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**System for Environmental and Agricultural Modelling;
Linking European Science and Society**

A generic template for FSSIM

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SEAMLESS integrated project aims at developing an integrated framework that allows ex-ante assessment of agricultural and environmental policies and technological innovations. The framework will have multi-scale capabilities ranging from field and farm to the EU25 and globe; it will be generic, modular and open and using state-of-the art software. The project is carried out by a consortium of 30 partners, led by Wageningen University (NL).

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General information

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Executive summary

The aim of this deliverable is to describe the generic template of the Farm System Simulator (FSSIM) designed to be applied for any farming systems across Europe for simulating farmer behaviour and assessing policy impacts. FSSIM is a bio-economic farm model which integrates biophysical processes, farm decision making and resource endowment. It consists of an agricultural management module (FSSIM-AM) and a mathematical programming model (FSSIM-MP). FSSIM-AM aims to identify current and alternative activities and to quantify their input output coefficients (both yields and environmental effects). FSSIM-MP seeks to describe the farmer's behaviour given a set of biophysical, socio-economic and policy constraints and to predict his/her reactions under news technologies, policy and market changes.

This deliverable focuses mainly on the Mathematical Programming module (FSSIM-MP) of FSSIM, in particularly its structure, main components, module linking and component integration. FSSIM-MP was designed sufficiently generic and with a transparent syntaxes in order to be applied to many different farming systems across Europe and elsewhere. It has a modular setup to be re-usable, adaptable and easily extendable to achieve different modelling goals. It includes a set of modules, namely crops, perennial, premium, Positive Mathematical Programming (PMP), risk, trend and policy. These modules are solved simultaneously; they are linked indirectly by an integrative module named the "common module" involving the objective function and the common constraints. Thanks to its modularity, FSSIM-MP provides the ability to add and remove modules (and their corresponding constraints) following the needs of the simulation, to select one or several calibration approaches between different options (risk and three PMP variants) and to control the flow of data between the database and software tools. FSSIM-MP can be run with simple or detailed survey data (i.e. according to the level of detail of the available data). Additionally, it can read input data stored in any database (e.g. SEAMLESS database, Access DB), Excel or include text files, provided that they are structured in the required format.

In term of policy representation, FSSIM-MP includes the major EU policy instruments related to agricultural activities such as price and market support, quotas systems, set-aside schema, cross-compliance and specific agro-environmental measures... The implementation of these instruments depends on the analysed policy scenarios which are presently the Agenda 2000 in 2003 for the base year and the recent CAP reform of June 2003 in Luxembourg, as it would be implemented in 2013, for the baseline scenario.

FSSIM-MP structure offers the possibility to build a specific baseline scenario to use as reference for the interpretation and analysis of different policy scenarios. The principal outlook parameters predefined in the FSSIM-trend module to be used for building a specific baseline scenario are the following: inflation rate, price change based on market projections,

yield trends, change of structural (linked to farm resource endowment) and policy parameters. FSSIM-MP provides as well the possibility to test a wide range of policy options related to agricultural and environmental policies such as abolishing quota, changing set-aside regulation and modifying the basic premiums.

FSSIM-MP has been implemented and designed in GAMS[1] language to facilitate the integration with SeamFrame and develop components that are reusable and extensible and that can be decoupled. The objectives during development were to completely separate algorithm from data to facilitate easy linkage to other databases and to make the algorithms easily extensible and comprehendible.

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[1] General Algebraic Modelling System which is used to program the model (www.gams.com).

1 FSSIM modelling system

1.1 Purpose

Impact assessment of the European agricultural and environmental policies on farm's performance and sustainability has become a central issue for researchers, producers and policy makers. An increasing body of literature has been developed on methods for the evaluation of present policies, with special attention to the economic aspects. In contrast, there is a lack of tools to support the design of future policy schemes through *ex-ante* assessment and to take into account the impact of policies in terms of technical, environmental and landscape issues. This seems to be due on the one hand to the complexity of new policy schemes, and on the other hand to the necessary of multi-disciplinary approach of policy decision making. Such integrated assessment can be performed through the Farm System Simulator (FSSIM) developed within the SEAMLESS project.

FSSIM is an integrated modelling system developed to assess the economic and ecological impacts of agricultural and environmental policies and technological innovations. Based on the link of biophysical and micro-economic models, FSSIM seeks to describe the technical aspects at the farm level given specific biophysical conditions, using different sets of constraints to derive a set of feasible technological alternatives for each farm type. It constitutes the primary models for taking into account both economic and ecological aspects of the agricultural activity and to make the complex relationship between biological processes and economic decisions more transparent. This ecological-economic articulation is essential, in order to analyse the whole farming system in an integrated manner. The principal characteristic of this type of models is the application of engineering production and environmental functions derived from biophysical models (APES) and other sources (experiments, expert knowledge, surveys, etc.). These functions constitute the essential linkage between the biophysical and economic models.

FSSIM is aimed to be applied to any farming system across Europe and elsewhere for simulating farm level behavior and assessing different policies under various conditions. This issue required the development of a generic model able to represent all categories of farming systems that exist in EU, instead of each farm type having its own specific model. Indeed, the development of farm models used for policy evaluation is often characterized by poor transferability and reusability, lack of quality assessment and poor usage comfort. To tackle these problems in the SEAMLESS project, a generic and automatic frame for FSSIM was developed. The automatic procedure was needed to generate a set of agricultural activities, defined as a coherent set of production enterprises with a specified production technique, and the corresponding technical coefficients. The generic procedure consists to build a model enabling to describe a wide range of geographical and political situations and various agro-environmental conditions and to be re-usable, adaptable and easily extendable to achieve different modelling goals.

1.2 Conception and specification of FSSIM

FSSIM consists of a data module for agricultural management (FSSIM-AM) and a mathematical programming model (FSSIM-MP). FSSIM-AM aims to identify current and alternative activities and to quantify their input and output coefficients (both yields and environmental effects) using the biophysical field model APES (Agricultural Production and Externalities Simulator) and other data sources. Once these activities have been generated, FSSIM-MP chooses those that best fit the farmer's behaviour, given the set of resources, the technological and political constraints, and forecasts farmer responses to new technologies, as

well as to policy and market changes. The principal outputs generated from FSSIM for a specific policy are forecasts on land use, production, input use, farm income and environmental externalities (e.g. nitrogen surplus, nitrate leaching, pesticide use, etc.). These outputs can be used directly or translated into indicators to provide measures of the impact of policies (Figure 1).
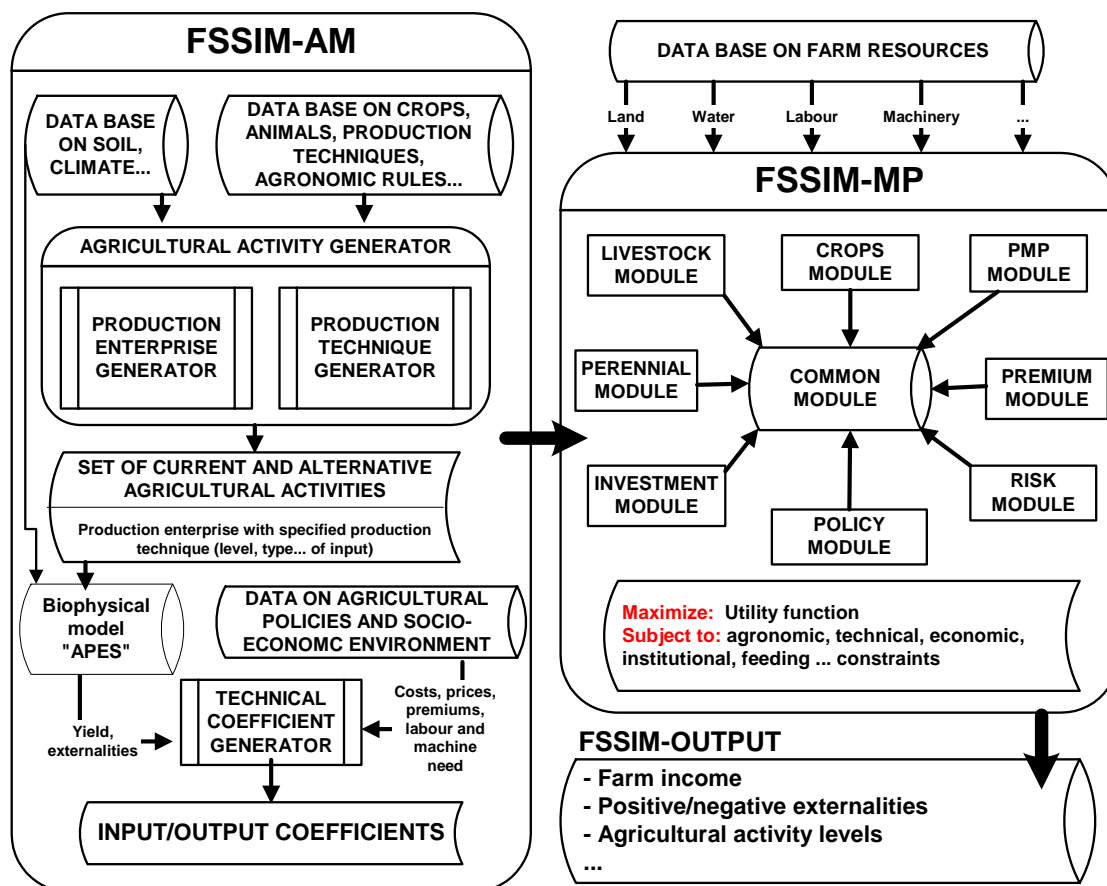
Figure 1. An overview of FSSIM as a combination of Agricultural Management module and Mathematical Programming module.

The general context of SEAMLESS and the variety of policy questions that FSSIM is called to address leads to a number of choices that makes this model unique:

- **Constraint optimisation model:** FSSIM is a constraint optimisation model which maximizes an objective function subject to a number of constraints. The assumptions behind this type of models are very consistent with the fundamental concepts of microeconomic theory: rationality and optimisation.
- **Non-linear programming model:** the objective function of FSSIM is based on non-linear utility function in order to avoid the common problems of linear programming models: overspecialization and exaggerate reactions under exogenous shocks.
- **Risk programming model:** FSSIM take into account the risk according to the Mean-Standard deviation method in which expected utility is defined under expected income and risk. Ignoring-risk-averse behaviour in farm planning models leads often to unacceptable results as agricultural production processes are inherently risky and farms' decision making is severally affected by risk and incertitude (Hazell and Norton, 1986).
- **Positive model:** the first objective of FSSIM is to be able to reproduce the observed production situation as precisely as possible by making use of the observed behaviour

of economic agents (Janssen and Van Ittersum, 2007). Traditionally, optimization models (OM) such as linear programming are often based on *normative* assumptions aimed at identifying the "best" production combination under the hypothesis that the initial situation is not binding in terms of production choices. This assumption, which induces a wide divergence between base period model outcomes and observed production patterns, is hardly acceptable when aiming to conduct impact policy analysis. That is why *normative* OM has been left behind for the *positive* type model, where the main objective is to reproduce the observed production situation as precisely as possible, to make plausible the forecast of farmers' behaviour when simulating changes of the parameters determined by agricultural policy interventions and/or technological innovations.

- **Comparative static model:** FSSIM is a mono-periodic model which optimizes an objective function for one period (i.e. one year) over which decisions are taken. This implies that it does not explicitly take account of time. Nevertheless, to incorporate some temporal effects, agricultural activities are based on "crop rotations" and "dressed animal[2]" rather than individual crops and animals.

- **Primal based-approach:** FSSIM follows a primal-based approach, where technology is explicitly represented in order to simulate the switch between production techniques as well as between production systems (Louhichi et al, 1999).

- **Discrete based functions:** FSSIM is based on discrete functions in order to integrate easily the engineering production functions generated from agronomic theory and biophysical models (Hengsdijk and Van Ittersum, 2003). These engineering functions constitute the essential linkage between the biophysical and economic models. This discrete mathematical programming approach can (better) capture the technological and policy constraints than pre-determined behavioural functional form, as used in most econometric models.

- **Activity based:** input output coefficients used in FSSIM are related with activities (i.e. production process) in order to make suitable integrated assessment of new policies which are linked to activity and not to product and to allow a good consistency with the outputs of biophysical models.

- **Multi-inputs and multi-output functions:** FSSIM is based on multi-inputs and multi-output production functions to account positive and negative jointness in outputs (i.e., joint production) associated with the production process.

- **Generic model**: it was designed sufficiently generic and with a transparent syntaxes in order to be applied to many different farming systems across Europe and elsewhere, and to assess different policies under various conditions.

- **Modular model:** it has a modular setup to be re-usable, adaptable and easily extendable to achieve different modelling goals. Thanks to this modularity, FSSIM provides the capabilities to activate and deactivate modules according to regions and conditions. It allows also the subsequent incorporation of additional modules which might be needed to simulate activities not included in the existing version, such as perennial activities, and the replacement of modules with alternative versions.

- **Automatic and integrated components:** it includes several components, which have been linked and integrated. The communication between these different components is based on explicit definitions of spatial scales and software for model integration. It is foreseen that each component can be reused independently for other applications and modeling exercises. New components can also be added in later stages.

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[2] The concept of 'dressed animal' represents an adult animal and young stock taking into account the replacement rate.

> ▪ **Template based model:** FSSIM uses a model template for all the application, i.e. the equations and the variables used in FSSIM-MP are the same everywhere but the set of parameters depend on farm data.

According to these specifications, the general mathematical formulation of FSSIM can be presented as follow:

> Maximise: $U=Z-\phi\sigma$

> Subject to: $Ax \le b, x \ge 0$

Where **U** is the objective function to maximise, **z** is the expected income, **x** is the (n x 1) vector of the simulated levels of the agricultural activities, ϕ is the risk aversion coefficient which is different between farm types, σ is the standard deviation of income due to price and yield variation, **A** is the (m x n) matrix of technical coefficients, and b is the (m x 1) vector of available resource levels and upper bounds to the policy constraints.

1.3   FSSIM design and components

The technical design of FSSIM is based on the theory of software components, semantically aware components and layered application. As FSSIM-AM and MP are quire large entities, these have been further sub-divided into components or sub-modules that have a more specific role and a stand-alone. Every component could be reused independently for other applications and modelling exercises.

FSSIM-AM is based on several components named the Simple/detailed Survey Component, the Production Enterprise Generator (PEG), the Production Technique Generator (PTG) and the Technological Coefficient Generator (TCG) which are integrated automatically. The Survey Component is used to collect data on current activities, the PEG and the PTG to generate and describe a set of alternative activities and the TCG to convert on monetary terms the agronomic input-output coefficients generated by PEG, PTG and APES and to prepare the technical matrix required by FSSIM-MP.

FSSIM-MP includes a set of modules, namely crops, perennial, premium, Positive Mathematical Programming (PMP), risk, trend and policy. These modules are solved simultaneously; they are linked indirectly by an integrative module named the "common module" involving the objective function and the common constraints (Figure 2). Each module includes two GAMS[3] files. The first one links the data-definition and the module's equations and the second one contains the module's equations. Each module generates at least one variable which is used to define the common module's equations, thus providing a link between the different modules. Thanks to its modularity, FSSIM-MP provides the ability to add and remove modules (and their corresponding constraints) following the needs of the simulation, to select one or several calibration approaches between different options (risk, standard PMP, Rhöm and Dabbert' s PMP approach, Kanellopoulos et al.' s PMP approach) and to control the flow of data between the database and software tools. FSSIM-MP can be run with simple or detailed survey data (i.e. according to the level of detail of the available data). Additionally, it can read input data stored in any database (e.g. Access DB), Excel or GAMS include files, provided that they are structured in the required format.

The interaction between FSSIM-MP and FSSIM-AM and their respective components is shown in the diagram below (Figure 2):

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[3] General Algebraic Modelling System is used to program the model. (http://www.gams.com)

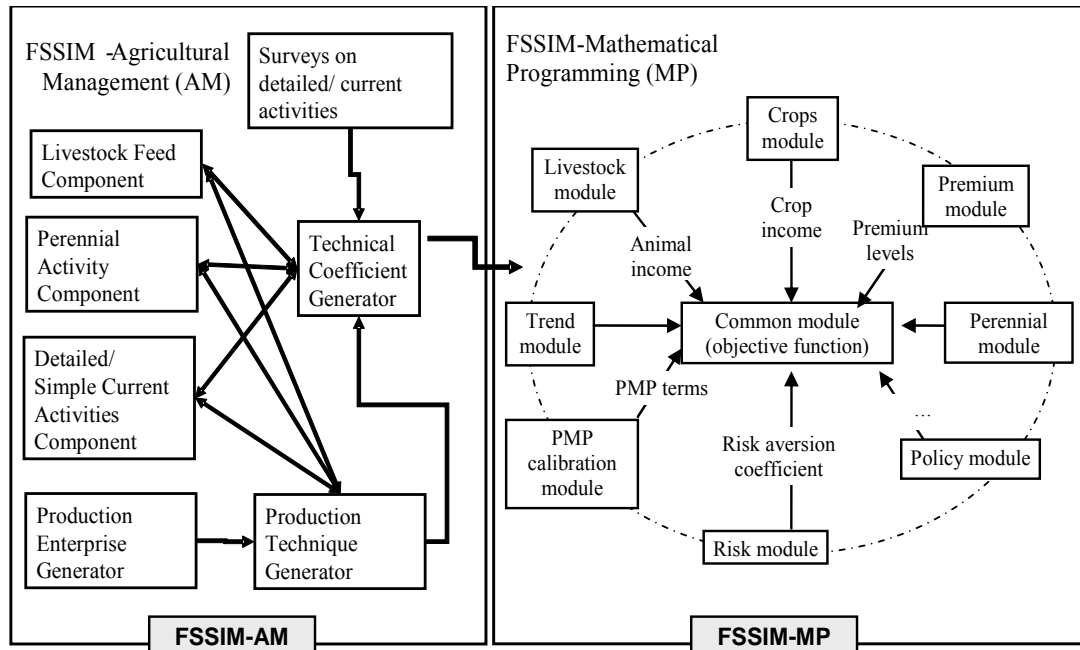**Figure 2.** FSSIM-MP and AM with their individual components or modules

FSSIM exists both as stand-alone version and as a version integrated within SEAMLESS-IF. In order to make all FSSIM components easier to manipulate a Graphical User Interface (GUI) was developed. This GUI assists users in setting up scenarios, running the simulations and exploring model outputs in response to changing inputs.

2 FSSIM-AM: Agricultural Management Module (PD3.3, 3.3.4., 3.3.9)

The purpose of the Agricultural Management Module is to describe, generate and quantify alternative and current activities that can be evaluated by APES (in terms of yields and environmental effects or other quantitative features). The fully quantified agricultural activities i.e. the complete sets of inputs and outputs are inputs for FSSIM to assess their contribution to the goals considered. Alternative activities are activities that are not currently used, but are technically feasible alternatives for the future, often technological innovations or newly developed cropping or husbandry practices (PD3.3.1), while current activities are activities that are currently practiced and can be derived from observed data.

The procedures for constructing production enterprises and production techniques are quite different for current and alternative activities, while the addition of costs and labour requirements and the processing of APES outputs are largely the same for current and alternative activities. Current activities e.g. current production enterprises and current production techniques will be identified on the basis of expert knowledge. Variable and fixed costs and labour requirements will be derived from statistical sources, which can also be used for alternative activities.

The main calculation components or modules of the Agricultural Management Module in FSSIM are:

(i) Simple/detailed Survey Component: a tool to identify and collect data on current activities

(ii) Production Enterprise Generator (PEG): a tool to generate a feasible set of production enterprises (crop rotations) of the farm based on biophysical filters, such as soil and climate characteristics and for annual arable crops rotational filters (or for animal husbandry systems herd composition constraints) set of production enterprises including a coherent set of crops and animals.

(iii) Production Technique Generator (PTG): a tool to describe production techniques of agricultural activities on the basis of the feasible set of production enterprises. A production technique is a complete set of agronomic inputs characterized by type, level, timing and application technique.

(iv) Technical Coefficient Generator (TCG): a tool to link the agronomic input and output coefficients generated by PEG, PTG and APES to socio-economic inputs and outputs by simple calculations. The TCG also describes and adds the standard management operations that do not lead to alternatives in production techniques. In addition, the TCG quantifies other or remaining inputs of each crop in each agricultural activity, i.e. the inputs not simulated through APES. The result of the TCG is a fully quantified set of agricultural activities (Technical Coefficient Matrix) that can be offered to FSSIM-MP.

Database structures are used to collect and (temporary) store input and output information for the different components. The different components result together in the quantification of agricultural activities in terms of technical coefficients (inputs and outputs) that are offered to the FSSIM model to assess their contribution to goal achievement. The different components are linked through a framework that is part of SEAMLESS-IF. This framework is developed according to the guidelines provided by WP5. Figure 3 shows in more detail how the PEG and the PTG result in the construction of agricultural activities.

Agricultural Management Module

```
  ┌──────────────────────┐        ┌──────────────────────┐
  │ (1a) database on     │        │ (1b) database on     │
  │ weather, soils, crops│        │ agronomic rules      │
  │ and animals          │        │                      │
  └──────────────────────┘        └──────────────────────┘
```

((2) Production enterprise generator)

(4c)   Expert knowledge

(3a) Production technique generator

(3b) database on production techniques (Also uses 4a)

(4a) Databases with costs, labour and machine needs, etc.

((4b) APES (APES uses (1a) and (1b)))

(4d) Survey & Database on current activities.

((5) Technical Coefficient Generator:)

(6) Matrix or relational database for FSSIM

○ = Algorithm

▭ = Database

⟶ = input- output relations

Figure 3. Agricultural Management Module and its components: algorithms, databases and connections

Starting point for the Agricultural Management Module is the farm typology developed by WP4. This farm typology provides for each region a set of typical well defined farms in terms of size and specialisation and which are spatially allocated with certain soil and climate characteristics.

