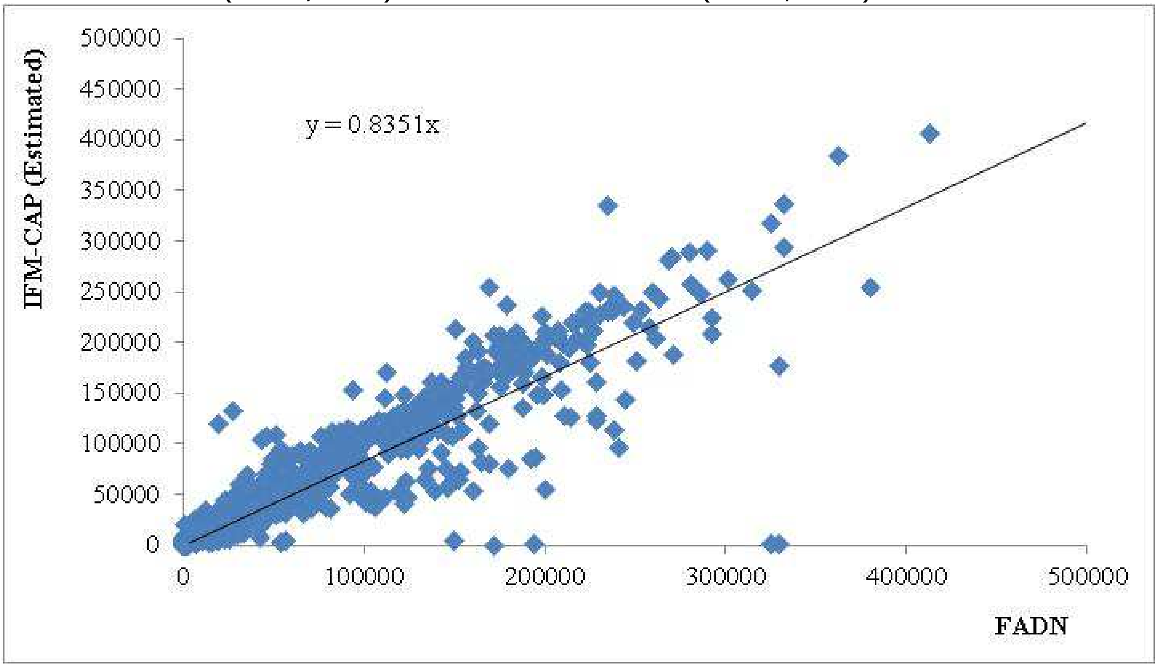


Figure 4. Estimated FADN own feed costs (F68, F69, F70) versus IFM-CAP estimated costs (euros/farm) for all IFM-CAP farms (euros/farm)

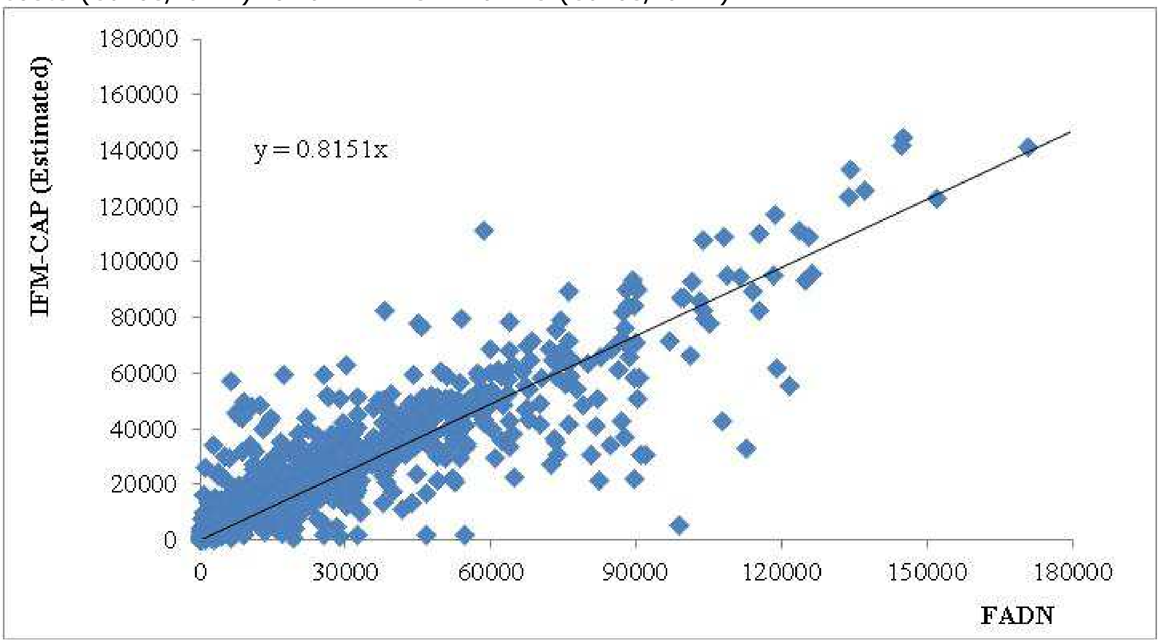
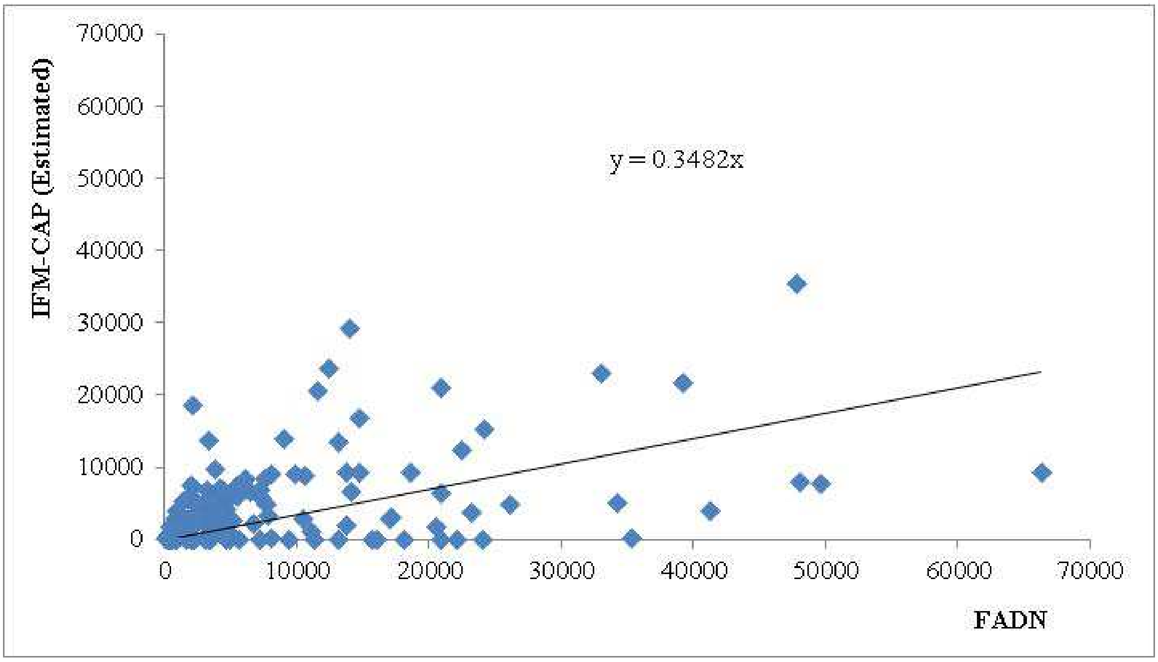


Figure 5. Estimated FADN purchased fodder costs (F64, F66, F67) versus IFM-CAP estimated costs (euros/farm) for all IFM-CAP farms (euros/farm)



Figures 6 to 12 compare the estimated animal intake requirements, with their lower and upper bounds, for dairy cows (DCOW), fattening of pigs (PIGF) and sheep and goat activity (SHGM) for selected nutrients for all farms modelled in IFM-CAP. As reported in Figure 6 and Figure 7, the estimated energy (ENNE) and protein (CPRP) intakes of dairy cows are around the lower bound for most farms. In contrast, the estimated intake of fibre (FIDI) is around the upper bound for most farms (Figure 8). The main explanation for the underestimation of energy and protein and overestimation of fibre is that the HPD estimation model cannot balance them within the bounds for the given set of feeds (determined by the constraints described by equations (32), (33) and (34)). The ratio of the energy and protein content to fibre content of the available feed cannot be matched with the ratio of these requirements for dairy cows such that they remain within the lower and upper bounds. This could be because the nutrient contents of feed in our model are not farm level specific but are provided at MS level, and thus may depart from the actual values. This is particularly problematic for fodder feed, the nutrient content of which may vary widely across regions and farms. Similarly to the balancing problem of dairy cows, the estimates for energy requirements for fattening of pigs (PIGF) are around the lower bound for most farms, whereas the estimates for protein intake are around the upper bound (Figure 9 and Figure 10). In contrast to dairy cows and fattening of pigs, the energy and protein requirements for sheep and goat activity (Figure 11 and Figure 12) are mostly within lower and upper bounds. This could be because of a less heterogeneous diet, reflected in less constraining minimum and maximum shares imposed by equations (32), (33) and (34).

Figure 6. Estimated ENNE intake for DCOW for all IFM-CAP farms

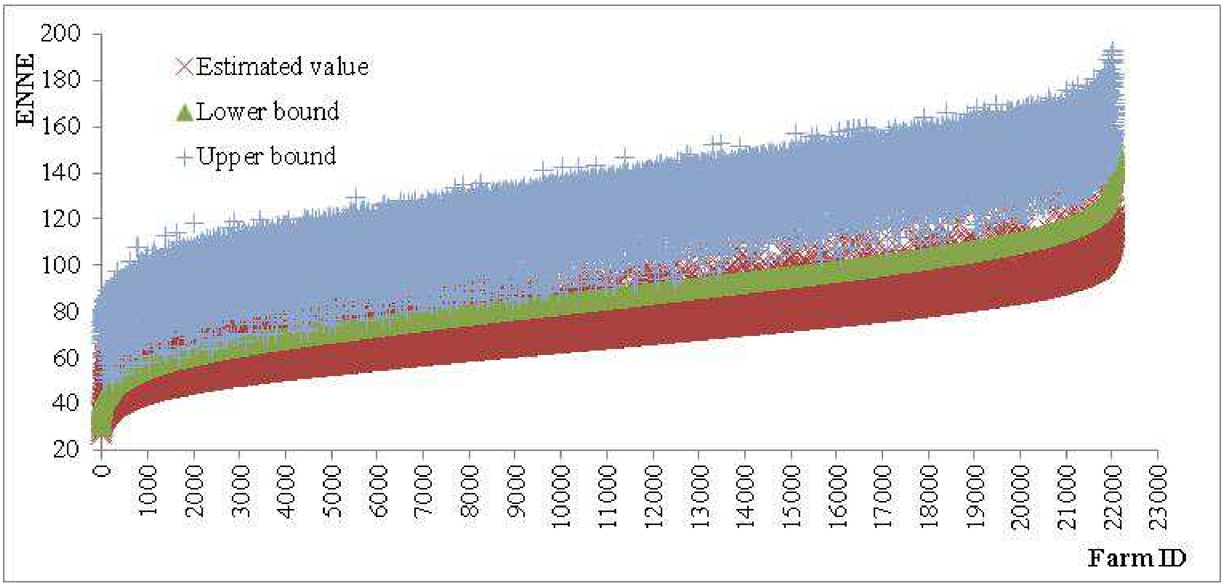


Figure 7. Estimated CPRP intake for DCOW for all IFM-CAP farms

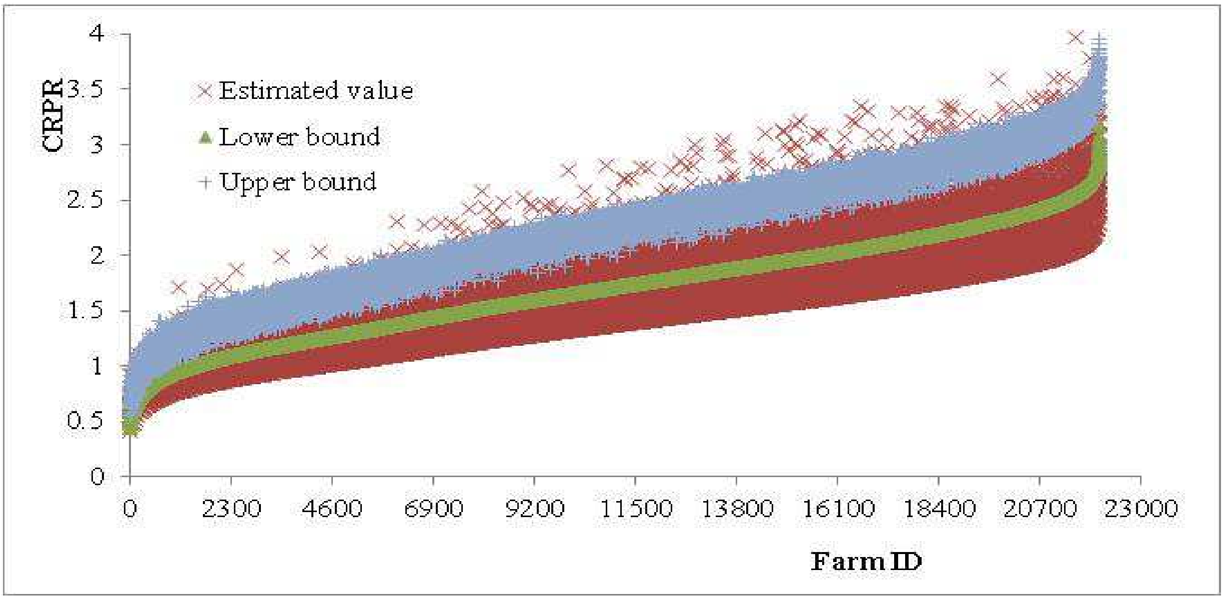


Figure 8. Estimated FIDI intake for DCOW for all IFM-CAP farms

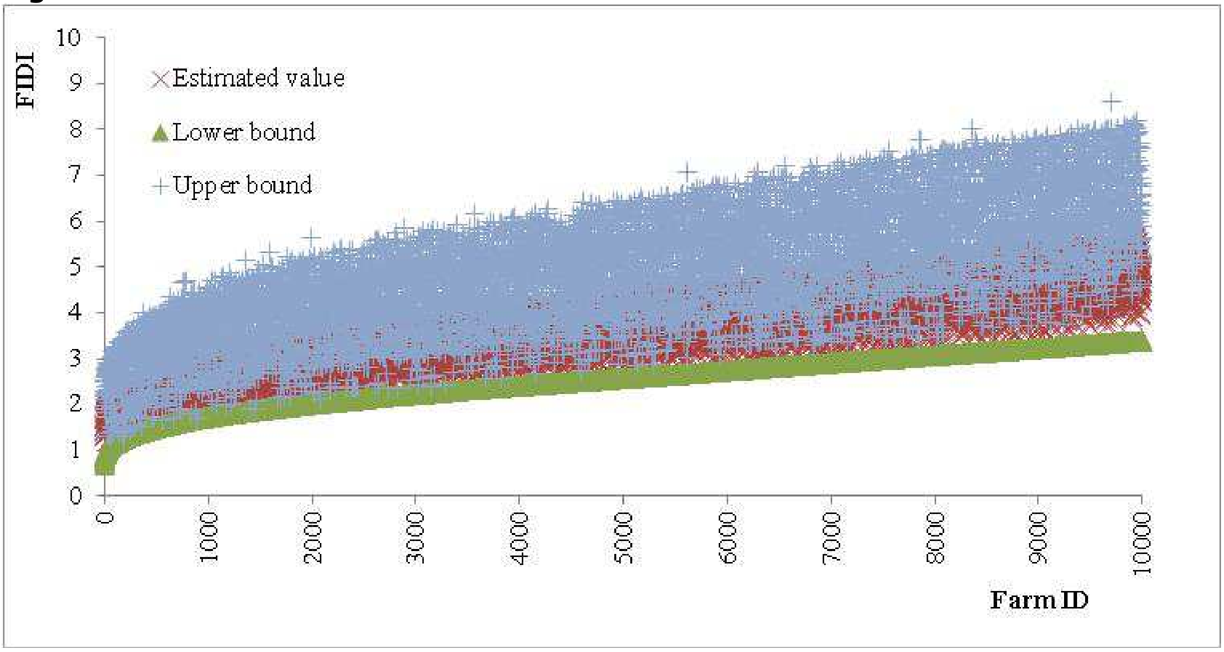


Figure 9. Estimated ENNE intake for PIGF for all IFM-CAP farms

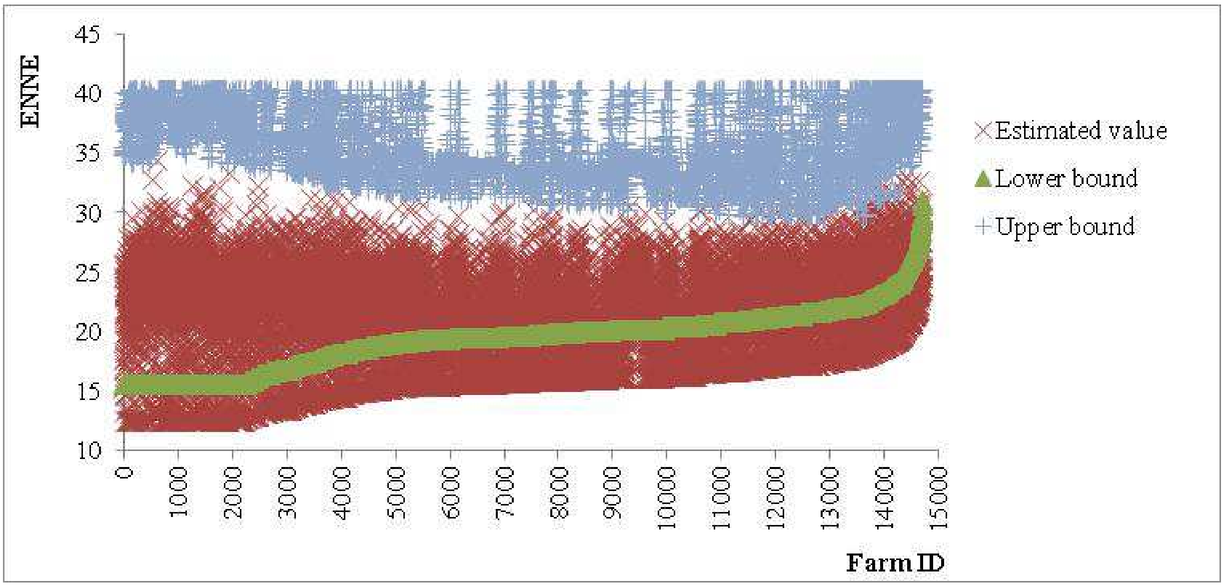


Figure 10. Estimated CRPR intake for PIGF for all IFM-CAP farms

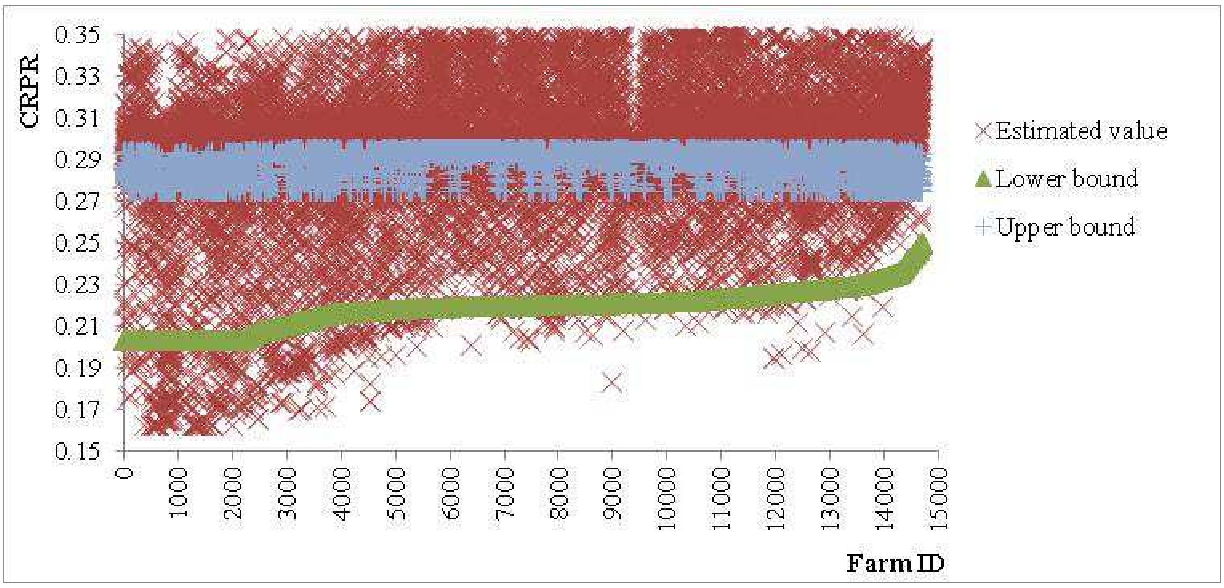


Figure 11. Estimated ENNE intake for SHGM for all IFM-CAP farms

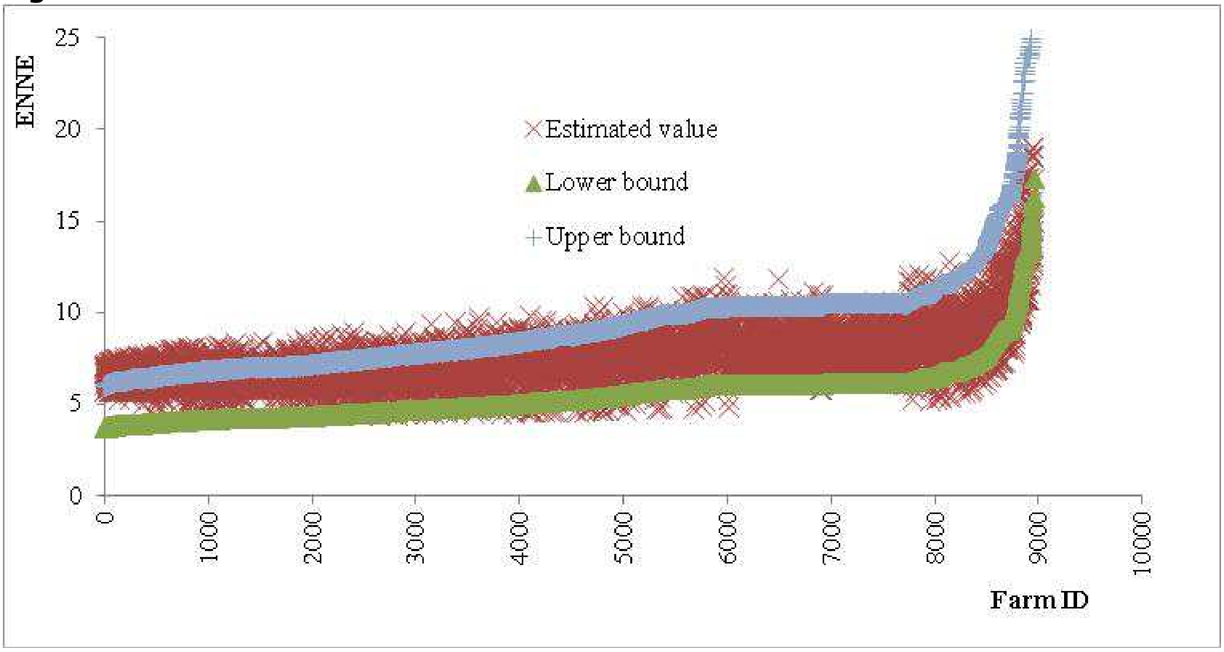
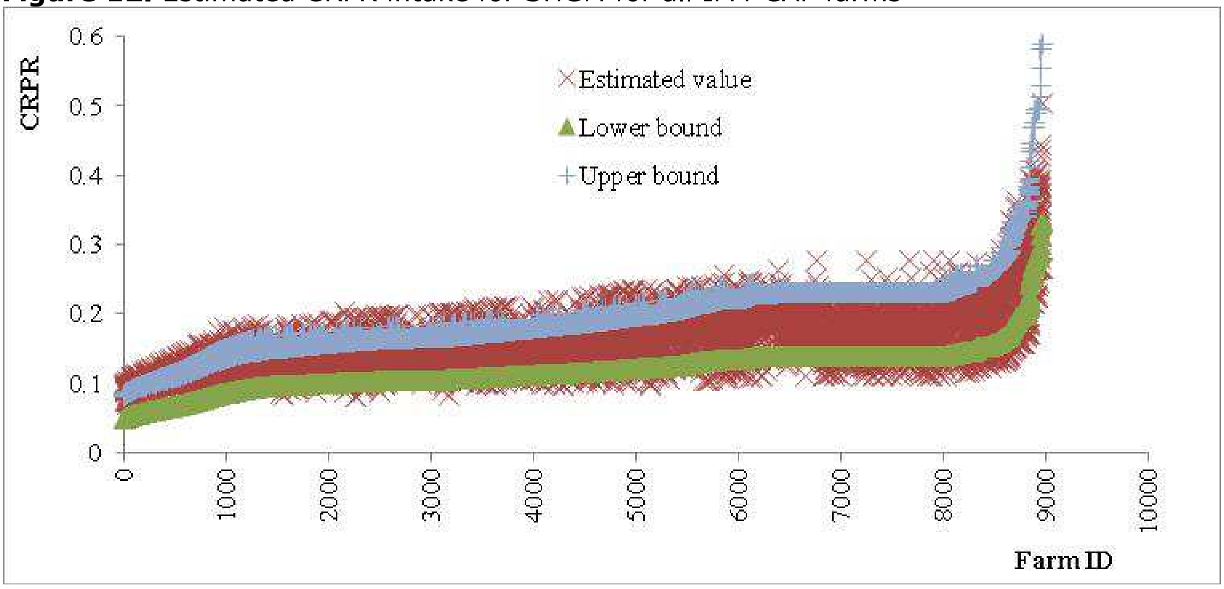


Figure 12. Estimated CRPR intake for SHGM for all IFM-CAP farms



8 Model calibration

8.1 Aims and methodology

The aim of the calibration process is to ensure that the observed crop and animal activity levels during the base year period are exactly reproduced by the optimal solution of the programming model. Effectively, this consists of recovering the set of unknown parameters (**d, Q,** ρ, **φ** and Σ), so that the optimisation model as described in equations (2) and (3) replicates exactly the observed activity levels ($\mathbf{x^0}$) of the base year 2012.

