Chapter 5
A Generic Farming System Simulator

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Introduction

The prime decision making unit in agriculture is the farm. It is the unit where agro-ecological innovations start and where agricultural and agri-environmental policies trigger changes in land use, production and externalities (e.g. nitrate leaching, soil erosion and pesticide use). The European Union (27 member states) counts ca. 15 million farms with a wide variation in endowments, specialisation and land use (Eurostat 2007). As a consequence of these differences and the diversity in entrepreneurship and personal or household aims, responses to a specific policy or innovation may differ across the farming community. This seriously complicates the devise and selection of effective and efficient policies, i.e. what may be an effective (realizing the desired effect with respect to for instance the environment) and efficient (realizing a desired effect at low cost for a farm or community) for one type of farms may not be so for another type.

Evaluation of present policies can be done based on empirical data, for instance using systematic data collected for a sample of farms throughout a region, nation or continent. The Farm Accountancy Data Network (FADN) provides such a source of information for the European Union. This is indeed useful to evaluate effectiveness of policies in terms of some indicators, particularly economic ones. However, such sources generally lack information on agricultural management and environmental issues. Moreover, these two data gaps are interrelated: the lack of agricultural management makes the application of for instance crop simulation models to assess environmental issues largely impossible. Hence, only FADN data complemented with detailed surveys and measurements enable the full ex-post evaluation of policy measures. For *ex-ante* assessment of policies, i.e. assessment of policies before their introduction, there is little empirical basis. Here, mathematical modelling can

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F.M. Brouwer and M. van Ittersum (eds.), *Environmental and Agricultural Modelling: Integrated Approaches for Policy Impact Assessment,* DOI 10.1007/978-90-481-3619-3_5,

potentially be an important source of information for the assessment. But for larger areas and systems, it requires a consistent and efficient application of such models to the great variation in prevailing farm types.

Recently, there has been increasing interest in so-called bio-economic farm models (Thompson 1982; Deybe and Flichman 1991; Wossink et al. 1992; Janssen and Van Ittersum 2007). These models link formulations describing farmers' resource management decisions to formulations that describe current and alternative production possibilities in terms of required inputs to achieve certain outputs and associated externalities (Kruseman and Bade 1998; Janssen and Van Ittersum 2007). One of their applications is to assess farm responses to policies and how these may differ across various farm types. More precisely for the European Union (EU), such applications might focus on assessing supply responses of farms across the EU and their effect on markets, and on more detailed regional assessments of policies in terms of economic, environmental and landscape issues. For application of a bio-economic farm model across the European Union, the model must 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. Application of one consistent bio-economic farm model to a broad range of farm types differing in size, intensity, specialisation and land use (Andersen et al. 2007) in our view requires a modular set-up.

The aim of this chapter is to present a bio-economic farm model, FSSIM (Farm System Simulator) with a modular set-up, which can be used as a standalone model and as a model within the framework for integrated assessment, i.e. SEAMLESS-IF (Van Ittersum et al. 2008). This farm model includes a data module for agricultural management (FSSIM-AM) and a mathematical programming model (FSSIM-MP). It offers a structure to flexibly apply it to farm types that may differ in: soils and climate, resource endowments, agricultural activities and their management options and utility functions, and that may be subject to a broad range of agricultural and agri-environmental policies (Fig. 5.1).

The chapter starts with a brief description of the farm typology that is used as a basis to simulate European farms. We present the mathematical programming part of FSSIM (FSSIM-MP), in which information on farm activities, resource constraints, policies and utility function of the farm is integrated. The following section presents the agricultural management part (FSSIM-AM) and its optional link to biophysical simulation models. The software implementation of FSSIM is presented and an application is provided at the end of this chapter.