For more detailed information concerning FSSIM-Agricultural Management please see these project deliverables: PD3.3.9 for current activities, PD3.3.3 for alternatives activities and PD3.3.4 for livestock components. This deliverable will be focused only on the FSSIM-MP Mathematical Programming model.

3 FSSIM-MP: Mathematical Programming Model

The Mathematical Programming Model (FSSIM-MP) constitutes the core of the bio-economic farm model (FSSIM). Based on mathematical programming approach, FSSIM-MP seeks to capture the farmer's major objectives and resource, socio-economic and policy constraints. The use of a mathematical programming approach has the advantage to explicitly model technological and political constraints (set-aside obligations, production quotas and cross-compliance restrictions) under which behavioural functions can not be derived easily or at all (Heckelei and Wolf, 2003). It allows also mixed ecological-economic analysis (Falconer and Hodge 2001).

The main challenges for FSSIM-MP are: (i) to be generic and flexible enough to capture for instance the range of conditions from North to South in biophysical terms and from West to East in socio-economic aspects; (ii) to allow detailed integrated assessment of policies and technological innovations at farm level; and (iii) to facilitate the link of micro and macro levels in an integrated way.

The principal components of FSSIM-MP are:

(i)   A matrix of input output coefficients that describes agricultural activities,

(ii) A vector of available resources representing farm resource endowments,

(iii) A set of endogenous variables that are explained, or predicted, by the solution of the model equations,

(iv) An objective function describing the farmers' behaviour and goals in particular concerning risk,

(v)   A set of explicit physical, technical, economic, agronomic … constraints, representing specifications for system operation,

(vi) A set of policy and environmental measures (price and market support, quota and set-aside obligations, cross-compliance restrictions, etc) as included in the Common Market Organisations (CMOs) regulations and some specific regulations.

The following section describes in detail and in mathematical term the main FSSIM-MP components and how they are mobilised for modelling arable and livestock farming systems.

3.1   Representation of Agricultural Activities

3.1.1   Crop activities

In FSSIM, a crop activity is defined as a crop rotation grown in specific soil and climate conditions under a specific management (including sowing, irrigating, fertilizing) and a specific production orientation. It consists in a combination of one crop rotation[4], one agri-environmental zone, one production technique (i.e. management type) and one production orientation. Using the concept of crop rotations to represent crop activities is a simple method to account for temporal interactions between different crops. The alternative would be to model such temporal interactions between crops in an explicit way by adding additional constraints to the model. This would increases data requirements and introduces additional complexity that is in contradiction with the model requirements of FSSIM.

To formalize the representation of the set of crop activities we use the denotation i defined as follow:

$i = \{i_1, i_2, \ldots\} = \{(r_1, s_1, t_1, sys_1), (r_2, s_1, t_1, sys_1), \ldots\} \subseteq R \times S \times T \times Sys$, where:

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[4] Agricultural activities can be based on individual crops (i.e. mono- crop rotations) if data on crop rotations are not availability.

- **R** = {r_1, r_2...} denote the set of crop rotations (including mono-crop rotations of arable, grass and permanents crops),
- **S** = {s_1, s_2...} the set of agri-environmental zones,
- **T** = {t_1, t_2...} the set of production techniques (i.e. management types)
- **Sys** = {sys_1, sys_2...} the set of production orientations.

3.1.2 Livestock activities

Two approaches may be used for modelling herd demography and representing livestock activities in farm decision model: a dynamic and a static approach.

- The dynamic approach reflects the demographic growth and the production process in time. Each animal category is analysed separately but linked to other animal categories by explicit relations. Culling and fertility rates, which depend on farmers' strategies in terms of renewal and performance, are taken as exogenous parameter, whereas traded animals (sold and purchased animals) are determined endogenously (Louhichi *et al.*, 2004). An example of this approach is shown in Figure 4, which reflects, for a dairy herd, the demographic change at the herd level between years. It also reflects the diverse possibilities concerning purchases, sales and stocks of animals. The same structure can be applied to modelling demography for suckling cows, sheep and goats.
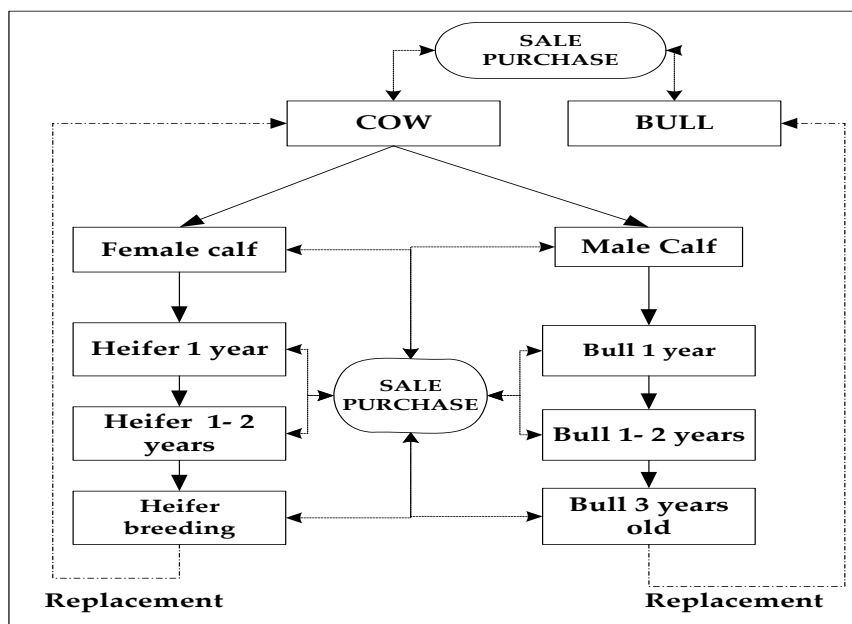
Figure 4. Modelling dairy herd demography using a dynamic approach.

- In contrast, the static approach is based on specifying animal activities in terms of a 'dressed animal' (DA). A dressed animal represents an adult animal and a share of young animals, which are defined according to production intensity level and replacement and fertility rates. That is, all the animal categories of the same "family" are regrouped together under a dressed animal component, assuming a fixed herd size. In the case of the dairy herd, one dressed animal may comprise one dairy cow plus so many heifers and so many calves. Several dressed animals can be considered, depending on the livestock activities undertaken (e.g., dairy, beef) and production intensity level (lower, medium or high), and taking into account the link between intensity level and replacement and fertility rates. According to this specification, renewal and performance rates associated with each dressed animal are chosen exogenously according to livestock activities and

associated production goals, and the number of dressed animal sold, purchased and stocked are calculated by the model endogenously.
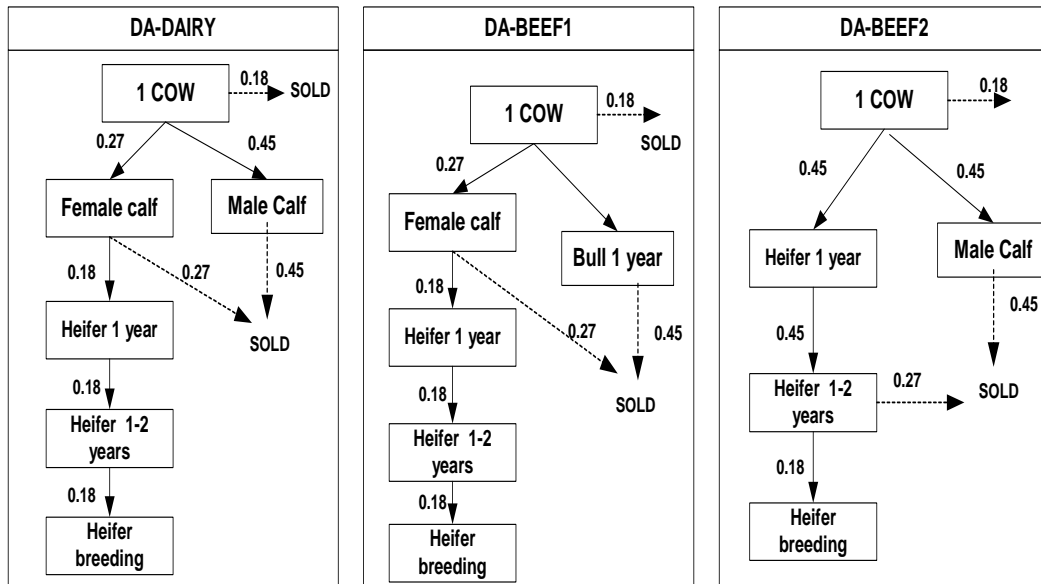
Figure 5. Modelling herd demography through the static approach (e.g., cattle herd).

In FSSIM, the static approach has been adopted because of its consistency with the approach taken for crop activities and also because it will allows capturing some temporal effects, even if the model is operated on a static, comparative basis.

To represent the set of livestock activities we adopt the same denotation used for crop activities:

i = { i_1, i_2 …} = {(dr_1,tl_1,sys_1), (dr_2,tl_1,sys_1),…} ⊆ Dr x T x Sys. Where:
- **Dr** = {dr_1, dr_2…} denote the set of dressed animals,
- **T** = {tl_1, tl_2…} the set of production techniques (i.e. production intensity levels)
- **Sys** = {sys_1, sys_2…} the set of production orientations.

3.1.3 Input-output matrix

An agricultural activity can be defined as process producing several outputs and using several inputs (Figure 6). To quantify the amount of inputs and outputs (e.g. costs, labor requirements, input of agrochemicals, yields, externalities) associated to each agricultural activity, a simple survey was used completed by data generated from the agricultural management component (FSSIM-AM) and the biophysical model APES (PD3.3.6)

To represent the input-output matrix associated to agricultural activities we use the following notations:
- Let's call **J** = {j_1, j_2…} the set of economic outputs produced by each agricultural activity,
- **O** = {O_1, O_2…} the set of environmental (i.e. externalities) outputs produced by each agricultural activity,
- **I** = {I_1, I_2…} the set of inputs applied in production of agricultural activities.
- **t**, a positive integer, denote the number of year in a rotation
- And, finally, let **Y**, **E** and **F** ∈ $\Re^{txm}$, where $\Re$ is the set of real numbers, represent, respectively, the vector of economic outputs produced by each agricultural activity,

the vector of environmental outputs associated to each agricultural activity and the vector of inputs used by each agricultural activity. To be more specific, $Y_{i,j,t}$ denotes the amount of the jth economic output produced in the tth year of the agricultural activity i, $E_{i,O,t}$ denotes the amount of the Oth environmental output produced in the tth year of the agricultural activity i and $F_{i,I,t}$ denotes the amount of the Ith input used in the tth year in production.

Each economic output *J* associated to agricultural activities is defined as a combination of one production activity (i.e. crop and animal) and one product type. To be more specific, let denote by:

- **Pact** = { c_1, c_2,…an_1, an_2…} the set of crops and animals selected in FSSIM *(where C = { c_1, c_2,... } the set of crops and An = { an_1, an_2... } the set of animals, with An $\in$ Pact and C $\in$ Pact)*
- **Prd** = { prd_1, prd_2…} the set of product types.
- **J** = { j_1, j_2,…} = {(c_1, prd_1), (c_1, prd_2), (an_1, prd_3), (an_1, prd_4)…} $\subseteq$ (Pact x prd) the set of economic outputs.
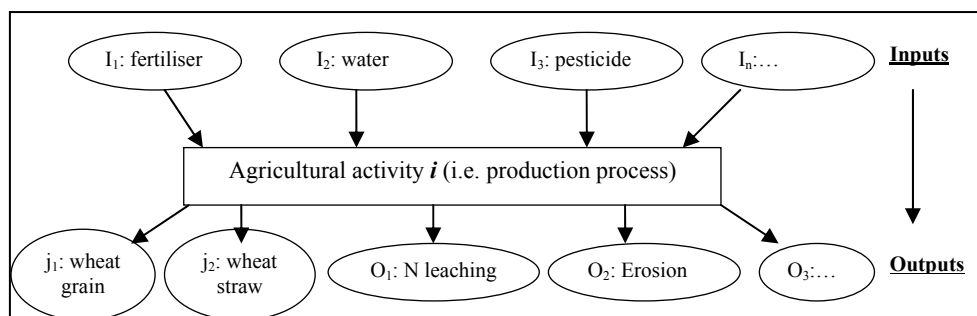
Figure 6. An agricultural activity as a production process with multi-inputs multi-outputs

3.2 Objective function

Most practical programming models used for representing farmer decision-making involve a single objective function which is either maximizing profit or minimising cost. This doesn't, however, imply that problems with multiple objectives can not be tackled. Various modelling techniques can be applied to such problems. They have just assumed that farmers are rational and their production decisions are influenced mainly by the relative prices of inputs and products (Falconer and Hodge 2001). They have nevertheless ignored the reality that decisions of farmers are generally influenced by the issue of risk[5], of responding to uncertain events and maybe minimizing the probability of adverse states. Ignoring-risk-averse behaviour in farm planning models leads to results that are unacceptable to the farmer, or that bear little relation to the decision he actually makes (Hazell and Norton, 1986).

Many different programming formulations have been posed for risk problems (Hazell and Norton, 1986; Hardaker *et al*., 2004). Among the most common risk specifications we find: a) methods based on the expected utility theory, such as the Mean-Variance Analysis (Freund, 1956), their linear approximation MOTAD (Hazell, 1971), and the Mean-Standard deviation

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[5] Some writers distinguish between uncertainty and risk. For example, Roumasset (1979) has described uncertainty as "*a state of mind in which the individual perceives alternative outcomes to a particular action. Risk, on the other hand, has to do with a degree of uncertainty in a given situation.*" However, no distinction is made between the two concepts in expected utility maximization models, where they simply imply that some variables in the objective function are random.

method (Markowitz, 1959); b) safety-first approaches assuming that decision makers will choose plans to first assure a given safety level for income, such as Target MOTAD (Tauer, 1983) or Focus-Loss (Boussard, 1971); c) chance-constrained programming (Charnes and Cooper, 1959) for considering random resource availability and d) sequential risk approaches such as discrete stochastic programming (Cocks, 1968).

FSSIM is a Risk Programming Model which takes into account the risk and uncertainty through the Mean-Standard Deviation method in which expected utility is defined under two arguments: the expected income (E) and its standard deviation (σ). The model's objective function presumes that the farmers make their decisions in order to maximise the expected income minus some measure of its variability, according to different states of nature and market defined under two different sources of instability: yield (due to climatic condition) and price.

The attractiveness of the Mean-Standard method is that leads to relatively convenient solutions using quadratic programming and also it has a straightforward interpretation. The exact formulation of the problem can vary. The common used approach consists to maximize a quadratic function of activity levels subjects to linear constraints as follow:

$$(1) \quad \text{Max} \ \ U = Z - \phi\sigma$$

- **U**: the variable to be maximised (i.e. utility),
- **Z**: the expected income (i.e. the average annual income)
- ϕ: the risk aversion coefficient,
- σ: the standard deviation of income according to states of nature defined under two different sources of variation: yield (due to climatic conditions) and prices.

The expected income (**Z**) is a non-linear profit function. Using mathematical notation, this gives:

$$(2) \quad Z = \sum_J p_J q_J + \sum_{J,l} p_{J,l}^a q_{J,l}^a + \sum_{i,t} \frac{s_{i,t}}{\eta_i} x_i (1 - \alpha b) - \sum_{i,t} \frac{c_{i,t}}{\eta_i} x_i + \sum_{i,t} \left(\frac{d_{i,t}}{\eta_i} + \frac{\psi_{i,t} x_i}{2\eta_i} \right) x_i - \varpi L$$

- **i** indexes agricultural activities
- **J** indexes crop and animal products
- **l** indexes quota types (e.g. for sugar beet it's A and B)
- **t** indexes number of years in a rotation for crop activities
- **p** is a vector of average product prices
- **q** is a vector of sold production

$$(3) \quad \sum_{i,t} \frac{y_{i,J,t}}{\eta i} x_{i,J} = q_J + u_J$$

- **y** is a vector of average yield of each crop product within agricultural activity
- **x** is a vector of agricultural activity levels
- **u** is a vector of on-farm used production
- η is a vector representing the length of a rotation within each crop activity
- **p^a** is a vector of additional price that the farmer gets when selling within quota l
- **q^a** is a vector of sold production within quota l

$$(4) \quad q_j = \sum_l q_{j,l}^a + q_j^{wa}$$

- **q^{wa}** is a vector of sold production outside quota

- **s** is a vector of subsidies per crop and animal within agricultural activity *i* (depending on the Common Market Organisations (CMOs))
- **α** is a scalar of percent modulation (i.e. reduction of agricultural support in case of received premium exceed a certain ceiling*)*
- **b** is a binary variables[6] that can only take values of 0 or 1 (i.e. b∈ {0,1})
- **c** is a vector of variable costs per crop and animal within agricultural activity *i*
- **d** is a vector representing the linear term used to calibrate the model (depending on the calibration approaches)
- **Ψ** is a symmetric, positive (semi-) definite matrix of quadratic term used to calibrate the model (depending on the calibration approaches)
- **ϖ** is a scalar representing the labour costs per hour
- **L** is the number of hours rented labour

The standard deviation of income (σ) is calculated according to the following formulation:

$$(5) \quad \sigma = \sqrt{\frac{\sum_k (Z_k - Z)^2}{N}}$$

- **Z:** expected income
- **Z$_k$:** income over states of nature (k). Z_k is calculated using the same equation applied for calculating the expected income Z (i.e. equation (4)). The unique difference was that the average producer price (p) and the average yield (y) are replaced, respectively, by the producer price (p_k) and the yield (y_k) over state of nature (k). p_k and y_k are vectors of independent random numbers normally distributed (i.e. they are calculated using a normal distribution function based on the average and the standard deviation of price and yield). We assumed that there is no dependence between yield and price variation (i.e. no covariance).
- **N** is the number of states of nature
- **σ** is the standard deviation of income according to states of nature (k)

The risk aversion coefficient (ϕ) which measure the "degree" of risk aversion of the agent is used in FSSIM to partially calibrate the model. This coefficient is often exogenously specified and according to the literature and especially to the studies developed by Hazell et al (1983), Kutcher and Scandizzo (1981), and Brink and McCarl (1978), its value are often ranging from 0 to 1.65. If ϕ = 0 implies farmer is risk neutral and the problem collapses to an income maximization problem. As risk becomes increasingly important, the risk aversion coefficient increases and diversification increases.

For estimating the risk coefficient to include in FSSIM, three options are proposed in the FSSIM-GUI to be selected by users:

o **Risk neutral:** implies that the risk aversion coefficient is equal to zero (ϕ = 0).

o **Risk averse: set risk aversion coefficient:** implies that the user has to choose the value to attribute to the risk aversion coefficient. The chosen value should range from 0 to 1.65 (0< ϕ ≤1.65).

o **Risk averse: automatic choose of risk aversion coefficient:** implies that the model will attribute automatically a value to the risk coefficient which gives the best fit between the model's predicted crop pattern and the observed values in the base year. This value ranges between 0 and 1.65 (0 < ϕ ≤1.65).

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[6] A mixed-integer nonlinear programming (MINLP) solver is used to solve this type of problem.

3.3 Set of generic constraints

The constraint system constitutes the second principal component of an optimisation model. A good identification and specification of this system will help much in the comprehension of the farming system and facilitate the model calibration. In FSSIM, this system was handled in a generic way by implementing the most common types of constraint which could face European farmers and then the user can activate and deactivate constraints according to the farm type and the needs of the simulation. These constraints are related to farm resource endowment (land, water, labour, equipment, feed requirement…) as well as to agronomic, social, economic, institutional… contexts (finances, cash flow, risk, quotas…). The deactivation of constraints could be done through the FSSIM-GUI or by setting a big value in its right-hand side coefficient.

3.3.1 Productive capacity constraints

These are the sorts of constraints which arise in most of farm optimisation model. They are linked to farm resource endowments and try to match between the available resources that can be used in a production operation and the possible uses made of it by the different activities.

The principal productive capacity constraints implemented in FSSIM are: land, labour and water constraints. The same rule was applied for all of these constraints: the sum of the resource requirements of the selected agricultural activities cannot exceed farm resource endowments.

Let denote by **w** = {Totland, Irland, Flabour, Plabour, Water…} the set of farm resources, **A** and **B** $\in \Re^{txm}$, where $\Re$ is the set of real numbers, represent, respectively, the matrix of resource use coefficients and the vector of resource endowments. To be more specific, $A_{w,i,t}$ represents the amount of the wth resource required in the tth year by one unit of the ith agricultural activity and B_w is the amount of the wth available in the farm.

The general structure of the productive capacity constraints can be formulated as fallow:

$$(6) \quad \sum_{i,t} \frac{A_{w,i,t}}{\eta_i} x_i \leq B_w$$

Where:
- **w** indexes farm resources
- **i** indexes agricultural activities
- **t** indexes number of years in a rotation
- **A** is a matrix of resource use coefficients (called also left hand side coefficients),
- **B** is a vector of available resource endowments (called also right hand side coefficients),
- **x** is a vector of agricultural activity levels (i.e. x is a decisional variable)
- η is a vector representing the length of a rotation within each crop activity

More details on the implementation of these resources constraints are given in the following section.