Over the last decade, several PMP approaches have been developed to derive the parameters of the behavioural functions (**d** and **Q**) and to accurately calibrate programming models ([29]). However, as the number of observations is usually not sufficient to allow a traditional econometric estimation ('an ill-posed' problem), most of the proposed approaches go without any type of estimation by setting all off-diagonal elements of **Q** to zero and calculating the remaining parameters using ad hoc assumptions. To reduce the arbitrary parameter specifications and estimate more reliable behavioural functions covering all the parameters, the more recent applied programming models have either (i) used exogenous information on supply elasticities (Britz and Witzke, 2014; Mérel and Bucaram, 2010) and/or on shadow prices of resources (de Frahan et al., 2007) or (ii) estimated programming model parameters in an econometric sense using either cross-sectional data (Heckelei and Britz, 2000; Heckelei and Wolff, 2003; Buysse et al., 2007; Arfini et al., 2008) or time-series data (Jansson and Heckelei, 2011).

In this analysis, we use both multiple observations (cross-sectional data) and prior information on (i) NUTS2 ([30]) supply elasticities ($\bar{\varepsilon}_r$), (ii) dual values of constraints ($\bar{\rho}_{f,m}$) and (iii) farm type covariance matrix of activity revenues ($\bar{\Sigma}_{ft,i,i}$) to calibrate the model to the 2012 condition. Supply elasticities for crops are taken from available econometric studies at the NUTS2 level (Jansson and Heckelei, 2011) ([31]). Elasticities of 1 and 0.1 are used for annual crops and permanent crops, respectively, when prior information is unavailable. Supply elasticities for livestock activities, as well as feed demand elasticities, are taken from CAPRI. Prior information on dual values of resources and on the farm type covariance matrix of activity revenues are derived from FADN.

The use of multiple observations (i.e. cross-sectional data) allows the model to estimate the full set of Q coefficients for crop and livestock activities and to base the model specification on observed differences in behaviour. The use of exogenous information avoids arbitrary behaviour of the model in the simulation phase. More precisely, with the proposed calibration method, we aim not only to reproduce exactly the observed activities in the base year 2012, x^0, as most of the PMP methods do, but also to ensure that (i) the estimated farm dual values ($\rho_{f,m}$), farm type covariance matrix of revenues ($\bar{\Sigma}_{ft,i,i}$), NUTS2 own-price supply elasticities ($\bar{\varepsilon}_r$) and the own-price feed demand elasticities ($\boldsymbol{\varepsilon}^{feed}$) are as close as possible to the prior information and (ii) the estimated farmers' constant absolute (φ_f) and relative risk aversion coefficients are consistent with the range indicated in the literature.

To perform the estimation, we derive the FOCs of the optimisation model, equations (2) and (3), which are assumed to approximate farmer behaviour (Heckelei, 2002), and then

([29]) For a review on PMP models see Heckelei and Britz (2005), de Frahan et al. (2007), Mérel and Bucaram (2010), Paris (2011) and Heckelei et al. (2012).

([30]) NUTS2 refers to regions belonging to the second level of the Nomenclature of Territorial Units for Statistics of the European Union.

([31]) Note that IFM-CAP considers land allocation elasticities with respect to gross margins as in Heckelei (2002) and Heckelei and Wolf (2003). The use of supply elasticities from Jansson and Heckelei (2011) is motivated by the fact that they provide estimates at EU regional level; there are no other studies available that would provide better regional resolution and/or estimates of land allocation elasticities across EU regions. Moreover, IFM-CAP assumes fixed yields, meaning that land allocation elasticities correspond to supply elasticities.

apply the HPD method (Heckelei et al., 2005) ([32]) to estimate the unknown parameters (d, Q, ρ, φ and Σ).

The use of the HPD approach for parameter estimation is carried out under the following assumptions:

- The HPD model minimises, in each NUTS2 region, the weighted sum of normalised squared deviations of estimated (i) regional own-price (diagonal) supply elasticities; (ii) farm type covariance matrix of activity revenues per hectare or per head; (iii) feed own-price (diagonal) demand elasticities; and (vi) farm dual values from the prior information subject to a set of data consistency (FOC) constraints.
- The normalised squared deviations of farm dual values are weighted with the proportion of the farm in the NUTS2 region, $\omega_f^{\rho} = w_f / \sum_f w_f$, to obtain a weighted average normalised squared deviation at the NUTS2 level, where w_f is the farm weighting factor reflecting the number of farms in the population that is represented by farm f.
- The normalised squared deviations of regional supply elasticities are weighted with the proportion of observed activity level in total regional land, $\omega_r^{\varepsilon} = N_r \, x_{i,r}^0 / \sum_i x_{i,r}^0$, to allow activities with a high proportion of area to dominate, where N_r is the number of observed crop activities (for $x_{r,i}^0 > 0$) in NUTS2 region r.
- The normalised squared deviations of farm type covariance matrix of activity revenues are weighted with the share of the farm type in the NUTS 2 region and the share of observed activity level in the total regional land to allow activity with a high share of area to dominate.
- The normalised squared deviations of feed demand elasticities are weighted with the share of the farm in the NUTS 2 region to obtain a weighted average normalised squared deviation at NUTS 2 level.
- Prior information on dual values, $\bar{\rho}_{r,m}$, is set to the average land rental price at regional (NUTS2) level (arable land and grassland), to the gross margin differential between sugar beet and the next best alternative crop for the sugar beet quota restriction, and to arable land rental prices (i.e. knowing that the only constraints in the base year for crops are land and (sugar beet and milk) quota obligations). Large standard deviations for prior information are used to allow the data to dominate.
- The calibration to the exogenous supply elasticities is performed in a non-myopic way, that is, we take into account the effects of changing dual values on the simulation response (Heckelei, 2002; Mérel and Bucaram, 2010).
- The estimated $B_{ft,i,i'}$ parameters related to the $Q_{f,i,i'}$ (see below) are common across farms belonging to the same region and the same farm type (group), ft. Farms are grouped based on 14 production specialisations, that is $ft = 1,2,\ldots, 14$. However, the $Q_{f,i,i'}$ parameters are activity and farm specific owing to the farm-specific scaling factors, as suggested in Heckelei and Britz (2000); in other words, we exploit information contained in the cross-sectional sample to specify (farm-specific) quadratic activity functions with cross-effects for production (crop and livestock) activities.
- The inequality on quota restriction is replaced with equality to simplify the already complex estimation problem. Moreover, the non-negativity condition was omitted owing to the heavy computational requirement. That is, all optimal activity levels are assumed to be positive. This implies that we overestimate the profitability of non-observed activities.

([32]) This Bayesian approach was proposed by Heckelei et al. (2005) as an alternative to entropy methods for deriving solutions to underdetermined systems of equations. They argued that the main advantage of this approach is that it allows a more direct and straightforward interpretable formulation of available a priori information and a clearly defined estimation objective.

- The estimation of $B_{ft,i,i'}$ (and thus $Q_{f,i,i'}$) parameters relies only on observed activities, meaning that the well-known self-selection problem is not explicitly handled in this estimation. To cope with this problem, we adopted the following ad hoc modelling decision ([33]) in the simulation phase: in each NUTS2 region, the gross margin of the non-observed activities is equal to the farm type average gross margin, the activity's quadratic function parameter equals the activity's average quadratic function parameter within the farm type, and the linear term's quadratic function is derived from the difference between the gross margin and the dual values of constraints ([34]).
- The estimation procedure is applied for both crops and livestock activities.
- The exchange of production factors and production rights between farms is not allowed (i.e. assuming there are neither land nor quota markets).
- The general formulation of the corresponding HPD problem is now straightforward:

$$Min\ HPD_r = \left[\begin{array}{l} \sum_i \omega_r^{\varepsilon} \frac{(\varepsilon_{r,i,i} - \bar{\varepsilon}_{r,i,i})^2}{(\sigma_{r,i,i}^{\varepsilon})^2} + \sum_{ft,i,i'} \omega_r^{V} \frac{(\Sigma_{ft,i,i'} - \bar{\Sigma}_{ft,i,i'})^2}{(\sigma_{ft,i,i'}^{\Sigma})^2} \\ + \sum_{f,m} \omega_f \frac{(\rho_{f,m} - \bar{\rho}_{r,m})^2}{(\sigma_{r,m}^{\rho})^2} \end{array} \right] \quad (35)$$

$$E[gm_{f,i}] - d_{f,i} - \sum_{i'} T_{f,i,i'} x_{f,i'}^0 - \sum_m A_{f,i,m} \rho_{f,m} = 0 \quad (36)$$

$$E[y_{f,i} p_{f,i}^q] + s_{f,i} - \sum_k E[C_{f,i,k}] - d_{f,i} - \sum_{i'} T_{f,i,i'} x_{f,i'}^0 - \sum_m A_{f,i,m} \rho_{f,m} = 0 \quad (37)$$

$$b_{f,m} - \sum_i A_{f,i,m} x_{f,i}^0 = 0 \quad (38)$$

$$b_{f,m} - \sum_i A_{f,i,m} q_{f,i}^p = 0 \quad (39)$$

$$T_{f,i,i'} = Q_{f,i,i'} + \sum_{ft} \varphi_f \Sigma_{ft,i,i'} \quad (40)$$

$$\varepsilon_{f,i,i'} = \left[\begin{array}{l} T_{f,i,i'}^{-1} - \\ \sum_m (\sum_j A_{f,j,m} T_{f,i,j}^{-1} (\sum_{j,j'} A_{f,j,m} T_{f,j,j'}^{-1} A_{f,j',m})^{-1} \sum_j A_{f,j,m} T_{f,j,i'}^{-1}) \end{array} \right] \frac{E[gm_{f,i'}]}{x_{f,i}^0} \quad (41)$$

([33]) Different arbitrary assumptions were tested for setting the behavioural function's parameters for the non-observed activities, such as the use of the highest *Q* matrix, or the use of *B* matrix, but the results were not conclusive. In the end, we opted for this specification following methods often used in the literature.

([34]) This approach does not allow farms to choose activities that are not observed in the same region and farm type, which may restrict their choices and thus also the simulated results. However, the set of activities observed in the same farm type and region is indicative of the probable feasible options that a farm faces when choosing production structure. If activities are not observed in other similar farms, it indicates that they were probably not economically feasible because various unobserved factors (e.g. experience, skills, fixed costs, natural constraints) that are not accounted for in our model would make such an activity choice unprofitable. Hence, our approach for modelling non-observed activities partially accounts for unobserved factors that may impact farms' choices. A similar approach, but with more restrictive selection criteria, was used by Mahy et al. (2015), who consider the closest peers to address the self-selection problem. They select the closest peers based on the total farm area, crop area allocation, number of crops, geographical distance between farms and permanent grassland; our approach, in contrast, is based on only two criteria, NUTS2 region and farm type.

$$\varepsilon_{r,i,i'} = \frac{\sum_f w_f x^0_{f,i} \varepsilon_{f,i,i'}}{\sum_f w_f x^0_{f,i}} \tag{42}$$

$$Q_{f,i,i'} = \sum_{ft} \delta_{f,i} B_{ft,i,i'} \delta_{f,i'} \tag{43}$$

$$B_{ft,i,i'} = \sum_j Lb_{ft,i,j} Lb_{ft,i',j} \quad Lb_{ft,i,i'} = 0 \quad for \quad i' > i \tag{44}$$

$$V_{ft,i,i'} = \sum_j Lv_{ft,i,j} Lv_{ft,i',j} \quad Lv_{ft,i,i'} = 0 \quad for \quad i' > i \tag{45}$$

$$\sum_l T_{f,i,l} T^{-1}_{f,l,i'} = 1 \quad \forall i = i' \tag{46}$$

$$\sum_l T_{f,i,l} T^{-1}_{f,l,i'} = 0 \quad \forall i \neq i'$$

where indices *f* denote farms, *ft* farm type, *r* NUTS2 region and *j, j′* (similar to *i*, *i′*) the agricultural activities and products; $p^q_{f,i}$ is the farm in-quota price (euros/tonne); $q^q_{f,i}$ is the farm in-quota production (Ton); $gm_{f,i}$ is the expected gross margin for activity *i* (EUR/ha); $T_{f,i,i'}$ are the farm-specific behaviour and risk parameters; $\bar{\rho}_{r,m}$, $\sigma^{\rho}_{r,m}$ are the mean and standard deviation of the regional dual values of resource and policy constraints (land rental prices, in-quota prices) used as prior information; $\bar{\varepsilon}_{r,i,i}$, $\sigma^{\varepsilon}_{r,i,i}$ are the mean and standard deviation of regional own-price elasticities of supply used as prior information (Jansson and Heckelei, 2011); and $\delta_{f,i}$ is scaling factor with $\delta_{f,i} = \sqrt{1/x^0_{f,i}}$.

Prior information on dual values of constraints is assumed to be normally distributed with the means ($\bar{\rho}_{r,m}$) and standard deviations ($\sigma^{\rho}_{r,m}$) calculated at NUTS2 level using the farm weights. The standard deviation of NUTS2 elasticities ($\sigma^{\varepsilon}_{r,i,i}$) is assumed to be 50 % of the mean.

The endogenous variables of the HPD problem defined in equations (3) to (11) are as follows: the dual values of resource and policy constraints, $\rho_{r,m}$; the farm price elasticities of supply, $\varepsilon_{f,i,i'}$; the regional price elasticities of supply, $\varepsilon_{r,i,i'}$; the behavioural parameters, $B_{ft,i,i'}$, common across farms belonging to the same region and the same farm type (group), *ft*; the elements of the lower triangular Cholesky decomposition related to $B_{ft,i,i'}$ and $\Sigma_{ft,i,i'}$ parameters, $Lb_{ft,i,i'}$ and $Lv_{ft,i,i'}$; the farmers' absolute risk aversion coefficients, φ_f; the behavioural parameters, $d_{f,i}$ and $Q_{f,i,i'}$; and the behaviour risk parameters, $T_{f,i,i'}$ (including the inverse value $T^{-1}_{f,i,i'}$).

The constraints in equations (4) and (5) represent the FOCs of the optimisation model for production activities and in-quota sugar beet production, respectively. Equations (6) and (7) represent the FOC for land and quota constraints. Equation (8) calculates the farm-specific behaviour risk parameters $T_{f,i,i'}$. Equations (9) and (10) compute supply elasticities at farm and NUTS2 level, respectively ([35]). Equation (11) calculates the farm-specific $Q_{f,i,i'}$ parameters of the cost behavioural function. Equations (12) and (13) are the Cholesky decomposition of *B* and *Σ* matrix, respectively, which ensures appropriate

([35]) Note that this specification implies that farms may not necessarily calibrate to the exogenous regional elasticity but allows for farm supply responses to deviate from the regional average to guarantee farm-level heterogeneity.

curvature properties of the estimated quadratic cost function (i.e. convex in activity levels). Finally, equation (14) calculates the inverse of farm-specific $T_{f,i,i'}$ parameters.

The estimated parameters in equations ((35) to (46)) guarantee the reproduction of the actually observed production activity levels when the model (equations (2) and (3)) is run for the base year ([36]).

8.2 Evaluation of model behaviour/performance

The calibration of IFM-CAP model for the EU-27 is fully accomplished. We report here the results of model calibration and simulation for only three MSs as examples: Belgium, Ireland and Denmark.

The evaluation of model behaviour includes two complementary analyses:

- robustness analysis, focusing on the quality of the outcome of the HPD estimator, measured in terms of computation times and reliability of the estimation of the CARA (and CRRA) coefficients and supply elasticities;
- sensitivity analysis of the simulations obtained with the calibrated models for the observed variables beyond the base year.

In general, the inclusion of the risk component in the model increases the computation time of both estimation and calibration phases 1.5- to 3-fold depending on the number of individual farms in each NUTS2 regions and MSs. However, this is not surprising, since a new quadratic term, namely risk activity, has been included, which increases the number of decision variables and, therefore, the complexity of the estimation and optimisation. Setting enhanced values for bounds or improving initial values for some variables may improve computation time, mainly during the estimation phase, but it could also hinder model convergence (i.e. increase the number of infeasibilities). However, this should not be a major issue because the estimation and calibration processes are performed only once.

The inclusion of the risk component also negatively affects the performance of the HPD estimator in replicating the NUTS2 own-price supply elasticities. This is also expected because, in the new model specification, we minimise not only the sum of normalised square deviations of the estimated own-price supply elasticities and farm dual values from prior information but also the deviation of the estimated covariance matrix from the observed one. This means that there is a balance in the estimation process between fitting the prior information (i.e. elasticities and farm dual values) and the observed covariance matrix.

In general, the estimated elasticities overestimate prior information. Around 90 % of the estimates are bigger than their prior values (Table 12). However, in the majority of cases, the difference is small. Moreover, for the crops with the largest land shares, such as soft wheat, barley, maize, potatoes and permanent crops, elasticities are mostly in agreement with the prior information, especially in Ireland. For crops with low land shares, such as other cereals and oats, the results are quite different. This can be partially explained by the fact that the deviation of the estimated own-price supply elasticities from the prior values is weighted by the crop land share, which allows activities with a high share to dominate.

In contrast, the HPD estimator reproduces perfectly the observed covariance matrix of activity revenues. Figure 13 compares the estimated diagonal matrix of the variance activity revenues with the observed one for all the activities and farm types of the three selected MSs. We also report here the slope (lower than 1) of the linear model to show that we slightly underestimate the observed diagonal matrix for some activities and farm types. This implies that the minimisation of the normalised squared deviation of the

([36]) A detailed mathematical description of the estimation/calibration module is given in Table A-2.

covariance matrix from the prior information dominates the estimation, although it is scaled by the number of matrix elements.

We have tested several specifications of the HPD estimator's objective function by minimising, for example, the chi-squared distance instead of normalised squared deviation, or by using different scaling factors, but the results were not satisfactory. Some of these specifications improve the fitting of the other terms in the objective function (e.g. supply elasticities) but they provide constant absolute and relative aversion coefficients (CARA and CRRA) that are out of range for many farms. After these different tests, we found that normalised squared deviation was more 'comparable' to the other three terms in the objective function and provides better estimates for the CARA and CRRA coefficients, even though the estimated NUTS2 supply elasticities deviate from the prior values for most of the activities. As shown in Figure 14, the estimated farmers' relative risk aversion (CRRA) coefficients are quite consistent with the range indicated in the literature (0–7.5) for several farms in the three MSs. The average CRRA coefficients for Ireland, Belgium and Denmark are, respectively, 3.1, 11.3 and 9.1, which are more or less in line with the average value of 6.1 indicated in Chavas and Holt (1996). However, there is a high dispersion in the estimated values of both the CARA and CRAA coefficients.

Figure 13. Estimated farm type covariance matrix of activity revenues versus the prior values in the three selected Member States (Ireland, Belgium and Denmark)

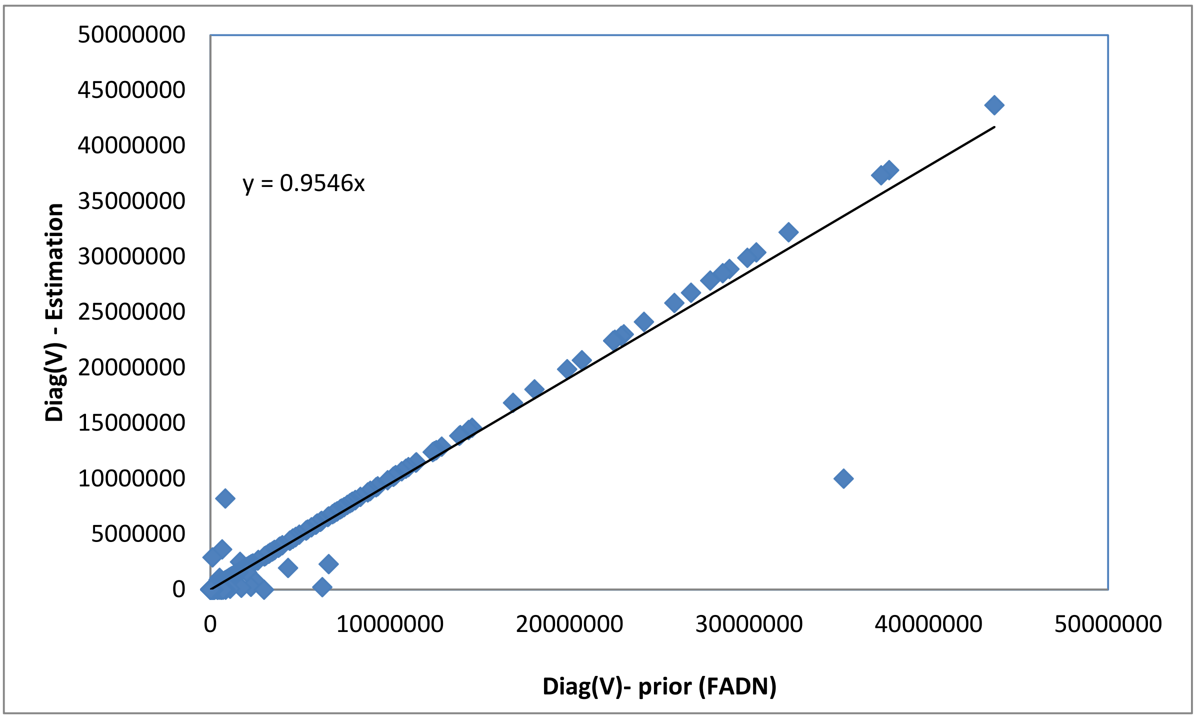
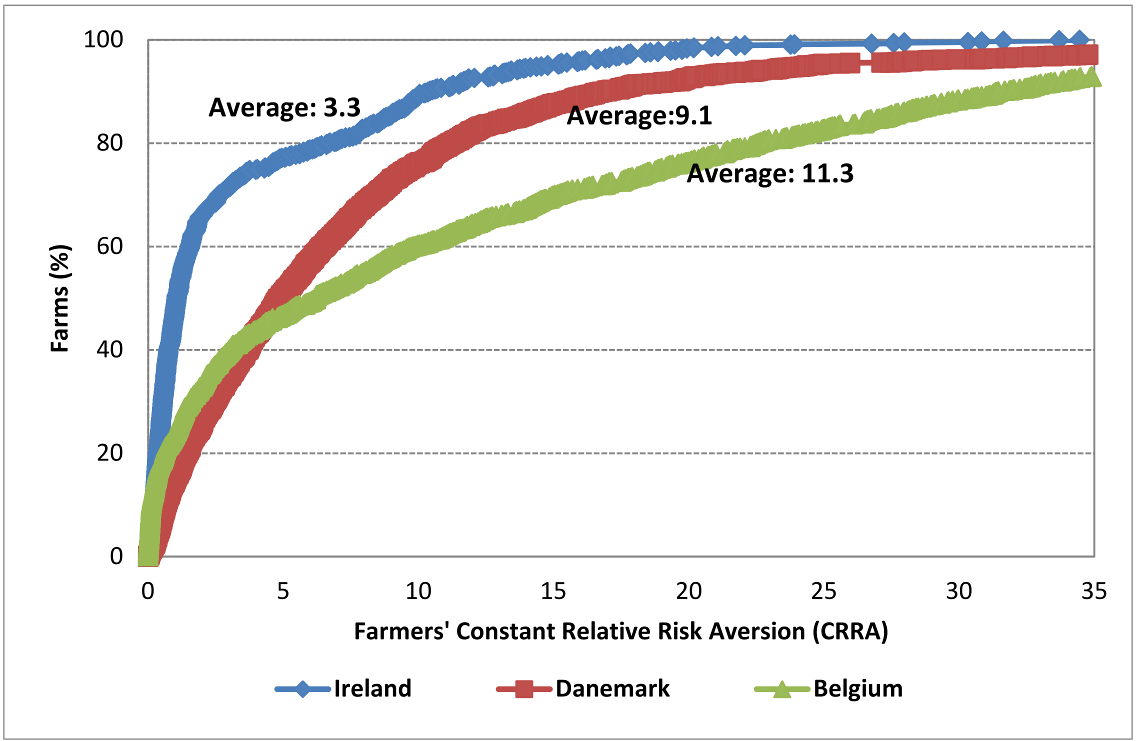


Figure 14. Distribution of farmers' constant relative risk aversion coefficients (CRRA) in the three selected Member States (Ireland, Belgium and Denmark)



In the sensitivity analysis, we run some simulation experiments assuming a price increase of 10 % for single products and calculate the aggregated regional percentage change in production related to the price change. Table 12 compares our simulated elasticities with both the prior values (Jansson and Heckelei, 2011) and the estimated ones for the main crops at MS level.

The results show that the simulated own-price elasticities are in a plausible range for most crops. However, in 90 % of the cases, the simulated own-price elasticities are larger than the prior values, although the difference is small in many cases. As expected, simulated and estimated elasticities coincide in the majority of cases.

Table 12. Comparison between simulated and estimated own price elasticities and the prior values

	Belgium (BL) *n* = 1695				Denmark (DK) *n* = 1818				Ireland (IR) *n* = 939			
	Land share	**Prior**	**Estimated**	**Simulated**	**Land share**	**Prior**	**Estimated**	**Simulated**	**Land share**	**Prior**	**Estimated**	**Simulated**
Soft wheat	0.154	0.855	3.581	3.124	0.235	0.860	2.708	2.812	0.031	2.624	2.602	3.219
Rye and meslin	0.001	1.000	2.071	0.202	0.027	3.950	7.082	6.935	n.a	n.a	n.a	n.a
Barley	0.036	2.326	5.242	6.090	0.300	0.757	3.068	2.980	0.051	1.952	2.609	2.887
Oats	0.002	2.740	4.849	6.944	0.021	2.672	6.158	6.583	0.005	2.959	6.081	7.386
Maize	0.045	1.334	3.714	3.713	0.005	1.000	3.327	3.618	n.a	n.a	n.a	n.a
Other cereals	0.009	1.294	1.390	6.972	0.013	1.498	4.414	4.430	0.001	7.287	6.531	7.766
Rape	0.012	0.758	3.449	3.685	0.053	1.357	4.547	5.237	0.005	8.107	8.548	8.908
Pulses	0.002	0.728	1.474	2.129	0.003	5.781	10.658	10.280	0.003	4.393	11.637	12.839
Potatoes	0.042	0.100	0.023	0.118	0.019	1.611	2.309	3.067	0.001	8.170	6.945	10.468
Apples	0.011	0.050	0.762	0.432	0.000	0.100	0.325	0.450	0.000	0.100	0.645	0.712
Permanent grassland	0.404	5.000	6.361	5.865	0.037	0.050	0.481	0.040	0.771	0.050	0.245	0.068
Other crops	0.008	0.568	4.693	1.996	0.038	5.000	5.621	5.723	0.0005	5.000	10.607	8.346
Fodder maize	0.130	1.000	1.236	1.270	0.067	2.125	36.736	12.020	0.002	6.494	12.068	14.815
Fodder root crops	0.003	0.541	2.395	2.623	0.002	1.000	8.266	7.596	0.003	1.000	5.953	5.651
Other fodders	0.059	0.855	3.581	3.124	0.122	0.686	15.759	4.550	0.028	0.217	1.862	1.502

Note: n, number of farms; n.a., not applicable.

Source: model results.