Farm Typology

Aim of the Farm Typology

Modelling all individual farms within the EU is not feasible because of the large number of farms, and the existing diversity among different farming systems. For that reason it was decided to develop a farm typology that captures the heterogeneity

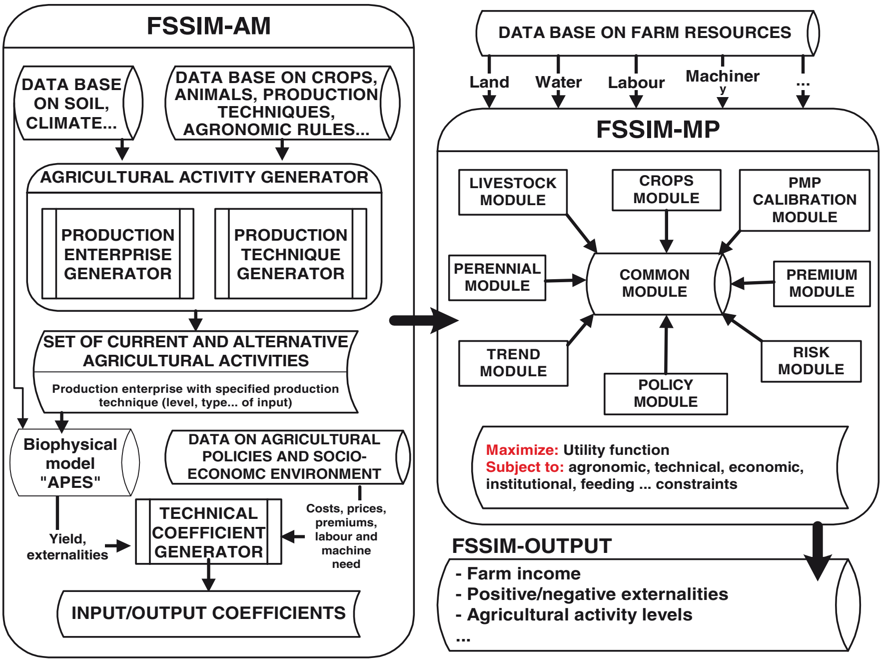

Fig. 5.1 FSSIM and its components

in farming systems. Based on FADN and Farm Structure Survey (FSS), this farm typology provides for each region in the EU (so called NUTS2 regions) a set of typical, well defined farm types in terms of size (i.e. total available agricultural land), intensity of production (i.e. output per hectare), land use and specialisation. The thresholds that are used to allocate farms to a specific farm type are the same for all Europe.

A spatial allocation procedure was also used for allocating the farm types to spatial units, with more homogenous bio-physical endowments (Chapter 7, this Volume). The aim was to enable the aggregation of farm types to both natural (territorial) and administrative regions. Each farm type of the SEAMLESS farm typology is linked to a number of agri-environmental zones defined as a combination of climatic conditions, soil characteristics and other geographical attributes.

Representation of the Farm Type: Average Versus Typical Farm

The farm type consists of a group of farms with similar socio-economic and agri-environmental characteristics. To simulate the behaviour of a certain farm type with a farm model (like FSSIM) it is important to select/construct a farm that represents adequately the whole group of farms that are classified in the same farm type.

Table 5.1 Advantages and disadvantages of the average and the typical farm

Average farm	Typical farm
• More observed production activities at the regional and market scale	• Representative for a group of holdings that meet the group criteria
• Lower additional data requirements (compared with FADN)	• Only the production activities of a specific farm are observed
• The average farm does not exist	• Farm scale data are required which are not always available
• More constraints and non-zero terms are needed for calibration	• The typical farm is observed in reality • Less constraints and non-zero terms are needed for calibration

Representation of the farm type could be achieved either by the average or the typical farm. The average farm could be defined as a virtual (not observed in reality) farm which is derived by averaging historical data from farms that are grouped in the same farm type. A typical farm is an existing (observed) farm with representative, for a certain farm type, properties and characteristics. Different approaches could be used when trying to identify a representative typical farm (e.g. selecting the farm that is close to the average farm or the one with the median profit).

The advantages and disadvantages of using one of the two approaches are summarized in Table 5.1.

The average farm was selected to represent all farms that belong to the same farm type in a certain region. The advantage of using the average instead of the typical farm is that this enables upscaling of farm type analyses to regional or even EU level. Generally the simulated farm plans of an average farm are less specialized (i.e. include a broader range of activities) than the results of a typical farm. This is mainly because production activities of all farms that belong to the same farm type will be represented in the base year data which is used for calibration. Even less common activities that are not so interesting to include in a farm level analysis but which may be important at the aggregated regional or EU level analysis will be represented in the base year data. In contrast, the base year data of a typical farm are restricted to the few production activities that are observed in the farm plan of a single farm.