3.3.1.1 Land constraints

3.3.1.1.1 Total cultivated land

This constraint limits the level of the selected activities to total cultivated land available on the farm (i.e. including arable, permanent cropland and grassland). That is, in each agri-

environmental zone (s), the sum of area allocated to both irrigated and rain-fed activities should not exceed the initial available cultivate land ($B_{'Totland'}$) plus land-in (Tin) minus land-out (Tou).

$$(7) \quad \sum_{R,T,Sys} x_{R,S,T,Sys} \le B_{'Totland'} d_{'Totland',S} + Tin_S - Tou_S$$

- ▪ **$X_{R,S,T,Sys}$**: level of the selected agricultural activity $i \subseteq R \times S \times T \times Sys$ (in ha)
- ▪ **$B_{'Totland'}$**: initial total land available on the farm (in ha)
- ▪ **$d_{'Totland',S}$**: distribution of total available land over agri-environmental zones
- ▪ **Tin_S**: land-in per agri-environmental zone (in ha)
- ▪ **Tou_S**: land-out per agri-environmental zone (in ha)

The land-in (Tin) which depends on land market availability can not exceed the estimated upper bound (UpLd) and the land-out (Tou) can not exceed on-farm available total land.

$$(8) \quad Tin_S \le UpLd_S$$

$$(9) \quad Tou_S \le B_{'Totland'} d_{'Totland',S}$$

- ▪ **Tin_S**: land-in per agri-environmental zone (in ha)
- ▪ **Tou_S**: land-out per agri-environmental zone (in ha)
- ▪ **$B_{'Totland'}$**: initial total land available on the farm (in ha)
- ▪ **$d_{'Totland',S}$**: distribution of total available land over agri-environmental zones
- ▪ **$UpLd_S$**: upper bound of land-in per agri-environmental zone (in ha)

In this FSSIM version the possibility of land-in and land-out was frozen.

3.3.1.1.2 Grassland

Three types of grassland activities are retained in FSSIM: 1) ley grass (called "grsl") which are considered as annual crop and included within the rotations of annual crops; 2) temporary grass (named "grst") integrated through mono-crop rotations of minimum 3 years; and 3) permanent grass (called "grss") included as mono-crop rotations of several years (more then 5 years). The principal differences between temporary and permanent grass are linked to agro-management type, yield and roughage qualities.

The allocations of these activities over the on-farm available grassland are restricted by the following constraints:

The devoted area to permanent grassland activities can not exceed the initial permanent grassland available on the farm.

$$(10) \quad \sum_{T,Sys,S} x_{'Grss',S,T,Sys} \le B_{'Pergland'} d_{'Pergland',S}$$

- ▪ **MGrss**: indexes permanent grass (Grss $\in$ C)
- ▪ **$X_{Grss,S,T,SYS}$**: level of the selected permanent grass per agri-environmental zone, production technique and system (in ha)
- ▪ **$B_{'Pergland'}$**: permanent grassland available on the farm (in ha)
- ▪ **$d_{'Pergland',S}$**: distribution of available permanent grassland over agri-environmental zones

The allocated area to temporary grassland activities can not exceed the initial temporary grassland available on the farm.

(11) $\sum_{T,Sys,S} x_{'Grst',S,T,Sys} \leq B_{'Temgland'} d_{'Temgland',S}$

- **Grst**: indexes temporary grass (grst $\in$ C)
- **X**$_{'Grst',S,T,Sys}$: level of the selected temporary grass per agri-environmental zone, production technique and system (in ha)
- **B**$_{'Temgland'}$: temporary grassland available in the farm (in ha)
- **d**$_{'Temgland',S}$: distribution of available temporary grassland over agri-environmental zones

According to these specifications, we presume that there is:

- No land market for grassland neither for selling nor for the hiring;
- No interaction between arable land and grassland; i.e. possibilities of converting arable land to grassland and, inversely, from grassland to arable land are not taken into account for the moment.
- No exchange between grassland and forest; forest areas were not considered in the model, since a primary interest was to find strategies for the existing pasture land, rather than considering the possibility of clearing forest for pasture production or abandoning grassland to return to the forest.

3.3.1.1.3 Permanent cropland

All permanents crops (Citrus, Apples, Olives, Tobacco, Table grapes, Table olives, Table wine, Tobacco…) are linked to long-term investment decisions and should be analysed preferably with dynamic programming models or an econometric framework to forecast the possible evolution of these crops.

To implement these activities in a static model we have adopted a simplest way. It consists to assume that the simulated level of each perennial crop is equal to its observed level of the base year period. However, this will be improved when the module for permanent crops will be finalised.

(12) $\sum_{S,T,Sys} x_{percrops,S,T,Sys} = x^0_{percrops}$

- **percrops**: indexes of permanent crops (Percrop $\in$ C)
- **X**$_{percrops,s,t,sys}$**:** level of the selected permanents crops per agri-environmental zone, production technique and production orientation (in ha)
- **X**$^0_{percrops}$**:** the observed level of permanent crops on the base year (in ha).

3.3.1.1.4 Irrigable land

The sum of area devoted to irrigated activities cannot exceed the available irrigable land.

(13) $\sum_{R,S,Ti,Sys} x_{R,S,Ti,Sys} \leq B_{'Irland'}$

- **Ti**: set of irrigated production techniques (i.e. Ti $\subset$ T)
- $x_{R,S,Ti,Sys}$: level of the selected irrigated activities (in ha)
- **B**$_{'Irland'}$: available irrigable land on the farm (in ha)

The available irrigable land (B'Irland') can be taken into account under two formulations:

- If investment possibility is neglected, availability of irrigable land is specified as an exogenous variable, and its suitable value will be the one observed on the base year.

- If investment possibility is taken into account, the available irrigable land will be an endogenous variable which depend on initial irrigable land observed on the base year but also on investment in irrigation equipment.

The first option was retained in the current FSSIM version (i.e. no investment possibility is included).

3.3.1.2 Labour constraints

These constraints have to be considered carefully because even normally there is not a strict amount of labour available at annual level but, firstly, there are different types of labour, for doing different things, with different costs and, secondly, available workers can be limited in certain seasons of the year.

To take into account these specifications in FSSIM, we have adopted the following generic constraint which specifies that the sum of labour required for each selected activity, expressed in hour, should be less than the amount of family and permanent labour available in the farm, plus the amount of temporary labour if needed. Labour requirement and availability could be defined by year or by season according to data availability and region specification.

$$(14) \quad \sum_{i,t} \frac{A_{'labour',i,t} dr_{'labour',i,t,se}}{\eta_i} x_i \leq B_{'Flabour'} da_{'Flabour',se} + B_{'Plabour'} da_{'Plabour',se} + L_{se}$$

- **Se**: indexes of seasons
- **X**: level of the selected activity i (in ha)
- **A'labour',i,t**: labour requirement for each crop/animal within agricultural activity *i* (in hour/year)
- **B'Flabour'**: family labour available (in hour/year)
- **B'Plabour'**: permanent labour available (in hour/year)
- **L**: temporary labour per season (in hour/season)
- η: a vector representing the length of a rotation within each crop activity
- **dr'labour',i,t,se**: distribution of labour requirement over seasons
- **da'flabour',se**: distribution of family labour availability over seasons
- **da'plabour',se**: distribution of family requirement over seasons

If only one season was retained it means that the labour constraint is defined at annual level and the coefficients *dr* and *da* are equal to one (dr = 1; da = 1) and if it's more than one season the labour constraint is working at seasonal level and the coefficients *dr* and *da* are less or equal to one (dr ≤1; da ≤ 1).

The available temporary labour is implemented as unbounded variable. However, if in a certain region this appears as a real constraint, user can activate the following equation and introduce an upper bound.

$$(15) \quad L_{se} \leq Upla_{se}$$

- **UpLa**: upper bound of available temporary labour (in hour/season)

3.3.1.3 Water constraints

The sum of water required for the selected irrigated activities should not exceed the water volume available.

$$(16) \quad \sum_{R,S,Ti,Sys,t} \frac{A_{water',R,S,Ti,Sys,t}}{\eta_R} x_{R,S,Ti,Sys} \leq B_{water'}$$

- **Ti**: set of irrigated production techniques (i.e. Ti⊂ T)
- **Error! Objects cannot be created from editing field codes.**: level of the selected irrigated activities (in ha)
- **Error! Objects cannot be created from editing field codes.**: water requirement for each irrigated crop within agricultural activity i (m³/year)
- η_R: length of crop rotations
- **B'water'**: total water available per year (m3/year)

3.3.2 Lower-upper bound constraints

A set of generic constraints are implemented in FSSIM in order to impose if needed a lower or/and an upper bound on.
- activity levels
- production levels due to marketing limitation
- certain activities based on input output coefficients,

3.3.2.1 Lower-upper bound on activity level

These sorts of constraints can be activated in order to limit the level of certain agricultural activities i or certain crops/animals due to for example to institutional restrictions (e.g. set-aside regulation in EU)

$$(17) \quad Min\_AL_i \leq x_i \leq Max\_AL_i$$

- **Min_AL** is a vector of min bound per agricultural activity i (default value is 0)
- **Max_AL** is a vector of max bound per agricultural activity i (default value is + ∞)

3.3.2.2 Lower-upper bound on production level

A lower or/and upper bound on production level of certain products j could be imposed to bind the amount of a product which can be sold (due for example to market limitation or less of the product being manufactured...) or/and to make a certain amount of product to satisfy some demand (e.g. auto-consumption). Such as limitations are captured through the following formulation:

$$(18) \quad Min\_AL_i \leq x_i \leq Max\_AL_i$$

o **Min_PL** is a vector of min bound per product j (default value is 0)
o **Max_PL** is a vector of max bound per product j (default value is + ∞)

3.3.2.3 Lower-upper bound on activity level based on input output coefficients

$$(19) \quad Min\_IO_{i,o,t} \frac{x_i}{\eta_i} \leq E_{i,o,t} \frac{x_i}{\eta_i} \leq Max\_IO_{i,o,t} \frac{x_i}{\eta_i}$$

- **O** indexes the set of environmental outputs associated to crop within agricultural activity i
- **Min_IO** is a vector of min bound per input/output of crop within agricultural activity i (default value is 0)
- **Max_IO** is a vector of max bound per input/output of crop within agricultural activity i (default value is $+\infty$)
- **$E_{i,o,t}$** is a vector of environmental outputs associated to crop within agricultural activity used in the baseline
- **x** is a vector of agricultural activity levels

$$(20) \quad Min\_IO_{i,j,t} \frac{x_i}{\eta_i} \leq Y_{i,j,t} \frac{x_i}{\eta_i} \leq Max\_IO_{i,j,t} \frac{x_i}{\eta_i}$$

- **j** indexes the set of economic outputs associated to crop within agricultural activity i
- **$Y_{i,j,t}$** is a vector of economic outputs associated to crop within agricultural activity used in the baseline

$$(21) \quad Min\_IO_{i,I,t} \frac{x_i}{\eta_i} \leq F_{i,I,t} \frac{x_i}{\eta_i} \sum_t \leq Max\_IO_{i,I,t} \frac{x_i}{\eta_i}$$

- **I** indexes the set of inputs associated to crop within agricultural activity i
- **$F_{i,I,t}$** is a vector of inputs used by crop within agricultural activity used in the baseline

3.3.3 Livestock constraints

The FSSIM livestock components allow the simulation of the relations amongst available feed quantity and quality, feed intake by the relevant animal species (cattle, small ruminants, pigs, poultry), animal production (meat, milk, eggs), and nutrient excretion (manure, slurry). These relations are critical, particularly in a mixed farming system where part of the crop production is used as animal feed. Quality characteristics of the available feed as well as animal feed requirements are quantified in FSSIM using the French feed evaluation and rationing system for protein and energy (Jarrige, 1988; 1989). Feed availability and feed requirements are matched endogenously in FSSIM-MP via a set of constraints developed below.

3.3.3.1 Feed requirement

The main constraint for feeding is that the feed produced for on-farm use plus the supplement feed purchased must cover herd requirements. The feed ration is based on silage, fresh grass (grazed or cut), hay, pulses, straw and grain cereals that are produced on the farm and those bought from the market as well as on purchased concentrates. Feed production depends on many factors, such as available amounts of water and nutrients, growing conditions, length of the growing season, harvesting frequency, etc.

Two methods can be applied for modelling the feeding constraint:

• The first involves identifying for each animal several feeding systems described in terms of level, duration, and type of feed. The selection of these feed systems is based on current systems applied in practice on some farms or regions as well as alternatives systems. A potential problem with this method is its rigidity. In order to avoid this difficulty, it is necessary to define a large number of feeding systems from the outset.

• The second approach, adopted in our model (Figure 7), consists of specifying animal requirements and feed availability in a nutrient term (nut), particularly in terms of energy (UF) and protein (PDI), and then ensuring that the available quantity of nutrients covers animal requirements. In this case, the distributed quantity of each feed category (silage, fresh grass, hay, pulses, straw, grain, concentrates) as well as the grazed activity level are endogenously determined. The advantage of this method is that the model is more flexible, as we have significant substitution amongst the various categories of feed. This approach does, however, require the definition of additional constraints to limit potential excess of consumption of certain feed components:

$$(22) \qquad \sum_J u_J v_{J,nut} + \sum_{sf} pf_{sf,\text{nut}} v_{sf,nut} \geq \sum_i x_i A_{nut,i}$$

- **Nut**: indexes nutrient term, such as energy (UF) and protein (PDI)
- **Sf**: indexes the set of purchased supplement feed.
- **V**: nutrient value of the feed produced for on-farm use (grass, fodder and crop products) as well as of the purchased feed expressed in term of protein and energy per t DM.
- **pf**: quantity of purchased supplement feed (t DM).
- **u** is a vector of on-farm used production (t DM)
- **A:** feed requirement per livestock activity (i.e. dressed animal, intensity level, and production system) expressed in term of energy and protein. This requirement is calculated taking into account requirements for maintenance, milk production, growth, gestation period, and grazing/moving.
- **X:** level of the selected livestock activity i (in head)
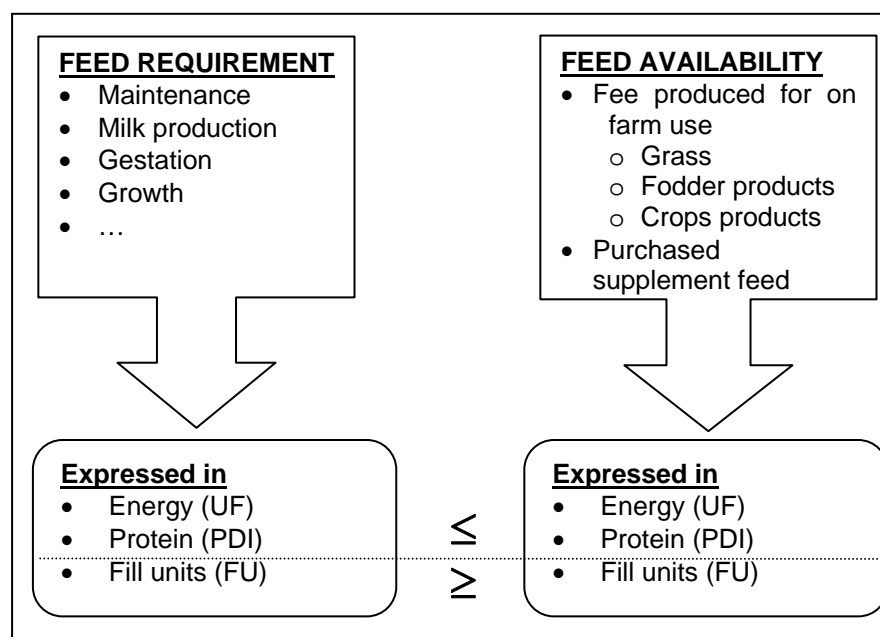
Figure 7. Feed requirements versus feed availability

3.3.3.2 Feed restrictions

Three feed restrictions are retained in the FSSIM model:

❖ **Fill unit distributed should be lower or equal to intake capacity**

$$(23) \qquad \sum_{J} u_J v_{J,'fu'} + \sum_{sf} pf_{sf,\text{nut}} v_{sf,'fu'} \leq \sum_i x_i A_{'fu',i}$$

- **FU**: indexes fill units
- **V:** the fill units contain in the produced feed (grazed or cut grass, fodder and crop products) for on-farm use.
- **pf**: the fill units contain on the purchased supplementary feed.
- **A:** is the fill units per livestock activity (i.e. dressed animal, intensity level, and production system)
- X: level of the selected livestock activity i (in head)

❖ **Share of concentrates in animal diets expressed in energy term is bounded to a maximum,**

$$(24) \quad \sum_{con} pf_{con,"uf"} v_{con,"uf"} \leq Max\_con \sum_i x_i A_{"uf",i}$$

- **Con:** indexes the set of purchased concentrates (con ⊂ sf).
- **Maxcon:** maximum share of concentrates in the ration (in %). This share depends on farm type/region (i.e. it is independent to production levels inside the same farm type).
- **V$_{con,"uf"}$**: energy value (UF) of purchased concentrates.
- **pf**: quantity of purchased concentrates (t DM).
- **A $_{con,"uf"}$**: energy requirement per livestock activity i
- **X:** level of the selected livestock activity i (in head)

❖ **Maximum feed availability from grazing**

The feed available from grazing varies according to season and is highly weather-dependent. This variability is represented in the model by the length of grazing period. For example, a grazing season of 120 days means that about 120/365 of the energy and protein requirements can be met by grazing systems, and the remainder should be met by others feeds (silage, hay, etc.).

$$(25) \quad u_{c,"graz"} v_{c,"graz",nut} \leq Grzday \sum_i x_i A_{nut,i}$$

- **Grzday**: a scalar representing the length of grazing period which depends on farm type and region..
- **V**: nutrient value of the grazed grass expressed in term of protein and energy per t DM.
- **u**: the quantity of grazed grass (t DM)
- **A:** feed requirement per livestock activity (i.e. dressed animal, intensity level, and production system) expressed in term of energy, protein and intake capacity.
- **X:** level of the selected livestock activity i (in head)

3.3.3.3 Livestock building constraints

This constraint limits the animal population to the livestock building capacity which depends on the initial farm building availability and the investment in new building. The livestock building enlargement depends on farm investment capacity and to animal requirement for building:

$$(26) \quad \sum_i x_i . A_{Build',i} \le B_{'Build'} + N_{'Build'}$$

- X: level of the selected animal activities i (in head)
- A: animal requirement for building (m^2/head)
- B: initial building availability (m^2)
- N: investment in new building (m^2)

3.3.4 Risk constraints

As written earlier in this report, risk is introduced in the FSSIM according to the Mean-Standard deviation approach, inspired by Freund (1957). This method computes for each combination of states of nature the negative deviation of actual income from its expected value. Each state of nature and market (k) is defined under two different sources of instability: yield (due to climatic condition) and price.

For the moment, we assume that there is no dependence (no covariance) between yield and price variation, as prices in EU25 are generally defined at higher scales (international market or EU25) and not on local scales.

$$(27) \quad Z_k + \mathrm{Dev}_k = Z$$

- **Dev$_k$:** deviation dependent upon different states of nature and market (k)
- **Z:** expected income
- **Z$_k$:** income over states of nature (k). Z$_k$ is calculated using the same equation applied for calculating the expected income Z (i.e. equation (4)). The unique difference was that the average producer price (p) and the average yield (y) are replaced, respectively, by the producer price (p$_k$) and the yield (y$_k$) over state of nature (k). p$_k$ and y$_k$ are vectors of independent random numbers normally distributed (i.e. they are calculated using a normal distribution function based on the average and the standard deviation of price and yield). We assumed that there is no dependence between yield and price variation (i.e. no covariance).

$$(28) \quad \sigma = \sqrt{\frac{\sum_k (Dev_k)^2}{N}}$$

- **Dev$_k$:** deviation dependent upon different states of nature and market (k)
- **N:** the number of states of nature
- **σ:** the standard deviation of income according to states of nature (k)

3.4 Modelling of CAP instruments in FSSIM

Thanks to its generic structure FSSIM provides the possibility to handle a broad range of policy instruments. Some of these instruments are linked to European agricultural and environmental policies, either proposed or actual, and others are more generals. These

involve the Common Agricultural Policy (CAP) support regime (price and market support, set-aside schema, quota system, etc.) as included in the Common Market Organisation (CMOs) regulations as well as certain cross-compliance and agro-environmental measures included in Horizontal and Rural Development regulations.

The modelling of these policy instruments in FSSIM are captured either by embedding them in the objective function (e.g. premiums), or by including them as constraints (e.g. set-aside is not allowed to exceed more than a certain percentage of COP crops). The Table 1 gives a brief description of the different policy instruments linked to crop and livestock activities that are taken into account in FSSIM and how they are modelled in the policy and the premium modules. In case of a non-EU application these policy instruments can be deactivated.

Table 1. Policy instruments already implemented in FSSIM

Instrument	Modelling
CAP compensation payment (including Single Farm Payment)	Linked to crop within agricultural activities and included in the objective function
Modulation of payment	Constraints in the system (controlled by binary-variables)
Quota regime (e.g. milk and sugar beet quotas)	Constraints in the system, upper bounds on sold quantities
Set-aside regulation: *compulsory set-aside*	Constraints in the system, restrict set-aside to minimum certain % of COP (cereals, oilseeds and protein) crops
Set-aside regulation: *voluntary set-aside*	Constraints in the system, restrict total set-aside to certain % of COP crops
Environmental condition/cross-compliance	Constraints in the system (controlled by binary-variables)
Agri-environmental measures	Constraints in the system

CMOs: Common Market Organisation

Modelling all these instruments was an important challenge for FSSIM, as they have quite different implementation according to the analysed policy scenarios. In addition, the information on the administrative implementation of some measures is usually scarce, and often not systematically monitored, not published or even not open to the public.

3.4.1 CAP compensation payment

3.4.1.1 Compensation payment under Agenda 2000: Direct Payments

The method of supporting EU agriculture has changed since 1992. The first CAP Reform in 1992 and free trade pressures in world trade agreements have forced EU farmers to take lower prices for their produce and in return they receive direct payments. Direct payments are paid as income supports to the cattle, sheep, and the tillage sector who suffered major price reductions as a result of the first CAP Reform.