9 IFM-CAP baseline

As explained in the earlier sections, IFM-CAP is a comparative static supply model that does not take into account the dynamics of market developments and market interlinkages (price feedbacks) and therefore the baseline construction relies on an external baseline. A second key reason for using an external baseline is IFM-CAP is intended to be employed mainly for counterfactual policy scenario analysis and not for the projection of future developments of EU farming sector ([37]). More precisely, we use CAPRI projections ([38]) to construct the IFM-CAP baseline, taken as the time horizon for policy simulations in this report. One important feature of the CAPRI baseline is that it is developed in conjunction with the European Commission (EC) baseline. The EC constructs medium-term projections for the agricultural commodity markets on an annual basis. The projections present a consistent set of market and sectoral income prospects elaborated on the basis of specific policy and macroeconomic assumptions (Himics et al., 2013; Britz and Witzke, 2014).

To construct the IFM-CAP baseline, the following assumptions are adopted: (i) a continuation of the current CAP (i.e. the 2013 CAP reform in the current version; see next section for more details); (ii) an assumed inflation rate of 1.9 % per year for input costs as in CAPRI baseline; (iii) an adjustment of baseline prices and yields using growth rates from the CAPRI baseline; and (iv) an application of the same time horizon as in CAPRI (e.g. 2025, 2030). The regional yield growth attempts to capture both technical change and input intensification effects and the regional price growth represents nominal price projection. As the CAPRI growth rates of yields and prices are defined at NUTS2 level, we impose the same growth rate on all farms belonging to the same NUTS2 region. All the other parameters (e.g. farm resource endowments and farm weighting factors) are assumed to remain unchanged in the baseline.

The generated baseline scenario is used as a reference point for the comparison of the effects of the CAP greening scenario.

([37]) The advantage of this approach is that we can indirectly benefit from specialised expert knowledge on market projections/outlooks employed for the construction of the external baseline. The second advantage is that IFM-CAP is used for policy impact assessment, which ensures consistency and comparability with other models for which the same baseline is used. The drawback of this choice is that consistency may not be fully achievable between IFM-CAP and the model assumptions used for the baseline construction, as each model may rely on specific methodology, data sources, commodity coverage and policy assumptions (Blanco-Fonseca 2010).

([38]) For more information, refer to Blanco-Fonseca (2010), Britz and Witzke (2014), Himics et al. (2013) and Himics et al. (2014).

10 Modelling the 2013 CAP reform

The 2013 CAP reform has introduced various changes that modify the value of direct payments (i.e. coupled and decoupled payments) and their implementation. The first key change is the reduction of the overall CAP budget (3.5 % in real terms) in the period 2014–2020 compared with the 2007–2013 period (when the MSs numbered 27) due to the fiscal austerity pursued within the EU.

The second important element of the 2013 CAP reform that alters the availability of funds for direct payments is the possibility that MSs can transfer funds between Pillar I (direct payments) and Pillar II (rural development payments). MSs may move up to 15 % of the annual ceiling for direct payment to Pillar II or vice versa. MSs with average direct payments per hectare below 90 % of the EU average are allowed to transfer up to 25 % of the Rural Development Programme (RDP) to direct payments (EU, 2013; European Commission, 2015).

An additional element of the 2013 CAP reform that changed the allocation of direct payments between MS is the external convergence of direct payments. The aim of external convergence is to rebalance the CAP support among MS. External convergence partially harmonises the payments among MS; they are adjusted either upwards or downwards to bring them closer to the EU average level. More specifically, the national budgets of MS where the average payment (in EUR per hectare) is below 90 % of the EU average are gradually increased (by one third of the difference between their current rate and 90 % of the EU average). This convergence is financed proportionally by MS that have payment levels above the EU average level (EU, 2013) ([39]).

The other key elements introduced by the 2013 CAP reform can be summarised as follows (EU, 2013; European Commission, 2015, 2016):

1. The SPS and SAPS were replaced by the *Basic Payment Scheme* (BPS), which operates on the same principle, but is slightly modified in terms of terms its implementation (see in Table A-8 in Annex A for the implementation direct payments by MSs). MSs may apply the BPS at the regional level by splitting the country into separate regions among which the reform implementation can differ. The main consequence of the regional implementation of decoupled payments is that the payment value per hectare may differ between regions within the same MS even if each region implements a flat-rate system.
2. *Internal convergence of decoupled payments.* The 2013 CAP reform aims to eliminate or reduce the heterogeneity of per hectare payments that farmers receive in a region or MS. MSs could choose to apply for either (i) full convergence (i.e. introduction of flat-rate payments) or (ii) partial convergence. Under full convergence, an equal per hectare payment is granted to all farms in a given region. Under partial convergence, the payment heterogeneity across farms is reduced, but is not completely eliminated. The mechanism of the partial harmonisation consists of reducing the unit value of payments to farms with higher value and increasing the unit value of payments to farms with lower values ([40]). MSs could choose to implement full or partial convergence fully in the first year of the reform implementation in 2015 or gradually until 2019. Concerning the specific application of partial convergence, MSs could choose the distance to the target value that should be reduced for the farmers receiving payments below the average. Therefore, farmers can receive a higher value

([39]) According to the CAP regulation, the average direct payment per hectare in a MS cannot be lower than EUR 196/ha (in nominal prices).

([40]) Under partial convergence, farms receiving less than 90 % of the regional/national average rate are granted a higher-value payment with a guarantee that the decoupled payment is not lower than 60 % of the national/regional average. The increase in payments is financed by proportionally reducing the payments available to farmers receiving more than the regional/national average, with an option for MSs to limit the maximum loss of 30 % relative to pre-reform payments. In a similar way to full convergence, MSs may choose full implementation of partial convergence in the first year of the reform implementation in 2015 or gradual implementation up to 2019.

of payment entitlements by an amount that reduces the distance relative to the target value by 33 %, 70 % or 83 % (see column increase target in Table A-8). This target value is set at either 90 % or 100 % of the average in 2019 (see reference value in Table A-8). In addition, MSs could decide on the minimum level (compared with the average) of the payment value in 2019 (see minimum in Table A-8) and the maximum decrease in the payment value for farmers receiving above the average (see maximum in Table A-8). Finally, MSs could decide whether the reduction in the payment value above the average is applied linearly or proportionally (see model in Table A-8). In the case of linear reduction, the same percentage reduction is applied to all payment values above the average, while in the proportional reduction method the percentage reduction increases in proportion to the difference between the payment value and the 2019 average.

3. *Redistributive payment.* Redistributive payments aim to increase support for small and medium-sized farms by granting a higher payment value for the first 30 ha (or up to the average farm size if higher than 30 ha) than for the rest of the farm area. MSs can allocate up to 30 % of the direct payments budget to redistributive payments. The redistributive payment is a voluntary instrument.
4. *Degressivity/capping payments.* Degressivity and capping of decoupled payments aims to reduce the decoupled payments for the largest farms. In a similar way to redistributive payments, capping aims to generate a more equitable distribution of direct payments between farms. MSs are required to reduce (degressivity) decoupled payments by at least 5 % for payments above EUR 150 000. MSs can increase the 5 % rate up to 100 %, effectively capping payments ([41]). MSs are exempted from applying the payment reduction if they implement redistributive payments and these account for more than 5 % of direct payments.
5. *Entitlement allocation*. The MSs that implemented SPS in the pre-reform period can choose either (i) to maintain old (pre-reform) entitlements or (ii) to allocate new entitlements based on the eligible area in the first year of reform implementation (i.e. in 2015) to farms that were eligible for direct payments in 2013. Under the first option, MSs could impose an additional restriction that the number of entitlements does not exceed the eligible area in 2015. Under the second option, MSs could limit the number of allocated entitlements to the minimum between the eligible area in 2013 and the declared eligible area in 2015. Moreover, under both options MSs could choose to allocate fewer entitlements to grassland (i.e. to apply the reduction coefficient) or to exclude land cultivated with vineyards and greenhouses. Alternatively, MSs could grant new entitlements to farmers that were not eligible to receive direct payments under the old system (in 2013), such as vegetable producers, wine producers, etc. (European Commission, 2016).
6. *Extension of SAPS application*. MSs applying SAPS in the pre-reform period may extend the use of this system until 2020.
7. *CAP greening*. The reformed CAP imposes a stronger linkage between the decoupled payments and 'agricultural practices beneficial to the climate and environment' through three CAP greening measures: crop diversification, maintenance of permanent grassland and ecological focus area (EFA). CAP greening accounts for 30 % of the total direct payment funds. Not respecting these requirements may lead to a reduction or a complete loss of the decoupled payments.
8. Introduction of new measures such as the *young farmer scheme*, *Areas of Natural Constraints (ANC)* and the *small farmer scheme* (see Table 13).
9. *Coupled direct payments application* (referred to as Voluntary Coupled Support (VCS) in the CAP regulation). VCS are linked to a specific production activity and take the form of area payments granted to a particular crop or per head in the case of livestock. According to the 2013 CAP reform, MSs can allocate to VCS up to 15 % of the total national direct payment budget of decoupled payments (European Parliament, 2015).

([41]) Funds generated from the payment reduction and capping are shifted to Rural Development Programme (Pillar II).

10. The 2013 CAP reform attempts to prevent non-farmers from obtaining direct payments by more closely defining the concept of 'active farmer'.

The 2013 CAP reform offers some flexibility to MSs regarding the specific implementation of the above reform elements. Therefore, the actual adoption of different reform elements differs between MS. However, this choice is not fully flexible and depends on the past implementation system of direct payments. For example, MSs that had a heterogeneous value of payments across farms (e.g. the historical SPS model) are required to (fully or partially) harmonise them. MSs applying the SAPS may extend the use of this system; however, this scheme is not available to MSs that implemented the SPS under the previous CAP.

Table 13. New design of direct payments (and share of direct payments envelopes)

<table>
<tr><td rowspan="6">Cross compliance</td><td>Basic payment scheme*
- No fixed percentage
- 5 % degressivity over EUR 150 000</td><td rowspan="6">Small farmer scheme**
- Up to 10 %
- Maximum EUR 1 250
- Simplified</td></tr>
<tr><td>Green payment *
- Mandatory 30 %
- Greening practices or equivalent</td></tr>
<tr><td>Redistributive payment*
- Up to 30 %
- Maximum of 65 % of average direct payments (first hectare)</td></tr>
<tr><td>Young farmer**
- Up to 2 %
- +25 % payments (maximum 5 years)</td></tr>
<tr><td>Natural constraint support**
- Up to 5 %</td></tr>
<tr><td>Coupled support**
- Up to 15 %</td></tr>
</table>

* Compulsory
** Voluntary

Source: DG AGRI (2013).

10.1 Member State implementation of direct payments

As explained in the previous section, the 2013 CAP reform offers the MSs certain flexibility regarding its implementation. Table A-8 in Annex A shows the options taken by MSs regarding the application of the decoupled payments (i.e. internal convergence mechanism, the redistributing of payments, the capping, and internal convergence).

The 10 new MSs previously applying SAPS have decided to maintain this form of basic payment until the end of 2020. Among the 18 remaining MS, six decided to regionalise the BPS: France (two regions: Corsica and Hexagon), Germany (by administrative regions), Finland (two regions determined by natural constraints), Spain (50 regions determined by historical land uses (irrigated land, non-irrigated land, permanent crop land and grassland) and by county), Greece (regions determined by historical land uses: grazing areas, arable land and permanent crops) and the UK (in England three regions determined by natural characteristics ([42]) and, in Scotland, three regions determined by land uses and natural characteristics). The remaining 12 MS applying BPS have implemented it at national level.

Eleven MSs (and Northern Ireland) have decided to apply partial convergence, while six MSs (as well as England, Scotland and Wales) have opted for a flat rate (Germany, Malta and England in 2015 and the rest of MSs/regions by 2019). The percentage of the national ceiling dedicated to the BPS (including SAPS) is very heterogeneous among MS, ranging from 34 % in France to 68 % in Luxembourg.

Regarding the allocation of the payment entitlements, most MSs have adopted an entitlement allocation mechanism under which they replace old entitlements with new ones. Only four MSs decided to maintain existing (old) entitlements. The type of farmers eligible for payment entitlements was expanded to include virtually all active farmers. As a result, new payment entitlements have been allocated to farmers who (i) were producing fruit and vegetables, ware potatoes, seed potatoes, ornamental plants and grapes; (ii) had entitlements from the national reserve; and (iii) had never held, owned or leased entitlements, but could prove that they were exercising agricultural activity. In addition, some MSs limit the entitlements to those in 2013 (Denmark, Finland, Sweden, UK-England), while others limit the number of entitlements to the eligible hectares in 2013 (Belgium-Flanders, Ireland, Portugal and Spain) if that number is lower than the hectares declared in 2015. Furthermore, in France, vineyards are not eligible, while in Greece and the Netherlands arable land under permanent greenhouses is not eligible. Austria and UK-Scotland have applied a reduction coefficient to permanent grassland (1 ha of permanent grassland gives the right to 0.2 entitlements in Austria and 0.9 in UK-Scotland).

Eight MSs – Belgium (Wallonia only), Bulgaria, Croatia, France, Germany, Lithuania, Poland and Romania, implement the redistributive payment – ranging from 5 % of the national ceiling in Bulgaria to 20 % in France. Among these MSs, six have decided not to apply the reduction of payments mechanism; Bulgaria and Poland grant redistributive payments while applying the reduction of payments mechanism. Nine MSs ([43]) cap the basic payments at values ranging from EUR 150 000 to EUR 600 000 (Table A-8 in Annex A), while 15 MSs have opted to apply only the minimum reduction of 5 % to values of basic payments above EUR 150 000.

Concerning internal convergence the 10 new MS previously applying SAPS have decided to maintain this form of basic payment until the end of 2020. Amongst the 18 remaining MS, 6 decided to regionalize the BPS: France (2 regions: Corcega and Hexagon), Germany (by administrative regions), Finland (2 regions determined by natural constraints), Spain (50 regions determined by historical land uses (irrigated, non-irrigated, permanent crop and grassland) and county), Greece (regions determined by historical land uses: grazing areas, arable land and permanent crops), United Kingdom (in England three regions determined by natural characteristics([44]) and Scotland three regions determined by land uses and natural characteristics). The remaining 12 MS applying BPS have implemented it at national level. 11 MS (and Northern Ireland) have decided to apply a Partial Convergence, while 6 MS (and England, Scotland and Wales) have opted for a flat rate (Germany, Malta and England already in 2015, while the rest of MS/regions by 2019) (Table A-8 in Annex A).

Regarding the other direct payment measures, the ANC (Areas of Natural Constraints) is implemented only in Denmark (with only 0.35 % of the direct payment budget and with an average unit value of EUR 99/ha).

([42]) English non-SDA (Severely Disadvantage Area); English SDA non-moorland; English SDA moorland.

([43]) Nine Member States will make use of the option to subtract the salaries actually paid by farmers before applying the reduction.

([44]) English non-SDA (Severely Disadvantage Area); English-SDA non-moorland; English SDA-moorland.

Table A-9 shows the implementation of VCS across MSs. The livestock sector is the main beneficiary of the VCS, especially the beef and veal sector and the milk and dairy products sector (accounting for 41 % and 20 % of the VCS envelope, respectively).

Aid for cotton (not included in the direct payment envelop of VCS) is available in Bulgaria, Greece, Spain and Portugal. The payment value per hectare of eligible area is EUR 815.3, EUR 749.4, EUR 1 268.5 and EUR 501.6, respectively.

10.2 Technical implementation of direct payments in IFM-CAP

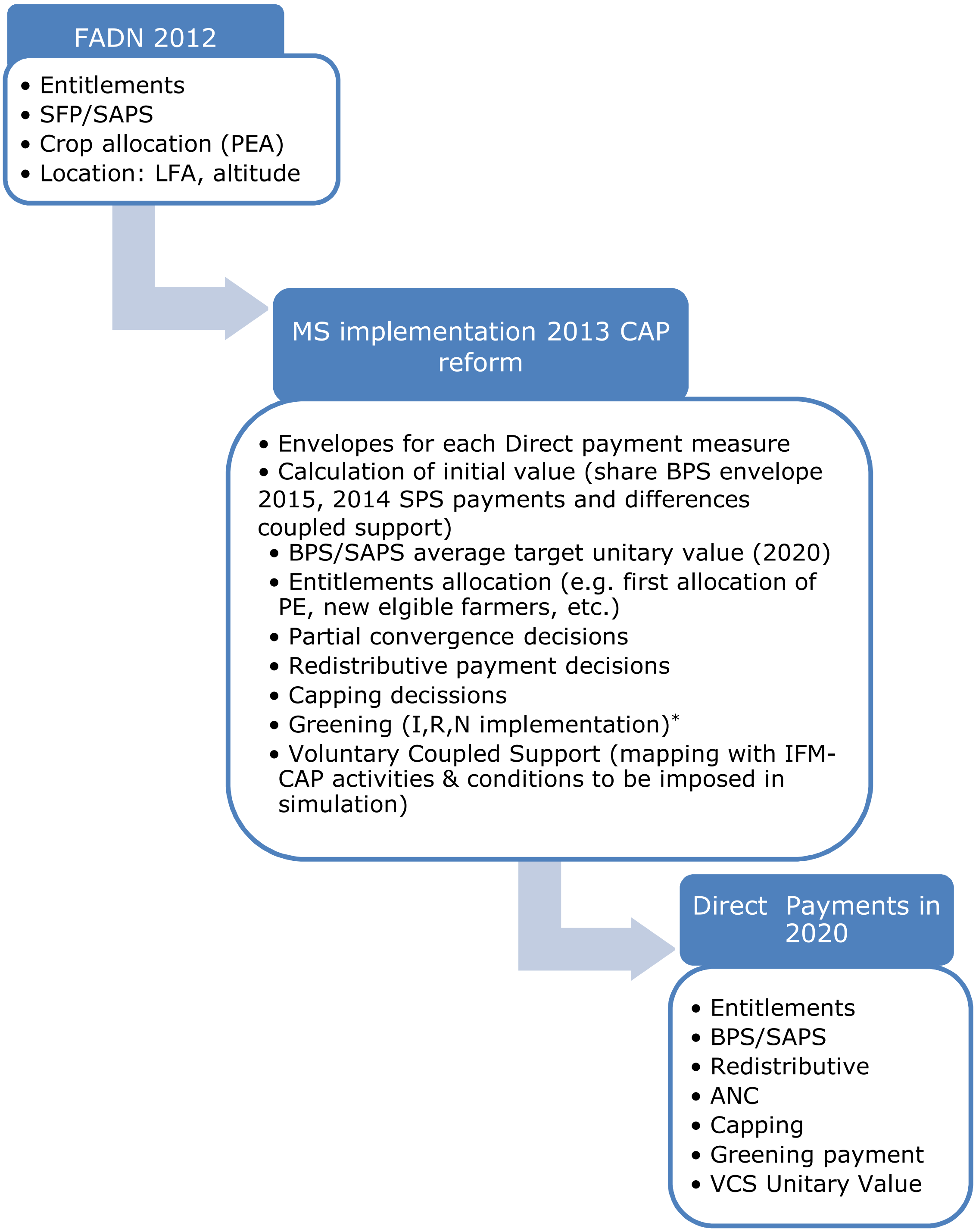
The new direct payments adopted by the 2013 CAP reform are incorporated in the IFM-CAP baseline. The IFM-CAP baseline considers direct payment as implemented in 2020 when full reform takes effect. Moreover, the IFM-CAP baseline considers MS-specific implementation of direct payments. Figure 10.1 illustrates information used to construct baseline direct payments in the IFM-CAP. Note that the direct payments need to be implemented at farm level in IFM-CAP, meaning that they might be heterogeneous in farms in a given MS depending on the implementation (e.g. in case of partial convergence of decoupled payments).

Several data sources are used to construct the baseline direct payments at farm level: 2012 FADN data (i.e. IFM-CAP base year), MS decisions on their implementation and CAP legislation. Following the 2013 CAP reform, the key policy variables that need to be calculated at farm level in the IFM-CAP baseline include BPS (including SAPS) payment value, entitlements, redistributive payments, greening, capping, ANC payments and the unitary value of coupled support.

The primary challenge of modelling the 2013 CAP reform is to capture the heterogeneity of decoupled payments between farms in a given MS. This concerns mainly decoupled payments for farms in MSs where historical or hybrid SPS models were implemented in the pre-reform period, while, after the reform, partial convergence was applied. To construct the farm decoupled payments, we start with the decoupled subsidies as available in the 2012 FADN data (see section 3.4). This reflects the situation before the implantation of the 2013 CAP reform (i.e. in base year). Then we apply the MS implementation formula of the 2013 CAP reform to the FADN 2012 decoupled payments to obtain post-reform (i.e. baseline) subsidies. The MS implementation formula of the 2013 CAP reform is based on the decision made by MSs in 2015 on the application of the reform until 2020. We apply a similar strategy for redistributive payments, greening payments, capping and ANC payments (Figure 15).

Regarding the coupled support, the measures implemented in IFM-CAP can be accurately implemented in the model in terms of eligibility condition (e.g. farms in mountain areas, organic farms, etc.) and the activities that can be identified in the model (e.g. silkworms are not an activity in IFM-CAP). If a maximum/minimum number of hectares/animals is eligible to receive coupled support, this has been considered in the model.

Figure 15. Implementation of the 2013 CAP reform in IFM-CAP



*I, individual; R, regional; and N, national; PEA, Potential Eligible Area; PE, Payment Entitlements

Below we list key assumptions made for the 2013 CAP reform implementation in IFM-CAP:

- All FADN farms are assumed to comply with the definition of active farmer and are therefore eligible for subsidies.
- The CAP regulation establishing that afforested areas and areas under the Water Framework Directive, Birds Directive or Habitat Directive are eligible for decoupled payments if they had the right to a payment in 2008 is not considered in this study because the necessary data are unavailable.

- In some MSs, we may underestimate the total decoupled payments in IFM-CAP for some farms (Ciaian et al., 2014) because we do not take into account entitlements for common land that can be activated by some farms. To partially control for this effect, we calculate the new entitlements in the baseline as the maximum between the farm's entitlements and the farm's UAA in the base year (2012) ([45]).
- In MSs implementing SAPS, there is a discrepancy between the UAA and the hectares receiving SAPS payments in some farms because, for example, the person who receives the SAPS payments is not always the farmer, but may be the landowner. To partially overcome this effect, we calculate the area eligible for SAPS payments as the maximum between the farm area that received SAPS payment in the base year and the farm's UAA.
- Some MSs give preferences to farmers applying for decoupled payments as a legal person or a group of natural or legal persons (e.g. related to the reduction of payments and the redistributive payment). These preferences were not considered in IFM-CAP because of data limitations.
- To calculate the 'capping' of decoupled payments, we subtract salaries paid by farmers in 2012 (i.e. the base year) rather than salaries paid in the previous calendar year, as considered in the CAP regulation.
- In Denmark, we assume that the ANC corresponds to the LFA as available in FADN in 2012 ([46]).
- The young farmer scheme and the small farmer scheme are not modelled in IFM-CAP. There are no data available in FADN to accurately assess the young farmer scheme ([47]), while the small farmer scheme is a voluntary measure that is not easily modelled in the current version of IFM-CAP. In terms of budget, these two schemes are minor. The young farmer scheme may represent only up to 2 % of the direct payment budget, while the small farmer scheme is applied in 15 MSs and is disbursed only to (small) farmers applying for it, which is difficult to assess (European Commission, 2017).

10.3 Modelling of CAP greening

The 2013 CAP reform introduced specific measures to enhance the provision of public goods by farmers, the greening measures (EU, 2013, 2014a,b). Under the CAP greening measures, 30 % of direct payments are conditional on complying with three mandatory requirements: (i) crop diversification for arable crops; (ii) maintenance of permanent grassland; and (iii) allocation of land to EFAs.

The IFM-CAP baseline considers all three greening measures. Following the EU regulation (EU, 2014a, 2015)., the modelling of greening measures assumes full compliance with the three greening measures without allowing farmers to trade off income reductions with full compliance against direct payment reduction as a consequence of partial or full non-compliance. Most studies in the literature model full compliance with CAP greening requirements (e.g. Was et al., 2014; Cortignani and Dono, 2015; Mahy et al., 2015; Gocht et al., 2017); a few allow farmers to choose the level of (non-)compliance (e.g. Vosough-Ahmadi et al., 2015; Solazzo and Pierangeli, 2016; Cortignani et al., 2017).

As shown in Table 14, the crop diversification measure applies only to farms with an arable area greater than 10 ha. Farms with more than 75 % of their total eligible land

([45]) There are exceptions to that formula for MSs keeping existing Payment Entitlements (PE) (Denmark, Finland, Sweden, UK-England) and MSs applying Article 24(4) , which limits the allocated entitlements to the minimum between the eligible area in 2013 and the declared eligible area in 2015 (translated to PE = UAA). In addition, the extension list of eligible farmers, the reduction coefficient for grassland and the exclusion for land cultivated with vineyards and greenhouses for some MS has been taken into consideration.

([46]) According to article 32(1) of Regulation 1305/2013 MS have to designate the areas facing natural and other specific constraints.

([47]) FADN does not contain information on whether a farmer has become the head of the farm for the first time.

covered by grassland and farms with 75 % of their arable area cultivated with forage are also not subject to the crop diversification measure. Furthermore, there are stricter requirements for farms having more than 30 ha of arable land (group 2) than for farms with between 10 and 30 ha of arable land (group 1). Farms in the latter group need to have at least two different crops and the main crop should not exceed 75 % of the arable land. Farms in the former group are required to have at least three crops; the main crop should not cover more than 75 % of the arable land and the two main crops together should not cover more than 95 % of the arable land.

Table 14. Crop diversification measure as implemented in IFM-CAP

	Exempted farms	**Farms group 1**	**Farms group 2**
Arable land (*AL*)	< 10 ha*	10 ha to 30 ha	≥ 30 ha
Minimum number of cultivated crops	–	2	3
Maximum proportion of main crop in *AL* (%)	–	75 %	
Maximum proportion of two main crops in *AL* (%)	–	–	95 %

*Farms are excluded if (i) fodder area + fallow area ≥ 75 % of *AL* and *AL* – (fodder + fallow) < 30 ha; (ii) grassland + other herbaceous fodder crops > 75 % UAA and *AL* – other herbaceous crops < 30 ha; or (iii) the farming is organic.

Source: compiled based on the Regulation No 1307/2013 (EU, 2013) and the Delegated Regulations No 639/2014 (EU, 2014a) and No 640/2014 (EU, 2014b).

Under the maintenance of permanent grassland measure, the ratio of grassland to total agricultural area cannot decrease by more than 5 % compared with the reference ratio in 2015. Moreover, under this measure, farms are prevented from ploughing and converting permanent grassland in areas designated by MSs as environmentally sensitive ([48]).

The calculation of the reference ratio can be applied at national, regional or sub-regional levels: 23 MSs apply it at national level, four MSs do so at regional level and one MS is without permanent grassland (Malta). If the ratio of grassland to total agricultural area has decreased by more than 5 % at the national or regional level (depending on the implementation), the obligation needs to be imposed at farm level (EU, 2013, 2014a,b).