One problem associated with the use of the average farm for representing a farm type is related to the fact that the average farm is not observed in reality. All different activities observed in the farm plans of individual farms of a certain farm type, are included in the farm plan of the average farm. Calibration of FSSIM to reproduce base year data of the average farm becomes a complicated procedure. It is expected, that a much larger number of binding constraints are required for calibration, when simulating the average farm than when simulating an individual farm. To overcome this problem a calibration method which is based on Positive Mathematical Programming (PMP) (Howitt 1995) has been developed and used in FSSIM.

The specification of the average farm and the calculation of its resource endowments are obtained by dividing the resources endowments of all the farms that are classified in this group by their numbers (i.e. number of farms of the group). The simple calculation is demonstrated in Table 5.2 with data from three farm types that have been identified in Midi-Pyrénées (France).

Table 5.2 Crop areas (ha) of two farm types (average farms) in Midi-Pyrénées

	Farm type 3201		Farm type 3202	
Size	Large		Large	
Intensity	Medium		Medium	
Specialization – land use	Arable/cereals		Arable/set-aside	
Number of farms represented	2,330		991	
	Total	Per farm	Total	Per farm
Barley	9,550	4.1	1,559	1.6
Dry pulses	8,749	3.8	3,593	3.6
Maize (grain)	81,764	35.1	24,820	25
Oil seeds	44,112	18.9	17,509	17.7
Other cereals	7,344	3.2	2,026	2
Peas	8,259	3.5	3,593	3.6
Set-aside	21,780	9.3	18,739	18.9
Soya	6,936	3	3,612	3.6
Sunflower	33,267	14.3	12,509	12.6
Wheat (durum)	40,313	17.3	11,326	11.4
Wheat (soft)	30,570	13.1	12,182	12.3
Permanent crops and vineyards	15,034	6.5	10,212	10.3
Irrigated area	97,375	41.8	30,085	30.4

FSSIM-MP: Mathematical Programming Model

Aim of FSSIM-MP

Based on mathematical programming, FSSIM-MP seeks to capture resource, socio-economic and policy constraints and the farmer's major objectives. 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 cannot be derived easily or at all (Heckelei and Wolff 2003). It allows also mixed ecological-economic analysis (Falconer and Hodge 2000; Louhichi et al. 2004).

The principal components of FSSIM-MP are:

– A set of decision variables that describe the agricultural activities and state of the system.
– An objective function describing the farmer's behaviour and goals in particular concerning risk.
– A set of explicit physical, financial, technical, economic and agronomic constraints, representing specifications for system operation.
– A set of policy and environmental measures (price and market support, quota and seta-side obligations, cross-compliance restrictions, etc.) as included in the Common Market Organizations (CMOs) regulations and some specific regulations.

FSSIM-MP is linked to a data module for agricultural management (FSSIM-AM), which aims to describe or generate current and alternative activities and quantifies their input-output coefficients (both yields and environmental effects) (see the following section). Once the potential activities have been generated, FSSIM-MP chooses those that best fit the farmer's objectives, given the set of resource, technological and political constraints. The principal outputs generated by the FSSIM-MP model are land use, production, input use, farm income and environmental effects of the farm type for a specific policy. These outputs can be used directly or translated into indicators (simple or composite) to provide measures of the impact of policies.

FSSIM-MP Overview

FSSIM-MP is a comparative static programming model with a non-linear objective function representing important elements of a farmer's behaviour. FSSIM uses exogenous prices that can come from different sources (in the base year they come from Eurostat or/and FADN data and in the simulation they can come from a market model, such as CAPRI). The principal FSSIM-MP specifications are:

(i) A mono-periodic model which optimizes an objective function for one period (i.e. 1 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 defined as "crop rotations" and "dressed animal" instead of individual crops and animals.
(ii) A risk programming model based on the Mean-Standard deviation method in which expected utility is defined under two arguments: expected income and risk (Hazell and Norton 1986).
(iii) An activity based model to enable integrated assessment of new policies which are linked to an activity (i.e. production process).
(iv) A primal based model where technology is explicitly represented in order to simulate the switch between production techniques as well as between production systems.
(v) A model with discrete activities to integrate easily the engineering production functions generated from biophysical models and to account for positive and negative jointness in outputs (i.e., joint production) associated with the production process.
(vi) A positive model in the sense that its empirical applications exploit the observed behaviour of economic agents and where the main objective is to reproduce the observed production situation as precisely as possible.
(vii) A generic model designed with the aim to be flexible, re-usable, adaptable and easily extendable to achieve different modelling goals.