In general direct payments are production or area based and are financed directly by the EU and administered by the Department of Agriculture in each member state. All EU cattle, sheep and cereal farmers are entitled to these payments. In practice most of the payments have an upper limit (i.e. regional or national ceilings). These payments are standard across Europe and the rules and regulations pertaining to them are the same for all of Europe's 7 million farmers.

For modelling the direct payments, the same approach used in the CAPRI modelling system was adopted (Britz et al, 2002). It consists of defining a set of premium schemes linked to specific groups of crops and for each premium scheme, two types of information are needed:

the default amount of the premium (basic premium, uncut) according to regulatory texts (e.g. 63 €/ton for cereals, oilseeds and protein crops) and the way that this premium should be applied: per activity level (ha), per slaughtered head, per main output (e.g. yield per hectare) or depending on historical yield of 2002. Starting from these two types of information, the support rate (per ha) per premium scheme is calculated. For example, the support rate for direct payment to COP crops (DPGCU) is calculated by multiplication of the regional historical yield in ton per hectare with the basic premium (€ per ton) for the respective crop (Table 2).

Support rate for DPGCU= basic premium per ton * regional historical yield

To break down the support rate from activity groups to individual activities, a preparatory calculation using all this information is carried out in a specific GAMS file called "policy_cal.gms". The output from this calculation process is the amount of premium per hectare (PRME) associated to each crop or animal activity and which will be introduced in the objective function of FSSIM-MP.

Table 2. EU compensation payments for crop and animal activities under Agenda 2000 (in 2003)

Premium schemes	Linked crop and animal groups	Basic premium (€/ha or €/ton)	Type of application	Support rate (€/ha)
Direct payment to COP (cereals, oilseeds and protein) crops (DPGCU)	Cereal, Oleaginous and Protein crops	63 €/ton	Per regional historical yield	63 €/ton * historical yield (T/ha)
Supplement direct payment to protein crops (DPPROT)	Protein crops	9,5 €/ton	Per regional historical yield	9,5 €/ton * historical yield (T/ha)
Direct payment to set-aside (DPSETA)	Fallow	63 €/ton	Per regional historical yield	63 €/ton * historical yield (T/ha)
Supplement direct payment to durum wheat in traditional areas (DPDWHETR)	Durum wheat	344,5 €/ha	Per activity level	344,5 €/ha
Supplement direct payment to durum wheat in established areas (DPDWHEES)	Durum wheat	138,9 €/ha	Per activity level	138,9 €/ha
Direct payment to rice (DPPARI_fa)	Rice	52 €/ton	Per regional historical yield	52 €/ton * historical yield (T/ha)
Direct payment to suckler cows (DPSCOW)	Suckler cows	200 €/head	Per activity level	200 €/head
Direct payment to bulls (DPBULF)	Bulls	210 €/head	Per activity level	210 €/head
Slaughter premium for adult cattle (DPSL_ADCT)	Adult cattle	80 €/head	Per slaughtered head	80 €/head
Slaughter premium for calves (DPSL_CALV)	Calves	50 €/head	Per slaughtered head	50 €/head

* Two regional historic yields are considered in FSSIM, according to irrigated and rainfed crops. These yields are based on the average over the three years around 2001.

To break down the support rate from crop and animal groups to individual crop and animal, a preparatory calculation using all this information is carried out in a specific GAMS file called "policy_cal.gms". The output from this calculation process is the vector of subsidies (i.e. compensation payment) per crop and animal within agricultural activity i ($\mathbf{s}$) used to calculate the total amount of premiums received by farmer during the year.

$$(29) \quad s_{i,t} = \sum_g \theta_{g,i,t}$$

- ▪ **g** indexes premium schemes
- ▪ θ is a vector of support rate per premium scheme and crop/animal
- ▪ **s** is a vector of subsidies per crop/animal within agricultural activity i

(30) $Total\ premium\ /\ year = \left(\sum\limits_{i,t} \dfrac{s_{i,t}}{\eta_i} x_i \right)$

- **x** is a vector of agricultural activity levels
- **η** is a vector representing the length of a rotation within each agricultural activity

3.4.1.2 Compensation payment under 2003 CAP reform: : Single Farm Payment[7]

The most important measures of this reform are the adoption of decoupled direct payment, the introduction of a new modulation system, and the enforcement of agri-environment schemes. The decoupled payment consist on the replacement of all Direct Producer Payments associated with beef, sheep, and crops production (and planned future dairy payments) with a 'single payment per farm (SFP)' received by beginning in 2005. Such single farm payments are calculated on the basis of 'a reference amount in a reference period 2000-2002' and are paid to those holding land with a payment entitlement. This implies that the amount of the payment would not depend on what and how much the farmer actually produces but essentially on area and historical entitlement. Farmers are free to decide what they want to produce in response to demand without losing their entitlement to support. The reform, however, gives each EU Member State the possibility to choose a 'degree of decoupling' among the following options, which can be applied at national or regional level (OECD, 2004):

- 25% of hectare payments or, alternatively up to 40% of the supplementary durum wheat aid,
- 50% of sheep and goat premium
- 100% of suckler cow premium and up to 40% of slaughter premium, or instead, 100% of the slaughter premium or 75% of the special male premium

The modulation system introduced in this reform aims to finance the additional Rural Development Regulation (RDR) measures through the reduction of direct payments by 5% from 2007 for farms with more than 5000€ direct payment a year. This 5% reduction, known as "modulation", will result in additional RDR funds of EUR 1.2 billion a year (CEC, 2003b).

For modelling the compensation payments under the 2003 CAP reform, as it would be implemented in 2013, three steps are developed. First of all, the premiums from Agenda 2000 were adjusted according to the new reform, secondly the partially redefined premiums falling under the new uniform per farm, labelled "decoupled", are calculated using the average of individual historic areas from 2000-2002, and finally the premiums were "dynamically modulated".

3.4.1.2.1 Adjustments of premium payments according to 2003 CAP reform (summarised in Table 3)

- The direct payment of EUR 63/T for **COP (cereal, oilseed and protein) crops** (DPGCU) is retained. The payment will become part of the single farm payment (SFP).

- A reduction of the supplementary payment in **durum wheat** (DPDWHETR) to 285 €/ha (down from € 344.5/ha in 2002) in "traditional areas" bundled with an abolishment of

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[7] The main measures of the 2003 CAP reform are summarised in Table A.2 in the appendix in comparison with the continuation of Agenda 2000.

the supplement in "established areas" (DPDWHEES). A new quality premium of € 40/ha is provided to farmers who are using a certain quantity of certified seeds of selected varieties, within the limits of current Maximum Guaranteed Areas (MGA).

- The supplement direct payment per ton for **protein crops** (9.5 €/ton) will be converted into a crop-specific area payment of 55.5 7€/ha, which will not be included in the SFP.

- The supplement direct payment for **oilseeds** (9.37 €/ton) is abolished in order to align the premiums for cereals and oilseeds.

- A payment of 45€/ha (DPENERCRP) will be offered to farmers who produce **energy crops** (coupled to non-food production set-aside), if the production is covered by a contract between the farmer and the processing industry concerned or if the processing takes place on the farm.

- Compensation payments to **milk producers** (DPDCOW) are fixed as follows: EUR 11.81/tonne in 2004, EUR 23.65 in 2005 and EUR 35.5 from 2006 onwards. The SFP will only apply in the dairy sector once the reform is fully implemented (i.e. 2007), but Member States may decide to introduce it earlier (from 2005) in the context of a regional implementation of the SFP.

- Existing payments for **rice** will increase from € 52/T to € 177/T. Of this, € 102/T (DPPARI_fa) will become part of the single payment per farm. The remaining € 75/T will remain as a crop specific aid (DPPARI).

- In February 2006, a reform of the sugar regime was decided. This will be developed in detail in the next section.

All other premiums were kept unchanged. Support to Nuts is not included in the runs, as well as direct payments for dehydrated or sun dried fodder.

Table 3. Changes in EU basic premiums for crop and animal activities under the 2003 CAP reform (2013)

Premium schemes	Basic premium under Agenda 2000 (in 2003)	Basic premium under 2003 CAP reform (in 2013)
Direct payment (DP) to COP crops (DPGCU)	63 €/ton	Unchanged
Supplement DP to protein crops (DPPROT)	9,5 €/ton	Converted into a crop-specific area payment of 55,57€/ha
Supplement DP to oilseeds (DPOILS)	9,37€/ton	Abolished
Supplement DP to durum wheat in traditional areas (DPDWHETR)	344,5 €/ha	305 €/ha
Supplement DP to durum wheat in established area (DPDWHEES)	138,9 €/ha	Abolished
DP to energy crops (DPENERCRP)	-	45 €/ha
Farm income rice premiums (DPPARI_fa)	52 €/ton	102 €/ton
Specific rice premium (DPPARI)	-	75 €/ton
Direct payment to suckler cows (DPSCOW)	200 €/head	200 €/head
Direct payment to dairy cows (DPDCOW)	-	35.5 €/ton (limited by historic quota level)
Direct payment to bulls (DPBULF)	210 €/head	210 €/head
Slaughter premium for adult cattle (DPSL_ADCT)	80 €/head	80 €/head
Slaughter premium for calves (DPSL_CALV)	50 €/head	50 €/head

3.4.1.2.2 *Single farm payment scheme*

The decoupled payment consists on the replacement of all Direct Producer Payments associated with beef, sheep, and crops production with a 'single payment per farm (SFP)'. The direct payments included in the single payment are: (i) Premiums for cereals, oilseeds, protein crops and energy crops, (ii) traditional and established durum wheat premiums, (iii) direct income support for dairy cows, (iv) direct payments to sheep and goat, (v) national envelopes for dairy cows, sheep & goat and bovine meat cattle, (vi) slaughter premiums for adult cattle and claves, and (vii) national premiums to dairy cows in northern Sweden and Finland.

Two methods from which Member States can choose to apply the SFP schema: (i) at the farm level using the individual historical payment received by farmer from 2000-2002; (ii) at the regional level taking a region's historical average of direct payments and then doling it out per farmer based on their hectares, referred to as the "flat-rate" (Schroeer, 2004). The first method was adopted in FSSIM for modelling the single payment scheme.

The calculation of the support rate under the single farm payment is based on the number of payment entitlements which, in general, equal to the number of eligible hectares declared for

payment. Each entitlement has a single value. The calculation of payment entitlement's value is based on averages over the reference period 2000-2002 and is made up of 2 elements:

- **Reference amount**: calculated on the basis of the historic aid received during the reference period, multiplied by a percentage of decoupling. This percentage will be different according to Member state.
- **Reference area**: consists on the average of land claimed over the three years. This average determines how many SFP 'entitlements' a farmer has (i.e. number of payment entitlements). The reference amount is divided by the reference area to get a value for each entitlement.

Two kinds of payment entitlements are calculated separately (i) normal payment entitlements and (ii) fallow payment entitlements.

Normal payment entitlements: based on the income support in the reference period for arable claims without including set-aside payment.
- Number of normal payment entitlements: based on the average of hectares (minus compulsory set-aside) for which income support was received during the reference period 2000-2002.
- Value of a normal payment entitlement: the total reference amount reduced with the total value of the fallow payment entitlements and divided by the farm area (minus compulsory set-aside) for which support was received in the reference period, gives the value of the normal of payment entitlement.

Fallow payment entitlements: Fallow land payment entitlements are separately calculated, based on compulsory fallow during the reference period (when farm production was more than 92 tons per year).
- Number of fallow payment entitlements: For each reference year it is determined if compulsory fallow was applicable (farm production > 92 ton). The fallow payment entitlements equal 10% of the farmland. The average for the reference period equals the number of fallow payment entitlements. Voluntary fallow is included on the normal payment entitlement.
- Value of a fallow payment entitlement: the value of a fallow payment entitlement equals the norm of production multiplied with the rate of subsidy which was in effect in 2002 for fallow land.

3.4.1.2.3 Compensation payment calculation

The calculation of the payment entitlement in FSSIM-MP is done as described below:

1. The premiums from Agenda 2000 are adjusted according to the new reform. The aim is to redefine the premium according to the new reform but also to separate between the remained coupled payment and decoupled payment, which will be included in the Single Farm Payment.

$$(31) \quad s_{i,t}^{c} = \sum_{g} \theta_{g,i,t} \delta_{g}$$

- S^c: a vector of remained coupled payment per crop/animal within agricultural activity i
- θ: a vector of support rate per premium scheme and crop
- δ: a vector of coupling degree per premium scheme (%) : the coupling (or decoupling) degree represents the likely options of the 2003 CAP reform envisaged by each Member State

2. The partially redefined premiums falling under the new uniform per farm premium and category, labelled "decoupled", are determined using the three year average 2001 areas.

The idea is to calculate the normal and fallow reference amounts as well as the value of the normal and the fallow payment entitlements for each farm type using the reference area.

(32) vn = normal reference amount/ normal reference area $= \dfrac{\sum\limits_{g,e,i,t} \theta_{g,i,t}\left(1-\delta_g\right)x_e^r}{\sum\limits_e x_e^r}$

- **e:** indexes eligible crops (except fallow) /animals (i.e. e $\subseteq$ C)
- **v^n** : a scalar representing the value of normal payment entitlement for eligible crops (except fallow)
- **x^r**: a vector representing the area of eligible crops in the reference period 2000-2002'

(33) vf   =   fallow   reference   amount/   fallow   reference   area
$= \dfrac{\sum\limits_{i,t} \theta_{'DPSETA',i,t}\left(1-\delta_{'DPSETA'}\right)x_{'Fall'}^r}{x_{'Fall'}^r}$

- **v^f**: a scalar representing the value of fallow payment entitlement
- **x^r'fall'**: a scalar representing the area of fallow in the reference period 2000-2002'

3. Afterwards, the vector of subsidies (i.e. compensation payment) per crop/animal within agricultural activity i (**s**) is calculated using the remained coupled payment and the value of payment entitlement.

(34) Compensation payment for eligible crops (except set-aside) = remained coupled payment + value of the normal payment entitlement: $s_{i,t} = s_{i,t}^c + v^n$

(35) Compensation payment for obligatory set-aside = remained coupled payment + value of the fallow payment entitlement : $s_{'fall'} = s_{'fall'}^c + v^f$

4. Finally, the premiums are "modulated", i.e. a percent cuts from the original level. Only payments above a certain ceiling – 5.000 € per farm are subject to the modulation.

(36) $Total\ premium/\ year = \left(\sum\limits_{i,t} s_{i,t}\dfrac{\mathrm{x}_i}{\eta_i}\right)(1-\alpha b)$

- **x** is a vector of agricultural activity levels
- η is a vector representing the length of a rotation within each agricultural activity
- α is a scalar of percent modulation
- **b** is a binary variables that can only take values of 0 or 1 (i.e. b$\in \{0,1\}$)
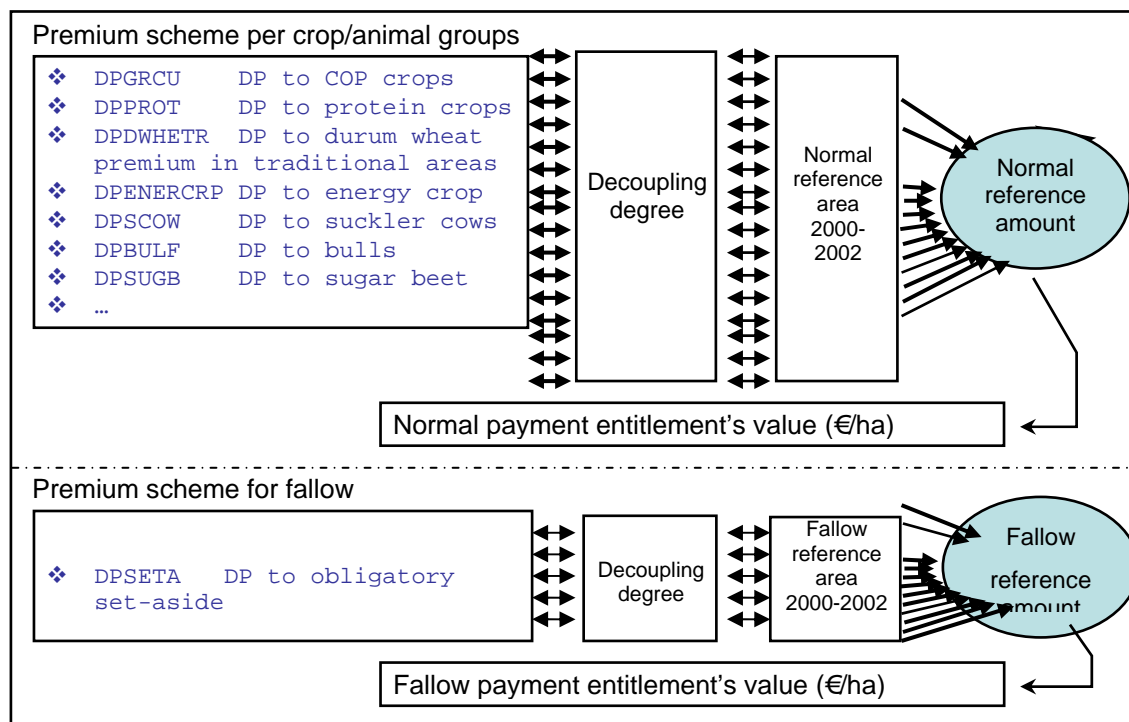
Figure 8. Calculation of compensation payment under 2003 CAP reform

3.4.2 Production quota regime

The production quota regime is a typical EU's CMO instrument introduced in the sugar and milk sectors in order to increase productivity, ensure a fair standard of living for the agricultural community, stabilise markets and ensure that supplies reach consumers at reasonable prices.

The principal instruments that are generally associated to the production quota regime are: (i) a minimum support prices and (ii) a production quotas system to limit the quantity eligible for support price through intervention mechanism. In the sugar sector, a system of A and B production quotas allotted to each Member State, in order to limit the total quantity eligible for price support. The "A" quota receives full price support through the intervention price which is, however, discounted by a 2% producer levy, and the "B" quota receives substantially lower price support due to a maximum of 39.5% producer levy being charged on the intervention price. Any quantities sold beyond the combined A and B quotas and called "C" sugar have to be exported at international prices without refund (CEC, 2003a).

The implementation of production quota regime in FSSIM was done in a generic way in order to be applied for all existing quoted products but also for new quota based policies of another product. It was captured by embedding in the objective function the additional sales values obtained when selling within quota using the additional price (i.e. the difference between support and market price), and by including a constraint in the system to limit the total quantity eligible for support price (i.e. to bind the sales within quota to the quota level).

The additional sales values obtained when selling within quota is equal to the sales within quota of product J and level l multiplied by the additional price in product J that the farmer gets when he sells within quota level l.

$$(37) \quad \sum_{J,l} p_{J,l}^a q_{J,l}^a$$

- **p^a** is a vector of additional price that the farmer gets when selling within quota l (€/ton)
- **q^a** is a vector of sold production within quota l (per Ton)

The following constraint was used to capture the quota system: for all quoted products (Quota$_{prd,l}$ ≠ 0), the sales within quota cannot exceed the quota level.

(38) $q_{j,l}^{a} \leq Quota_{j,l}$

- **j** indexes crop products
- **l** indexes quota types (e.g. for sugar it's A and B)
- **q^a** is a vector of sold production within quota
- **Quota** is a vector of quota level

3.4.3 Set aside regulation

The set-aside regulation is linked to the practice of fallowing agricultural land, by which a proportion of a farm's land resources are removed from production. This regulation includes the obligatory and the voluntary set-asides. The compulsory constraint simply means that in order to receive area payment, the producer is subject to obligatory set-aside a defined percentage of his COP (cereals, oilseeds and protein) area (called also minimum set-aside and fixed to 10% in the Agenda 2000 and in the 2003 CAP reform). In addition to the minimum obligatory set-aside, producers may put up a certain percentage of their total arable area into voluntary set-aside (named also maximum set-aside and fixed to 33% in the Agenda 2000 and to 100% under the 2003 CAP reform). Producers who apply for direct payment to an area smaller than the one needed to produce 92t of cereals are excepted from the obligatory set-aside (Junker et *al*, 2003).

(39) $\sum_{Cop,S,T,sys} x_{Cop,S,T,Sys} Min\_s \leq \sum_{S,T,Sys} x_{'Fall',S,T,Sys}$

(40) $\sum_{S,T,Sys} x_{'Fall',S,T,Sys} \leq \sum_{R,S,T,Sys} x_{R,S,T,Sys} Max\_s$

- **Cop** indexes COP (cereals, oilseeds and protein) crops (i.e. Cop ⊆ C)
- **X$_{Cop,S,T,Sys}$**: level of COP area per agri-environmental zone, production technique and production orientation (in ha)
- **X$_{'FALL',S,T,Sys}$**: level of fallow per agri-environmental zone, production technique and production orientation area (in ha)
- **X$_{R,S,T,Sys}$**: level of selected crop per agri-environmental zone, production technique and system (in ha)
- **Min_s** is a scalar representing minimum obligation set-aside (e.g. 0.1)
- **Max_s** is a scalar representing maximum voluntary set-aside (e.g. 0.3)

Permanent and rotational fallow are used in order calculate the obligatory and the voluntary set-aside.

3.4.4 Agri-environmental policies

The 2003 CAP reform has been also promoting the multifunctional role of agricultural. Farmers are viewed not only as food suppliers but also as the custodians of the countryside. This role of farmers has been acknowledged in the EU Common Agricultural Policy through a number of regulations that enforce agri-environment schemes and cross-compliance. These

measures have been introduced under the Agenda 2000 regulation as optional but the 2003 CAP reform made them obligatory for all farmers receiving compensation payments.