We take 2012 as the reference year for modelling the grassland measure, as this is the IFM-CAP base year. That is, we calculate the ratio of grassland to total agricultural area for 2012 and compare it with the ratio in the baseline (2025). If in an MS or region (depending on the implementation) the ratio decreases by more than 5 % in the baseline relative to the base year, we impose the obligation at farm level in the greening scenario.

Two categories of grassland are modelled in IFM-CAP: permanent grassland and rough grazing area. Permanent grassland is assumed to be fully replaceable with arable land if relative returns change, while rough grazing area is assumed to be fixed, as this type of land is usually low quality. Both grassland categories are assumed to be subject to the grassland measure in the greening scenario.

In the case of environmentally sensitive areas, we consider that grassland located in a Natura 2000 area sis ubject to the grassland measure of no conversion to arable land.

The EFA measure requires farms with more than 15 ha of arable land to allocate at least 5 % of that land (excluding areas under grassland) to an EFA. The areas that qualify as

([48]) These areas could be located inside or outside Natura 2000 areas.

EFAs include land left fallow, terraces, landscape features, buffer strips, agroforestry, areas with short rotation, afforested areas, catch crops and nitrogen-fixing crops (Table 15) (EU, 2013, 2014a). MSs can choose which land elements they classify as eligible for EFA status. As reported in Table 15, land cultivated with nitrogen-fixing crops is the most common type of EFA-eligible area across MSs (in 27 MSs), followed by fallow land (26 MSs) and areas with short rotation (20 MSs). The eligible land elements have different weights in contributing to EFA levels (varying between 0.3 and 30), depending on their conversion and weighting factors ([49]).

Table 15. Land elements eligible for EFA

Eligible area	No of implementing MS	Conversion factor	Weighting factor	Modelling in IFM-CAP
Fallow land	26	n.a.	1	Yes
Terraces	8	2	1	No
Hedges or wooded strips	13	5	2	No
Isolated trees	13	20	1.5	No
Trees in line	16	5	1.5	No
Trees in groups	17	n.a.	1.5	No
Field margins	16	6	1.5	No
Ponds	12	n.a.	1.5	No
Ditches	15	3	2	No
Traditional stone walls	7	1	1	No
Other landscape features under GAEC or SMR	11	n.a.	1	No
Buffer strips	17	6	1.5	No
Agroforestry	11	n.a.	1	No
Strips along forest edges (no production)	9	6	1.5	No
Strips along forest edges (with production)	6	6	0.3	No
Areas with short rotation	20	n.a.	0.3	No
Afforested areas	14	n.a.	1	Yes
Catch crops or green cover	19	n.a.	0.3	Yes
Nitrogen fixing crops	27	n.a.	0.7	Yes

Note: n.a., not applicable; GAEC, Good Agricultural and Environmental Conditions; SMR, Statutory Management Requirements.

Source: compiled based on EU Regulations (EU, 2014a, 2015).

The EFA measure is the most challenging measure to model, as no data available that would enable us to capture different eligible land elements are available. Because of missing data in FADN, only the following four elements of EFA are considered in IFM-CAP: fallow land (including voluntary set-aside), afforested area, catch crops and nitrogen-fixing crops. Fallow land and nitrogen-fixing crops are endogenous activities in the IFM-CAP model. Forests and catch crops are not endogenously modelled in IFM-CAP and, therefore, their areas are set as equal to the base year level. The EU regulation specifies the list of crops that can be considered catch crops/green cover or nitrogen-fixing crops. Given that, in the IFM-CAP model, some minor activities are aggregated, they cannot be mapped exactly to this list of eligible crops. Therefore, we assumed that all cereals and pulses can be considered catch crops and that pulses and soya can be considered nitrogen-fixing crops. MSs with more than 50 % of their land surface area covered by forest may decide that the EFA measure will not be applied in areas in which more than 50 % of the land surface area at LAU-2 level ([50]) (or other contiguous

([49]) As in the case of the crop diversification measure (Table 15), farms with more than 75 % of their total eligible land covered by grassland and farms with 75 % of their arable area cultivated with forage are not subject to the EFA measure.

([50]) Local administrative unit (LAU) is a low-level administrative division of an MS defined at two levels: LAU-1 and LAU-2.

geographical area) is covered by forest and the ratio of forest land to agricultural land is higher than 3:1. This forest exemption is applied in Estonia, Finland, Latvia and Sweden. Given that FADN (and IFM-CAP) does not include any information on the LAU-2 level, the forest exemption is assessed at farm level, but only for farms located in NUTS3 regions in which the exemption is applied (European Commission, 2016).

It is important to note that MSs can change the elements that are eligible to be counted as EFAs on a yearly basis. Table 15 reports the notifications applied in 2016 that correspond to the assumptions in the modelling of CAP greening in IFM-CAP.

11 Model environment

The IFM-CAP model is programmed in GAMS and solved using CONOPT and SBB (Standard Branch and Bound algorithm) solvers. CONOPT is applied to solve the non-linear program (NLP) in calibration and baseline, while SBB is used to solve the mixed integer non-linear program (MINLP) induced by the modelling of the CAP greening scenario because of discrete choice decisions linked to, for example, the restriction on the minimum number of crops cultivated on-farm. GAMS permits the compact representation of the programming model by using concise algebraic statements that are easily read by model users.

IFM-CAP has also been linked to a GUI to support users in building and preparing the database, run the model and exploit the results. Written in Java, this GUI targeted users who would like to apply IFM-CAP without having a deep knowledge of GAMS programming language. It is an update of the CAPRI-GUI developed by the Institute for Food and Resource Economics, University of Bonn (Britz, 2011).

The current GUI version is still at the trial stage and has a limited number of functionalities that are organised into work steps and tasks. The left-hand panel allows the selection of the different IFM-CAP work steps and their corresponding tasks. The right-hand panel offers controls depending on the properties of the task. Each work step may comprise several tasks, which are shown in the second panel, below the work step panel. The content of the panel may change when the user selects a different work step. Only one work step and one task can be activated at a time. In each task, the user can compile (and test if the program compiles without errors), start (execute the program) or stop the GAMS program. The user can also load and visualise the results generated from the task.

Three work steps can be performed through the IFM-CAP GUI: generate base year, generate baseline and run policy scenario. The fourth work step, 'prepare FADN data', is simply used to convert original FADN csv files into gdx files.

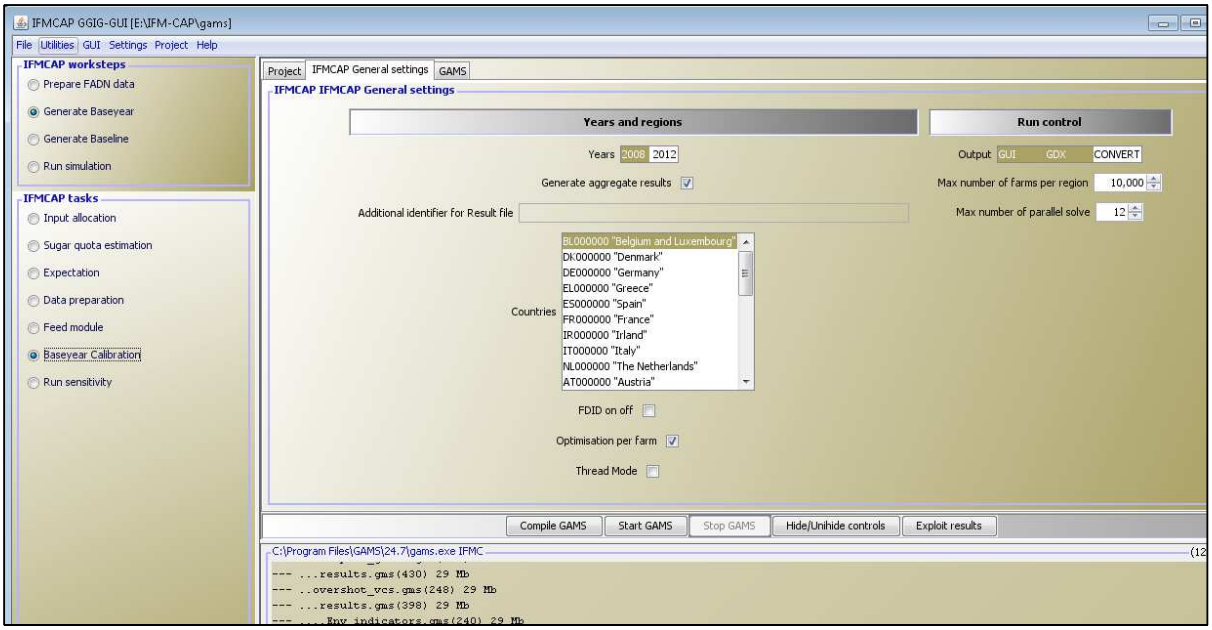
'Generate base year' work step (Figure 16): this consists of seven tasks: input allocation, sugar quota estimation, expectation, data preparation, feed module, base year calibration and run sensitivity analysis.

- The input allocation panel allows the estimation of the unit input costs of agricultural activities using the HPD approach. By running the input allocation program for the selected countries, the set of input–output coefficients, as well as the unit input costs by activity at single farm and at NUTS2 level, are generated and stored in gdx files. This task is controlled by the 'InputAlloca_HPD_IFM.gms' GAMS file.
- The sugar quota panel allows the estimation of, using the HPD approach, the in- and out-of-quota sugar beet production and prices in each FADN farm producing sugar beet. This task is controlled by the 'Estima_sugb_quota.gms' GAMS file.
- The expectation panel allows the calculation of the expected yields, prices and input costs for the base year 2012, assuming adaptive expectations (based on the past 3 years with declining weights). This task is controlled by the 'expectation.gms' GAMS file.
- In the data preparation task, the user can build the database and generate the dataset for the selected countries. By running the GAMS program in this task, all the input data needed by IFM-CAP for the base year and for the selected countries are generated and stored in gdx files. The user can run the program for a single country, a set of countries or all EU-27 countries. This task is controlled by the 'DataPrep.gms' GAMS file.
- The feed module panel allows the estimation of the nutrient requirements and physical quantity of feed for each feed and each animal activity, as well as the quantity of purchased, sale and other use of feed using the HPD approach. By running

the program (‘feed_module.gms’) for the selected countries, the results at single farm level are generated and stored in the gdx file ‘results_feed.gdx’.

- The base year calibration panel allows IFM-CAP to be run for the base year period for the selected countries by either using data already stored in gdx files or running the ‘data preparation program’ as explained above. After running the GAMS program in this task, the user can check the model calibration and evaluate model performance by visualising the results, stored under gdx files, accessible from the ‘exploit results’ button. The ‘IFMCAP_experiments.gms’ GAMS file is used for running this task.
- In the run sensitivity panel, the user can derive point elasticities at NUTS2 level for a 10 % change in output prices. This step also allows the analysis of the sensitivity of the simulations obtained with the calibrated models for the key variables (mainly land allocation and production) beyond the base year. The ‘IFMCAP_experiments.gms’ GAMS file is used for running this task.

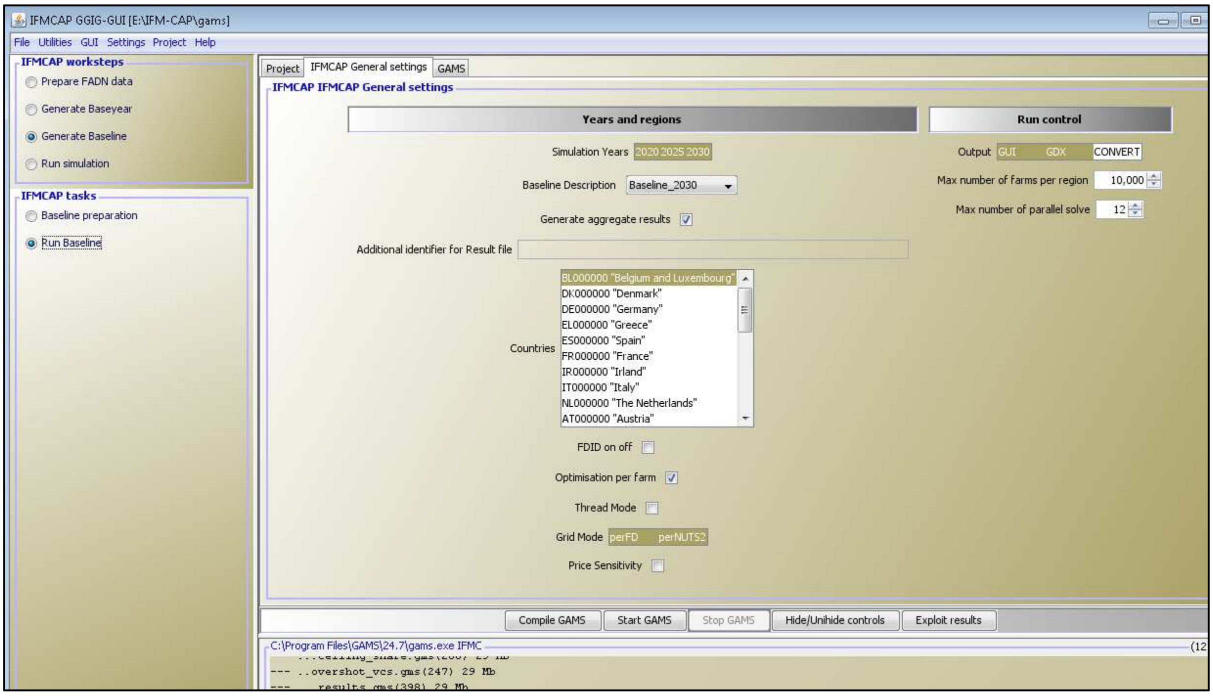
Figure 16. Task panels of the ‘generate base year’ work step in IFM-CAP GUI



‘Generate baseline’ work step (Figure 17): this work step involves two tasks.

- In the ‘Generation trend projection’ task, the results from the trend projection from the CAPRI model are used to generate the IFM-CAP baseline prices and yields. Since the CAPRI growth rates of yields and prices are defined at NUTS2 level, we impose the same growth rate on all farms belonging to the same NUTS2 region. In this step, we also inflate the input costs, as well as the PMP terms, to the chosen simulation year.
- In the ‘Run baseline’ task, the user runs the IFM-CAP baseline using the base year data (inflating the costs and PMP terms to the chosen simulation year) and the trend projection of yield and prices generated in the previous task. The user should also select the simulation year and the ‘baseline description’ file. The generated baseline (i.e. reference run) scenario is used as a reference for comparing simulated policy scenarios. This task is controlled by the ‘IFMCAP_experiments.gms’ GAMS file.

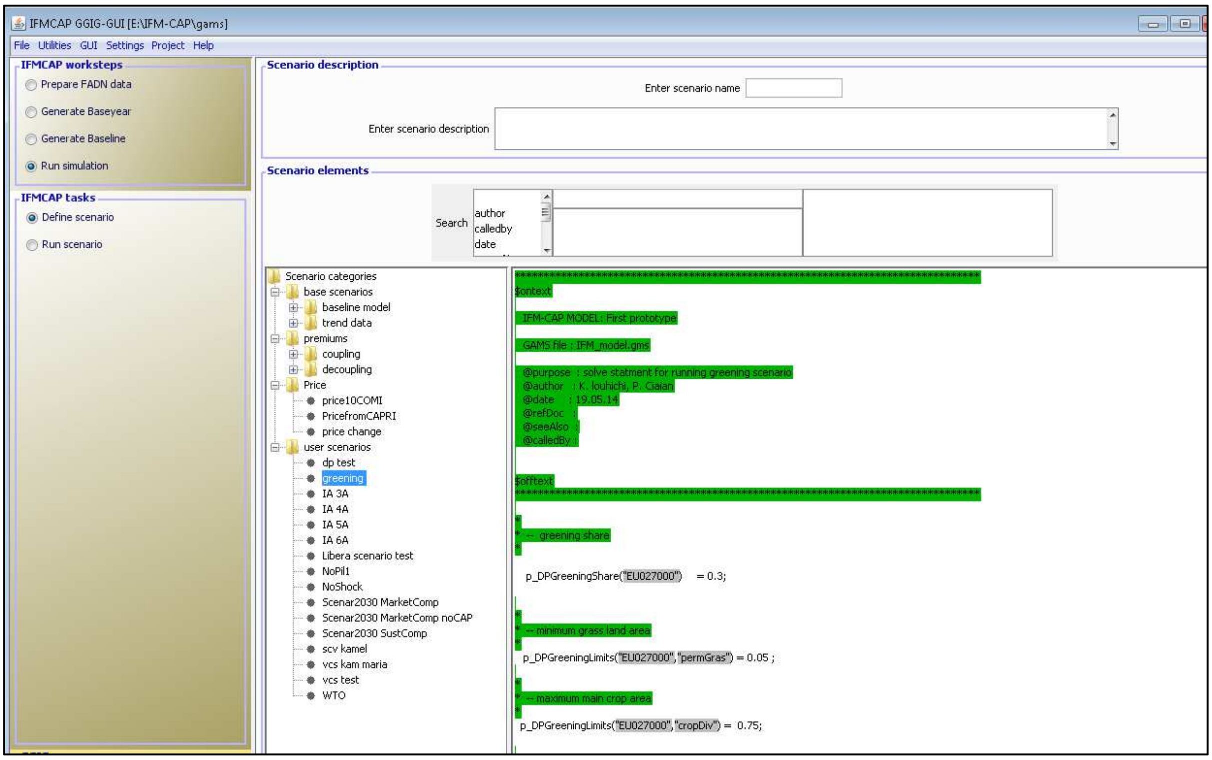
Figure 17. Task panels of the 'generate baseline' work step in IFM-CAP GUI



'Run simulation' work step (Figure 18 and Figure 19): two different tasks can be performed under this work step.

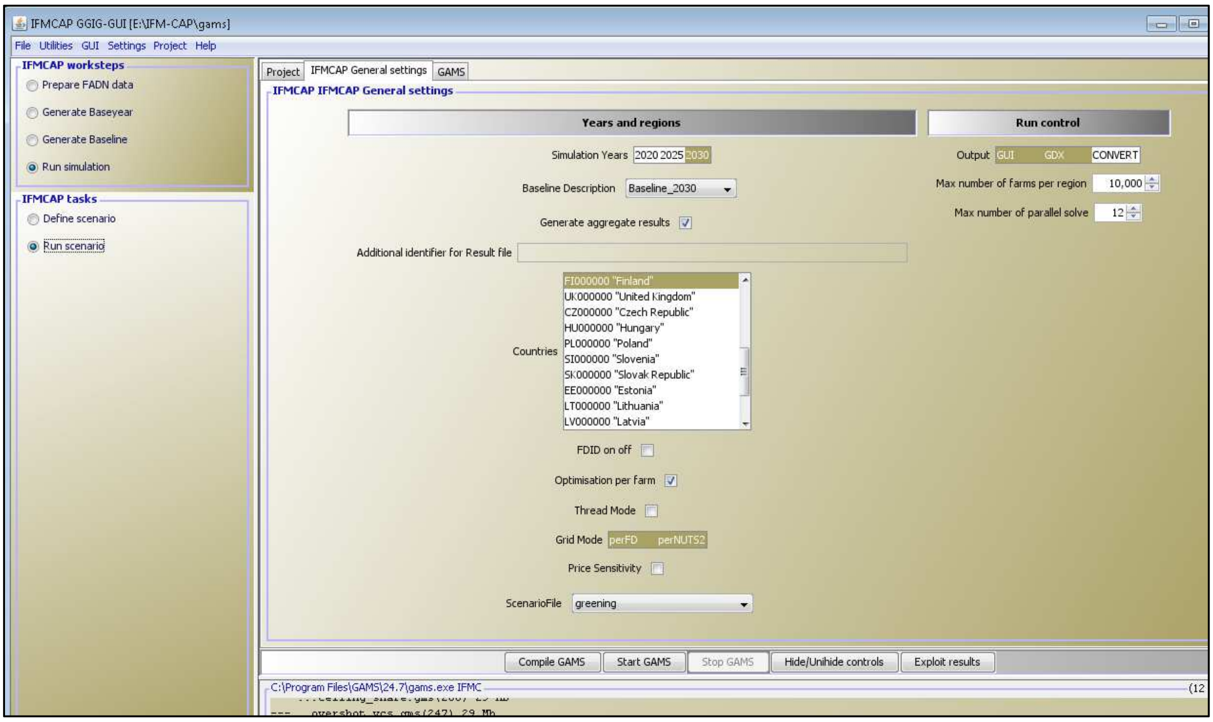
- Through the 'Define policy scenario' task – the policy editor – the user may build up a policy scenario that specifies an assessment exercise. A scenario is characterised by a name and a short description of the problem that it is trying to solve or study, and it incorporates at least one experiment defined in a scenario file. The policy editor allows separate directories for the pre-edited 'snippets' to be defined, which can be edited and combined by the user to generate scenario files. The related file dialogs only allow the user to navigate under these directories and use filters for the 'gms' extensions. The policy editor also allows searching for files in all tags, that is, the header lines of the files. A tag is a line in the file header where the tag's name on the right is separated from the tag's content on the left. The user can select any tag name and either use a free search field or select from a list of found contents. Potentially useful tags for IFM-CAP are for instance, 'Key words', 'Policy context' and 'Project'. The aim of these tags is to allow a user to find quickly files that constitute code relevant for the scenario to be implemented.

Figure 18. Task panels for 'Define policy scenario' in the IFM-CAP GUI



- In the 'Run policy scenario' task, the user runs the policy experiment selected in the previous step. The user should specify the simulation year, select the baseline description file and choose the scenario file related to the policy experiment. This task is controlled by the 'IFMCAP_experiments.gms' GAMS file.

Figure 19. Task panel for 'run policy scenario' in the IFM-CAP GUI



A post-modelling routine is developed to facilitate the management and use of model results. Specifically, this routine aims to do the following:

- report model outputs, such as activity levels, production, on-farm use, sales/purchases, sales within quota, etc., for both individual production activities and single farms;
- calculate activity-specific income indicators (revenues, variable costs, premiums, gross margins and PMP terms per hectare or head) for single farms and any relevant aggregation by farm specialisation, farm size, NUTS2/NUTS3/FADN/regions, socio-demographic characteristics (e.g age), MSs and the whole EU.
- report different income and environmental indicators at farm level, such as farm income, revenues, variable costs, premiums, PMP terms, etc.
- aggregate model outputs, such as activity level, production, revenues, income, etc., at farm-type, NUTS2 and national levels (and other classification relevant for the policy maker) using farm weights.
- visualise the results in maps, graphs and interactive charts.

12 Model application: CAP greening[51]

12.1 Baseline

The baseline construction for this application follows the same procedure as described in section 9. The only difference is that it assumes a continuation of the 2013 CAP reform up to 2025 without the greening restrictions. This baseline assumption about CAP is considered only in this specific application of IFM-CAP model. This assumption was made to identify the impacts of CAP greening on the EU farming sector. In the standard IFM-CAP baseline, the entire current CAP is considered, including CAP greening.

12.2 CAP greening scenario

As explained in section 10.3, the 2013 CAP reform introduced three measures to enhance the provision of public goods by farmers: (i) crop diversification for arable crops; (ii) maintenance of permanent grassland; and (iii) allocation of land to EFAs. The greening scenario simulated in this application includes all three greening measures, while keeping the direct payments and other policies unchanged relative to the baseline scenario (see section 10.3 on modelling of CAP greening in IFM-CAP).

([51]) The results presented in this section are based on Louhichi et al. (2017b).

13 Simulation results: farm-level impacts of CAP greening

13.1 The analysis of baseline results

Before presenting the greening scenario simulation results, we provide some statistics on the number of farms subject to CAP greening measures in the baseline. Of around 5 million commercial farms represented in IFM-CAP for the EU-27, around 55 % are subject to at least one CAP greening measure, while the rest (45 %) are exempt from all three measures. The MSs with the largest proportions of farms subject to CAP greening include Ireland (99 %), the UK (93 %), Denmark (90 %), Slovakia (88 %), Germany (85 %), Belgium–Luxembourg (85 %), Sweden (82 %), France (81 %), Poland (80 %), Slovenia (80 %) and Finland (80 %). In contrast, the smallest proportions of farms subject to CAP greening are found in Mediterranean countries – Malta (1 %), Cyprus (18 %), Greece (22 %) and Italy (27 %) – because they have relatively high proportions of small farms that are exempted from the diversification and EFA measures. The remaining MSs have proportions of farms subject to CAP greening ranging between 45 % and 75 % (Table 16).

Table 16. Non-compliant farms with CAP greening in baseline (% of farms)

	Exempted farms	Concerned farms	Baseline				
			Complying farms (% of total farms)	Non-complying farms			
				Greening all	CropDiv	EFA	Grass
EU-27	45.1	54.9	70.8	29.2	9.2	13.5	14.3
Belgium and Luxembourg	14.8	85.2	63.6	36.4	8.1	34.1	0.8
Bulgaria	53.6	46.4	60.0	40.0	10.9	12.6	25.9
Czech Republic	29.1	70.9	46.9	53.1	26.0	41.5	17.3
Denmark	10.2	89.8	15.6	84.4	29.3	80.2	30.4
Germany	15.1	84.9	55.1	44.9	13.4	32.2	12.8
Estonia	26.2	73.8	70.9	29.1	11.5	23.5	0.7
Ireland	1.0	99.0	85.0	15.0	8.4	5.9	9.7
Greece	77.8	22.2	90.8	9.2	5.5	6.5	0.0
Spain	52.3	47.7	66.8	33.2	18.7	19.3	10.7
France	19.5	80.5	63.2	36.8	16.0	29.7	0.5
Italy	73.0	27.0	90.0	10.0	6.6	6.8	0.0
Cyprus	81.8	18.2	91.4	8.6	3.2	6.6	0.7
Latvia	26.8	73.2	65.4	34.6	9.6	23.1	10.3
Lithuania	35.6	64.4	66.0	34.0	18.6	27.0	4.4
Hungary	36.2	63.8	54.5	45.5	30.1	33.1	7.0
Malta	99.2	0.8	99.8	0.2	0.1	0.1	0.0
Netherlands	24.6	75.4	75.7	24.3	14.2	19.9	2.0
Austria	32.3	67.7	85.8	14.2	1.5	13.1	0.0
Poland	19.6	80.4	67.0	33.0	6.3	10.7	22.5
Portugal	52.2	47.8	71.7	28.3	5.7	4.4	21.4
Romania	54.6	45.4	64.5	35.5	2.5	3.6	31.7
Slovenia	19.6	80.4	47.0	53.0	0.8	7.8	49.8
Slovakia	11.6	88.4	24.1	75.9	37.8	64.6	21.8
Finland	19.9	80.1	49.3	50.7	21.3	40.0	14.2
Sweden	17.9	82.1	54.1	45.9	11.1	30.2	24.6
UK	7.2	92.8	58.5	41.5	15.1	29.0	12.8

Although a significant proportion of farmers are subject to CAP greening (i.e. 55 %), not all of them are affected by CAP greening. In fact, the proportion of farms not complying with CAP greening, in the baseline scenario, represents only around 29 % of all the commercial farms in the EU-27. This proportion varies between 0.2 % in Malta and 84 %

in Denmark (Table 16). In terms of the specific measures, the non-complying proportion of EU farms is 9 % for crop diversification, 13 % for EFA and 14 % for grassland measures ([52]). The non-compliant farms in the baseline scenario represent a hypothetical situation that is in breach of at least one greening measure. These farms need to adjust their land allocation to comply with the CAP greening measures if they do not want to face a reduction in subsidy (i.e. lower greening payments). The remaining 26 % (i.e. 55 % to 29 %) of farms subject to CAP greening in the EU-27 are effectively not affected by CAP greening because their area allocation in the baseline complies with all greening requirements.