The mathematical structure of FSSIM-MP is formulated as follows:

$$\text{Maximise: } U = Z - \phi\,\sigma \tag{5.1}$$

$$\text{Subject to: } Ax \leq B;\ x \geq 0 \tag{5.2}$$

Where: U is the variable to be maximised (i.e. utility), Z is the expected income (i.e. the average annual income), x is a (n × 1) vector of agricultural activity levels, A is a (m × n) matrix of technical coefficients, B is a (m × 1) vector of available resource levels, ϕ is a scalar for the risk aversion coefficient and σ is 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 matrix denotation, this gives:

$$Z = \sum_j p_j q_j + \sum_{j,l} p^a_{j,l}\, q^a_{j,l} + \sum_{i,t} \left(s_{i,t} - c_{i,t}\right)\frac{x_i}{\eta_i} + \sum_{i,t}\left(d_{i,t} + \frac{\psi_{i,t} x_i}{2}\right)\frac{x_i}{\eta_i} - \varpi L \tag{5.3}$$

Where: i indexes agricultural activities, j indexes crop products, l indexes quota types (e.g. for sugar beet A and B quota exist), t indexes number of years in a rotation, p is a vector of average product prices, q is a vector of sold production, 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, s is a vector of subsidies per crop within agricultural activity *i* (depending on the Common Market Organisations [CMOs]), c is a vector to account for variable cost per crop within agricultural activity *i,* d is a vector of linear terms used to calibrate the model (depending on the calibration approach), Ψ is a symmetric, positive (semi-) definite matrix of quadratic terms used to calibrate the model (depending on the calibration approaches), η is a vector representing the length of a rotation within each agricultural activity, ϖ is a scalar for the labour cost and L is the number of hours of rented labour.

An agricultural activity is defined in FSSIM as a way of growing a rotation (including mono-crop rotations) taking into account the agri-environmental zone (or soil type), the management practice, and the production orientation. It consists of a combination of one crop rotation, one agri-environmental zone, one production technique (i.e. management type) and one production orientation. Let R denote the set of crop rotations (including mono-crop rotations), S the set of agri-environmental zones, T the set of production techniques and Sys the set of production orientations. The set of agricultural activities i can be defined as follows:

$$\mathbf{i} = \{i_1, i_2, \ldots\} = \{(R_1,S_1,T_1,Sys_1), (R_2,S_1,T_1,Sys_1), \ldots\} \subseteq R \times S \times T \times Sys.$$

Agricultural activities can be based on individual crops if data on crop rotations are not available.

The principal technical and socio-economic constraints that are implemented in FSSIM-MP are: arable land per soil type (or agri-environmental zone), irrigable land per soil type, labour and water constraints. The same rule was applied for all of these constraints: the sum of the requirements for each resource cannot exceed resource availability.

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

- Risk neutral: implies that the risk aversion coefficient is equal to zero ($\phi = 0$).
- 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 can vary from 0 to 1.65 ($0 < \phi \leq 1.65$).
- Risk averse: automatically calibrate the 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 ($0 < \phi \leq 1.65$).

FSSIM-MP can be calibrated using any of the following approaches, depending on the application type:

(i) The risk approach;
(ii) The standard PMP procedure (Howitt 1995);
(iii) The Rhöm and Dabbert's PMP approach (Röhm and Dabbert 2003); and
(iv) The approach described in Kanellopoulos et al. (2009).

The base year information for which the model is calibrated stems from a 3-year average around 2003 (or any update of this baseyear). In terms of policy representation, FSSIM includes the major policy instruments related to production activities such as price and market support and set-aside schema as well as cross-compliance and agro-environmental measures. The following section gives an overview of the different policy instruments linked to arable crops and how they are considered in FSSIM-MP.

Modelling of Policy Instruments in FSSIM-MP

FSSIM is developed to analyse the European agricultural and environmental policies, either proposed or actual, and to enable ex-ante assessments of policy and market changes. To achieve this goal, it is necessary to take into account a wide range of the proposed EU policy instruments.