FSSIM involves several environmental policy instruments which can be handled by users to evaluate the impact of different alternative policies. Based on conventional policy instruments (such as tax, subsidises, norms…) as well as on new policies like the cross-compliance restrictions, these instruments operate only while running policy scenarios (i.e. they are not included in base year and baseline scenarios). They consist in imposing restrictions (min or/and max bounds), subsiding, taxing or penalising[8]:

- certain activities based on input output coefficients,
- activity levels
- sum over input/output coefficients times activity levels (i.e. production, externalities (e.g. nitrate leaching, erosion) … at farm level)

o *Min or/and max bounds on sum over input/output coefficients times activity levels (i.e. production, externalities (e.g. nitrate leaching, erosion) … at farm level).*

$$(41) \quad Min\_FL_o \leq \sum_{i,t} E_{i,o,t} \frac{x_i}{\eta_i} \bigg/ \sum_i x_i \leq Max\_FL_0$$

$$(42) \quad Min\_FL_j \leq \sum_{i,t} Y_{i,j,t} \frac{x_i}{\eta_i} \bigg/ \sum_i x_i \leq Max\_FL_j$$

$$(43) \quad Min\_FL_I \leq \sum_{i,t} F_{i,I,t} \frac{x_i}{\eta_i} \bigg/ \sum_i x_i \leq Max\_FL_I$$

- **I** indexes the set of inputs applied in production of agricultural activities.
- **J** indexes the set of economic outputs
- **O** indexes the set of environmental (i.e. externalities)
- **F** is a vector of inputs used by each agricultural activity
- **Y** is a vector of economic outputs (i.e. yield) produced by each agricultural activity
- **E** is a vector of environmental outputs associated to each agricultural activity (most of these data are generated by the biophysical model)
- **X** is a vector of agricultural activity levels
- **Min_FL** is a vector of min bound per input/output at farm level (default value is 0)
- **Max_FL** is a vector of max bound per input/output at farm level (default value is $+\infty$)

o *Subsidising or/and taxing certain activities based on input output coefficients*

$$(44) \quad \begin{aligned} OF: ... &+ \sum_{i,o,t} \left(Sub\_IO_{i,o,t} - Tax\_IO_{i,o,t}\right)\left[\left(Max\_IO_{i,o,t} - E_{i,o,t}\right) + \left(E_{i,o,t} - Min\_IO_{i,o,t}\right)\right]x_i \\ &+ \sum_{i,j,t} \left(Sub\_IO_{i,j,t} - Tax\_IO_{i,j,t}\right)\left[\left(Max\_IO_{i,j,t} - Y_{j,i,t}\right) + \left(Y_{i,j,t} - Min\_IO_{i,j,t}\right)\right]x_i \\ &+ \sum_{i,I,t} \left(Sub\_IO_{i,I,t} - Tax\_IO_{i,I,t}\right)\left[\left(Max\_IO_{i,I,t} - F_{i,I,t}\right) + \left(F_{i,I,t} - Min\_IO_{i,I,t}\right)\right]x_i \end{aligned}$$

---

[8] Penalising means cutting the EU premiums received by the farmer if he does not respect the conditions.

- **Sub_IO** is a vector representing subsidises per input/output of crop within agricultural activity *i* (default value is 0)
- **Tax_IO** is a vector representing tax per input/output of crop within agricultural activity *i* (default value is 0)

o *Subsidising or/and taxing certain activity levels*

$$(45) \quad OF : ... + \sum_i \left(Sub\_AL_i - Tax\_AL_i \right) \left[\left(Max\_AL_i - x_i \right) + \left(x_i - Min\_AL_i \right) \right]$$

- **Sub_AL** is a vector representing subsidises per agricultural activity *i* (default value is 0)
- **Tax_AL** is a vector representing tax per agricultural activity *i* (default value is 0)

o *Subsidising or/and taxing sum over input/output coefficients times activity levels (i.e. production, externalities (e.g. nitrate leaching, erosion) ... at farm level)*

$$
\begin{aligned}
(46) \quad OF: ... &+ \sum_o \left(Sub\_FL_o - Tax\_FL_o \right) \left[\left(Max\_FL_o - \sum_{i,t} E_{i,o,t} \frac{x_i}{\eta_i} \bigg/ \sum_i x_i \right) + \left(\sum_{i,t} E_{i,o,t} \frac{x_i}{\eta_i} \bigg/ \sum_i x_i - Min\_FL_o \right) \right] \\
&+ \sum_j \left(Sub\_FL_j - Tax\_FL_j \right) \left[\left(Max\_FL_j - \sum_{i,t} Y_{i,j,t} \frac{x_i}{\eta_i} \bigg/ \sum_i x_i \right) + \left(\sum_{i,t} Y_{i,j,t} \frac{x_i}{\eta_i} \bigg/ \sum_i x_i - Min\_FL_j \right) \right] \\
&+ \sum_I \left(Sub\_FL_I - Tax\_FL_I \right) \left[\left(Max\_FL_I - \sum_{i,t} F_{i,I,t} \frac{x_i}{\eta_i} \bigg/ \sum_i x_i \right) + \left(\sum_{i,t} F_{i,I,t} \frac{x_i}{\eta_i} \bigg/ \sum_i x_i - Min\_FL_I \right) \right]
\end{aligned}
$$

- **Sub_FL** is a vector representing subsidises per input/output at farm level (default value is 0)
- **Tax_FL** is a vector representing tax per input/output at farm level (default value is 0)

o *Penalising certain activities based on input output coefficients*

$$(47) \quad OF: ... + \sum_{i,t} s_i \frac{x_i}{\eta_i} (1-ob) \left[\left(1 - \sum_{i,o} Pen\_IO_{i,o} Bv\_IO_o + \sum_{i,j} Pen\_IO_{i,j} Bv\_FL_{t,j} + \sum_{i,I} Pen\_IO_{i,I} Bv\_IO_{i,I} \right) \right]$$

Subject to:

$$(48) \quad Min\_IO_{i,o,t} \frac{x_i}{\eta_i} - Bv\_IO_{i,o} \Omega \le E_{i,o,t} \frac{x_i}{\eta_i} \le Max\_IO_{i,o,t} \frac{x_i}{\eta_i} + Bv\_IO_{i,o} \Omega$$

$$(49) \quad Min\_IO_{i,j,t} \frac{x_i}{\eta_i} - Bv\_IO_{i,j} \Omega \le Y_{i,j,t} \frac{x_i}{\eta_i} \le Max\_IO_{i,j,t} \frac{x_i}{\eta_i} + Bv\_IO_{i,j} \Omega$$

$$(50) \quad Min\_IO_{i,I,t} \frac{x_i}{\eta_i} - Bv\_IO_{i,I} \Omega \le F_{i,I,t} \frac{x_i}{\eta_i} \sum_t \le Max\_IO_{i,I,t} \frac{x_i}{\eta_i} + Bv\_IO_{i,I} \Omega$$

- **Pen_IO** is a vector representing penalty per input/output of crop within agricultural activity *i* (default value is 0)

- **Bv_IO** is a vector of binary variable per input/output of crop within agricultural activity *i* (default value is 0)
- **Ω** is a scalar representing a big number (e.g. 10^6)

o *Penalising certain activity levels*

$$(51) \quad OF: ... + \sum_{i,t} s_i \frac{x_i}{\eta_i}(1-\alpha b)\left[\left(1 - \sum_i Pen\_AL_i Bv\_AL_i\right)\right]$$

Subject to:

$$(52) \quad Min\_AL_i - Bv\_AL_i\Omega \le x_i \le Max\_AL_i + Bv\_AL_i\Omega$$

- **Pen_AL** is a vector representing penalty per agricultural activity *i* (default value is 0)
- **Bv_AL** is a vector of binary variable per agricultural activity *i* (default value is 0)

o *Penalising sum over input/output coefficients times activity levels (i.e. production, externalities (e.g. nitrate leaching, erosion) ... at farm level)*

$$(53) \quad OF: ... + \sum_{i,t} s_i \frac{x_i}{\eta_i}(1-\alpha b)\left[1 - \left(\sum_o Pen\_FL_o Bv\_FL_o + \sum_j Pen\_FL_j Bv\_FL_j + \sum_I Pen\_FL_I Bv\_FL_I\right)\right]$$

Subject to:

$$(54) \quad Min\_FL_o - Bv\_FL_o\Omega \le \sum_{i,t} E_{i,o,t}\frac{x_i}{\eta_i} \bigg/ \sum_i x_i \le Max\_FL_0 + Bv\_FL_o\Omega$$

$$(55) \quad Min\_FL_j - Bv\_FL_j\Omega \le \sum_{i,t} Y_{i,j,t}\frac{x_i}{\eta_i} \bigg/ \sum_i x_i \le Max\_FL_j + Bv\_FL_j\Omega$$

$$(56) \quad Min\_FL_I - Bv\_FL_I\Omega \le \sum_{i,t} F_{i,I,t}\frac{x_i}{\eta_i} \bigg/ \sum_i x_i \le Max\_FL_I + Bv\_FLI\Omega$$

- **Pen_FL** is a vector representing penalty per input/output at farm level (default value is 0)
- **Bv_FL** is a vector of binary variable per input/output at farm level (default value is 0)

Table 4. Overview of the FSSIM-MP current version

Constraints and restrictions	Agricultural activities		Absolute deviation counters for income			Standard deviation	Right-Hand Side
	Activities for on-farm use	Activities for sale	Dev_1	…	Dev_n	σ	
Productive capacity constraints							
Total land	+ 1	+ 1					<= Available arable land
Irrigable land	+ 1	+ 1					<= Available irrigable land
Grassland	+ 1	+ 1					<= Available Grassland
Permanent cropland	+ 1	+ 1					<= Available permanent cropland
Labour	+ a^*_{iw}	+ a_{iw}					<= Available labour
Water	+ a_{iw}	+ a_{iw}					<= Available water
EU Policy obligations/restrictions							
Quotas		+ a_{iw}					<= Ref. quantity
Obligatory set-aside	+/-	+/-					> = Ref. Hectares
Voluntary set-aside	+/-	+/-					<= Ref. Hectares
Cross-compliance restrictions							
Agri-environmental measures							
Livestock constraints							
Feed requirements	+ a_{iw}	+ a_{iw}					>= 0
Feed restrictions	+ a_{iw}	+ a_{iw}					>= 0
Nutrient balance	+ a_{iw}	+ a_{iw}					= Surplus
…	+ a_{iw}	+ a_{iw}					…
Risk rows							
State S_1		+ $r_{i1} - \bar{r}_i$	+ 1				= 0
$\vdots$				$\ddots$			= 0
S_n		+ $r_{in} - \bar{r}_i$			+1		= 0
Objective function	- Costs + PMP terms	+ Expected gross margin ($\bar{r}_i$) + PMP terms				- risk aversion (Φ)	Maximise

* a_{iw} is the technical coefficient that relates activity i to resource w; S: state of nature and market; $\bar{r}_i$ **:** expected gross margin per unit for activity *i*.;

3.5 Pre-modelled methods for calibrating FSSIM

FSSIM can be calibrated using the risk or/and the Positive Mathematical Programming (PMP) approach. The first approach calibrates the model approximately and the former calibrates it exactly exploiting the observed farmer's behaviour. Three PMP variants are implemented in FSSIM to be selected by user according to data availability: (i) the standard PMP approach (Howitt, 1995a), (ii) the Rhöm and Dabbert's PMP approach (Röhm and Dabbert, 2003) and the (iii) Kanellopoulos et al.'s PMP approach.

3.5.1 The risk approach

Most of these risk methods presume that a non-correspondence between simulated and observed results means one of these two factors: (i) omission of some important element of the cost structure, such as specialized management skills in growing high-value vegetable; (ii) inadequate specification of the crops' riskiness and farmer' risk aversion (Hazell and Norton, 1986). To capture this last factor adequately the objective function should include the risk-averse behaviour. To estimate this parameter the more common method is to parameterize the model for different values of risk aversion and then to choose the value of the parameter that gives fit between the model's predicted crop allocation and the observed values. The difference between both values is assessed statistically by using the Percent Absolute Deviation[9] (PAD).

The main weakness of risk approach is that it cannot calibrate the model exactly. Another shortcoming is how credible the model is, and what is the level of confidence that can be placed on the model predictions in this case? There is no consensus on the statistic to be used to judge model quality. In FSSIM, we have adopted Hazell and Norton's suggestion which shows that a Percent Absolute Deviation (PAD) for production and acreage below 10% is good, equal to 5% is exceptional and more than 15% indicates that the model may need improvement before it can be used.

3.5.2 The standard PMP approach

The PMP approach stipulates that, a divergence between model's prediction and the observed reality of a base period means that both technical constraints and cost (or yield) specification were not taken into account, and so they had to be included in the objective function via a nonlinear cost (or/and production) function (Gohin et Chantreuil, 1999). The principal advantages of this approach -compared to *ad hoc* calibration procedure- are: automatically and exact calibration of optimization models, lower data requirements, and that it ensures "soft" continuous changes while varying exogenous variables (Röhn and Dabbert, 2003). Inconvenient is that it implies to some extent the use of a "black box".

The original PMP approach (i.e. standard approach) involves three phases: calibration, estimation and simulation.

1. *The calibration phase:* consists of writing an LP model as usual but adding to the set of limiting resource constraints a set of calibration constraints that bind the activities to the observed levels of the base year period. The sole purpose of this phase is to

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[9]

$$PAD\ (\%) = \frac{\sum_{i=1}^{n} \left| \hat{X}_i - X_i \right|}{\sum_{i=1}^{n} \hat{X}_i} \cdot 100$$

Where $\hat{X}_i$ is the observed value of the variable i and X_i is the simulated value (the model prediction). The best calibration is reached when PAD is close to 0.

obtain an accurate and consistent measure of the vector of dual values associated with the calibration constraints, but as pointed out by Heckelei and Wolff (2003) this phase can be integrated in the estimation phase by means of Lagrangean multipliers (Howitt, 1995a). Paris and Howitt (1998) interpret this vector as capturing any type of model mis-specification, data errors, risk behaviour and prices expectations.

(57) $\max Z = p'x - c'x$ Subject to $Ax \le b[\lambda], \quad x \le x^o + \varepsilon [\rho], \quad x \ge 0$

Where Z is the objective function value, **p**, **x** and **c** are (n x 1) vectors of product prices, non-negative activity levels, and accounting costs per unit of activity. **A** represents an (m x n) matrix of coefficients in resource constraints, **b** and λ are (m x 1) vectors of resource availability and their corresponding shadow prices. The (n x 1) **x**[o] non-negative vector of observed activity levels, **ε** is an (n x 1) vector of small positive numbers for preventing linear dependency between the structural and the calibration constraints, and **ρ** is an (n x 1) vector of duals associated with the calibration constraints.

2. *The estimation phase:* consists of employing the dual values **ρ** delivered by the first phase to specify additional non-linear terms in the objective function which allows reproducing the observed activity levels without calibration constraints. These terms mostly refer to increasing marginal cost (Arfini and Paris, 2000), or/and a decreasing marginal yields (Howitt, 1995a; Barkaoui et Butault, 1998), or a *neutral* form[10] (Röhm and Dabbert, 2003). A frequent case considers calibrating the parameters of a variable cost function **C**[v]**(x**[o]**)**, such that the 'variable marginal' cost **MC**[v] of the activities is equal to the sum of the known cost **c** and the 'non-specified' marginal cost **ρ.** In case of a quadratic function form[11], the following condition for calibration is implied:

(58) $MC^v = \dfrac{\partial C^v(x)}{\partial x} = d + Q\,x^o = c + \rho$

Where d is an (n x 1) vector of parameters of the cost function and Q is an (n x n) symmetric, positive (semi-) matrix.

To solve this system of n equations for [N+(N+1)/2] parameters, the literature suggests many solutions, which include simple *ad hoc* procedures with some parameters set a priori (Howitt, 1995a), the use of supply elasticities (Helming et al, 2001), the direct derivation of the unknown parameters from the Kuhn-Tucker conditions (Judez et al, 2001), and the employment of maximum entropy criterion (Paris and Howitt, 1998).

3. *The simulation phase*: consists of adding the estimated non-linear terms (cost (production) function) to the PL objective function in order to simulate the farm's behaviour when some condition changes, such as prices, yields, policy, etc.

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[10] For neutral form: $= \rho_i x_i (1 - \frac{x_i}{x_i^o})$ where ρ_i is the dual value associated with the calibration constraint of activity i, x_i^o is the observed level of activity *i,* and x_i is the simulated activity level.

[11] Other functional forms are possible. The generalized Leontief and the weighted-entropy variable cost function (Paris and Howitt, 1998) and the constant elasticity of substitution (CES) production function (Howitt, 1995b) in addition to the constant elasticity of transformation production function (Graindorge *et al.*, 2001) have also been used. A von Neumann-Morgenstern expected utility approach has been used to account for a constant absolute risk aversion to price volatility (Paris, 1997).

During the last decade, PMP has become a popular method for farm, regional and sectors models. It established itself as a widely used approach for the specification of programming models designed for analysing agricultural and environmental policies. It has generated numerous applications and extensions. Among the works developed using PMP we should mention the models of University of Bonn (Heckelei and Britz, 2000), INRA-Nancy (Barkaoui et Butault, 1998), University of Madrid (Judez et al, 2001), University of Galway (Garvey and Steele, 1998), the FAL model (Kleinhanss, 2002) and the CAPSET model (Paris et al, 2003). Some other applications are shown in Howitt and Gardner (1986), House (1987), Kasnakoglu and Bauer (1988), Arfini and Paris (1995), Cypris (2000) and Helming et al (2001).

While being an appealing method for calibration, the standard PMP has shown shortcomings in model calibration that, in turn, motivated further developments. One of these shortcomings is the missing representation of economic behaviours with regard to activities of farms whose initial observed supply level is zero during the reference period. To overcome this self-selection problem during the calibration as well as during the simulation steps, Paris and Arfini (2000) add to the *F* PMP models a supplementary PMP model for the whole farm sample and calibrate a frontier cost function for all the activities included in the whole farm sample.

The second PMP shortcoming discussed at several occasions in the literature is the unequal treatment of the marginal and preferable activities (i.e. the problems of zero-marginal product (cost) for one of the calibrating constraints) (Gohin and Chantreuil, 1999; Paris and Howitt, 2001).

Another PMP shortcoming is the inclusion of greater competitiveness among close competitive activities whose requirements for limiting resources are more similar than with other activities (Röhm and Dabbert, 2003).

Due to these limitations and others, a number of Positive Mathematical Programming (PMP) variants have been developed in the recent years. Among them the Rhöm and Dabbert's PMP approach and Kanellopoulos et al.' s PMP PMP approach used in FSSIM. All these PMP variants guarantee exact calibration. Nevertheless, different variant can produce different results when they are used to predict the future behaviour of the farmer (De Frahan B., 2005).

3.5.3 The Röhm and Dabbert's PMP approach

As explained above, the Röhm and Dabbert (2003) approach was developed to solve the problem of considering the same activity grown under different variants (e.g. different agro-managements) as two separate activities. To handle this problem, they add in the first step of PMP a set of additional calibration constraints which restricts the level of each variant activity to its observed level. In another term, they divide the slope of the cost function of each activity into two parts. One part depends on the different variants of a certain activity and the other depends on the activity.

(59) $MaxZ = p^{'}x - c^{'}x, S.t.Ax \leq b[\lambda], x_C \leq x_C^0 + \varepsilon_1[\rho_1], x_{C,T} \leq x_{C,T}^0 + \varepsilon_2[\rho_2], x \geq 0$

Where, **C** denotes the set of crops and **T** the set of management type. The first calibration constraint is related to crop specified by management type and the second one is related only to crop. As in the PMP standard approach, the dual values ρ1 and ρ2 are used to estimate the linear and the non-linear PMP terms. The application of this approach for FSSIM requires data availability on the observed crop levels as well as the observed level per crop, soil type (i.e. agri-environmental zone) and management type.

3.5.4 The Kanellopoulos et al.'s PMP approach

This PMP approach was developed to handle the problems of zero-marginal cost for one of the calibrating constraints and the unequal treatment of the marginal and preferable activities. Because the differential marginal costs of the marginal activities captured by the dual vector ρ are zero, the actual marginal costs of supplying these activities are independent of their levels while those of supplying the preferable activities are not under the average cost approach of calibration. For these marginal activities, calibrated marginal costs are equal to average costs and marginal profits are equal to average profits. Gohin and Chantreuil (1999) show that an exogenous choc on one preferable activity would uniquely modify the levels of this activity and the levels of the marginal activities, not those of the other preferable activities.

One *ad hoc* solution to obtain an increasing marginal cost function for these marginal activities consists in retrieving some share of one limiting resource dual value λ and adding it to the calibration dual vector ρ to obtain a modified calibration dual vector ρ_M (Rohm and Dabbert, 2003). A more severe solution consists in skipping the first step of PMP altogether.

The solution proposed by Kanellopoulos is based on the use of the land rental values to estimate the non-linear cost term of marginal activity. It consists to add in the first step of PMP the values of the rented land and a set of calibration constraints.

$$(60) \quad MaxZ = p^{'}x - c^{'}x - gl, S.t. Ax \leq b[\lambda], x \leq l, x \leq x^0 + \varepsilon_1[\rho_1], x \geq x^0 - \varepsilon_2[\rho_2], x \geq 0$$

Where, **g** denotes the average gross margin and **l** the rented land in ha. As in the PMP standard approach, the dual values $\rho1$ and $\rho2$ are used to estimate the linear and the non-linear PMP terms (more details are given in Kanellopoulos et al, 2009).