Table 17 reports the UAA subject to CAP greening and non-complying UAA with CAP greening requirements in the baseline scenario ([53]). Compared with the proportions of farms reported in Table 16 for the EU-27, the proportions of UAA subject to CAP greening and non-complying UAA are significantly higher, reaching 86 % and 49 %, respectively. By specific measure, the proportion of non-complying UAA in the EU-27 is 16 % for crop diversification, 39 % for EFA and 11 % for grassland measures. This implies that larger farms (in terms of area) tend to be more affected by greening than smaller farms. This result is expected, as many small farms are excluded from CAP greening (in particular from crop diversification and EFA measures).

Table 17. Non-compliant area with CAP greening in baseline (% of UAA)

	Exempted UAA	Concerned UAA	Baseline				
			Complying UAA	Non-complying UAA			
				Greening all	CropDiv	EFA	Grass
EU-27	14.2	85.8	50.7	49.3	15.5	39.1	10.9
Belgium and Luxembourg	5.3	94.7	55.1	44.9	6.8	43.6	1.4
Bulgaria	4.0	96.0	28.9	71.1	13.6	61.9	10.9
Czech Republic	13.6	86.4	29.3	70.7	10.4	67.0	18.7
Denmark	6.3	93.7	9.5	90.5	19.0	89.2	27.6
Germany	6.7	93.3	39.4	60.6	12.0	52.0	9.9
Estonia	9.9	90.1	62.4	37.6	6.2	34.5	0.5
Ireland	1.0	99.0	82.2	17.8	9.6	9.1	10.3
Greece	41.9	58.1	74.9	25.1	13.7	20.9	0.0
Spain	21.5	78.5	52.2	47.8	25.8	33.2	12.9
France	5.3	94.7	54.9	45.1	15.0	39.5	0.5
Italy	36.5	63.5	74.2	25.8	15.3	20.0	0.1
Cyprus	39.0	61.0	65.5	34.5	12.9	27.2	3.9
Latvia	21.6	78.4	52.3	47.7	11.2	41.5	7.9
Lithuania	22.8	77.2	42.7	57.3	19.7	52.8	7.5
Hungary	4.6	95.4	24.0	76.0	32.2	67.2	14.5
Malta	95.9	4.1	98.7	1.3	0.4	1.1	0.0
Netherlands	11.9	88.1	62.5	37.5	19.6	34.3	2.0
Austria	32.5	67.5	78.6	21.4	1.8	20.2	0.0
Poland	9.3	90.7	49.6	50.4	11.5	32.4	23.8
Portugal	24.2	75.8	49.1	50.9	18.6	15.1	28.7
Romania	19.1	80.9	31.0	69.0	12.1	46.6	24.1
Slovenia	16.9	83.1	40.4	59.6	1.9	23.8	49.3
Slovakia	9.8	90.2	17.3	82.7	17.7	74.7	30.1
Finland	16.8	83.2	46.5	53.5	20.1	45.1	13.1
Sweden	22.0	78.0	51.3	48.7	9.5	35.3	22.9
UK	7.3	92.7	61.7	38.3	11.4	31.4	7.2

A full comparison of the results reported in Table 16 and Table 17 with literature findings is not always possible, as the studies are heterogeneous in terms of the methodologies

([52]) Note that the sum of non-complying farms by measure (i.e. 9 % + 13 % + 14 %) might not be equal to the figure reported for non-complying farms for all three measures combined (i.e. 29 %) because some farms may be in breach of more than one measure in the baseline.

([53]) These two indicators are calculated as the sum of UAA of farms subject to CAP greening and non-complying UAA with CAP greening requirements across all farms, respectively.

used, data sources, geographical scope and farm coverage. In general, studies that use data covering the total farm population find smaller proportions of farms and areas subject to CAP greening and affected by CAP greening than our results suggest. This is expected, as we modelled only commercial farms, whereas total farm population data include small non-commercial farms, which are exempt from some greening measures (e.g. Vanni and Cardillo, 2013; EU, 2014a,b). The findings of studies based on farm sample data (e.g. FADN) depend on the regional coverage, but, in general, they tend to be similar in magnitude to our results (e.g. Was et al., 2014; Solazzo and Pierangeli, 2016).

13.2 Land use effects

Table 18 shows the areas reallocated as a result of CAP greening measures in the EU-27. The figures were calculated as the total area of crops that changed land allocation over all EU-27 farms, by farm specialisation and farm economic size. The total area reallocated as a result of CAP greening measures represents 4.5 % of the UAA in the EU-27. The standard deviation across MSs is about 2.4 % of UAA. As reported in Table 18, in relative terms, the area reallocated is mostly the result of the EFA measure (2.4 % of UAA), followed by the crop diversification measure (1.8 %). The grassland measure leads to the reallocation of 1.5 % of UAA ([54]). In the case of the crop diversification measure, the 75 % threshold imposed for the main crop cultivated on arable farms has the largest effect (1.4 % of UAA). At MS level, the contribution of the three measures to the total reallocated area is very heterogeneous. In several MSs, the EFA measure leads to a larger reallocated area than other measures (e.g. Denmark, Slovakia, Hungary), while in others the grassland measure has the strongest effect (e.g. Slovenia, Ireland).

Table 18. Reallocated area due to CAP greening in EU-27 (% of UAA)

Farm specialisation	**EU**	**s.d. at MS level**	**Farm size (EUR)**	**EU**	**s.d. at MS level**
Specialist COP	5.5	2.5	< 2 000	n.a.	n.a.
Specialist other field crops	6.4	2.9	2 000 < 4 000	8.2	1.0
Specialist horticulture	5.5	4.3	4 000 < 8 000	5.3	3.7
Specialist wine	1.1	0.8	8 000 < 15 000	4.8	4.3
Specialist orchards – fruits	0.9	1.6	15 000 < 25 000	5.5	5.0
Specialist olives	0.3	0.4	25 000 < 50 000	4.5	4.0
Permanent crops combined	1.1	4.4	50 000 < 100 000	4.0	3.1
Specialist milk	4.8	5.0	100 000 < 250 000	4.2	2.7
Specialist sheep and goats	4.3	5.3	250 000 < 500 000	4.1	2.4
Specialist cattle	3.4	6.6	500 000 < 750 000	4.8	3.2
Specialist granivores	4.2	2.1	750 000 < 1 000 000	4.9	2.4
Mixed crops	4.2	3.1	1 000 000 < 1 500 000	4.8	3.5
Mixed livestock	3.7	2.9	1 500 000 < 3 000 000	4.6	3.0
Mixed crops and livestock	4.0	2.4	≥ 3 000 000	3.6	4.1
EU-27	4.5	2.4			

Note: s.d., standard deviation; n.a., not applicable.

As shown in Table 18, the farms with the largest proportion of reallocated UAA as a result of CAP greening measures are those that specialise in COP, other field crops, horticulture, cattle, sheep and goats, and mixed farms. Regarding farm economic size, the effects tend to be rather homogeneous, although small and large farms report slightly greater reallocated areas than medium-sized farms, driven mainly by the EFA and crop diversification measures (Table 18). Note that many farms that have a small

([54]) Note that the sum of area changes due to the crop diversification, EFA and grassland measures reported in Table 19 may not equate to the aggregate reallocated areas reported in Table 18 because of the interactions between the measures, as some farms are affected by more than one measure. For example, under certain circumstances, the introduction of a new crop that is eligible under the EFA measure (e.g. pulses) in the greening scenario may simultaneously help farmers to comply with the diversification and EFA measures if they were in breach of these two measures in the baseline scenario.

area but specialise in capital- and labour-intensive production activities (e.g. horticulture, pigs and poultry production) are categorised as middle economic size in FADN, which may explain the smaller CAP greening effect for this class.

Similar results are found in the literature, although it is not always straightforward to compare the farm classifications between studies. For example, Gocht et al. (2017) show that the land use effects of CAP greening in the EU are larger for farms specialising in COP, cattle, sheep, goats and other grazing livestock, and mixed livestock holdings. Cortignani and Dono (2015), who used a farm-type model for an irrigated area in west-central Sardinia (Italy), found that CAP greening has a substantial impact on dairy farms that specialise in arable fodder crops.

Figure 13.1 shows the distribution of the reallocated area across all individual farms represented in FADN for the EU-27 (i.e. the total number of farms in the EU-27 is equal to 100) compared with the baseline. This figure is constructed by sorting, in increasing order, all the farms according to the size of the reallocated area until all farms (100 %) ([55]) are reported. The vertical axis in Figure 13.1 starts at 65 % to better illustrate the changes for the affected farms. Consistent with the aggregate results reported in Table 16, only 29 % of farms change land allocation as a result of CAP greening. The remaining 71 % of farms do not change land allocation at all, because they already comply in the baseline or because they are not subject to CAP greening (i.e. they are exempted farms). As depicted in Figure 20, most of the affected farms (27 % all farms) reallocate between 1 % and 50 % of their UAA as a result of CAP greening. However, around 1 % of farms reallocate more than 50 % of their total UAA. This large proportion of reallocated area is a consequence of the grassland measure, particularly on farms with a small UAA and a large proportion of grassland; these farms need to reconvert the land when greening is introduced. The other two measures have an impact on land allocation that is less than 50 %. By design, the diversification measure may result in a reallocation of a maximum of 25 % of UAA, for example, in mono-crop farms. The EFA measure may result in a reallocation of a maximum of 5 % of UAA in farms that have no EFAs in the baseline.

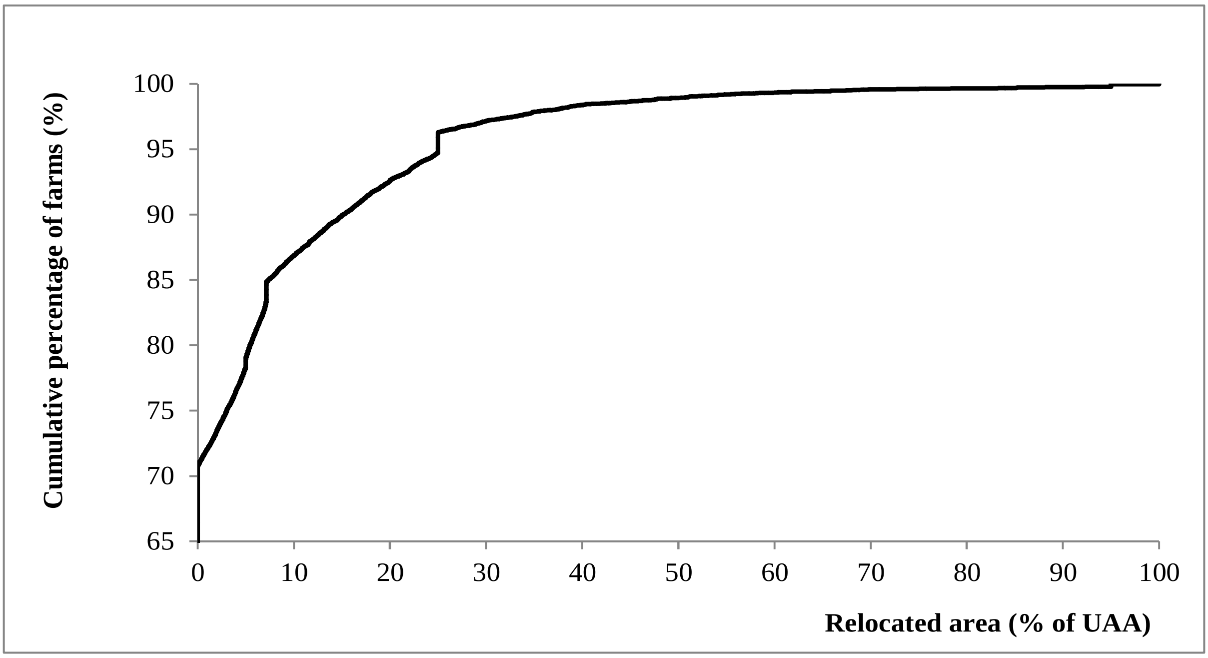
([55]) Note that we apply FADN farm weights to represent the farm population in the figure.

Table 19. Reallocated area due to specific greening measures in EU-27 (% of UAA)

		Reallocated area by measure (% of UAA)	s.d. at MS level
Crop diversification	Total change	1.8	1.0
	75 % threshold	1.4	0.8
	95 % threshold	0.4	0.2
EFA	No weight adjusted	2.4	1.2
	Weight adjusted	1.9	0.9
Grassland		1.5	2.1

Note: s.d., standard deviation.

Figure 20. The distribution of reallocated area due to CAP greening across farm population in EU-27 (all farms, % change relative to baseline)



13.3 Production effects

The production effects of CAP greening follow similar tendencies to land use effects. They depend on the production structures of farms in the baseline and on the extent to which they are in breach of the greening measures. The production of crops that have a large land share in the baseline will tend to decrease, whereas the production of crops with a small land share will tend to increase as a result of the diversification measure. The production of crops eligible for EFA is expected to increase with the introduction of this measure. The grassland measure is expected to have a negative impact on arable crop production and it may stimulate livestock production.

Table 20 reports the production quantity effects of CAP greening for the EU-27. The results show that the production changes caused by CAP greening are relatively small. The total production change at EU-27 level represents a decline of around 0.9 % compared with the baseline. Total production declines because farms are required to adjust land allocation in line with the CAP greening requirements, which they would not do otherwise. At MS level, the total production change varies between 0 % and –4.5 % (not reported in Table 20).

Table 20. Production quantity change caused by CAP greening for selected crops and total production in the EU-27 (% change relative to the baseline)

Farm specialisation	Wheat	Barley	Rape	Pulses	Total production	Farm size (EUR)	Wheat	Barley	Rapeseed	Pulses	Total production
Specialist COP	−3.4	−6.9	−3.8	44.2	−2.2	< 2 000					
Specialist other field crops	−1.1	−5.5	−3.2	59.3	−1.9	> 2 000 ≤ 4 000	−2.9	−3.7	−12.4	−41.0	−3.0
Specialist horticulture	6.3	4.0	−3.9	33.8	−1.6	> 4 000 ≤ 8 000	−2.5	−4.2	−7.1	−3.9	−1.8
Specialist wine	−2.0	−3.5	6.1	4.4	−0.1	> 8 000 ≤ 15 000	−4.3	−10.6	−6.0	1.8	−1.5
Specialist orchards – fruits	−2.6	−3.4	−11.2	1.6	−0.3	> 15 000 ≤ 25 000	−5.5	−10.2	−7.3	3.0	−1.6
Specialist olives	−3.4	−2.9	n.a.	3.4	0.0	> 25 000 ≤ 50 000	−4.7	−6.7	−4.6	6.9	−1.2
Permanent crops combined	−4.0	−6.3	7.0	3.5	−0.2	> 50 000 ≤ 100 000	−3.7	−5.9	−4.8	18.1	−0.9
Specialist milk	−3.3	−5.1	−3.6	−3.9	−0.2	> 100 000 ≤ 250 000	−2.6	−5.2	−3.5	19.0	−0.7
Specialist sheep and goats	−6.9	−12.0	−2.1	−19.1	−0.7	> 250 000 ≤ 500 000	−2.6	−4.7	−2.9	33.9	−0.6
Specialist cattle	−6.2	−9.2	−12.1	−24.9	−1.1	> 500 000 ≤ 750 000	−2.5	−5.5	−4.2	51.4	−0.8
Specialist granivores	−3.3	−4.3	−3.9	40.4	−0.7	> 750 000 ≤ 1 000 000	−2.9	−5.9	−5.0	51.7	−0.8
Mixed crops	−2.6	−7.9	−9.6	18.6	−0.7	> 1 000 000 ≤ 1 500 000	−3.0	−6.9	−3.7	42.9	−1.0
Mixed livestock	−1.9	−3.4	−3.0	9.1	−0.6	> 1 500 000 ≤ 3 000 000	−1.8	−6.3	−5.0	99.8	−1.2
Mixed crops and livestock	−3.2	−5.1	−4.1	37.4	−1.0	> 3 000 000	−2.3	−4.1	−3.2	92.9	−1.2
EU-27	−3.1	−6.2	−4.0	20.3	−0.9						

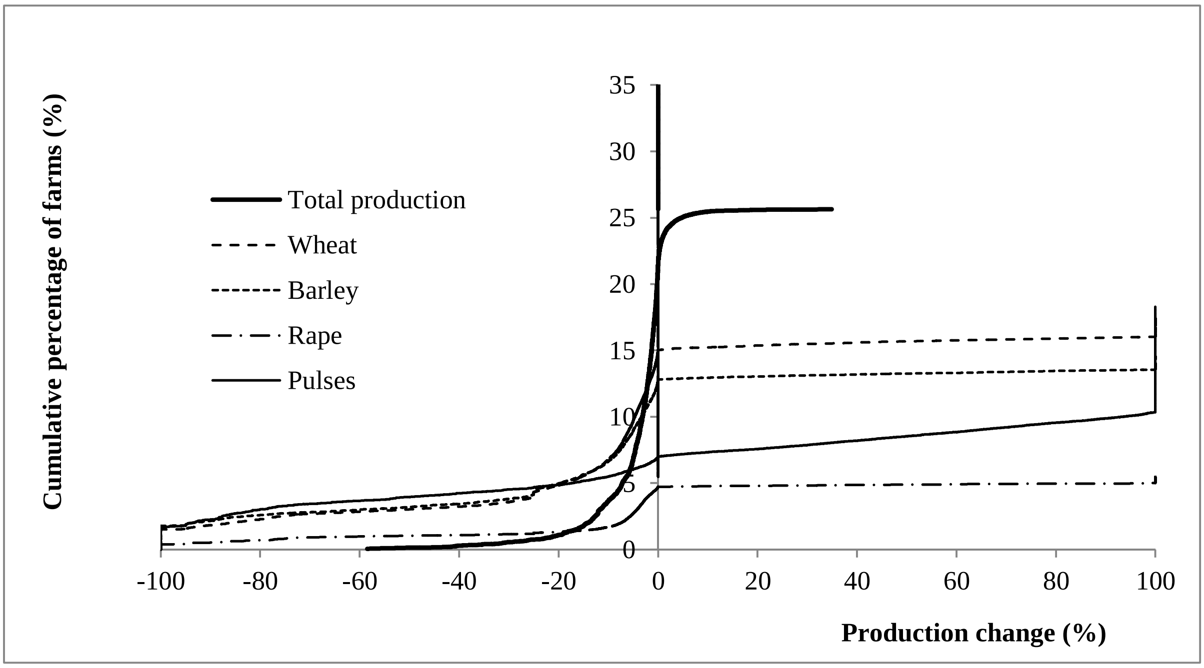
Note: the production change is calculated as the average of production changes over all main sectors (including animal sectors) weighted by production value. Only selected sectors are reported in the table, while the figures for total production reflect the changes over all sectors (including those not reported in the table). Only some marginal sectors are excluded from the total production calculation (e.g. other vegetables, other industrial crops, other crops, nurseries, flowers) because these sectors are not accurately represented in FADN. n.a., not available.

The production at sectoral level tends to decrease for major crops such as wheat, barley and rapeseed. The main causes of these effects are the EFA and grassland measures, which require farmers to reallocate land from main arable crops to EFA-eligible crops and grassland, respectively. As a result, the production levels of smaller crops that are EFA eligible will increase. For example, the production of pulses was simulated to increase by 20 % relative to the baseline in the EU-27. The impact of CAP greening on animal production (not reported) is small, as the impact on grassland has two opposite effects. The expansion of grassland due to the grassland measure stimulates on-farm feed production, while the corresponding decrease in arable crop area (contributed to by the EFA measure as set-aside is promoted) has the opposite effect, as it reduces on-farm production of arable-based feed (Table 20).

The total production changes by farm specialisation and farm size aggregated at EU-27 level reveal larger production effects for certain farm specialisations, but they are still below −3 %. For individual crops, the change is greater, in particular for some farm specialisations (e.g. permanent crops, COP, sheep and goats, cattle and mixed farms). Permanent crop and livestock farms tend to be particularly affected by the crop diversification measure because of the less diversified production structure of these farms on arable land and because of the low production levels in the baseline of some of the affected arable crops. In terms of farm size groups, the most affected are the small and large farm economic size classes, whereas middle-sized farms show smaller changes in production (Table 20) ([56]).

Figure 21 shows the distribution of production change across individual farms in the EU-27 for total production and for selected sectors. The vertical axis is similar to that in Figure 13.1, although the axis has a maximum of 35 % to better illustrate the changes for the affected farms. The remaining farms (65 %) not shown in the figure have no change in production.

Figure 21. The distribution of production change due to CAP greening for selected crop sectors and total production across farm population in EU-27 (all farms, % change)



Note: to avoid the division by zero, the sectoral production changes are calculated by dividing the production difference between the CAP greening and the baseline scenarios by the maximum production quantity between the two scenarios. The aggregate farm production change is calculated as the average over sectoral production

([56]) For comparison, the simulation results of Gocht et al. (2017) show that the CAP greening production effects at sector level for different farms types in EU varies between ±4%.

changes weighted by production value and farm weight in the total population. This implies that the farm-level production changes in the figure are not fully comparable to the results presented in Table 20.

As Figure 21 shows, around 29 % of farms in the EU-27 (in line with Table 16) register a change in total production. Although some farms report a large total production change ([57]), for the vast majority of farms affected by CAP greening (25 % of total farms) the rate of change varies between −25 % and 10 %. The production changes for selected crops vary between −100 % and 100 %. A 100 % production change occurs for an individual crop if farms introduce it as a new crop to comply with the diversification requirements or because it is an EFA-eligible crop. Similarly, a −100 % production change occurs when farms replace an arable crop with an EFA-eligible crop or with grassland to comply with the grassland measure.

The proportion of affected farms is around 18 % for pulses, 17 % for wheat, 15 % for barley and 5 % for rape (Figure 21). Figure 21 shows that a substantial proportion of farms (8 %) increase pulse production by 100 %, meaning that it is a new crop on these farms and has been introduced mainly as a result of the EFA measure. There are also some farms (7 %) that decrease pulse production. These farms include those that already have more than the required EFA in the baseline or are exempt from the EFA measure but not from the diversification and/or grassland measures, which cause pulse cultivation area (and pulse production) to decrease when farms need to reallocate pulse cultivation area to other uses to comply with those measures.

13.4 Income effects

The land reallocation and production effects induced by CAP greening reported above largely explain the income changes ([58]). The results reported in Table 21 show that the decrease in income caused by the implementation of CAP greening measures is rather small when aggregated at the EU-27 level, at around 1 % compared with the baseline. The standard deviation of the income changes at MS level is about 1.3 %.

([57]) The large total production changes at farm level (i.e. the extreme negative and positive production charges) are often only a statistical effect caused by a shift in production from higher-value outputs to lower-value outputs and vice versa. This shift in production structure affects the production-value-based weights used to aggregate production changes at farm level by increasing the importance of higher-value sectors in total production and thus also their weight used for the aggregation.

([58]) The income is calculated as the difference between total revenues (production sales and subsidies) and variable costs (e.g. expenditures on fertilisers, pesticides, seeds, feeding).

Table 21. Income change due to CAP greening in EU-27 (% change relative to baseline)

Farm specialisation	EU	S. d. at MS level	Farm size (EUR)	EU	s.d. at MS level
Specialist COP	−1.74	1.75	< 2 000	n.a.	n.a.
Specialist other field crops	−1.80	2.91	2 000 < 4 000	−3.19	0.84
Specialist horticulture	−1.72	4.34	4 000 < 8 000	−1.82	1.76
Specialist wine	−0.06	0.24	8 000 < 15 000	−1.48	2.27
Specialist orchards – fruits	−0.30	0.62	15 000 < 25 000	−1.51	2.04
Specialist olives	0.00	0.08	25 000 < 50 000	−1.18	1.99
Permanent crops combined	−0.13	2.66	50 000 < 100 000	−1.05	1.59
Specialist milk	−0.56	1.65	100 000 < 250 000	−0.80	1.75
Specialist sheep and goats	−0.81	4.58	250 000 < 500 000	−0.62	1.86
Specialist cattle	−2.40	18.34	500 000 < 750 000	−0.79	2.75
Specialist granivores	−19.32	5.57	750 000 < 1 000 000	−0.87	3.96
Mixed crops	−0.72	2.16	1 000 000 < 1 500 000	−1.08	3.99
Mixed livestock	−1.13	1.89	1 500 000 < 3 000 000	−1.37	6.23
Mixed crops and livestock	−1.11	2.92	≥ 3 000 000	−2.24	4.55
EU-27	−1.05	1.27			

Note: we calculate the farm income as the difference between farm revenues and variable costs (including subsidies); s.d., standard deviation.

The results by production specialisation and farm size aggregated at EU level reveal a more significant income effect for certain farm specialisations, but they remain below 2 % (Table 21). The exceptions are farms that specialise in granivores and specialist cattle. Farms that specialise in livestock experience the biggest drop in income because they are affected by both the permanent grassland and the crop diversification measures. They tend to have a less diversified production structure on their arable land, given that their main activity is not necessarily linked to arable cropping. Livestock farms are more likely to breach the minimum requirement on number of crops in the baseline and thus need to introduce new crops to comply with the diversification measure, which is more costly than the reallocation of land among existing crops (as is more often required in COP-specialised farms).

By farm size, the most affected are farms with a large economic size, followed by small farms. Middle-sized farms are less affected by CAP greening (Table 21). As explained above, this is due to the relatively minor impact of CAP greening on land use and production for these farms.