3.6 Outlook parameters for building baseline scenario

FSSIM structure offers the possibility of building a specific baseline scenario (also known as 'reference' or 'benchmark' or 'non-intervention' scenarios) to use as reference for the interpretation and analysis of different policy scenarios. The baseline scenario is interpreted as a projection in time covering the most probable future development in term of technological, structural and market changes. In some case, the baseline may be a simple projection of the current situation assuming no changes (the expression "*Business as Usual*" scenario is generally used to specify this kind of baseline) and in other cases, the baseline may change drastically. The principal outlook parameters predefined in the FSSIM-trend module that can be manipulated by user to build the baseline scenario are the following: inflation rate, price change based on market projections, yield trends, change of structural (linked to farm resource endowment) and policy (especially quota, set-aside regulation and premiums) parameters.

Regarding inflation the user have to precise the inflation rate and the years of base year and baseline and the model inflates automatically all monetary values (i.e. all input out puts prices as well as premiums and PMP terms) using the following inflation coefficient:

$$(61) \quad Inflation = (1 + \inf)^{(Ybl\_Yby)}$$

- Ybl is the year in which baseline was performed
- Yby is the year in which base year was performed
- Inf is a scalar representing the inflation rate
- Inflation is a scalar representing the inflation coefficient

To take into account a possible technological and market changes between baseline and base year, FSSIM offers the possibility of varying producer prices as well as yields based on extrapolation of current trends developed in the CAPRI market model or others sources /studies.

$$(62) \quad p_j^{bl} = p_j^{by}\left(1 + \Delta p_j\right)$$

- **Error! Objects cannot be created from editing field codes.** is a vector of average product prices used in the base year
- **Error! Objects cannot be created from editing field codes.** is a vector of average product prices used in the baseline scenario
- **Error! Objects cannot be created from editing field codes.** is a vector representing the change of average product prices between base year and baseline

$$(63) \quad Y_{j,i,t}^{bl} = Y_{j,i,t}^{by}\left(1 + \Delta y_{j,i,t}\right)$$

- **Error! Objects cannot be created from editing field codes.** is a vector of average yield of each crop product within agricultural activity used in the base year
- $Y_{j,i,t}^{bl}$ is a vector of average yield of each crop product within agricultural activity used in the baseline scenario
- **Error! Objects cannot be created from editing field codes.** is a vector representing the change of average yield between base year and baseline

The structural parameters retained on the FSSIM outlook screen are related to farm resource endowments especially, land, labour and water availabilities. Included in the constraint system, these parameters offer the opportunity of activating or deactivating predefined resource constraints or varying theirs Right-Hand Side (RHS) coefficients (i.e. increases or decreases farm size, available irrigable land, available labour, available water …). These parameters are implemented as follows:

$$(64) \quad B_w^{bl} = B_w^{by}\left(1 + \Delta r_w\right)$$

- B_w^{by} is a vector of RHS coefficients of resource constraints used in the base year
- B_w^{bl} is a vector of RHS coefficients of resource constraints used in the baseline
- **Error! Objects cannot be created from editing field codes.** is a vector representing the change of RHS coefficients between base year and baseline

In term of EU policy assumptions, the FSSIM allows to build a baseline scenario based on the continuation of the agenda 2000 or on the adoption of the 2003 CAP reform (including the reform of quota regime).

3.7 Pre-modelled scenarios

A set of scenarios are already implemented in the current version of FSSIM:

3.7.1 Base year scenario

The base year information for which the model is currently calibrated stems from a three-year average around 2003. In term of policy representation the Agenda 2000 (since 2000) Regulation constitutes the base year policy. To run the baseyear scenario the following data are required:

- Bio-physical data characteristics of the agri-environmental zones used as input for the bio-physical model.
- Farm resource data such as available farm land per agri-environmental zone, irrigated land per agri-environmental zone, available family labour and observed crop allocation (i.e. crop pattern). These data are collected from the FADN sources and used in the FSSIM model for the definition of constraints' RHS coefficients and for the calibration process.
- Set of the current and alternative activities and theirs input output coefficients such as yield (average and variability), input use (e.g. fertiliser, water, labour…), prices (average and variability), costs, etc.
- Policy data: the default amount of the premium (basic premium, uncut) according to the Agenda 2000, the way that this premium is applied, the quota level for the quoted products (such as sugar beet and milk) and the minimum and maximum set-aside.
- Calibration procedure: the calibration procedure is based on two steps: in the first step, we apply the risk approach in order to calibrate the model, as precisely as possible. That consists of selecting in the risk module the option "automatic choice of risk aversion coefficient". The model assigns automatically a value to the risk aversion coefficient which gives the best fit between the model's predicted crop pattern and the observed values. The difference between both values is assessed statistically by using the Percent Absolute Deviation (PAD). The aim of this step is to ensure that the model produces acceptable results before going to the second step. To do this test, the following assumptions was taken: if the PAD is less than 15% the model is acceptable and we can start the second step, if PAD is more than 15%, the model should be improved before applying the second step. In the second step, a PMP variant is implemented in order to calibrate the model exactly to the observed situation.

3.7.2 Baseline scenario

The baseline scenario currently implemented in FSSIM was performed in year 2013, taken as simulation year, and includes a set of exogenous assumptions linked to technological innovations as well as to policy and market changes.

Regarding technological and market changes, three exogenous assumptions are adopted in this baseline:
- an assumed regional inflation rate of 1.19% per year;
- a projection in produce prices obtained from the market model CAPRI (Britz, 2002) and
- a yield trend to reflect technical progress coming also from CAPRI database.
- all the others parameters (including structural parameters as well as farm's weight on the region) are assumed to remain unchanged up to 2013.

In term of policy representation, the CAP reform of June 2003 as well as the sugar market reform constitute the principal policy assumptions operating in the baseline scenario.

- **2003 CAP reform:** The most important measures of this reform are the adoption of decoupled direct payment, the introduction of a new modulation system, and the enforcement of agri-environment schemes. To implement this reform in FSSIM the following data are used: the default amount of the premium (basic premium, uncut) according to the 2003 CAP reform, the way that this premium is applied and the likely options envisaged by each Member State to apply the decoupling system (Tableau 5).

Table 5. Most plausible implementation by EU25 Member States of the policy options proposed under Luxemburg Agreements

	25% hectare payments	40% durum wheat	100% suckler cow	100% bovine slaughter	40% bovine slaughter	75% special male	50% sheep & goat
Belgium Luxemburg Sweden				√			
Netherlands				√			√
Denmark Finland						√	√
Austria Portugal			√		√		
France Spain Greece	√		√		√		√
Italy Germany Ireland United Kingdom Rest (EU-10)	**Full decoupling**						

Source: CAPRI modelling system.

- **Sugar policy reform:** In February 2006 the decision-making concerning the sugar regime reforms has been finalized. The principal elements of the EU sugar reform proposal are the following (Figure 9):
  - A 39 percent price cut over two years beginning in 2006/07 to ensure sustainable market balance.
  - Compensation to farmers at 60% of the price cut. Inclusion of this aid in the Single Farm Payment and linking of payments to respect of environmental and land management standards.
  - Merging of 'A' and 'B' quota into a single production quota.
  - Abolition of the intervention system and the replacement of the intervention price by a reference price.
  - Sugar beet should qualify for set-aside payments when grown as a non-food crop and also be eligible for the energy crop aid of 45 Euros/hectare.
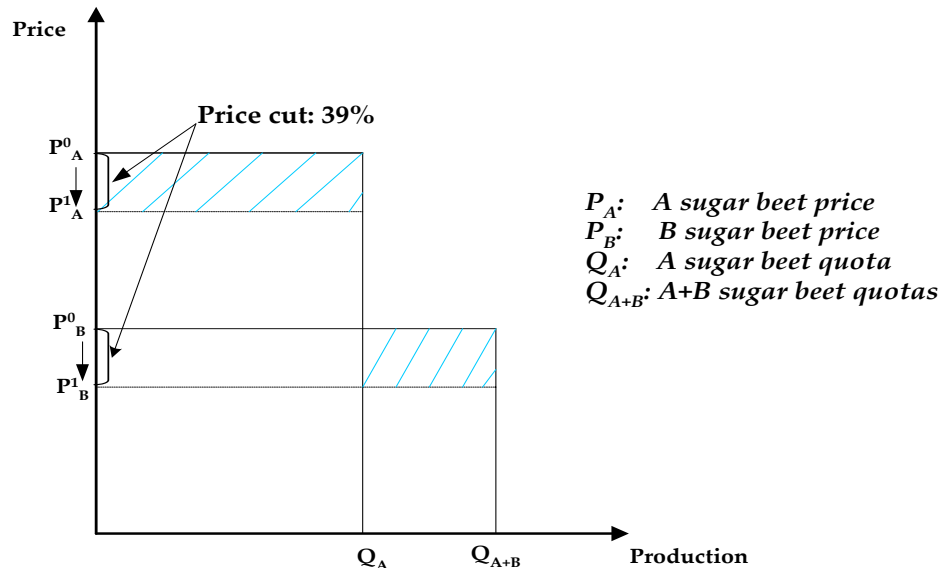 - Quota decrease for some Member States.

Figure 9. sugar regime reforms

Total compensation payment for the cut in the sugar beet price =
$60\% *[(P^0_A - P^1_A)*Q_A + (P^0_B - P^1_B)*(Q_{A+B} - Q_A)]$

$$\text{Premium/Tonne (A\&B)} = \frac{60\% *[(P^0_A - P^1_A)*Q_A + (P^0_B - P^1_B)*(Q_{A+B} - Q_A)]}{Q_{A+B}}$$

Premium/ha (A&B) = Premium/Tonne * Reference yield

3.7.3 Policy scenarios

In the SEAMLESS-IF framework, two test cases have been planned to "test the validity and functionality" of the system tools (models, indicators and data bases). Test Case 1 has been designed to analyse the effects of market policy changes and Test Case 2 aims to analyse the impact of specific environmental policies as well as technical change on European Agriculture. With this purpose two policy scenarios have been selected and implemented in FSSIM.

Trade liberalisation: the policy scenario defined under test case 1 is the integrated assessment of a trade liberalisation proposal by the so called G20 group of developing countries at the current Doha Round of the World Trade Organisation (WTO) (G20, 2005). This proposal was based on the reduction of tariffs for agricultural products and abolition of export subsidises by EU. In reality this scenario was implemented at the market (i.e. inside SEAMCAP) and the generated prices from SEAMCAP were used in FSSIM in order to analyse the impact of the price changes due to the liberalisation proposal at farm level. The policy case is illustrated with some economic indicators (farm income, production and premiums) and environmental indicators (nitrate leaching and soil organic matter) (Van Itterssum et al. 2007).

Nitrate directive in the Midi-Pyrénées region: the simulated policy scenario under test case

2 combines the 2003 CAP reform and the first measure of the Nitrate Directive. Tested in the Midi-Pyrénées region, this measure consists to apply better management of nitrogen mineral fertilisation in order to limit nitrate lixiviation without reducing yield. It stipulates that farmers should fertilize according to the crop requirement and the soil provision of nitrogen. The implementation of this measure in the FSSIM model was achieved through the following steps (Louhichi et al., 2008):

1. Generating a set of alternative activities (AA) based on current crops but with better management of nitrogen mineral fertilisation:

- Nitrogen from mineral fertilizers needed by AA are calculated based on the "local advisory services" recommendations (simple nitrogen balance) using the current yield as target yield since experts observed that the yield of this type of AA are very close to the corresponding current activities (CA).
- Yield and yield variability of AA are generated from the biophysical model.
- Costs of AA are calculated as the cost of the corresponding current activity minus the reduction in fertilizer costs due to reduction of N use.
- A 5% transaction cost related to the collection of information on policy implementation, the participation in training sessions… was introduced for AA.
- Environmental externalities associated to each AA are quantified by the biophysical model.

2. Application of cross-compliance restrictions related to AA: *3% cut of EU premiums if AA are not applied.*

Table 6. Definition of base year, baseline and policy scenarios

	Base year [2003]	**Baseline [2013]**	**Policy scenario: Nitrate Directive [2013]**
Exogenous assumptions		- Projection in producer prices from 2003 to 2013 - Yield trend from 2003 to 2013 - Inflation rate of 1.19% per year	
EU Common Agricultural Policy	Agenda 2000	2003 CAP reform (with an option of 25% partial coupling as arable crops area payments chosen for France and 5% modulation)	
Agricultural activities	Current activities (CA)		Current activities (CA) + Alternative activities (AA)
Measures	none		Cross-compliance restrictions: 3% cut of EU premiums if AA are not applied

In addition to these two policy scenarios, FSSIM policy editor provides the opportunity to test a wide range of policy options related to the farm structure as well to agricultural and environmental policies. These options are controlled by a set of parameters included in the FSSIM-GUI (Graphical User Interface) and which allows the following simulations:

- Changing (or abolishing) set-aside regulation (i.e. changing maximum and minimum set-asides)
- Modifying the basic premiums
- Varying the application type of premiums
- Changing the coupling degree
- Varying (or abolishing) the quota for the current quoted products
- Including quotas for new products
- Changing the output prices
- Selecting or deselecting predefined technical and socio-economic constraints or varying theirs Right-Hand Side (e.g. increasing farm size, increase labour availability…)

- ▪ Imposing restrictions (min or/and max bounds), subsiding, taxing or penalising
  - certain activities based on input output coefficients,
  - activity levels
  - sum over input/output coefficients times activity levels (i.e. production, externalities (e.g. nitrate leaching, erosion) … at farm level)

3.8 FSSIM outputs

A simulation for a specific farm type using FSSIM provides a set of outputs summarizing land use and selected production techniques, input use, farm income and externalities (e.g. nitrogen surplus, nitrate leaching, pesticide use, etc.) of the farm type. These outputs can be used directly or translate to indicators (simple or decomposed) in order to be easily analysed.

The following Table defines the list of outputs that can be generated by FSSIM at farm level for each simulation run.

Table 7. List of outputs generated by FSSIM at farm level

Type	Output	Unit
Economic	Farm income	Euros
	Income per ha	Euros/ha
	Total premiums per farm	Euros
	Gross production per farm	Euros
	Total costs per farm	Euros
	Share of premiums in farm income	%
	Share of gross production in farm income	%
	Share of total costs in farm income	%
	Land shadow price	Euros
	Production	Tons
	Sold quantity	Tons
	On-farm used quantity	Tons
Input use	Total nitrogen use	Kg N/ha
	Water use	mm/ha
	Nitrogen use	Kg N/ha
	Pesticide use	g/ha
	Labour use	Hours/ha
	Nitrate leaching	Kg N-NO3/ha
	Energy use of irrigation	toe/ha
	Energy use of tillage	toe/ha
	Energy use of mineral nitrogen	toe/ha
	Energy use of animal food	toe/ha
	Energy use of animal housing	toe/ha
	Total energy use for crops	toe/ha
	Total energy use for livestock	toe/ha
	Total energy use	toe/ha
	Nitrogen use per forage area	Kg N/ha
	Use of organic nitrogen	Kg N/ha
	Use of mineral nitrogen fertilizer	Kg N/ha
Environment (i.e. positive and negative externalities)	Soil erosion	T/ha
	Water drainage	mm/ha
	Nitrate volatilization	Kg NH3-N/ha
	Soil Fertility rate	Ha
	Soil Fertility gain	Ha

Soil organic matter	%
Pesticide volatilization	g/ha
Pesticide runoff	g/ha
Pesticide leaching	g/ha
Runoff	mm/ha
Average energy efficiency for crops	toe/tDM
Average energy efficiency for livestock	toe/tDM
Erosion peak	T/ha
Runoff Peak	mm/ha
Average farm nitrogen surplus	Kg N/ha
Farm gate N surplus	Kg N
Farm gate N efficiency	%
Crop diversity	Ha
Structural	Crop allocation (per crop)	Ha
	Crop activity level *i* (combination of crop rotation (r), agri-environmental zone (s), technique (t), and system (sys)	Ha
	Crop allocation per crop (c), agri-environmental zone (s), technique (t), and system (sys)	Ha
	Share of grassland in the forage area	%
	Animal level (per animal type(An)	Head
	Animal activity level *i* (combination of dressed animal (da), production intensity (int) and system (sys))	Head
	Stocking rate (livestock density)	LU/ha
	Stocking rate (livestock density) on the total forage area	LU/ha
	Stocking rate (livestock density) on the total grassland area	LU/ha

The following equations are used to calculate most of the cited outputs:

Input use:

$$(65)\quad MO_I = \sum_{i,t} F_{i,I,t} \frac{x_i}{\eta_i} \Big/ \sum_i x_i$$

- **I** indexes the set of inputs applied in production of agricultural activities.
- **F** is a vector of inputs used by each agricultural activity
- **MO** is a vector of model outputs at farm level
- **x** is a vector of agricultural activity levels

Production:

$$(66)\quad MO_J = \sum_{i,t} Y_{i,J,t} \frac{x_i}{\eta_i} \Big/ \sum_i x_i$$

- **J** indexes the set of economic outputs
- **Y** is a vector of economic outputs (i.e. yield) produced by each agricultural activity
- **MO** is a vector of model outputs at farm level

Externalities:

$$(67)\quad MO_o = \sum_{i,t} E_{i,o,t} \frac{x_i}{\eta_i} \Big/ \sum_i x_i$$

- **O** indexes the set of environmental (i.e. externalities)
- **E** is a vector of environmental outputs associated to each agricultural activity (most of these data are generated by the biophysical model)
- **MO**: vector of model outputs at farm level

For the others outputs such as farm income, nitrogen farm surplus, crop diversity… the used equations are developed in the Appendix A.1.

The following figure gives an example of simulation developed with FSSIM for a specific farm type: baseline versus a policy scenario with new agri-environmental policies.
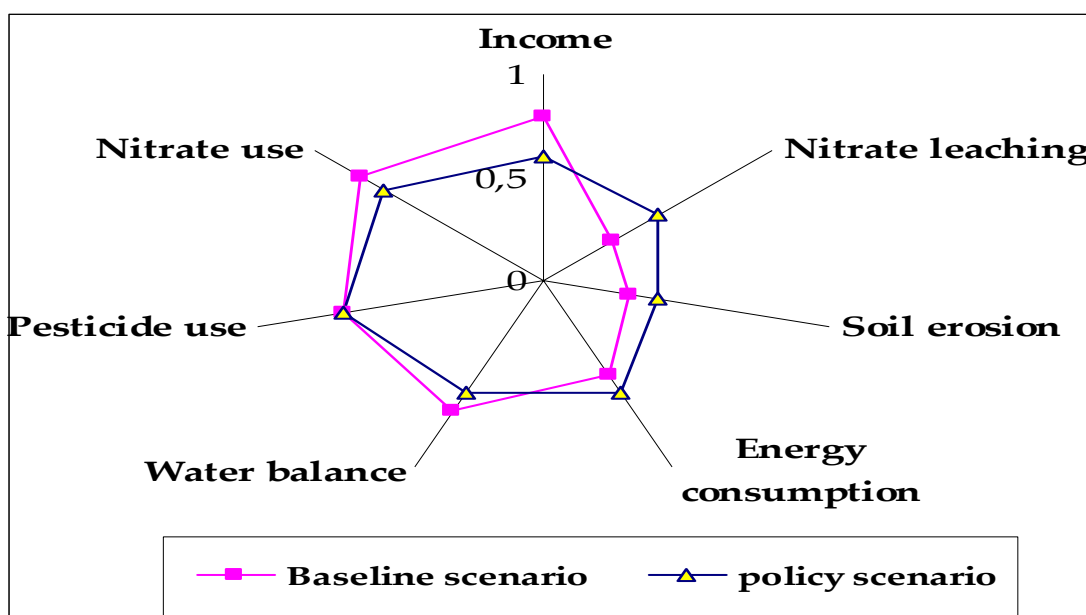
1: indicate best level; 0: indicate worst level

Figure 10. Example of FSSIM-outputs under different scenarios

3.9 GAMS implementation and linkable components

FSSIM-MP is developed within the GAMS modelling environment. GAMS is a high-level modelling system for mathematical programming and optimization. FSSIM-MP can run inside the whole SEAMLESS-IF system or independently through GAMS by using the input files generated by FSSIM-AM. Figure 11 gives an example of GAMS codes used in FSSIM-MP (cf. "FSSIM_model.gms" file).

```
* --- Crops income without premium

*           + sales valued with expected prices
*           - sum of variable costs (inputs are valued with expected prices)
*           - temporary labour costs

E_CINCOME .. sum(cp(c,prd),SOLD(c,prd)*price(c,prd))
             + sum((c,prd,l)$(cp(c,prd) and cl(prd,l)),QSALES(c,prd,l)*Addprice(c,prd,l))
             - sum((r,s,t,p,sys)$rst(r,s,t,sys),X(R,S,T,SYS)*costs(r,s,t,p,sys)/nr(r))
             - sum((r,ggrs,gprd,s,t,p,sys)$comb(r,ggrs,s,t,p,sys),X(r,S,T,SYS)*harv_costs(r,ggrs,gprd,s,t,p,sys)
             - TLABOUR*twage
             =e= Zc;
*
* --- Resources endowment constraints
*
E_TOLAND(s) ..   sum(rst(r,s,t,sys),X(R,S,T,SYS)) =l= toland(s);

E_PERGRLAND(s) ..   sum((grot,t,sys)$rst(grot,s,t,sys),X(grot,S,T,SYS))=E= PERGRLAND(S);

E_TEMGRLAND(s) ..   sum((tgrs,t,sys)$rst(tgrs,s,t,sys),X(tgrs,S,T,SYS))=E=TEMGRLAND(S);

E_LABOUR..   sum((r,s,t,p,sys)$rst(r,s,t,sys),X(R,S,T,SYS)*LABREQ(R,S,T,P,SYS)/nr(r))=l= FLABOUR + TLABOUR ;

E_IRLAND.. sum(rst(r,s,ti,sys),X(R,S,TI,SYS)) =l= irland;

E_WATER ..      WATER*sum(s,toland(s)) =l= towater;
*
```

Figure 11. Example of GAMS code used in FSSIM-MP

3.9.1 FSSIM-MP structure: modular setup

FSSIM-MP has a modular setup which includes a set of modules, namely crops, perennial, premium, Positive Mathematical Programming (PMP), risk, trend and policy module. Thanks to this modularity, FSSIM-MP provides the ability to add and remove modules (and their corresponding constraints) following the needs of the simulation, to select one or several calibration approaches between different options (risk and/or different PMP variants) and to control the flow of data between the database and software tools. FSSIM-MP can be run with simple or detailed survey data (i.e. according to the level of detail of the available data). Additionally, it can read input data stored in any database (e.g. Access DB), Excel or GAMS include files, provided that they are structured in the required format.

These modules are solved simultaneously; they are linked indirectly by an integrative module named the "common module" involving the objective function and the common constraints (Figure 12). Each module includes two GAMS files. The first one links the data-definition and the module's equations (…_data.gms) and the second one contains the module's equations (…_model.gms). Each module generates at least one variable which is used to define the common module's equations, thus providing a link between the different modules. All these GAMS files are controlled by the so-called "FSSIM_experiement.gms" file.
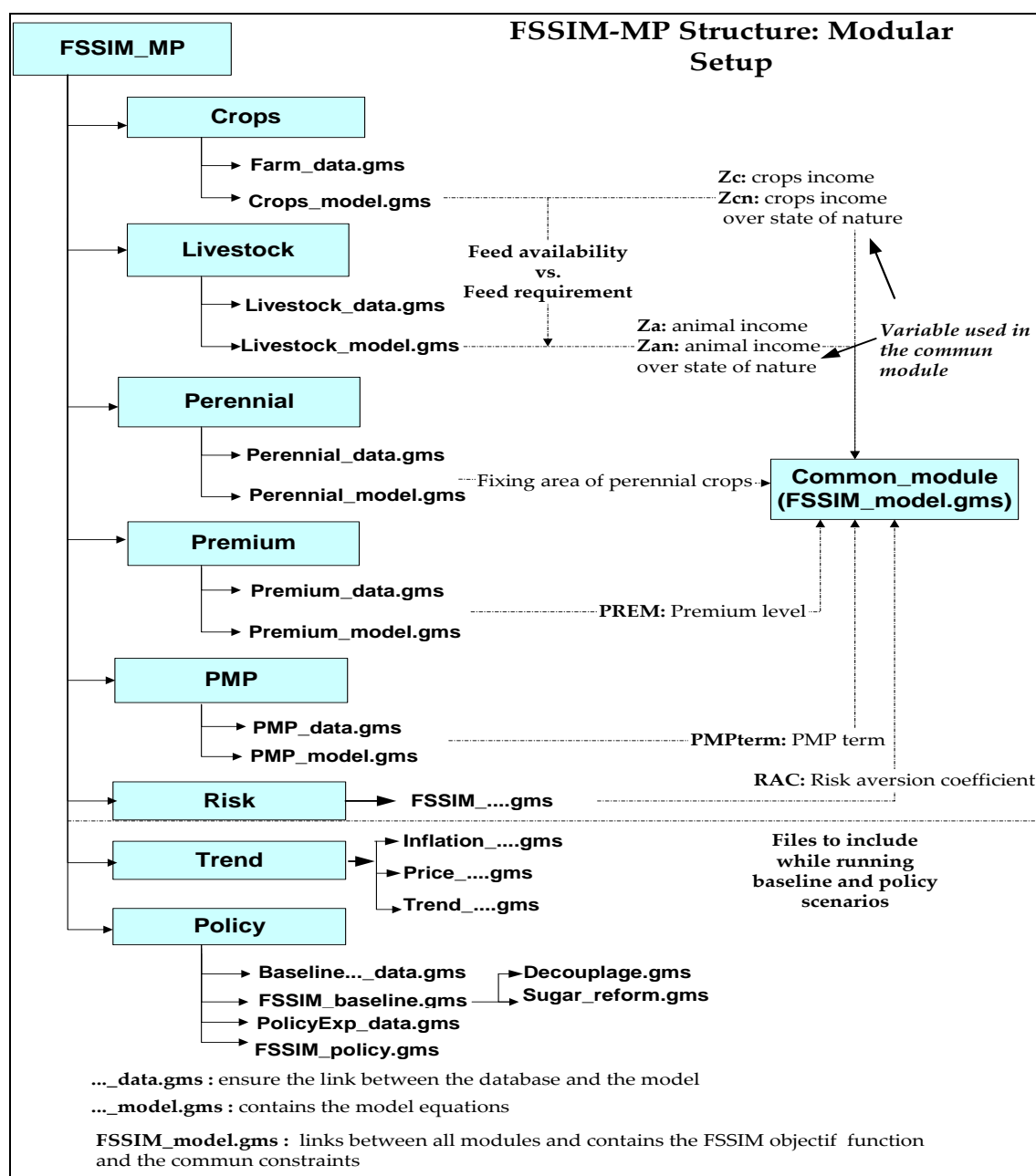
Figure 12. FSSIM-MP structure: modular setup

To organise the FSSIM GAMS files we have adopted the second style of the two common styles proposed by the GAMS programs (Figure 13):

- The first style places the data first, followed by the model and then the solution statements. In this style of organization, the sets are placed first. Then the data are specified with parameter, scalar, and table statements. Next the model is defined with the variable, equation declaration, equation definition, and model statement. Finally the model is solved and the results are displayed.

- The second style, used for FSSIM, emphasizes the model by placing it before the data. This is a particularly useful order when the model may be solved repeatedly with different data sets. There is a separation between declaration and definition.
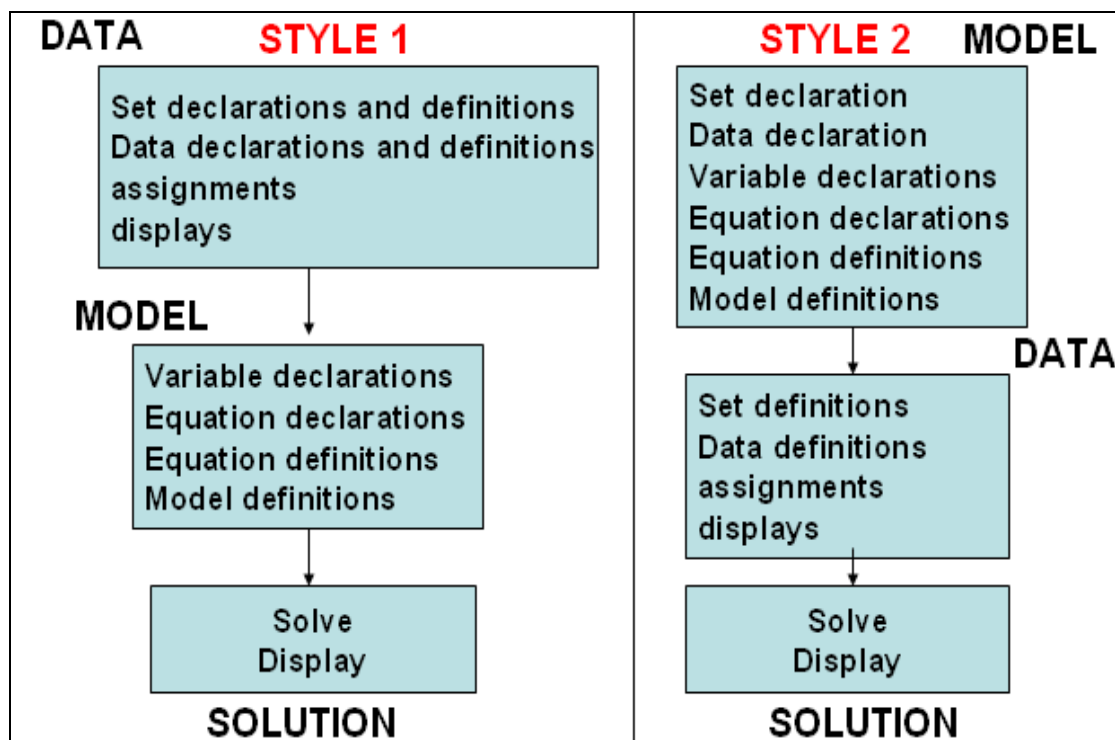
Source: GAMS user guide

Figure 13. Organization of GAMS program

According to the retained style, "FSSIM_experiement.gms" was split in different parts as follow (Figure 14):

1. part 1: includes files which contains the set declaration
2. part 2: includes files which contains data and variable declaration as well as the equation declaration and definition (i.e. all files which are extended…_model.gms)
3. part 3: includes files which contains data definition (i.e. all files which are extended …_data.gms).
4. part 4: solve statement according to the simulated scenarios (baseyear, baseline and policy scenarios and their linked files).
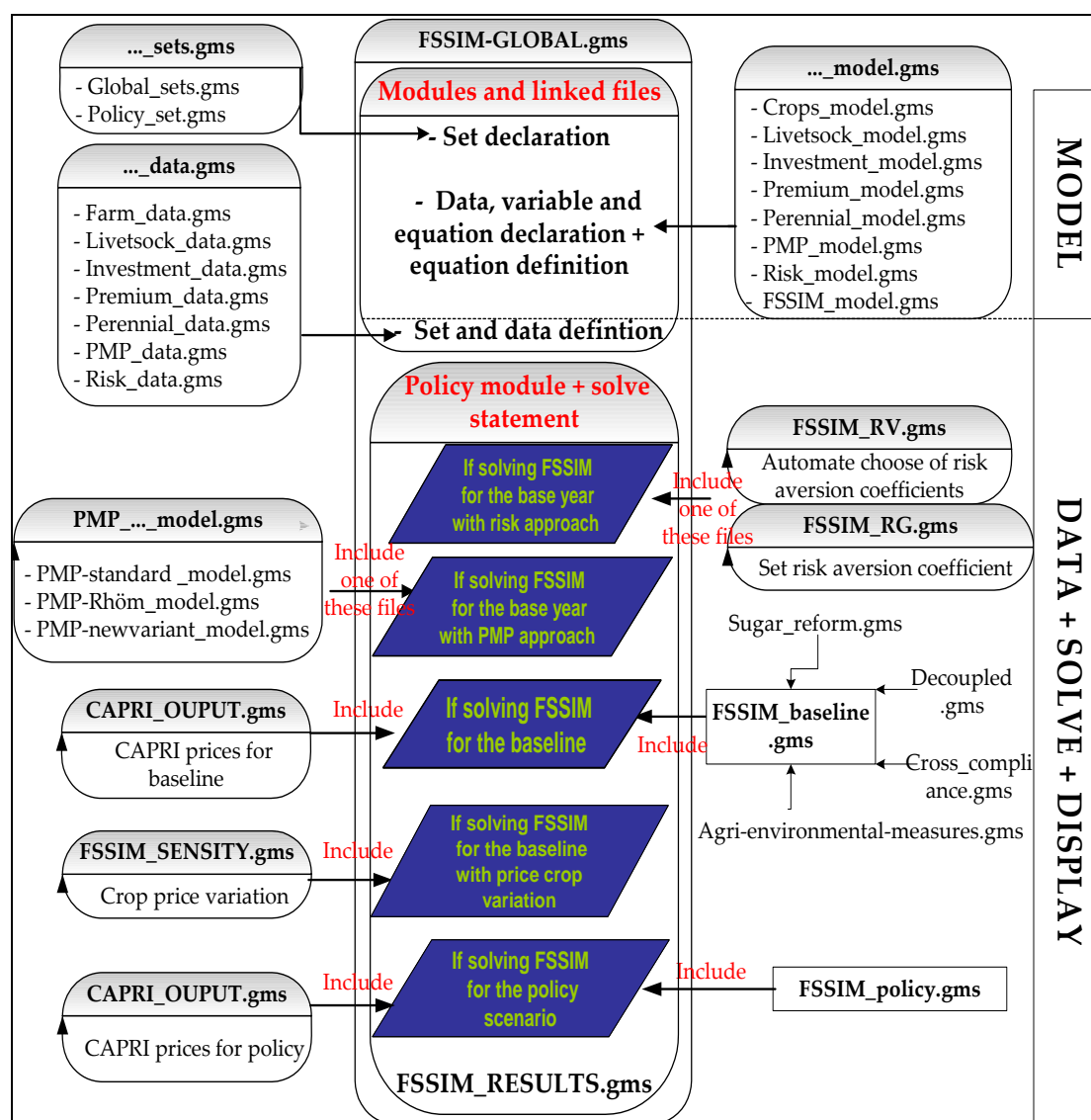
Figure 14. FSSIM-MP linkable components

3.9.2 FSSIM input data structure

The input data extracted from FSSIM database (Technical Coefficient Generator + WP4 database) and used in FSSIM-MP modules are stored in the folder FSSIM-DM and organized into different sub-folders based on their roles in the modelling:

- o Farm_set : sets definition of crops, animals, products, rotations, dressed animal, etc;
- o Farm_data: data concerning total land, irrigation land, permanent grass land, etc;
- o IO_data: all the input and outputs linked to crops and grass activities such as yields, labor requirements, externalities…;
- o Livestock_data: animal yields, animal costs, animal prices…,
- o Economic_data: crop products prices, etc;
- o Calibrat_data: data for model calibration.
- o Invest_data: long-term interest rate,
- o Premium_data: basic premium, coupling degree, historic yield, etc.
- o Policy_data: set-aside, quota, etc.
- o …

In order to use the legacy codes of FSSIM-MP, as explained, a generic wrapper was developed in order to prepare the FSSIM-MP input data and deliver OpenMI+ compliant components.

Seam:GAMS has been developed for this end. A set of classes used to deliver a wrapper around FSSIM-MP. The wrapper itself is a Java class called FSSIM-MP Component for FSSIM-MP.

The wrapper is able to correctly invoke the GAMS computation engine as an instance in the memory associated with the properly loaded model objects (e.g. based on their Uniform Resource Identifier (URIs)). For more detail about the wrapper please see the D3.3.6.
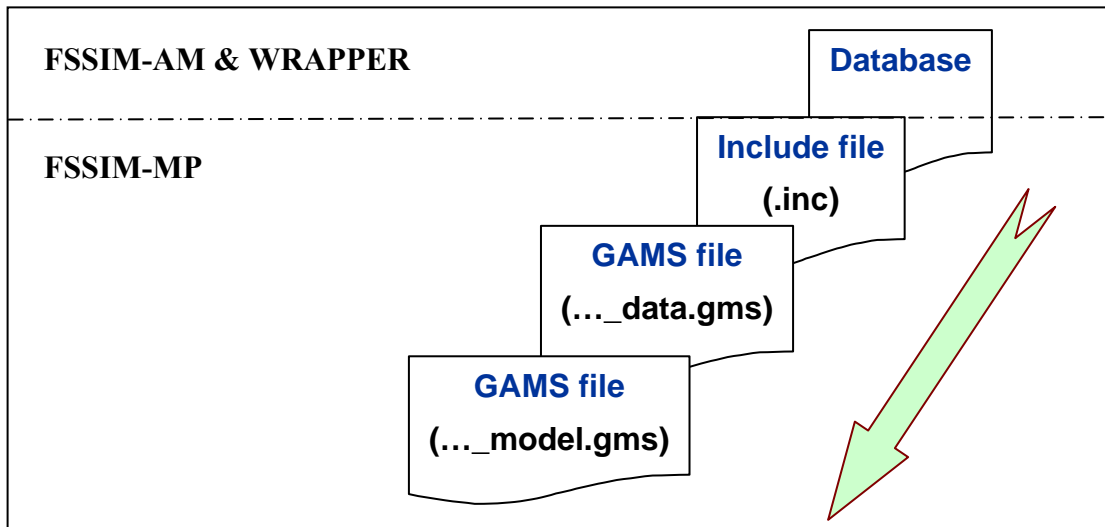

Figure 14. Link between database and GAMS files

4 Conclusion and future development

This report gives a detailed description of the Mathematical Programming (FSSIM-MP) module of the Farm System SIMultaor (FSSIM), especially its structure, components, model linking and component integration. It shows the flexibility, the transparency and the rigorousity of the model either in term of methodology choice or in term of GAMS modelling. Thanks to these specifications, FSSIM could be used to simulate different farming systems across EU25 and elsewhere and to assess different policies under various conditions. However, as any model, FSSIM presents certain limits which can be handled in a future version. The principal actions that we plan to develop in the future are:

- Updating FSSIM to include some policy specification included under the "Health Check" of the Common Agricultural Policy;
- Including the possibility of solving the model for several farm types simultaneously. The aim is to take into account endogenously the possible exchange of production factors and products between these farm types, or/and to distribute the common resources over different farm types, or/and to calculate endogenously certain input prices…
- Improving the calibration procedure especially the definition of risk aversion coefficient, testing others risk and PMP approaches…;
- Including others model specifications (e.g. other possible goals or/and constraints, more specification of the objective function, including new policies, etc.);
- Improving the implementation of perennial activities by developing the specific module for these activities;
- Extending the tools/models of FSSIM-MP for the other specific farming sectors (orchards, vineyards, etc.);
- Improving the integration between model components as well as the FSSIM-GUI;
- …

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Glossary

Agricultural activity   a coherent set of crops or animals plus the operations (also called 'production technique') with corresponding inputs and outputs, resulting in e.g. the delivery of a marketable product, the restoration of soil fertility, or the production of feedstuffs for on-farm use (Van Ittersum & Rabbinge, 1997; Ten Berge et al., 2000)

Alternative activities   Activities that are not currently used, but might be technically feasible alternative for the future, often technological innovations or newly developed cropping or husbandry practices (PD 3.3.1).

Current activities   Activities that are currently being practiced and can be derived from observed data.

Production enterprise   The description of a coherent set of crops (rotation) and animals without a specified (production) technique that form production systems of farming systems.

Production Coefficient   a row in the input-output matrix of FSSIM-MP, which describes for a crop in a rotation with a certain management what the technical coefficients are.

Production enterprise generator
a tool to generate a feasible set of production enterprises of the farm based on crop suitability filters, like soil-type, climate and for annual arable crops rotation constraints (or for animal husbandry systems herd composition constraints).

Production orientation   Value driven aims and restrictions of the agricultural activity that direct the input and output levels (Van Ittersum & Rabbinge, 1997), for example 'integrated', 'organic', 'conventional' or 'highly innovative.'

Production technique   Complete set of agronomic inputs (e.g. management practices) characterized by type, level, timing and application technique (Van Ittersum and Rabbinge, 1997).

Production technique generator
A tool to describe production techniques of agricultural activities on the basis of the feasible set of production enterprises.