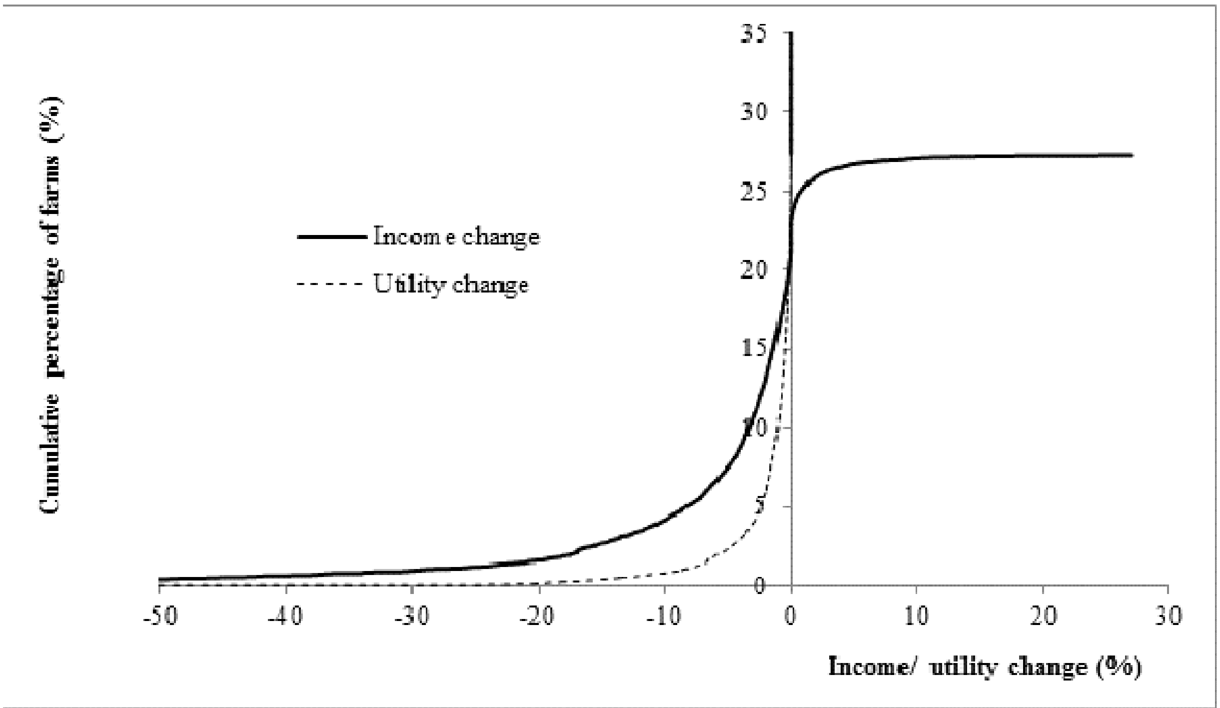
Similar magnitudes of income effects to those shown here were found in other studies using individual farm models (e.g. Solazzo et al., 2014; Cortignani and Dono, 2015; Vosough-Ahmadi et al., 2015). In contrast to individual farm models, regional representative farm models that account for the market effects of CAP greening have reported an increase in income (Van Zeijts et al., 2011; Gocht et al., 2017). This discrepancy in results between the two types of model can be explained by the fact that individual farm models (including IFM-CAP) do not account for the market price feedback effects of CAP greening, which, according to Van Zeijts et al. (2011) and Gocht et al. (2017), tend to offset the productivity reduction caused by greening measures.

Figure 22 shows the distribution of the income change relative to the baseline across the total farm population in the EU-27. The vertical axis has a maximum of 35 %, to better illustrate the changes for the affected farms. The remaining farms (84 %) have no change in income. Although the income decrease for some farms is substantial (a drop in income of more than 30 % for around 1 % of farms) ([59]), most farms affected by CAP

([59]) Note that the large income change for some farms shown in Figure 22 is often due to the low income level in the baseline.

greening (25 % of farms) experience an income decrease of less than 30 % or even close to zero. In around 2 % of the farms, an increase in income is observed, which is driven by the switch to riskier production activities. These farms experience improved profitability, but this is offset by a loss of utility. This is shown in Figure 13.3, which shows that all farms report a negative utility change as a result of the introduction of CAP greening.

Figure 22. The distribution of income and utility change due to CAP greening across farm population in EU-27 (all farms, % change relative to baseline)

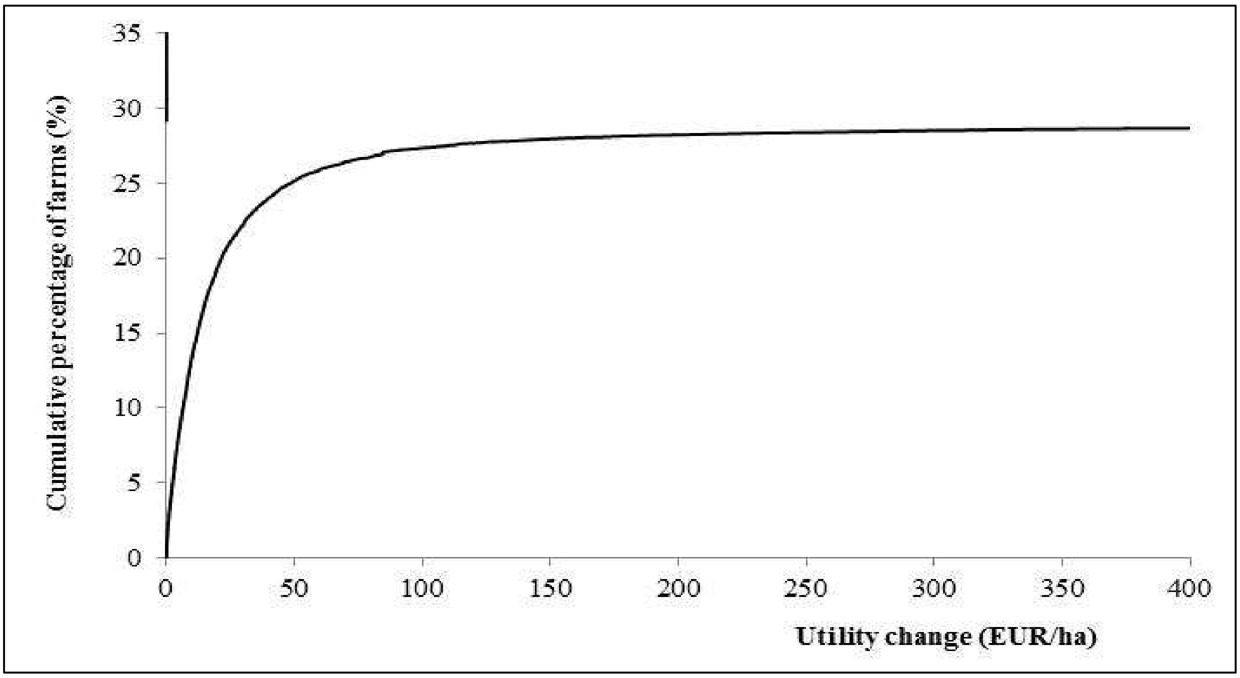


Note: the income and the utility changes shown for a given percentile of farms do not necessarily correspond to the same farm(s) because the ordered values from the smallest to the largest for the two indicators may not belong to the same farm(s).

Figure 23 shows the distribution of compliance costs resulting from CAP greening across the farm population in the EU-27. These costs represent the per hectare loss (or utility decrease) caused by the adoption of greening requirements. Most farms affected by CAP greening (14 % of all farms) have costs between EUR 10/ha and EUR 100/ha. Costs greater than EUR 100/ha are observed in 2 % of farms. These farms have high compliance costs, which is often because they own a small agricultural area and specialise in capital- and labour-intensive activities (e.g. vegetable production, granivores) with high per hectare production and profits. CAP greening inflicts considerable costs on these farms, as they are usually involved in more profitable activities and need to switch to less profitable crops to fulfil the CAP greening requirements, resulting in relatively large per hectare losses. Around 13 % of farms have rather insignificant compliance costs (between EUR 0/ha and EUR 10/ha). Although these farms are affected by CAP greening, they incur small compliance costs because the land adjustment (and thus the profitability loss) required by CAP greening is rather small.

In terms of the distribution of compliance costs across agricultural area affected by CAP greening (not shown in the figure), 51 % of all agricultural area is not affected by greening at all and incurs no related compliance costs. Of the 49 % area affected, around 80 % of this area incurs compliance costs below EUR 25/ha. For more than 50 % of the affected area, these costs are below 10 EUR/ha. However, around 5 % of total agricultural area (or 10 % of the 49 % affected area) has costs exceeding EUR 50/ha, while around 2.7 % of total agricultural area (or 5.6 % of the 49 % affected area) has costs exceeding EUR 100/ha.

Figure 23. The distribution of compliance costs of CAP greening across farm population in EU-27 (EUR/ha)



13.5 Limitations of the simulated CAP greening impacts

One needs to be aware when drawing conclusions that the CAP greening simulation results obviously reflect the assumptions in the model. First, the IFM-CAP model assumes a fixed organisational structure, implying that land can be reallocated only within farms in response to the introduction of CAP greening. In reality, farmers may reallocate land between farms or may decide to adjust other elements of farm organisation that are not necessarily linked to land allocation. For example, farms may enter into official or unofficial arrangements with neighbouring farms to rearrange claims for greening payments to ensure compliance and, thus, to avoid a decrease in income related to land reallocation. In such cases, the simulations overestimate the overall effect. However, this phenomenon is expected to have a limited impact on the simulated results. Modelling farmers' cooperation would require information on personal relationships, farm spatial location, etc., which is beyond the scope of the IFM-CAP model and the available data.

A second potential caveat for this IFM-CAP model application is that market feedback effects (output price changes) are not taken into account (see, for example, van Zeijts et al., 2011). This is, however, not a major drawback, given the limited EU-wide production effect of CAP greening. Third, certain crops are defined in the model as an aggregation of a set of individual crops (e.g. 'other cereals'), which may lead to a slight overestimation or underestimation of the simulated impacts, depending on farm production structure and the greening measure in question. Fourth, FADN includes only commercial farms; small non-commercial farms are underrepresented in the database, which may lead to an overestimation of the simulated impacts, as small farms are exempt from the greening measures.

Finally, not all the specificities regarding the 'greening' implementation are considered in the model. In particular, the IFM-CAP model does not consider exemptions from greening obligations for farmers in the 'small farmers' scheme', farmers north of the 62nd parallel and farms with more than 75 % of their crops under water. In addition, MSs can opt to define practices that result in a beneficial effect for the climate and the environment equivalent to or greater than that which would result from the three greening obligations. Farms adopting these practices are exempt from the greening measures; this was also not considered in this study.

A careful analysis of each of these limitations to the current model is needed to test the robustness of these results and to provide a complete picture of the EU-wide impact of CAP greening.

14 Conclusion

This report presents the first EU-wide individual farm level model (IFM-CAP) aiming to assess the impacts of CAP on farm economic and environmental indicators. The rationale for developing a farm-level model is based on the increasing demand for micro-simulation tools able to model farm-specific policies and to capture farm heterogeneity across the EU in terms of policy representation and impacts. Based on positive mathematical programming, IFM-CAP seeks to improve the quality of policy assessment compared with existing aggregate (regional and representative farm) models and to assess the distributional effects over the EU farm population. Model capability is illustrated in this study with an analysis of EU farmers' responses to the greening requirements introduced by the 2013 CAP reform.

The primary data source used to parameterise IFM-CAP is individual farm-level data from the FADN database complemented by other external EU-wide data sources such as the Farm Structure Survey (FSS), CAPRI database and Eurostat. Most of these external data are not used directly in the model but used as an input (i.e. prior information) for the estimations. To guarantee the highest representativeness of the EU agricultural sector, the model is applied to every FADN individual farm (83 292 farms).

IFM-CAP is a static PMP model applied to each individual FADN farm (83 292 farms). It assumes that farmers maximise their expected utility at given yields, product prices and CAP subsidies, subject to resource endowments (arable land, grassland and feed) and policy constraints, such as CAP greening restrictions. Farmers' expected utility is defined following the mean–variance approach with a CARA specification. Following this approach, expected utility is defined as expected income and the associated income variance. Effectively, it is assumed that farmers select a production plan that minimises the variance in income caused by a set of stochastic variables for a given expected income level.

Farmers' expected income is defined as the sum of expected gross margins minus a non-linear (quadratic) activity-specific function. The gross margin is the total revenue including sales from agricultural products and direct payments (coupled and decoupled payments) minus the accounting variable costs of production activities. Total revenue is calculated using expected prices and yields assuming adaptive expectations (based on the previous three observations with declining weights). The accounting costs include the costs of seeds, fertilisers and soil improvers, crop protection, feeding and other specific costs. The quadratic activity-specific function is a behavioural function introduced to calibrate the farm model to an observed base year situation, as usually done in positive programming models. This function intends to capture the effects of factors that are not explicitly included in the model, such as farmers' perceived costs of capital and labour, or model mis-specifications.

Regarding income variance, most of the models in the literature incorporate uncertainty in the gross margin per unit of activity or in the revenues per unit of activity. The former models assume that prices, yields and costs are stochastic. The latter models consider that costs are either non-random because they are assumed to be known when decisions are made or less stochastic than revenues from the farmer's perspective. Therefore, the variance in the gross margin can be approximated by the variance in revenues. In the IFM-CAP framework, the second approach is applied by considering uncertainty only in prices and yields (i.e. revenues) but without differentiating between sources of uncertainty.

A single model template was applied for all the modelled FADN farms to ensure uniform handling of all the individual farm models and their results. That is, all the individual farm models have an identical structure (i.e. they have the same equations and variables but the model parameters are farm specific) and no cross-farm constraints or relationship are assumed in the current version of the model, except in the calibration phase, when all individual farms in each region are pooled together to estimate the behavioural function parameters.

IFM-CAP is calibrated for the base year 2012 using cross-sectional analysis (i.e. multiple observations) and an HPD approach with prior information on regional supply elasticities and dual values of resources (e.g. land rental prices). The calibration to the exogenous supply elasticities is performed in a non-myopic way by taking into account the effects of changing dual values on the simulation response.

One needs to be aware when applying IFM-CAP that the policy simulations obviously reflect the assumptions in the model. First, the current version of IFM-CAP assumes a fixed farms structure, implying that land can be reallocated only within farms in response to the simulated policy changes. A second potential caveat of the model is that market feedback effects (output price changes) are not taken into account. Third, certain crops are defined in the model as an aggregation of a set of individual crops (e.g. 'other cereals'). Fourth, FADN includes only commercial farms; small non-commercial farms are underrepresented in the database. A careful analysis of each of these limitations of the current version of IFM-CAP model is needed to be taken into account when analysing the simulation results.

The application of IFM-CAP for modelling CAP greening highlighted, from the methodological viewpoint, the relevance of the IFM-CAP farm-level model for making finer policy analyses at an EU-wide scale and its strong potential to contribute to the policy debate on the efficacy and impacts of CAP.

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List of abbreviations

AES	Agri-environmental schemes
Aglink	Agribusiness Linkage Programme
AGRIPOLIS	Agricultural Policy Simulator
ANC	Areas of Natural Constraints
AROPAj	Agriculture, Recomposition de l'Offre et Politique Agricole
BPS	Basic Payment Scheme
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Impact Modelling System
CAPRI-FT	Farm type module within CAPRI
CARA	Constant absolute risk aversion
CNDP	Complementary National Direct Payments
COP	Cereals, oilseeds and protein crops
CRRA	Constant relative risk aversion
DARA	Decreasing absolute risk aversion
DG AGRI	Directorate-General for Agriculture and Rural Development
EC	European Commission
EFA	Ecological focus area
EoA	Economics of Agriculture
EU	European Union
Eurostat	European Statistics
FADN	Farm Accountancy Data Network
FAMOS	Forest and Agricultural Optimisation Model
FARMIS	Farm Modelling Information System
FOC	First-order condition
FSS	Farm Safety Survey
FSSIM	Farming System Simulator
GAMS	General Algebraic Modelling System
GUI	Graphical User Interface
HPD	Highest posterior density
IFM-CAP	Individual Farm Model for Common Agricultural Policy Analysis
INRA	Institut National de la Recherche Agronomique
IQR	Interquartile range
LFA	Less favourable area
MS	Member State(s)
NUTS	Nomenclature of Territorial Units for Statistics
OLS	Ordinary least squares
RCR	Residue-to-crop ratio

PMP	Positive mathematical programming
RDP	Rural Development Programme
SAPIM	Stylised Agri-Environmental Policy Impact Model
SAPS	Single Area Payments Scheme
SPS	Single Payment Scheme
SUR	Seemingly unrelated regressions
UAA	Utilised agricultural area
VCS	Voluntary Coupled Support

EU Member States

Code	Country	Code	Country
AT	Austria	IE	Ireland
BE	Belgium	IT	Italy
BL	Belgium and Luxembourg	LT	Lithuania
BG	Bulgaria	LU	Luxembourg
CY	Cyprus	LV	Latvia
CZ	Czech Republic	MT	Malta
DE	Germany	NL	Netherlands
DK	Denmark	PL	Poland
EE	Estonia	PT	Portugal
ES	Spain	RO	Romania
FI	Finland	SE	Sweden
FR	France	SI	Slovenia
GR	Greece	SK	Slovakia
HR	Croatia	UK	United Kingdom
HU	Hungary		

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Annex A: Data, allocation keys and thresholds used

Table A-1. Extraction rules - land use activities (from FADN Table K)

Production activity	GAMS abbr. for production activity	Extraction rule for area in ha (AA)	Extraction rule for output quantities (*QQ*) in tons	Extraction rule for total production value (*TP*) in EUR
ACER		**Cereals**		
Soft wheat	SWHE	120AA	120QQ	120TP
Durum wheat	DWHE	121AA	121QQ	121TP
Rye and meslin	RYEM	122AA	122QQ	122TP
Barley	BARL	123AA	123QQ	123TP
Oats	OATS	124AA	124QQ	124TP
Grain maize	MAIZ	126AA	126QQ	126TP
Paddy rice	PARI	127AA	127QQ	127TP
Other cereals	OCER	125AA+128AA	125QQ+128QQ	125TP+128TP
AOIL		**Oilseeds**		
Rape	RAPE	331AA	331QQ	331TP
Sunflower	SUNF	332AA	332QQ	332TP
Soya	SOYA	333AA	333QQ	333TP
Other oils	OOIL	334AA+364AA	334QQ+364QQ	334TP+364TP
AOAC		**Other arable crops**		
Pulses	PULS	129AA	129QQ	129TP
Potatoes	POTA	130AA	130QQ	130TP
Sugar beet	SUGB	131AA	131QQ	131TP
Cotton	TEXT	347AA	347QQ	347TP
Tobacco	TOBA	134AA	134QQ	134TP
Other industrial	OIND	133AA+135AA-347AA	133QQ+135QQ-347QQ	133TP+135TP-347TP
Other crops	OCRO	142AA+143AA+ 148AA+156AA+158AA+159A A	139QQ+142QQ+143QQ+ 146QQ+148QQ+156QQ+ 158QQ+159QQ+160QQ+ 161QQ+284QQ	139TP+142TP+143TP+ 146TP+148TP+156TP+ 158TP+159TP+160TP+ 161TP+284TP
APER		**Vegetables and permanent crops**		
Tomatoes	TOMA	337AA	337QQ	337TP
Other vegetables	OVEG	136AA+137AA+138AA -337AA-341AA	136QQ+137QQ+138QQ -337QQ-341QQ	136TP+137TP+138TP -337TP-341TP
Apples/pears	APPL	349AA	349QQ	349TP
Other fruits	OFRU	350AA+353AA +351AA+352AA+341AA	152QQ-349QQ+341QQ	152TP-349TP+341TP
Citrus fruits	CITR	354AA+355AA +356AA+357AA	153QQ	153TP
Table grapes	TAGR	285AA	285QQ	285TP
Olives for oil	OLIV	282AA+283AA	282QQ+283QQ/0.2	282TP+283TP
Table olives	TABO	281AA	281QQ	281TP
Table wine	TWIN	155AA-285AA	155QQ-285QQ	155TP-285TP
Nurseries	NURS	157AA	157QQ	157TP
Flowers	FLOW	If 140AA+141AA > 0 then 140AA+141AA else 342AA+343AA+344AA	If 140QQ+141QQ > 0 then 140QQ+141QQ else 342QQ+343QQ+344QQ	If 140TP+141TP > 0 then 140TP+141TP else 342TP+343TP+344TP
AFOD		**Fodder activities**		
Fodder maize	MAIF	326AA	326QQ	326TP
Fodder root crops	ROOF	144AA	144QQ	144TP
Pasture	PGRA	150AA	150QQ	150TP
Roughing	RGRA	151AA+314AA	151QQ+314QQ	151TP+314TP
Fodder other on arable land	OFAR	147AA+327AA+328AA	147QQ+327QQ+328QQ	147TP+327TP+328TP
ASET		**Set aside and fallow land**		
Set-aside/fallow land	SETA/ FALL	K146AA		

Source: adapted from Neuenfeldt S. and Gocht A. (2014).

Table A-2. Extraction rules for grants and subsidies per crop production activity

Total subsidies on crops	**GAMS abbr. for subsidies**		**Activities or categories of activities of crop production**	**Extraction rule for each category of subsidy and production activity**
Compensatory payments per area	*SUBCRO_COP*	*DPOILS*	*Oilseeds*	*M(603CP,623CP)*
		DPCER	*Cereals*	*M(622CP,625CP,626CP)*
		DPDWHETR	Durum wheat	*M(608CP,618CP,628CP,638CP)*
		DPSILA	Grass silage	*M(611CP,631CP)*
		DPPULS	Pulses	*M(604CP,614CP,624CP,634CP)*
		DPFODC	Fodder maize	*M(607CP)*
		DPTEXT	Other industrial	*M(612CP,613CP,632CP,633CP)*
		DPENERCP	Energy crops	*M(655CP)*
		DPOTHE	Other crops	*M(609CP,610CP,629CP)*
Compensatory payment set-aside	SUBCRO_SETA	DPSETA	Set aside	*M650CP*
Other crops subsidies	SUBCRO_OTHER		*Cereals*:	
		JCSWHE	Soft wheat	*JC120*
		JCDWHE	Durum wheat	*JC121*
		JCRYEM	Rye and Meslin	*JC122*
		JCBARL	Barley	*JC123*
		JCOATS	Oats	*JC124*
		JCMAIZ	Grain Maize	*JC126*
		JCPARI	Paddy rice	*JC127*
		JCOCER	Other cereals	*JC125+JC128*
			Oilseeds:	
		JCRAPE	Rape	*JC331*
		JCSUNF	Sunflower	*JC332*
		JCSOYA	Soya	*JC333*
		JCOOILS	Other oils	*JC334+JC364*
			Other arable crops:	
		JCPULS	Pulses	*JC129+JC330+JC360+JC361*
		JCPOTA	Potatoes	*JC130+JC362+JC363*
		JCSUGB	Sugar beet	*JC131*
		JCTEXT	Cotton	*JC347*
		JCTOBA	Tobacco	*JC134+JC(365...372)*
		JCOIND	Other industrial	*JC133+JC135+JC(345,346,348,373,374)*
		JCOCRO	Other crops	*JC(139,142,143,146,148,149,156,158,159,160,161,284,300,301),*
			Vegetables and permanent crops:	
		JCTOMA	Tomatoes	*JC337*
		JCOVEG	Other vegetables	*JC136+JC137+JC138+JC(335, 336,338...340)*
		JCAPPL	Apples/peaches	*JC339*
		JCOFRU	Other fruits	*JC(350...353)+JC341*
		JCCITR	Citrus fruits	*JC153+JC(354...357)*
		JCTAGR	Table grapes	*JCVINES*
		JCOLIV	Olives for oil	*JC154+JC(282…284)*
		JCTABO	Table olives	*JC281*
		JWINES	Wine	*JCWINE*
		JCNURS	Nurseries	*JC157*
		JCFLOW	Flowers	*JC140+JC141+JC(342...344)*
		JCFODC	Fodder activities:	*JC(144,145,147,150,151,326,327,328,329)*
		JCOTHER	*Other crop subsidies*	*JC952*
			Other crop subsidies	
		JCARTPARI	Art.69 payments for	*JC924*

	rice	
JCARTOCRO	Art. 69 other crops	*JC925*

Table A-3. Eligible crops and livestock activities by subsidy

Subsidy code	**Crops benefiting from the subsidy**
DPSFP	All crop activities (CACT)
DPSAP	CACT
DCNDP	CACT
DPCER	CERE,MAIF,OFAR
DPFODC	MAIF,GRAS,OFAR
DPOILS	OILS
DPPULS	PULS
DPOTHER	CACT
DPENERCRP	NONF,RAPE,SUGB,SWHE,SUNF,MAIF,MAIZ,BARL,SOYA
DPDWHETR	DWHE
JCPARI	PARI
DPSILA	OFAR
DPTEXT	OIND
DPSETA	SETA,NONF,FALL
JCSUGB	SUGB
JCOLIV	OLIV,TABO
JCTABO	TABO
JCTOMA	TOMA
JCOVEG	OVEG
JCAPPL	APPL
JCOFRU	OFRU
JCCITR	CITR
JCTAGR	TAGR
JCNURS	NURS
JCFLOW	FLOW
JCWINE	WINE
JCTOBA	TOBA
JCPOTA	POTA
JCSWHE	SWHE
JCDWHE	DWHE
JCRYEM	RYEM
JCBARL	BARL
JCOATS	OATS
JCMAIZ	MAIZ
JCOCER	OCER
JCRAPE	RAPE
JCSUNF	SUNF
JCSOYA	SOYA
JCOOILS	OOILS
JCPULS	PULS,OFAR,GRAS
JCTEXT	TEXT
JCOIND.	OIND,TEXT
JCOCRO	OCRO
JCFODC	OFAR,GRAS,ROOF,MAI
JCOTHER	CACT
JCARTPARI	PARI
JCARTOCRO	OCRO
DPDCOW	DCOW
DPBULF	BULF
DPEXTENS	SCOW,BULF,HEIF,HEIR,CAMF,CAFF,CAMR,CAFR
DPSCOW	SCOW,HEIR,HEIF
DPSL_ADCT	HEIF,BULF
DPSL_CALV	CAMF,CAFF
DPADDPNA	SCOW,BULF,HEIF,HEIR,CAMF,CAFF,CAMR,CAFR
JCHEIF	HEIF

JCHEIR	HEIR
JCOCAT	SCOW,CAMF,CAFF,CAMR,CAFR,BULF,HEIF,HEIR
JCCATT	SCOW,CAMF,CAFF,CAMR,CAFR,BULF,HEIF,HEIR,DCOW
JCCAR	CAMR,CAFR
JCSHGM	SHGM
JCSHGO	SHGM, SHGF
JCPIGF	PIGF
JCSOW	SOWS
JCHENS	HENS
JCPOUF	POUF
JCPOU	POUF, HENS
JCOANI	OANI
JCOTLI	All animal activities
JCARTDAIR	DCOW
JCARTOTCA	SCOW,CAMF,CAFF,CAMR,CAFR,BULF,HEIF,HEIR
JCARTSHGO	SHGM,SHGF
JCARTOTLI	POUF,HENS,PIGF,SOWS,OANI

Table A-4. Key for allocating input costs developed by DG AGRI

Cost item	IFM-CAP code	FADN code	Allocation key
Seeds and seedlings	SEED	SE290 (home-gown) + F72 (purchased)	Output of the crop analysed/output of arable crops
Fertiliser	NITF	SE295	Output of the crop analysed/output of crops and crop products
Crop protection	PLAP	SE300	Output of the crop analysed/output of crops and crop products
Other crop specific costs	CSPE	SE305	Output of the crop analysed/output of crops and crop products

Table A-5. Minimum and maximum feed thresholds

Activity	Feed group	Minimum threshold (%)	Maximum threshold (%)
NRUMI	FODDI		0
SOWS	FMAI		0.1
PIGF	FMAI		0.1
RUMI	FPRO		0.3
NRUMI	FPRO		0.2
NRUMI	FCER		0.6
DCOW, BULF, CALR, CALF	FCER	0.20	
HEIF, HEIR,SCOW	FCER	0.05	
OANI	FCER	0.50	
The rest of AACT	FCER	0.02	
DCOW, BULF, CALR, CALF	FPRO	0.10	
HEIF	FPRO	0.05	
The rest of AACT	FPRO	0.01	
AACT	FOTH	0.005	
SHGM	FOTH	0.001	
SHGF	FOTH	0.001	
SCOW	FOTH	0.001	
DCOW	FIRI	0.6	
SCOW	FIRI	0.9	
BULF	FIRI	0.5	
HEIF	FIRI	0.6	
CALR	FIRI	0.4	
CALF	FIRI	0.2	
SHGM	FIRI	0.8	
SHGF	FIRI	0.5	
RUMI	FSTR	0.01	0.05
SHGM, SHGF	Not FIRI		0.20
CALR, CALF	FMIL	0.05	
CALR, CALF	FCOM	0.10	
AACT	FCOM		0
ACATTLE	FCOM		0.01
AACT (except SHGF &SHGM)	FSGM		0
DCOW, SCOW	FCOM		0
CALF	FCOM		0.3
CALR	FCOM		1.0

Notes: FIRI= FOFA, FGRA, FMAI (used when there is production on farm); AACT: all animal activities; ACATTLE; cattle activities; RUMI: ruminant activities; NRUMI: non-ruminant activities; feed groups: ee Table 10.