Technical coefficients   Coefficients describing the inputs needed to achieve one unit of output or the activity's contribution to the realisation of user defined goals (or objective in modelling terms) (Ten Berge et al., 2000)

List of Abbreviations

ECC: Environmental cross compliance

COP: Cereals, Oilseeds and protein crops

GAMS: General Algebric Modeling System

CAP: Common Agricultural Policy

APES: Agricultural Production and Externalities Simulator

SEAMLESS: System for Environmental and Agricultural Modelling; Linking European Science and Society

FADN: Farm Accountancy Data Network

OM: optimization models

FSSIM: Farm Simulator System

FSSIM-AM: Farm Simulator System-Agricultural Management

FSSIM-MP: Farm Simulator System -Mathematical Programming model

CMOs: Common Market Organisations

Appendix

A.1. Formulation of certain FSSIM outputs

A.1.1. Farm income

(68) $Z = Z_c + Z_a + \Pr em + PMPterm$

- **Z**: the expected income (calculated in common module) (Euros)
- **Z_c**: crop income without premiums (calculated in crop module) (Euros)
- **Z_a**: livestock income without premiums (calculated in livestock module) (Euros)
- **Prem**: received EU premium (calculated in premium module) (Euros) (Euros)
- **PMPterm**: PMP terms (calculated in PMP calibration module) (Euros)

$$Z = \left[\sum_{pact,prd} Pr\,ice_{pact,prd}.\text{Sales}_{pact,prd} + \sum_{pac,prd,l} \text{Addprices}_{pact,prd,l}.\text{Qsales}_{pact,prd,l} \right]$$

(Gross production: price*sales quantity) + (Additional sales value when selling within quota)

$$+ \left[\sum_{da,int,An} Dasell_{da,int,sys}.Dacomp_{An,da,int} . \frac{Apprice_{An}}{Nad_{An}} \right]$$

(Sales animals valued with depreciation prices)

$$+ \left[(\sum_{r,s,t,sys,c} \Pr rme_c \frac{X_{r,s,t,sys}}{N_r} + \sum_{An} \Pr rme_{An}.Anlvl_{An}) \right].\left[(1 - \text{Prem\_Mod}/100) * \text{Bv\_modula} \right]$$

(Crops + animal premiums).(percent modulation if premiums exceed the franchise)

$$- \left[\sum_{da,int,An} Dapurs_{Da,int,sys}.Dacomp_{An,da,int}.Apprice_{An} \right]$$

(Purchased animals valued in market prices)

$$- \left[\sum_{r,s,t,p,sys} \text{Costs}_{r,s,t,p,sys}.\frac{X_{r,s,t,sys}}{N_r} + \sum_{r,ggrsgprds,t,p,sys} \text{Harv\_Costs}_{ggrsgprds,t,p,sys}.Bv_{r,ggrs,gprd,s,t,p,sys}.\frac{X_{r,s,t,sys}}{N_r} \right]$$

(Variable costs for crops without mineral fertiliser costs) + (Harvesting costs of grass)

$$- \left[\sum_{da,int,sys} Dalvl_{da,int,sys}.V\cos t_{da,int,sys} \right]$$

(Variable costs for animals other than feed costs)

$$- \left[\sum_{con} \text{Feedpr}_{con}.\text{Quantc}_{con} + \sum_{prd} \text{Feedpr}_{prd}.\text{Quantf}_{prd} \right]$$

(Concentrates and feed purchasing costs)

$$- \left[\text{Nfertiliser} * \text{pfertiliser} \right]$$

(Costs of purchased mineral fertilisers)

$$- \left[(NMAN\_export - NMAN\_import) * pmanure \right]$$

(Nman_export - Nman_import*1.2)

$$+ PMPterm$$

$$- \sum twage.Tlabour$$

(Average labour cost)

Index
o i: index for agricultural activities (defined for crops as a combination of crop rotation (*r*), soil type (*s*), production technique (*t*) and system (*s*) (i.e. $i \cong r,s,t,sys$) and for livestock as a combination of dressed animal (*da*), production intensity (*t*) and system (s) (i.e. $i \cong da,t,sys$)). This index will be used below in order to avoid the use of several dimensions (such as *r,s,t,sys* for crop and *da,int* for animal).
o r: crop rotations
o c: crops
o s: agri-environmental zone
o t: production techniques
o int: intensification levels (int $\subset$ t)
o sys: systems (i.e. production orientation)
o da: dressed animals
o An: animals
o pact: set of crops and animals
o prd: product types (grain, silage, hay, sugar, milk, meat,…)
o p: period (i.e. year)
o ggrs: grass groups (lye, temporary and permanent grassland)
o gprd: grass product types (silage, hay, fresh…)
o l: level of quota (e.g. for sugar it's A and B and for milk it's total)

Parameters (i.e. exogenous variables given to the model)
o $Price_{pact,prd}$: producer price of crop and animal products (Euro/Ton). Prices are taken in FSSIM as an exogenous set; assuming that farmer is a price-taker (not price-maker) in both its purchase of inputs and its sales of output. The sugar beet price used here is assumed to be equal to the one of C sugar beet.
o $Addprices_{pact,prd,l}$: Additional price in crop and animal products that the farmer gets when he sells within quota l (t/ha)
o $Apprice_{An}$: animal prices (Euro/head)
o $Feedpr_{con}$: concentrate price (Euro/Ton)
o $Feedpr_{prd}$: feed price (Euro/Ton)
o Pfertiliser: Mineral fertilizer prices (Euros/kg)
o $\overline{Yield_{i,c,prd,p}}$: average yield over various states of nature and market for each crop product *(c,prd)* within crop activity *i* (Ton/ha).
o $\overline{AnYield_{i,An,prd}}$: average yield over various states of nature and market for each animal product *(An,prd)* within livestock activity *i* (Ton/head).
o $Dis\_yield_{i,ggrs,gprd,p,cf}$: dis-aggregation of grass yield according to cutting frequency (T/ha)
o $Bv_{i,ggrs,gprd,p}$: grass product decision
o $Prme_{pact}$: compensation payment for each crop and animal type *pact* (Euro/ha or Euro/head) (depending on the Common Market Organisations (CMOs))
o $Costs_{i,p}$: variable cost per crop within agricultural activity *i* (Euro/ha).

o Harv_costs$_{i,gprd}$: harvesting cost per grass and product types *gprd* within activity *i* (Euro/ha).
o Vcosts$_i$: variable cost (other than feed cost) per animal type (Euro/head).
o Dacomp$_{An,da,int}$: share of animal type in each livestock activity *i* (i.e. share of calves and heifers per dressed animal and intensity level)
o Selco$_{An,da,int}$: share of sold animal type in each livestock activity *i* (i.e. share of sold calves and heifers per dressed animal and intensity level)
o Twage: labour cost (Euro/hour).
o Tlabour: average number of hours rented labour (in hours)
o N$_r$: number of years within each crop rotation, i.e. the length of crop rotation (2 years, 3 years, 4 years …)
o Nad: number of annual depreciation for each animal
o Prem_Mod: modulation rate (in %)
o Pmanure: price of manure (€/ton)

Variables (i.e. endogenous variables)
o X$_i$: level of selected crop activity *i* defined by a combination of crop rotation (*r*), soil type (s), production technique (*t*) and system (*s*) (in ha).
o X$_{c,s,t,sys}$: level of selected crop per soil type, production technique and system.
o Dalvl$_i$: level of selected animal activity *i* (head) defined by a combination of dressed animal (*da*) and production intensity (*int*).
o Anlvl$_{An}$: level of selected animal type (head)
o Prodt$_{pact,prd}$: total production of each crop and animal product *(pact, prd)* (Ton)
  ▪ *Crop production:*

$$\Pr odt_{c,prd} = \sum_{r,p,t,sys} \frac{\overline{Yield_{r,s,t,sys,c,prd,p}}}{N_r}.X_{r,s,t,sys}$$

  ▪ *Grass production:*

$$Prodt_{ggrsgprd} = \sum_{r,p,t,sys,cf} \frac{\overline{Yield_{r,s,t,sysggrsgprdp}}}{N_r}.Dis\_yield_{r,ggrsgprdp,s,t,sys,cf}.Bv_{r,ggrsgprdp,s,t,sys}.X_{r,s,t,sys}$$

  ▪ *Meat production:*

$$\Pr odt_{An,'meat'} = \sum_{da,int,sys} \overline{AnYield_{da,int,sys,An,'meat'}}.Dalvl_{da,int,sys}$$

  ▪ *Other animal production (e.g. Milk production):*

$$\Pr odt_{An,oaprd} = \sum_{da,int,sys} \overline{Yield_{da,int,sys,An,oaprd}}.Dalvl_{da,int,sys}$$

  ▪ *Product balance:*

$$\Pr odt_{pact,prd} = Sales_{pact,prd} + Use_{pact,prd}$$

o Sales$_{pact,prd}$: total sales of each crop and animal product *(pact, prd)* (Ton)
o Qsales$_{pact,prd,l}$: sales within quota of crop and animal product *(pact,prd)* and level *l* (Ton)
o Use$_{pact,prd}$: on-farm used production of each crop and animal product *(pact, prd)* (Ton)
o Quantf$_{prd}$: quantity of purchased feed per product type *prd* (Ton)
o Quantc$_{con}$: quantity of purchased concentrates per concentrate type *con* (Ton)
o Dasell$_i$: number of selling animal activity *i* (head)
o Nfertiliser: nitrogen mineral fertilizer purchased and used (Kg N/ha)
o Bv_modula: binary variable linked to modulation: modulation is applied only if the received premiums exceed the franchise
o Nman_import: nitrogen in manure imported (Kg N/herd)
o Nman_export: nitrogen in manure exported (Kg N/herd)
o PMPterm: the Positive Mathematical Programming term (this will be included only if

the PMP approach was selected to calibrate the FSSIM model and depends on the selected PMP variants).

A.1.2. Farm-level nitrogen balance

For livestock farms a nitrogen (N) balance at farm level is calculated in FSSM-MP based on the difference between the total N imported and the total N exported in products. The following variables are accounted for in the balance calculations (Schröder *et al*., 2003):

Imported:	Exported:
• Purchased feed	• Sold feed
• Fertilizer	• Sold milk
• Purchased animals	• Sold meat
• Imported manure N	• Sold animals
• N deposition	• Exported manure N
• Biological N fixation	

Based on the N balance at the farm level, the following environmental indicators have been defined:

- Average farm N surplus (kg N/ha) = $(N_{import} - N_{export})$ / farm area
- Farm gate N surplus (kg N) = $N_{import} - N_{export}$
- Farm gate N efficiency (%) = $(N_{export} / N_{import})*100$

In the following sections the different import and export components are described in detail.

A.1.2.1 Nitrogen imported to the farm (Nimport)

A.1.2.1.1 Purchased feed

The N in purchased feed refers to the amount of N imported through the purchase of additional concentrates and roughages that form part of the ration in the optimal FSSIM solution:

$$[64] \ N_{pfeed} = \sum_{sfeed} Quantf_{sfeed} Valf_{sfeed,NC}$$

Npfeed: total N in purchased feeds at farm level (kg N per farm).
sfeed: indices of different purchased feed types.
Quantf: quantity of purchased feed supplements (t DM).
Valf: N content (NC) of purchased feeds (kg N per t DM).

A.1.2.1.2 Fertilizer

The N in fertilizer refers to the amount of fertilizer N that is required to satisfy the N requirements of crops and grassland grown on the farm:

$$[65] \quad Nrequirement = \sum_{r,s,t,sys,p} Nuse_{r,s,t,sys,p} \frac{X_{r,s,t,sys}}{N_r}$$

$$[66] \quad Nfertilizer = Nrequirement - man\_used * Nman\_coef$$

r: indices of crop rotations,
s: indices of agri-environmental zones,

t: indices of production techniques,

sys: indices of production orientations,

p: indices of the number of years in a rotation,

$X_{r,s,t,sys}$: agricultural activities (ha),

N_r: length of a rotation (number of year),

Nuse: N requirement of each crop within each agricultural activity (kg N per ha),

Nrequirement: N requirement of all crops and grassland produced on the farm (kg N per farm),

Nman_used: amount of manure N that is used to satisfy the N requirements (kg N per farm),

Nfertiliser: amount of mineral N fertilizer that is used to satisfy the N requirements (kg N per farm),

Nmanure_coef: N manure coefficient (to equate manure N to fertilizer N; assumed to be 75%).

A.1.2.1.3 Imported manure N

The N in imported manure refers to the amount of manure N that is used to satisfy the N requirements of crops and grassland grown on the farm (see also Sections 9.2.4 and 9.3.1.1):

$$[67] \qquad N_{man\_import} = N_{man\_used} + N_{man\_export} - N_{man\_prod}$$

Nman_used: amount of manure N that is used to satisfy N requirements (kg N per farm),

Nman_prod: amount of manure N that is produced on the farm (kg N per farm),

Nman_export: amount of exported manure N (kg N per farm),

Nman_import: amount of imported manure N (kg N per farm).

A.1.2.1.4 N deposition

N deposition refers to region-specific atmospheric deposition of N, which is available in the CAPRI database at NUTS 2 level (Britz *et al.*, 2006):

$$[68] \qquad Ndeposition = \sum_{r,s,t,sys} X_{r,s,t,sys} Ndepo$$

Ndeposition: total N supplied at farm level through atmospheric deposition (kg N per farm),

N_depo: atmospheric N deposition (kg N per ha per year).

A.1.2.1.5 Biological N fixation

Biological N fixation refers to legume crops that are able to fix N from the atmosphere. Here we assume that 75% of the N uptake of the legumes grown on farm is fixed by biological processes:

$$[69] \qquad Nfixation = \sum_{r,s,t,sys,p} Nuse_{r,s,t,sys,p} \frac{X_{r,s,t,sys}}{N_r} (1 - Nfix_{r,p})$$

Nfixation: total amount of N supplied at farm level through biological N fixation (kg N per farm),

Nfix: biological N fixation of crops (75% for pulses).

A.1.2.1.6 Purchased animals

The N in purchased animals refers to the N contained in body tissue of purchased animals:

[70]

$$Npanimal = \sum_{da,\text{int},An} Dapurs_{da,\text{int}} Share_{da,\text{int},An} Weight_{da,\text{int},An} Nap\_content_{An,"meat"}$$

Npanimal: total amount of N in purchased animals at farm level (kg N per farm),
da: indices of dressed animal types (dairy, beef, sheep, goat),
int: indices of intensification levels (different milk and meat yields),
An: indices of age cohorts (cows, calves, heifers)**,**
Dapurs: purchased dressed animals per intensity level (head),
Share: share of age cohorts in dressed animal and intensity level,
Weight: live weight per age cohort at purchase (t),
Nap_content: N content of body tissue (%N).

A.1.2.2 Nitrogen exported from the farm (Nexport)

A.1.2.2.1 Sold feed

The N in sold feed refers to the amount of N in feed crops and roughages that is produced on farm and sold (exported from the farm):

$$Nsfeed = \sum_{c,prd} Sales_{c,prd} Valf_{prd,"NC"}$$

Nsfeed: total N in sold feeds produced on farm (kg N per farm),
c: indices of crops (wheat, barley, grass, etc),
prd: indices of product types (silage, hay, straw, etc),
Sales: total sold crop products (t per farm),
Valf: N content (NC) of feeds (kg N per t DM).

A.1.2.2.2 Sales of animal products (milk and meat)

The N in sold animal products refers to the amount of N in milk and meat that is sold:

$$Nsaproduct = \sum_{An} Sales_{An,prd} *1000* Nap\_content_{prd}$$

Nsaproduct: total N in sold animal products (kg N per farm),
Sales: sold animal products (t per farm).

A.1.2.2.3 Sold animals

The N in sold animals refers to the N contained in body tissue of sold animals:

[73]

$$Nsanimal = \sum_{da,\text{int},An} Dasell_{da,\text{int}} Share_{da,\text{int},An} Weight_{da,\text{int},An} Nap\_content_{"meat"}$$

Nsanimal: total N in body tissue of animals sold (kg N per farm),
Dasell: sold dressed animals per intensity level (head per farm).

A.1.2.2.4 Exported manure N

The N in exported manure N refers to the total amount of N in manure that is exported from the farm. In some regions with a manure surplus, such as the Netherlands, the export of manure is associated with costs, but in most other regions farmers will receive money for exported manure. The method to calculate the amount of manure N produced by animals on the farm is explained in more detail in the next section:

$$[74] \qquad Nman\_\exp ort = Nman\_prod + Nman\_import - Nman\_used$$

Nman_prod: production of manure N

Based on the approach of EC (1999) and Schröder *et al*. (2003), the production of manure N (Nman_prod) is the difference between feed N intake (Nration) by animals and the N retained (Nretention) in body tissue and in animal products (e.g. milk):

$$[75] \qquad Nman\_prod = Nration - Nretention$$

- **Nration** is the product of feed consumption and N content of the ration. The amount of each feed in the animal ration is the outcome of the FSSIM-MP optimization. The N contents of the individual feeds are available in the SEAMLESS database.
- **Nretention** is the product of live weight gain and N content of body tissue plus the product of milk production and N content of the milk. The various N contents are available in the SEAMLESS database, while milk production and live weight gain are a function of the production level and herd structure on the farm.

Nman_used: the use of manure N in crop and grassland activities

In FSSIM-MP, the available N in manure produced on farm (Section 7.2) is preferentially used to satisfy N requirements of crops and grassland in FSSIM-MP. If not all N requirements can be met with manure N, the rest is met with fertilizer (mineral) N (Section 9.1.2). Nitrogen requirements are quantified in FSSIM-AM and make up part of the technical coefficients describing the inputs and outputs of crop and grassland activities. It is assumed that the "effectiveness" coefficient of manure N is 75%, i.e., 100 kg of manure N is equivalent to 75 kg of fertilizer N. Depending on the region under study (Section 9.2.4), any manure N on the farm that is surplus to the N requirements of crops and grassland is sold (adding to the farm income) or exported against certain costs.

A.1.3 Other FSSIM outputs

Table A.1. Formulation of certain FSSIM outputs

Outputs	Unit	Formulations
Input use		$$MO_I = \sum_{i,t} F_{i,I,t} \frac{x_i}{\eta_i} \Big/ \sum_i x_i$$ **I** indexes the set of inputs applied in production of agricultural activities. **x** is a vector of agricultural activity levels **F** is a vector of inputs used by each agricultural activity **MO** is a vector of model outputs at farm level
Certain environmental outputs		$$MO_o = \sum_{i,t} E_{i,o,t} \frac{x_i}{\eta_i} \Big/ \sum_i x_i$$ - O indexes the set of environmental (i.e. externalities) - E is a vector of environmental outputs associated to each agricultural activity (most of these data are generated by the biophysical model) - MO: vector of model outputs at farm level
Crop diversity		$$P_{c,sys} = \sum_{s,t} X_{c,s,t,sys} \Big/ \sum_{c,s,t,sys} X_{c,s,t,sys}$$ $$CropDiv = 1 \Big/ \sum_{c,sys} P_{c,sys}^2$$ **x** is a vector of agricultural activity levels
Erosion Peak at farm level	T/ha	Max (Erosion Peak of selected activity i)
Runoff Peak at farm level	mm	Max (Runoff Peak of selected activity i)

Soil fertility loss	ha	For each selected activity i
		 If Organic Matter Rate *30 < -0.5% then
		  Soil fertility loss = Soil fertility loss + X_i
		else
		  Soil fertility loss = Soil fertility loss
		  X_i : activity level

Soil fertility gain	ha	For each selected activity i
		If Organic Matter Rate *30 > 0.5% then
		  Soil fertility loss = Soil fertility loss + X_i
		else
		  Soil fertility loss= Soil fertility loss
		  X_i : activity level

Table A.2 Comparison of the continuation of the Agenda 2000 and the legal texts of the June 2003 CAP reform

	Agenda 2000	**June 2003 CAP reform**
Cereals	- Intervention price at 101.31 EUR/t; - - Direct payments of 63 EUR/t multiplied with the reference yield - Monthly increments (seven steps each adding 0.93 EUR/t to intervention price)	- No cut in intervention price - No increase in direct payment - Cut of monthly increments by 50%
Durum wheat	Specific supplementary payment: - 344.5 EUR/ha in traditional areas - 138.9 EUR/ha in areas where the production is 'well-established' Within the limit of the Maximum Guaranteed Areas (MGA) Supplements depending on the use of certified seed	Decoupling from 2005 onwards and reduction of supplements - in "well-established areas" to 93 €/ha in 2004, 46 €/ha in 2005 and zero afterwards - in "traditional areas" to 313€/ha in 2004, 291 €/ha in 2005, 285€/ha from 2006 onwards - From 2004/05 introduction of special premium of 40 €/t, depending on certain criteria
Protein crops	Specific supplementary payment of 9.5 EUR/t times the reference yield	- Specific supplementary payment of 9,5 €/ton will be maintained and converted into crop specific area payment of 55,57 €/ha - Maximum Guaranteed Area of 1.4 mio. ha
Rice	Intervention price at 298.35 EUR/t (paddy rice) Direct payment of 52.65 EUR/t multiplied with the reference yield and paid per hectare, within MGAs	- 50 % cut in intervention price to 150 €/t, triggering intervention of limited quantity of max. 75000 t. - Compensation payments of 177 €/ton of which 75 €/ton granted as a crop-specific payment (blue box). - Reduce national MGAs to 1999-2001 average or the current MGA, whichever is the lower. - Mandate for the Commission to negotiate tariff quotas for rice imorts (article XXVIII)
Options - *Derogations*		Optional derogations may be applied by MS at national or regional level - 25% of hectare payments or, alternatively up to 40% of the suplementary durum wheat aid - 50% of sheep and goat premia - 100% of suckler cow premium and up to 40% of slaughter premium, or instead, 100% of the slaughter premium or 75% of the special male premium. MS may also - grant 10% of national ceiling as sector-specific payment in order to promote farm activites important for enhancing environment or improving quality and marketing of agricultural products - decide not to integrate drying aid and/or seeds into the single farm payment - exclude direct payments in outermost regions and Aegean Islands from single farm payment
Beef	Basic price at 2 224 EUR/t with private storage possible at 103 % of this price. Safety net intervention level of 1 560 EUR/t. Headage payments: 150 EUR for	No specific measure foreseen, however major implications of decoupling. Land dedicated to permanent pasture on 21.12.2002 must be maintained in that state (in relation to good farming practice).

	steers (two payments), 210 EUR for bulls/year and 200 EUR/year for suckler cows. Slaughter premium of 80 EUR (bulls, steers, cows) and 50 EUR (calves).	
Dairy	Quota-regime valid until 2008 Stepwise reduction of intervention price by 15 % from 2005/6 onwards Cow premium rising from 5.75 EUR/t to 17.24 EUR/t of quota from 2005/6 onwards plus additional payment ('top-up' premium and/or area payment) Global increase of quota by 2.39 % (first increase for Spain, Italy, Greece and Ireland in 1999-2001 and other Member States from 2005-2007)	- Quotas maintained to 2014/15 - Agenda 2000 decision (= price cut of 15%, compensated by direct payments, extra quota) will be replaced by assymetric price cuts: - butter: 7% in 2004, 7% in 2005, 7% ind 2006 and 4% in 2007 - SMP: 5 % in 2004, 5 % in 2005 and 5 % in 2006. - Compensation payments, including national envelope, will become on average 11.81€/ton in 2004, 23.65 €/ton in 2005, and 35.5 €/ton from 2006 onwards. - The pending quota increase for 11 MS will be postponed from 2005 to 2006, additional quota is allocated to Greece (120 000 t), Portugal (Azores) will obtain further exemption from the levy for 73 000 t in 2003/04 reduced stepwise to 50 000 t, to become permanent additional quota from 2005/06 onwards. - Ceiling to butter intervention: 70 000 t in 2004 to be reduced in annual steps of 10 000t to arrive at 30 000 t from 2008 onwards. - Intervention will only be open between 1 March and 31 August.
Modulation	Optional reduction of direct payments up to 20% Unspent money remains in Member State to be spent on accompanying measures	Modulation will start with a rate of 3% in 2005, 4% in 2006 and stay at 5% from 2007 onwards. Franchise of 5000 €, no further differentiation in reduction rates. Modulation will not be applied to Outermost Regions and the Aegaen Islands. Modulation money to be used for rural development from 2006 onwards. Allocation according to objective criteria, MS will receive at least 80% of its contribution to modulation.
Cross-Compliance	Optional use of reductions of direct payments for enforcing statuary environmental legislation and so-called specific environmental requirements	Compulsory cross-compliance as a whole farm approach: direct payments conditional on the respect of statuary legal standards (environment, food safety, and animal welfare) and keeping land in good agricultural conditions in line with environmental requirements.

Source: European Commission, 2003