Table A-6. Sugar/sugar beet information with an EU-coverage

Variable	Database	Scope
Sugar beet yield	FADN (derived)	Farm level
Sugar beet yield	FSS	MS level/NUTS 2 level
Sugar beet area	FADN	Farm level
Sugar beet area	FSS	MS level/NUTS 2 level
Sugar beet production	FSS	MS level/NUTS 2 level
Sugar beet-specific cost	FADN (estimated based on HPD estimator)	Farm level
Sugar quota	DG-AGRI	MS level
Sugar production	DG-AGRI	MS level

Table A-7. Comparison of sugar beet production based on FADN and FSS data (2007-2012)

	2007			2008			2009			2010			2011			2012		
	FADN	FSS	% DIF	FADN	FSS	% DIF	FADN	FSS	% DIF	FADN	FSS	% DIF	FADN	FSS	% DIF	FADN	FSS	% DIF
AT	3195.7	2656.2	-20.3	3625.3	3091.4	-17.3	3524.7	3083.1	-14.3	3470.7	3131.7	-10.8	3759.6	3456.2	-8.8	3122.6	3114.4	-0.3
BL	5834.4	5730.5	-1.8	4904.6	4713.5	-4.1	5379.4	5185.1	-3.7	4785.5	4464.8	-7.2	5771.8	5409.0	-6.7	5147.6	4830.4	-6.6
CZ	3076.5	2889.9	-6.5	3108.5	2884.6	-7.8	3501.0	3038.2	-15.2	3387.3	3065.0	-10.5	4341.3	3898.9	-11.3	4211.4	3868.8	-8.9
DE	25792.6	25139.1	-2.6	22972.0	23002.6	0.1	28260.3	25919.0	-9.0	25534.7	23431.9	-9.0	31482.8	29577.5	-6.4	28662.8	27686.8	-3.5
DK	2228.9	2255.3	1.2	2009.6	2187.2	8.1	2320.1	1898.2	-22.2	2105.9	2356.4	10.6	3093.5	2700.4	-14.6	2755.4	2648.9	-4.0
EL	641.5	855.0	25.0	686.4	1163.8	41.0	1191.8	1600.0	25.5	842.0	761.5	-10.6	319.8	324.4	1.4	356.5	434.9	18.0
ES	7929.1	4910.0	-61.5	6854.8	4170.7	-64.4	7626.4	4225.4	-80.5	7170.1	3534.5	-102.9	7023.9	4188.5	-67.7	7588.3	3460.2	-119.3
FI	903.3	673.1	-34.2	706.3	468.0	-50.9	694.0	559.0	-24.1	562.9	542.1	-3.8	563.3	675.7	16.6	472.9	398.7	-18.6
FR	28722.2	33212.7	13.5	28126.4	30306.3	7.2	33108.5	34913.0	5.2	30785.8	31874.9	3.4	35999.7	38106.1	5.5	32421.2	33739.0	3.9
HU	2435.8	1692.8	-43.9	858.7	573.2	-49.8	1041.9	737.0	-41.4	1165.2	818.9	-42.3	1056.0	856.4	-23.3	915.5	881.7	-3.8
IT	4910.8	4629.9	-6.1	3535.3	4390.0	19.5	3535.6	3307.7	-6.9	3984.3	3550.1	-12.2	3088.3	3547.9	13.0	3051.7	2501.2	-22.0
LT	1047.8	799.9	-31.0	518.2	339.1	-52.8	1159.0	682.0	-69.9	1077.1	706.7	-52.4	1008.1	877.8	-14.8	1108.4	1003.0	-10.5
NL	4168.8	5511.5	24.4	4022.0	5218.5	22.9	4793.9	5735.0	16.4	4966.1	5280.4	6.0	5600.4	5858.0	4.4	5522.3	5735.0	3.7
PL	14117.3	12681.6	-11.3	10828.3	8715.1	-24.2	11204.5	10849.2	-3.3	10053.0	9972.6	-0.8	11315.5	11674.2	3.1	12180.9	12349.5	1.4
SE	1936.1	748.8	-158.6	1829.5	706.7	-158.9	2213.6	816.8	-171.0	1678.1	853.0	-96.7	2158.8	650.1	-232.1	2408.2	719.8	-234.6
SI	1.5	2137.7	99.9	1.9	1974.9	99.9	4.1	2405.8	99.8	5.3	1976.2	99.7	4.7	2493.2	99.8	1.6	2314.2	99.9
SK	904.2	846.5	-6.8	925.7	678.9	-36.4	1134.5	898.8	-26.2	1161.8	977.7	-18.8	1498.6	1160.7	-29.1	1121.3	894.5	-25.4
UK	7077.6	6733.0	-5.1	8527.0	7641.0	-11.6	7474.4	8457.0	11.6	7554.5	6527.0	-15.7	9623.4	8504.0	-13.2	10769.0	7291.0	-47.7

Sources: FADN and FSS (Eurostat), (2007-2012)

Table A-8. Implementation decisions of the 2013 CAP reform by Member State on decoupled payments

MS		Pre-reform model	Internal Convergence			Convergence criteria for MS in PC					Redistributive payment			Capping	
			Model	% of total	NM/RM	Increase target	Ref. value	Min	Max	Model	ha	Euros/ha	%	Threshold (in 1000 EUR)	Payment reduction (%)
BL	WL	HI	PC	29.9	NM	0.33	0.9	0.6	0.3	RP	30	115	17	150	100
	FL	HI	PC	56.8	NM	0.33	0.9	0.6	0.3	RP				150	5
BG		SAPS	SAPS	47							30	77	7	150/300	5/100
CZ		SAPS	SAPS	54.8										150	5
DK		HYS	PC	65	NM	0.33	0.9			LR				150	5
DE		HYD	FR2015	62.1	RM						1-30/30-46	50/30	6.9		
ES		SAPS	SAPS	65.3										150	5
IR		HI	PC	67.8	NM	0.33	0.9	0.6		LR				150	100
EL		HI	PC	60	RM									150	100
ES		HI	PC	56	RM	0.33	0.9		0.3	LR				150	100
FR		HI	PC	34	RM	0.7	1	0.6	0.3	RP	52	25	20		
HR		HI	PC	43	NM	0.33	1	0.6		LR	20	34	10		
IT		HI	PC	58	NM	0.33	0.9	0.6	0.3	RP				150/500	50/100
CY		SAPS	SAPS	61.1										150	5
LV		SAPS	SAPS	55.1										150	5
LT		SAPS	SAPS	38.3							30	50	15		
LU		HYS	PC	68	NM	0.33	0.9	0.6	0.3	RP				150	5
HU		SAPS	SAPS	54.8										150/176	5/100
MT		R	FR2015	34	NM									150	5
NL		HI	FR2019	67.5	NM									150	5
AT		HI	FR2019	65.9	NM									150	100
PL		SAPS	SAPS	46							0-3/3-30	0/41	8	150	100
PT		HI	PC	47	NM	0.33	0.9	0.6	0.3	LR				150	5
RO		SAPS	SAPS	51							0-5/5-30	5/45	5		
SI		R	PC	54	NM	0.33	0.9	0.6	0.3	RP				150	5
SK		SAPS	SAPS	56.4	NM									150	5
FI		HYD	FR2019	49	RM									150	5
SE		HYS	PC	55.4		0.83	0.9			LR				150	5
UK	NI	HYS	PC	68	NM	0.7	1		LR	RP				150	100
	EN	HYD	FR2015	68	RM									150	5
	SC	HI	FR2019	61.8	RM									150/600	5/100
	WA	HI	FR2019	68	NM						54	128		150/200/250/300	15/30/55/100

WL=Wallonia; FL=Flanders; NI=Northern Ireland;SC=Scotland; WA=Wales
HI= Historical SPS model; HYS: Static Hybrid SPS model; HYD: Dynamic Hybrid SPS model
PC=Partial Convergence/FR2015=Flat Rate by 2015/FR2019=Flat rate by 2019/SAPS=Single Area Payment Scheme.
% of total = Percentage of the national financial allocation of the basic and the SAPS payments.
NM=National Model/ RM=Regional Model. In DE the regional model will change to a national one in 2019
RP=Reduction proportional to the distance to the average PE value/ LR= Linear reduction

Source: European Commission (2015)

Table A-9. Voluntary coupled support by MS (million euro and %)

	Beef & V eal	Milk	Sheep & goat	Prote in	Fruit & vVeg	Sugar -beet	Cereals	Olives	Rice	Grain legumes	Starch potato	Nuts	Seeds	Hops	Oilseeds	Hemp/ flax	Silkworms	Total	%
AT	12.4		0.9															13.4	0.3
BG	27.2	23.9	11.2	15.9	41.2												0.8	120.2	3.0
BL	79.7	3.2	0.6															83.5	2.1
CY		2.9	0.7		0.3													3.9	0.1
CZ	25.5	52.8	3.0	17.5	9.3	16.7					3.1			3.1				130.9	3.2
DK	24.1																	24.1	0.6
EE	1.0	2.0	0.4		0.8													4.2	0.1
EL	27.7		31.7	6.7	19.6	6.7	13.8			4.8			2.9					113.8	2.8
ES	227.9	93.6	168.5	44.5	6.4	16.8			12.2	1.0		14.0						584.9	14.4
FI	46.8			5.5							3.7							56.0	1.4
FI		3.2	2.6		1.1	1.0	1.5											9.4	0.2
FR	664.2	137.7	137.8	144.8	15.7		6.9				2.0		0.5	0.3		1.7		1111.6	27.4
HR	14.1	14.4	3.6	6.1	3.0	4.6												45.9	1.1
HU	37.3	65.1	20.8	25.4	32.5	7.5			1.9									190.4	4.7
IR				3.0														3.0	0.1
IT	102.3	84.6	14.3	22.8	10.7	16.3	56.8	66.8	21.6	11.2								407.5	10.1
LT	21.5	29.6	2.7	17.9	5.9													77.6	1.9
LU				0.2														0.2	0.0
LV	7.0	19.7	0.6	6.1	3.0		3.9				0.2		1.2		3.7			45.4	1.1
MT	0.5	1.6	0.1		0.9													3.0	0.1
NL	2.4		1.1															3.5	0.1
PL	155.7	137.7	4.5	61.2	17.4	73.6					7.9			0.8		0.6		459.2	11.3
PT	59.8	12.5	35.9		3.3				6.0									117.5	2.9
RO	13.1	101.2	42.0	68.3	33.6	18.9			6.3	0.5			0.8	0.1		0.2		285.1	7.0
SE	91.0																	91.0	2.2
SI	4.0	4.7		2.7	2.0		6.7											20.1	0.5
SK	7.2	29.9	5.1		1.8	7.2								0.1				51.3	1.3
UK	45.2		8.0															53.1	1.3
Total	1652.4	820.1	488.0	448.6	208.6	169.4	89.7	66.8	48.0	17.4	16.9	14.0	5.4	4.5		2.5		4052.2	
%	40.8	20.2	12.0	11.1	5.1	4.2	2.2	1.6	1.2	0.4	0.4	0.3	0.1	0.1	0.0	0.1	0.0		

Source: DG-AGRI (2015) and DG-AGRI (2015a,b).

Annex B: Literature review of modelling livestock activities

Table A-10. Reviewed papers that used a normative approach

Authors	Year	Type of model	Model purpose	Farm speciality	Scale	Data used	Livestock activities	Purchase and sale	Calibration	Intergenerational dependences	
										Base	Simulation
Jones and Salter	2013	Normative, static annual LP models with embedded, anaerobic digestion (AD) enterprise	Economic evaluation of farm-based AD	Arable, dairy, AD enterprise	Representative arable farm in east England, a larger than average dairy farm in south-east England	Defra Farm Business Survey data, literature, farm management handbooks	Adult cow, replacement heifers, calves that are sold at 3 weeks	Selling beef crosses (calves) at age of 3 weeks		Adult cows endogenous, herd size constrained 0.5–2 LSU/ha; Calves and heifers as shares of adult	Same
Lelyon et al.	2011	Normative LP, static annual with four seasons per year	Analysis of response to decoupling and the price variation	Grass-based farm, semi-intensive, milk plus cereals and, milk plus young bulls	Farm level, plains regions, France	The annual survey of the Institute de l'Elevage (2008) with more than 600 dairy producers	Dairy cows, heifers, calves and young bulls	Selling female and male calves, buying male calves for fattening, selling bulls (fattened male calves)	Technical coefficients were modified (2005 basis)	Adults cows endogenous; calves as a share of adults cows; bought-in male calves endogenous	Same
Acs et al.	2010	Normative, static LP	Analysis of impacts of CAP decoupling on a range of farm types	Regional, farm level, farm types in marginal hill area of Peak District, UK	Dairy, beef, breeding sheep, forage	Survey of 44 farms that identified six representative farm types in 2006/2007	Suckler cows, dairy cows, calves, heifers	Purchase heifers, selling young beef calves, selling fattened calves, selling young dairy calves, selling young fat dairy calves	Results compared with surveyed farms data	Dynamics determined exogenously (replacement rate) and by selling activities endogenous)	Same
Crosson et al	2006	Normative static LP for beef farming systems	Adaptation to variations in prices, technical development, participation in an agri-environmental	Beef animal and forage production	Irish beef production systems	Grass production data from experiments Teagasc, for the period 2001–2004	Suckler beef cow (young and adult), replacement heifer, calf, yearlings, and finishing activities	Sale activities for weaners and store animals at various ages of fattening; only replacement heifers are purchased	Based on expert judgement and based on financial and technical criteria	Adult cows endogenous; calves and heifers based on exogenous factors such replacement rate, feed requirements	Same

Authors	Year	Type of model	Model purpose	Farm speciality	Scale	Data used	Livestock activities	Purchase and sale	Calibration	Intergenerational dependences	
										Base	Simulation
			scheme								
Havlík et al.	2006	Normative, static LP	Environmental analysis of organic suckler cow farms	Specialised suckler cow production, crop	Protected Landscape Area White Carpathians, Czech Republic	FADN CZ 2002	Suckler cow, weaners, heifers, bulls at different ages	Replacement heifers from own breeding but they can be sold, calves can be sold	Results compared with 2002 survey	Dynamic determined exogenously	Same
Visagie and Ghebretsadik	2005	Normative static LP	Modelling risk in farm planning	Crop, adult dairy cattle, young cattle, sheep for wool	Farm level Swartland, South Africa	One farm data	Adult cow, Adult sheep	Buying/selling adult/young cows and sheep		Adults cows endogenous; young cattle as a share of adults cows	Same
Ducros et al.	2005	Normative, static LP	Analysis of impact of policies such as stocking density and nitrogen balance on environmental and economic performance	Breeding dairy cattle, forage and apples	Farm level, mixed crop-livestock-orchard farming Normandy, France	Literature	Dairy cows, fattening calves and heifers	Sales are considered for all livestock categories	Test the coherence of technical coefficients used in the model with data from surveyed farm.	Dynamics determined exogenously (replacement rate) and by selling activities (endogenous)	Same
Veysset et al.	2005	Normative, static LP with two seasons of summer and winter	Analysis of economic adaptation of two farm types to Agenda 2000 CAP reform	A mixed crop-livestock farm and a livestock farm	Farm-level Charolais suckler cattle, Northern from Massif Central, France	Data of 20 years from 90 Charolais suckler farms from three regions	Suckler cows, male and female calves, heifers	Male calves sold as store and fattened, female calves sold as store and fattened; 33-month heifers could be bought in	Based on expert judgement and based on four observed activities	Adult cows endogenous; calves determined by share (exogenous)	same
Ramsden et al.	1999	Normative, static annual	To evaluate the impact of changes in milk to milk-quota-leasing price ratios, nitrogen	Dairy cow, beef cow, forage	Farm level (only one farm modelled), dairy sector, UK	Literature	Dairy cows, heifers and calves. Cows have five milk production levels. Male animals from	Heifers bought in as 2-year olds, female calves can be sold	Results compared with actual farm data for England and Wales based on a survey	Adult cows endogenous, calves and heifers based on exogenous data such as	Same

Authors	Year	Type of model	Model purpose	Farm speciality	Scale	Data used	Livestock activities	Purchase and sale	Calibration	Intergenerational dependences	
										Base	Simulation
			fertiliser and concentrate				dairy go to beef			replacement rate	
Nicholson et al.	1994	Normative, multi-period LP	Analyse alterative nutritional management strategies	Farm level, representative lowlands of western region	Dairy, beef cattle, forage mixed milk-meat cattle farms, Venezuela	Data from 22 farms surveyed in the study region	Three cow status, one calves, two age groups heifers, three age groups steers	No purchase of animals modelled, but all animal categories can be sold	Validation by construct		Same

Table A-11. Reviewed papers that used a positive approach

Authors	Year	Type of model	Model purpose	Farm speciality	Scale	Data used	Livestock Activities	Purchase and sale	Calibration	Intergenerational dependences		Observed behaviour at simulation
										Base	Simulation	
Gill et al.	2015	PMP	Assessment of policy and price changes on hog sector	Crops, beef, breeding sow and growing pigs	Provincial, Canada	Regional data	Sows and growing pigs	Sows culled/move next cycle. Growers Slaughtered/exported as live animals or replace culled sows	Quadratic cost function (Howitt, 1995)	Sows exogenous; growers based on sows and farrowing cycles/year ; PMP applied to growers.	Same; PMP terms removed	Ratio of growers to sows, replacement rates, market hogs per sow, birth rates and death are exogenous
Jitea et al.	2015	PMP	*Ex-ante* analysis of 2014 CAP reform, land abandonment	Crop and livestock	On region in north-western Romania (NUTS2)	Independent survey (207 farms)	Dairy (m/f, age), beef, sheep, goat, pig	Selling meat and milk. They don't mention any purchase activity	quadratic cost function (Howitt ,1995)	Yes, exogenous parameters, such as fertility rate and replacement rate	Same	
Fragoso et al.	2011	PMP	Assessment of the effects of CAP on farm income, land, labour and capital	Forestry, beef cattle, sheep, extensive swine	Regional, Alentejo, Portugal	Regional data from the Official Network of Agricultural Account data	Beef (breeding, calves), sheep, swine	No purchase, but sale	Quadratic cost function (Howitt, 1995)	No	No	

Authors	Year	Type of model	Model purpose	Farm speciality	Scale	Data used	Livestock Activities	Purchase and sale	Calibration	Intergenerational dependences		Observed behaviour at simulation
										Base	Simulation	
						(RICA)						
Thorne et al.	2009	PMP	*Ex-ante* policy analysis	Crop and livestock	EU	FADN	Dairy, suckler, beef, sheep, goat	Only dressed animals (i.e. breeding adults)	quadratic cost function (Howitt 1995)	Yes, based on shares, static	Same	
Judez et al.	2001	PMP	*Ex-ante* analysis of agenda 2000	Crops and Beef and Veal	Regional farm types in Spain	Regional FADN	Suckler cows & young male	Selling 1< young male cattle	quadratic cost function (Howitt 1995)	Yes; share of young per cow	same	an increase of suckler cows and a decrease of young males

Annex C: Animal feed requirement functions in IFM-CAP

This annex presents the functions used in IFM-CAP to determine the nutrient requirement by animal category. These requirement functions are based on CAPRI (Nasuelli et al., 1997; IPCC, 2006; Britz and Witzke, 2014), LfL (2014); GfE (2006) and NRC (1994).

1. Dairy cows (DCOW) and suckler cows (SCOW)

The dry matter requirements for cows include minimum dry matter for lactation per year (*DRMN*) and maximum dry matter (*DRMX*):

$$DRMN_i = 305(0.0185LW_i + 0.305MC_i) + 60(0.0185LW_i)$$

$$DRMX_i = DRMN_i * 1.2$$

The energy requirements of cows are expressed as net energy for each of the main biological functions of the animal including lactation, maintenance, activity, pregnancy and growth: net energy lactation (*NEL*), net energy maintenance (*NEM*), net energy activity (*NEA*), net energy pregnancy (*NEP*) and net energy for growth (*NEG*).

$$NEL_i = (0.4MC_i + 1.47)MPD_i LP_i$$

$$NEM_i = 0.17(0.386LW_i^{0.75})365$$

$$NEA_i = 0.17(0.386LW_i^{0.75})365$$ *if there is grassland on-farm,*

otherwise $NEA_i = 0$

$$NEP_{DCOW} = (LW^{0.75} * 0.386) * 0.10 * 365$$

$$NEP_{SCOW} = (LW^{0.75} * 0.386) * 0.10 * CALV_{SC} / 1\,000$$

The total net energy (*ENNE*) is the sum of the above energy components:

$$ENNE_i = NEL_i + NEM_i + NEA_i + NEP_i$$

The crude protein requirement (*CRPR*) is calculated as follows:

$$CRPR_{DCOW} = \frac{14MC_{DCOW} + 28}{1\,000} MPD_{DCOW} LP_{DCOW} + \frac{117 + 0.6LW_{DCOW}}{1\,000} 365 + 1\,300 \cdot 42$$

$$CRPR_{SCOW} = \frac{14MC_{DCOW} + 28}{1\,000} MPD_{DCOW} LP_{DCOW} + \frac{1.27 + LW_{DCOW} + 127.3}{1\,000} 365 + 1\,300 \cdot 42$$

The requirements for fibre digestibility (*FIDI*), maximum fibre (*FICO*) and fibre long (*FILG*) are:

$$FIDI_i = DRMN_i(MC_i / 100 - 0.29 + 43.92/100)$$

$$FICO_i = 0.7(0.14LW_i^{0.75})365$$

$$FILG_i = FIDI_i / 3$$

where subscripts *DCOW* and *SCOW* stand for dairy cow and suckler cow, respectively, *i = DCOW*, *SCOW*; $CALC_{SG}$ is calves per cow; and *MC* is adjusted milk production per day corrected by fat milk content (*MF*). *MF* is extracted from Eurostat. *MC* depends on milk production per day (*MPD*), which it is derived from FADN; *COMI* and *COMF* are, respectively, milk production for feeding and milk production (not for feeding) for suckler/dairy cows derived from FADN (in kg per day). The raising period (*PD*) is 365 days, of which the duration of lactation (*LP*) is assumed to be 305 days for dairy cows and 125 days for suckler cows. The mean live weight (*LW*) is calculated by dividing the selling value of cows (*PRIC*) available from FADN by the meat price obtained from Eurostat.

$$MC_i = MPD_i(0.4 + 0.15MF_i)$$

$$MPD_i = (COMI_{DCOW/SCOW} + COMF_{DCOW})/125$$

Lower and upper bounds of nutrient requirements for dairy and suckler cows are obtained by varying the fat milk content (*MF*) and the mean live weight (*LW*) by three standard deviations around their mean values. The lower and upper bounds represent the interval within which the actual animal requirements most probably lie.

2. Fattening and raising of calves (CAMF/CAFF; CAMR/CAFR)

The nutrient requirements for fattening of male (*CAMF*) and female (*CAFF*) calves and raising of male (*CAMR*) and female (*CAFR*) calves are taken from LfL (2014) and are reported in Table A-12 and Table A-13. The requirement tables deliver the requirement on a daily basis from birth to about 800 days. The table provides average values as well as minimum (*min*) and maximum (*max*) values for daily weight increase (*DAILY*) (kg/day), animal weight in a given day (*XALW*) and nutrient requirements (*ENNE*, *ENMR*, *CRPR*, *DRMA*, *DRMN*, *DRMX*). The minimum and maximum values are used to derive the lower and upper bounds of animal requirements.

The annual requirements are calculated from Table A-12 and Table A-13 as follows:

$$X_i = 365 \frac{\sum_{DAY=startD}^{DAY=endD} X_{DAY}}{endD \text{ - } startD} \quad \text{for } i = CAMF, CAFF, CAMR, CAFR$$

where *DAY* stands for day for *DAY*0 to *DAY*805; *startD* is start day of the fattening/raising process and *endD* is end day of the fattening/raising process; and *X* = *ENNE*, *ENMR*, *CRPR*, *DRMA*, *DRMN*, *DRMX.*

The equations above calculate annual nutrient requirements for fattening and raising calves. All animal categories in IFM-CAP represent average number of head available on-farm in a year. This implies 365 production days for all animal categories including fattening of calves. The total requirements are calculated by multiplying the average nutrient per day by 365 days.

The mean value of the start day (*startD*) and end day (*endD*) are defined based on the FADN definition. The start day for fattening (raising) calves is assumed to be day zero, whereas the end day is set to 60 (180) days (Table A-14). However, the actual start and end day of calve activities of farms may depart significantly from the mean values. To account for this uncertainty we consider lower and upper bounds for these two parameters as defined in Table A-14.

The annual requirements for fibre are defined as follows:

$$FICT_i = DRMX_i \qquad \text{for } i = CAMF, CAFF, CAMR, CAFR$$

The lower and upper bounds of animal requirements for fattening and raising of calves are obtained by using minimum and maximum values of nutrient requirements as reported in Table A-12 and Table A-13 as well as by varying the start and end day as reported in Table A-14. Note that this variation implicitly implies that the daily weight increase (*DAILY*) (kg/day) and animal weight in a given day (*XALW*) (kg/animal) also change as reported in Table A-12 and Table A-13 following the duration of the fattening and the raising process defined by the minimum and maximum values of start and end days in Table A-14.

3. Adult cattle fattening (BULF, HEIF) and heifers for breeding (HEIR)

Similarly to calf activities, the nutrient requirements for male and female adult cattle fattening (*BULF, HEIF)* and heifers for breeding (*HEIR)* are taken from LfL (2014) and are reported in Table A-12 and Table A-13. The annual requirements are calculated from Table A-12 and Table A-13 as follows:

$$X_i = 365 \frac{\sum_{DAY=startD}^{DAY=endD} X_{DAY}}{endD - startD}$$

for *i* = *BULF*, *HEIF*, *HEIR*; for *X* = *ENNE*, *ENMR*, *CRPR*, *DRMA*, *DRMN*, *DRMX*

The annual requirements for fibre are defined as follows:

$$FICT_i = DRMX_i$$

for *i* = *BULF*, *HEIF*, *HEIR*

To obtain the end day (*endD*) of the adult cattle, first the mean live weight (*LW*) is calculated by dividing the selling value of adult cattle (*PRIC*) available from FADN by the meat price extracted from Eurostat. Second, to obtain the end day of the fattening process, we use the animal weight in a given day (*XALW*) from Table A-12 (for *BULF*) and Table A-13 (for *HEIF* and *HEIR*) to derive the period (days) needed to reach the derived mean live weight *LW*. The start day *startD* of the fattening process of *BULF*, *HEIF* and *HEIR* is defined based on the FADN definition and is reported in Table A-14.

To account for the uncertainty in the data, we vary the mean live weight by three standard deviations, which results in variation of the end day *endD* based on the corresponding information on *XALW* available from Table A-12 and Table A-13. The start day is varied as reported in Table A-14. The nutrient requirements are varied using the minimum and maximum values as reported in Table A-12 and Table A-13, while the start day is varied as reported in Table A-14.

4. Sows (SOWS)

The nutrient requirements for sows (*SOWS*) are taken from GfE (2006) and are reported in Table A-15. The table reports the daily nutrient needs over the whole year (365 days). The table assumes that the requirements of a medium breeding performance are independent of the number of piglets, as there is no reliable relation between number of piglets and milk yield described in GfE (2006).

The annual requirements are calculated from Table A-15 as follows:

$$X_{SOWS} = \sum_{DAY=0}^{DAY=364} X_{DAY}$$

for = *ENNE*, *ENMP*, *CRPR*

The minimum (*DRMN*) and maximum (*DRMX*) requirements of dry matter are calculated as follows:

$$DRMN_{SOWS} = ENMP_{SOWS} / 14.82$$

$$DRMX_{SOWS} = ENMP_{SOWS} / 13.47$$

The minimum and maximum values reported in Table A-15 are used to derive the lower and upper bounds of animal requirements. This is to account for the uncertainty in the underlying data (e.g. number of piglets, milk yield).

5. Fattening of pigs (PIGF)

Nutrients for fattening pigs are calculated by summing up the nutrient requirements over the growth period of pigs from the start day until the end day of the fattening process. The nutrient requirements are taken from GfE (2006) and are reported in Table A-16. The annual requirements are calculated from Table A-16 as follows:

$$X_{PIGF} = 365 \frac{\sum_{DAY=startD}^{DAY=endD} X_{DAY}}{endD - startD} \qquad \text{for } = ENNE, ENMP, CRPR$$

The minimum (*DRMN*) and maximum (*DRMX*) requirements of dry matter are calculated as follows:

$$DRMN_{PIGF} = ENMP_{PIGF} / (13.4 * 0.88 * 0.588)$$

$$DRMX_{PIGF} = ENMP_{PIGF} / (12.6 * 0.88 * 0.588)$$

As for adult cattle, to obtain the end day (*endD*) of the pig-fattening process, first the mean live weight (*LW*) is calculated by dividing the selling value of pigs (*PRIC*) available from FADN by the meat price extracted from Eurostat. Then, to obtain the end day of the fattening process, we use the animal weight in a given day (*XALW*) from Table A-16 to derive the period (days) needed to reach the derived mean live weight *LW*. The start day *startD* of the fattening process is defined based on the FADN definition and is reported in in Table A-14.

To account for the uncertainty in the data, we vary the mean live weight by three standard deviations, which results in variation of the end day based on the corresponding information on *XALW* available from Table A-16. The nutrient requirements are varied using the minimum and maximum values as reported in Table A-16, while the start day is varied as reported in Table A-14. Note that the main source of variation of requirements (around minimum and maximum values) is daily live weight gains of pigs. The growth rate of pigs can strongly vary across MS and across farms within a MS. Moreover, the relative ratios of different nutrient requirements vary across different growth stages of pigs. The minimum and maximum values of requirements reported in Table A-16 take into consideration both these sources of variation and are available from GfE (2006).

6. Laying hens (HENS)

$$ENMC_{HENS} = 365(0.46 LW_{HENS} + 0.57 EGGY_{HENS}) 1000 k_{ENMC}$$

$$DRMA_{HENS} = ENMC_{HENS} / 12$$

$$DRMN_{HENS} = ENMC_{HENS} / 15$$

$$DRMX_{HENS} = ENMC_{HENS} / 8$$

$$CRPR_{HENS} = 0.14 \frac{ENMC_{HENS}}{11.1}$$

$$LISI_{HENS} = 0.0095 EGGS_{HENS} + 1.9 \cdot 60$$

Where

$$EGGY_{HENS} = \frac{EGGS_{HENS} / 57}{365} \quad \mathrm{EGGY} = (\frac{\mathrm{EGGS}}{57})/365$$

ENMC is metabolisable energy for chicken; *EGGY* is number of eggs per laying hen per day with the assumption of average egg weight of 57 g and 365 production days; *EGGS* is egg production (in kg per 1 000 heads); LW_{HENS} is mean live weight assumed 1.62 kg, k_{ENMC} is unit conversion factor for energy requirements (Table A-19).

7. Poultry (POUF)

The nutrient requirements for poultry are taken from NRC (1994) and are reported in Table A-17. The requirement tables are for broilers and provide nutrient requirement on a daily basis from birth until the end day of the production process. The annual requirements are calculated from Table A-17 as follows:

$$X_{POUF} = 365 \frac{\sum_{DAY=startD}^{DAY=endD} X_{DAY}}{endD - startD} \qquad = ENNE, ENMC, CRPR, DRMA$$

The mean value of the start day (*startD*) and end day (*endD*) of the production process are defined based on FADN definition. The start day is assumed zero, whereas the end day is set to 40 days (Table A-14). To account for the uncertainty, we consider lower and upper bounds of the start and end day as defined in Table A-14.

The minimum (*DRMN*) and maximum (*DRMX*) requirements of dry matter are calculated as follows:

$$DRMN_{POUF} = ENMC_{POUF} / (13.4 * 0.88 * 0.717)$$

$$DRMX_{POUF} = ENMC_{POUF} / (12.6 * 0.88 * 0.717)$$

To account for the uncertainty in the data, the lower and upper bounds of poultry nutrient requirements are obtained by using minimum and maximum values of nutrient requirements as reported in Table A-17 as well as by varying the start and end day as reported in Table A-14. The main sources of uncertainty in deriving the poultry requirements are the duration of production process, the type of poultry (e.g. broiler, turkey) and daily growth rate.

8. Ewes and goats for milk (SHGM)

First, nutrient requirements are calculated for ewes (*EWES*) and goats (*GOAT*) separately, second, the nutrient requirements for the combined sheep and goat activity (*SHGM*) are obtained as the weighted average over *EWES* and *GOAT*.

8.1 Nutrient requirements for EWES and GOAT

$$NEM_i = 0.217 LW_i^{0.75} 0.107 PD_i$$

$NEA_i = 0.0107 LW_i \; PD_i$ *if there is grassland on-farm;*

otherwise $NEA_i = 0.009 LW_i \; PD_i$

$$NEL_i = 4.6 MPD_i 170$$

$$ENNE_i = NEM_i + NEA_i + NEL_i$$

$$CRPR_{\mathrm{EWES}} = 135(0.026 + 0.0014 LW_{\mathrm{EWES}})$$
$$+170(0.0634 + 0.0012 LW_{\mathrm{EWES}} + 0.0895 MPD_{\mathrm{EWES}})$$
$$+[1.35(2.22 LW_{\mathrm{EWES}} - 19.88)60]/1000$$

$$CRPR_{GOAT} = 305(12.66 + 0.8 LW_{GOAT})$$
$$+61 MPD_{GOAT} 170 + 60(1.425 LW_{GOAT} + 14.666)/1000$$

$$DRMN_{\mathrm{EWES}} = 135(0.36 + 0.023 LW_{\mathrm{EWES}}) + 170(1.112 + 0.0187 LW_{\mathrm{EWES}} + 0.279 MPD_{\mathrm{EWES}})$$
$$+60(0.0268 LW_{\mathrm{EWES}} - 0.24)$$

$$DRMN_{GOAT} = 305(0.55 + 0.013 LW_{GOAT}) + 0.3 MPD_{GOAT} 170 + 60(0.0122 LW_{GOAT} + 0.5316)$$

Where

$$MPD_i = \frac{SGMI_i + SGMF_i}{170}$$

i = EWES, GOAT; *MPD* is sheep/goat milk production per day. It is assumed that there are 170 milk production days, 135 days maintenance only and 60 days of final mating; *SGMI* is milk production per sheep/goat; *SGMF* and SGMI are milk production for feeding and milk production (not for feeding) for sheep and goats, respectively, derived from FADN (in kg per day); PD_i = 365; LW_{EWES} = 55; LW_{GOAT} = 60.

8.2 Nutrient requirements for sheep and goat activity (SHGM)

$$REQ_{SHGM} = sh_{EWES} REQ_{EWES} + sh_{GOAT} REQ_{GOAT}$$

$$DRMX_{SHGM} = 1.5 DRMN_{SHGM}$$

$$FISM_{SHGM} = 120 \frac{LW_{SHGM}^{0.75}}{1000} 365$$

where

$$LW_{SHGM} = sh_{EWES} LW_{EWES} + sh_{GOAT} LW_{GOAT}$$

REQ = *ENNE*, *CRPR*, *DRMN*; *FISM* is fibre for sheep and goats; sh_{EWES} and sh_{GOAT} are shares of ewes and goats in the total herd size, respectively, derived from FADN.

The lower and upper bounds of requirements are obtained by varying the average milk production per day and the mean live weight by 30 % around their mean values.

9. Sheep and goats fattening (SHGF)

$$ENNE_{SHGF} = (0.1596 LW_{SHGF} + 0.0303 DAILY_{SHGF} - 0.56)(1 - 0.2) FD_{SHGF} k_{ENMR}$$

$$CRPR_{SHGF} = [(21.778 + 0.33 LW_{SHGF}) + 0.258 DAILY_{SHGF} 1.35 FD_{SHGF} 1000] / 1000$$

$$DRMN_{SHGF} = (0.038286 LW_{SHGF} + 0.06381) FD_{SHGF}$$

$$DRMX_{SHGF} = 1.5 DRMN_{SHGF}$$

$$FISF_{SHGF} = 0.075 * LW_{SHGF}^{0.75} * FD_{SHGF}$$

where

$$FD_{SHGF} = Min\left[320; Max\left(45; \frac{SGMT_{SHGF} / CW_{SHGF}}{DAILY_{SHGF}}\right)\right]$$

$$LW = \frac{Max\,[8; Min\,(25; SGMT_{SHGF})] / CW_{SHGF}}{2}$$

SGMT is meat production per animal ([60]); *CW* = 0.6; *DAILY* = 0.250 kg; k_{ENMR} is conversion factor for metabolisable energy ruminants (*ENMR*) (Table A-18 and Table A-19).

The lower and upper bounds of requirements are obtained by varying the duration of the fattening period and the mean live weight up to 80 % around their mean values.

([60]) (39SN + 41SN)/(39AV + 41AV)*CW, where 39SN + 41SN and 39AV + 41AV are the number of sold and average number of sheep and goats for fattening derived from FADN.

Table A-12. Nutrient requirement table for male cattle fattening and raising (CAMF, CAMR, BULF)

		DAY 0	DAY 1	DAY 2	DAY 3	...	DAY 803	DAY 804	DAY 805
DAY	Average		1	2	3		803	804	805
	Min		1	2	3		803	804	805
	Max		1	2	3		803	804	805
DAILY	Average	800	800	800	800		1412	1412	1412
	Min	690	690	690	690		1290	1290	1290
	Max	800	800	800	800		1506	1506	1506
XALW	Average	80	80.8	81.6	82.4		1177.937	1179.349	1180.761
	Min	80	80.69	81.38	82.07		813.052	814.342	815.632
	Max	80	80.8	81.6	82.4		1259.177	1260.683	1262.189
ENNE	Average	10.659	10.659	10.659	10.659		75.4908	75.4908	75.4908
	Min	9.405	9.405	9.405	9.405		70.9137	70.9137	70.9137
	Max	11.286	11.286	11.286	11.286		78.375	78.375	78.375
ENMR	Average	17	17	17	17		120.4	120.4	120.4
	Min	15	15	15	15		113.1	113.1	113.1
	Max	18	18	18	18		125	125	125
CRPR	Average	0.239	0.239	0.239	0.239		1.213	1.213	1.213
	Min	0.213	0.213	0.213	0.213		1.213	1.213	1.213
	Max	0.265	0.265	0.265	0.265		1.32	1.32	1.32
DRMA	Average	1.05	1.05	1.05	1.05		10.03333	10.03333	10.03333
	Min	0.95	0.95	0.95	0.95		9.466667	9.466667	9.466667
	Max	1.15	1.15	1.15	1.15		10.33333	10.33333	10.33333
DRMX	Average	1.2	1.05	1.05	1.05		10.03333	10.03333	10.03333
	Min	1.1	0.95	0.95	0.95		9.466667	9.466667	9.466667
	Max	1.3	1.15	1.15	1.15		10.33333	10.33333	10.33333
DRMN	Average	0.9	1.05	1.05	1.05		10.03333	10.03333	10.03333
	Min	0.8	0.95	0.95	0.95		9.466667	9.466667	9.466667
	Max	1	1.15	1.15	1.15		10.33333	10.33333	10.33333

Source: LfL (2014).

Table A-13. Nutrient requirement table for female cattle fattening and raising (CAFF, CAFR, HEIF, HEIR)

		DAY 0	DAY 1	DAY 2	DAY 3	...	DAY 803	DAY 804	DAY 805
DAY	Average		1	2	3		803	804	805
	Min		1	2	3		803	804	805
	Max		1	2	3		803	804	805
DAILY	Average	690	690	690	690		825	825	825
	Min	690	690	690	690		825	825	825
	Max	690	690	690	690		825	825	825
XALW	Average	80	80.69	81.38	82.07		805.8	806.625	807.45
	Min	80	80.69	81.38	82.07		799.77	800.595	801.42
	Max	80	80.69	81.38	82.07		810.71	811.535	812.36
ENNE	Average	9.405	9.405	9.405	9.405		62.7	62.7	62.7
	Min	9.405	9.405	9.405	9.405		59.565	59.565	59.565
	Max	9.405	9.405	9.405	9.405		65.835	65.835	65.835
ENMR	Average	15	15	15	15		100	100	100
	Min	15	15	15	15		95	95	95
	Max	15	15	15	15		105	105	105
CRPR	Average	0.213	0.213	0.213	0.213		1.149	1.149	1.149
	Min	0.213	0.213	0.213	0.213		1.092	1.092	1.092
	Max	0.213	0.213	0.213	0.213		1.205	1.205	1.205
DRMA	Average	0.95	0.95	0.95	0.95		10.5	10.5	10.5
	Min	0.95	0.95	0.95	0.95		10.5	10.5	10.5
	Max	0.95	0.95	0.95	0.95		10.5	10.5	10.5
DRMX	Average	1.1	0.95	0.95	0.95		10.5	10.5	10.5
	Min	1.1	0.95	0.95	0.95		10.5	10.5	10.5
	Max	1.1	0.95	0.95	0.95		10.5	10.5	10.5
DRMN	Average	0.8	0.95	0.95	0.95		10.5	10.5	10.5
	Min	0.8	0.95	0.95	0.95		10.5	10.5	10.5
	Max	0.8	0.95	0.95	0.95		10.5	10.5	10.5

Source: LfL (2014).

Table A-14. Default values defining the start and the end day of the fattening/raising process of animal activities

	Start day (*startD*)			End day (*endD*)		
	Average	Min	Max	Average	Min	Max
CAFF	0	0	60	180	60	240
CAMF	0	0	60	180	60	240
CAFR	0	0	180	365	180	912.5
CAMR	0	0	180	365	180	912.5
HEIR	365	180	730	Calc.	s.d.	s.d.
HEIF	180	60	360	Calc.	s.d.	s.d.
BULF	272.5	120	545	Calc.	s.d.	s.d.
PIGF	0	0	17	Calc.	s.d.	s.d.
POUF	0	0	10	40	30	62

Notes: Calc.: calculated based on the mean live weight derived from FADN and Eurostat and corresponding values of *endD* from Table A-12 and Table A-13; s.d.: calculated based on the standard deviation of the *endD*.

Source: derived based on FADN definitions

Table A-15. Nutrient requirement table for sows (SOWS)

		DAY 0	DAY 1	DAY 2	DAY 3	...	DAY 362	DAY 363	DAY 364
DAY	Average		1	2	3		362	363	364
	Min		1	2	3		362	363	364
	Max		1	2	3		362	363	364
ENNE	Average	24.5196	24.5196	24.5196	24.5196		24.5196	24.5196	24.5196
	Min	23.0496	23.0496	23.0496	23.0496		23.0496	23.0496	23.0496
	Max	25.9896	25.9896	25.9896	25.9896		25.9896	25.9896	25.9896
ENMP	Average	41.7	41.7	41.7	41.7		41.7	41.7	41.7
	Min	39.2	39.2	39.2	39.2		39.2	39.2	39.2
	Max	44.2	44.2	44.2	44.2		44.2	44.2	44.2
CRPR	Average	0.33	0.33	0.33	0.33		0.33	0.33	0.33
	Min	0.3	0.3	0.3	0.3		0.3	0.3	0.3
	Max	0.36	0.36	0.36	0.36		0.36	0.36	0.36

Source: GfE (2006).

Table A-16. Nutrient requirement table for fattening of pigs (PIGF)

		DAY 0	DAY 1	DAY 2	DAY 3	...	DAY 175	DAY 176	DAY 177
DAY	Average		1	2	3		175	176	177
	Min		1	2	3		175	176	177
	Max		1	2	3		175	176	177
DAILY	Average	600	600	600	600		700	700	700
	Min	600	600	600	600		700	700	700
	Max	700	700	700	700		800	800	800
XALW	Average	20	20.6	21.2	21.8		150.2	150.9	151.6
	Min	20	20.6	21.2	21.8		150.2	150.9	151.6
	Max	20	20.7	21.4	22.1		166.9	167.7	168.5
ENNE	Average		7.644	7.644	7.644		21.168	21.168	21.168
	Min		7.644	7.644	7.644		21.168	21.168	21.168
	Max		8.82	8.82	8.82		22.932	22.932	22.932
ENMP	Average		13	13	13		36	36	36
	Min		13	13	13		36	36	36
	Max		15	15	15		39	39	39
CRPR	Average		0.202353	0.202353	0.202353		0.225882	0.225882	0.225882
	Min		0.202353	0.202353	0.202353		0.225882	0.225882	0.225882
	Max		0.235294	0.235294	0.235294		0.254118	0.254118	0.254118

Source: GfE (2006).

Table A-17. Nutrient requirement table for poultry (POUF)

		DAY 0	DAY 1	DAY 2	DAY 3	…	DAY 60	DAY 61	DAY 62
DAY	Average		1	2	3		60	61	62
	Min		1	2	3		60	61	62
	Max		1	2	3		60	61	62
DAILY	Average	21.14	21.14	21.14	21.14		57.86	57.86	57.86
	Min	21.14	21.14	21.14	21.14		57.86	57.86	57.86
	Max	21.14	21.14	21.14	21.14		57.86	57.86	57.86
XALW	Average		0.02	0.04	0.06		3.02	3.08	3.14
	Min		0.02	0.04	0.06		3.02	3.08	3.14
	Max		0.02	0.04	0.06		3.02	3.08	3.14
ENNE	Average	0.18	0.18	0.18	0.18		1.94	1.94	1.94
	Min	0.18	0.18	0.18	0.18		1.94	1.94	1.94
	Max	0.18	0.18	0.18	0.18		1.94	1.94	1.94
ENMC	Average	0.25	0.25	0.25	0.25		2.70	2.70	2.70
	Min	0.25	0.25	0.25	0.25		2.70	2.70	2.70
	Max	0.25	0.25	0.25	0.25		2.70	2.70	2.70
CRPR	Average	0.00	0.00	0.00	0.00		0.04	0.04	0.04
	Min	0.00	0.00	0.00	0.00		0.04	0.04	0.04
	Max	0.00	0.00	0.00	0.00		0.04	0.04	0.04
DRMA	Average	0.02	0.02	0.02	0.02		0.18	0.18	0.18
	Min	0.02	0.02	0.02	0.02		0.18	0.18	0.18
	Max	0.02	0.02	0.02	0.02		0.18	0.18	0.18

Source: NRC (1994).

Table A-18. Carcass share, live start weight and coefficient of energy for growth

	Carcass to live weight (*CW*) ***Coeff. 0-1***
SHGF	0.60
HENS	0.80

Source: CAPRI.

Table A-19. Conversion factors for energy requirements *(K_{ENMR}, K_{ENMC}, K_{ENMH}, K_{ENMP})*

ENMR	**ENMC**	**ENMH**	**ENMP**
0.627	0.717	0.631	0.588

Source: CAPRI.

Annex D: Calculation of STRAW yields

We calculate straw production using the RCR as a function of crop yield. The RCR indicates how much residue is produced as a function of the main agricultural crop produced measured on a total dry matter basis. The RCR can vary widely, depending, for example, on the type of crop, crop productivity, crop mix, crop variety, climate conditions and agricultural practices. Based on a review of literature, Scarlat et al. (2010) report an RCR of between 0.6 and 2.8, depending on the crop type and the reviewed study. Edwards et al. (2005) estimate a cereal RCR function for the EU based on a wide set of studies. Their estimated ratio ranges between 0.62 and 0.94 and is negatively correlated with the cereal yield. Koopmans and Koppejan (1997) report RCR for 13 crops of between 0.2 and 4, depending on the crop and reviewed study. Furthermore, this literature implies that the amount of residues produced can be linked to crop productivity and can be approximated by a functional form (negatively) depending on the crop yield (Edwards et al., 2005; Scarlat et al., 2010).

Following Scarlat et al. (2010), we assume the following relationship between RCR and yield for a number of crops:

(1) $RCR_{wheat} = 1.6057 - 0.3629\ ln(Yield_{wheat})$

(2) $RCR_{rye} = 1.5142 - 0.3007\ ln(Yield_{rye})$

(3) $RCR_{oats} = 1.3002 - 0.1874\ \ln(Yield_{oats})$

(4) $RCR_{Barley} = 1.3796 - \_0.2751\ ln(Yield_{Barley})$

(5) $RCR_{maize} = 1.3373 - 0.1807\ ln(Yield_{maize})$

(6) $RCR_{rice} = 3.845 - 1.2256\ ln(Yield_{rice})$

(7) $RCR_{sunflower} = 3.2189 - 1.1097\ ln(Yield_{sunflower})$

(8) $RCR_{rapeseed} = 2.0475 - 0.452\ ln(Yield_{rapeseed})$

– $-RCR_{other\ crops} = 2.0311 - 0.5118\ ln(Yield_{other\ crops})$

where $Yield_i$ is yield (t/ha) for crop *i*. Note that the coefficients corresponding to the RCP for *other crops* (equation –) is calculated as the average coefficient value over all crops.

The straw yield, *StrawYield$_i$*, for crop *i* is obtained by multiplying the calculated RCP in equations (1)–– with crop yield (in fresh weight per year) and the collection rate, *CollRate$_i$*:

(9) $StrawYield_i = CollRate_i\ RCR_i\ Yield_i$

The actual residue collection rate varies depending on a number of factors such as collection equipment, crop variety, the harvest height, yields, environmental requirements, etc. Studies provide estimates on the crop collection rates of between 30 % and 75 % (Bakker, 2013; Scarlat et al., 2010). Following Scarlat et al. (2010), we assume collection rates as reported in Table A-20.

Note that crop yields are usually not recorded on a dry matter basis in official statistical sources (e.g. Eurostat, FAO), but in the form in which it is harvested (fresh or wet weight). As a result, the straw yield calculated in equation (9) is not measured on a dry matter basis but contains the moisture level of the grain crop (i.e. between 15 % and 20 % depending on the crop).

Table A-20. Crop residue collection rates

	Collection rate, *Collrate*(%)
Wheat	40
Rye	40
Oats	40
Barley	40
Maize	50
Rice	50
Sunflower	50
Rapeseed	50

Source: Scarlat et al. (2010)

Annex E. Agri-environmental indicators

The table below reports the preselected indicators by JRC-IES MARS Unit, in collaboration with JRC-EoA Unit, that can be calculated using FADN database and other external sources. This table shows the state of the implementation in the current version of the IFM-CAP model.

Table A-21. Agri-environmental indicators in the IFM-CAP model

Domain/dimension	Indicator	Sub-indicator	Status
Public policy	Agri-environmental commitments	Agri-environmental payments per hectare	Operational
Market signals and production systems	Intensification/extensification	Inputs expenditure	Operational
	Intensification/extensification	Low, medium, high input expenditure	Not implemented
Climate change and air	GHG emissions	Methane (CH_4) Nitrous oxide (N_2O)	Implemented but not yet operational
	Ammonia emissions	Ammonia	Implemented but not yet operational
Water	Nutrient management	N budget	Implemented but not operational
		P budget	Implemented but not operational
	Nutrient management	Fertiliser consumption	Operational
		Fertiliser expenditure	Operational
	Pesticide risk	Expenditure in plant protection products	Operational
Soil	Soil erosion by water	Soil loss equation	Not yet implemented. Need of farm spatial allocation

	Soil erosion by water	Crop system and support practices factor	Operational
	Soil organic matter	Soil organic matter	To be designed
	Soil organic matter	Share of permanent grassland	Operational
Biodiversity and landscape	Crop richness	Crop richness from functional crop groups	Operational
	Crop diversity	Crop diversity from functional crop groups	Operational
	Diversity of land uses		Cannot be implemented until shifts between land uses are included in the model
	Extensiveness	Extensiveness in arable land	Cannot be implemented until farm yields are endogenised
		Extensiveness in grassland	Implementation forthcoming
	Extensive permanent grasslands	Share of extensive permanent grasslands	Operational
	Environmental compensation zones (ECZ)	Share of ECZ in UAA	Cannot be implemented until shifts between land uses are included in the model

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