The principal policy instruments that are implemented in FSSIM-MP are the Common Agricultural Policy (CAP) support regime (price and market support, set-aside schema, quota system, etc.) included in the CMOs regulations, as well as cross-compliance and agri-environmental measures included in Horizontal and Rural Development Regulations. These policy instruments are captured in FSSIM-MP either by embedding them in the objective function (e.g. premiums), or by including them as constraints (e.g. set-aside and non-food production must cover set-aside obligations, set-aside is not allowed to exceed more than a certain

Table 5.3 Policy instruments implemented in FSSIM-MP

Instrument	Modelling	Data source
CAP compensation payment (including Single Farm Payment)	Linked to agricultural activities and included in the objective function	CMOs
Milk and sugar beet quotas	Constraints; upper bounds on sales	CMOs
Compulsory set-aside	Constraints; restrict set-aside to minimum 10% of COP (cereals, oilseeds and protein) crops	CMOs
Voluntary set-aside	Constraints; restrict total set-aside to 33% of COP crops	CMOs
Environmental condition/ cross-compliance	Constraints; controlled by binary-variables	CMOs + specific national and regional implementation
Agri-environmental measures	Constraints; controlled by binary-variables	CMOs+ specific national and regional implementation
Modulation of payment	Constraints; controlled by binary-variables	CMOs
Member State (national) compensation payment	Linked to agricultural activities and included in the objective function	Specific national and regional implementation

CMO: Common Market Organisation

percentage of COP crops). Table 5.3 gives a brief description of how the different policy instruments are modelled in FSSIM-MP. In case of a non-EU application these policy instruments can be de-activated.

Modelling all these instruments was an important challenge for FSSIM-MP, as even if some of them are implemented in an identical way everywhere in the EU25 (e.g. direct payment), others such as environmental measures have quite different national/regional implementations. In addition, the information on the administrative implementation of these specific measures is usually scarce, and often not systematically monitored, not published or even not open to the public.

The implementation of these instruments depends on the analysed policy in different scenario assumptions which are the Agenda 2000 for the base year scenario and the 2003 CAP reform for the baseline scenario.

Using a time horizon of 2013, the baseline scenario is interpreted as a projection in time covering the most probable future development of the European agricultural policy, with the Luxemburg Agreements on Common Agricultural Policy Reform as the core, and including all future changes already foreseen in the current domestic, EU and international legislation (e.g. sugar market reform). Taken as reference run, the baseline scenario is used for the interpretation and analysis of different policy scenarios.

Exogenous Assumptions for a Baseline Scenario

The baseline scenario should capture the complex interrelations between technological, structural, policy, population and market changes related to agricultural production and commodities world-wide. A number of exogenous assumptions are adopted in FSSIM-MP while building the baseline scenario. Some of these are characteristic for all farm models; others are specific to our system, because there is a need of consistency with the other models in the model chain of SEAMLESS, especially with the regional market model.

The key underlying assumptions considered in FSSIM-MP are the following:

– Inflation: an assumed inflation rate of 1.9% per year was adopted.
– Prices: the FSSIM baseline prices are obtained indirectly from the market model CAPRI. It consists to multiply the FSSIM base year prices (coming from the survey or Eurostat) by the relative change of SEAMCAP prices between the base year and baseline scenarios.
– Technical progress: the technical innovation is captured through the set of alternative activities generated and assessed by other components of FSSIM (see next section). This means that in the base year analysis only current activities are considered and in the baseline scenario both current and alternative activities can be included without any trend on yield.

FSSIM-MP Structure: Modular Setup

FSSIM-MP has a modular set-up which includes crops, livestock, perennials, premium, Positive Mathematical Programming (PMP), risk, trend and policy modules. These modules are linked indirectly by an integrative module involving the objective function and the common constraints (Fig. 5.2). Each module includes two GAMS files. The first one links the data definition and the module's equations and the second file 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 this modularity, FSSIM-MP provides the capabilities to add and delete modules (and their corresponding constraints) following the needs of the simulation, to select one or several calibration approaches (risk, standard PMP, Rhöm and Dabbert PMP approach) and to control the flow of data between database and software tools. FSSIM-MP also has the advantage that it 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 relational database, in Excel or in GAMS-include files provided that they are structured in the required format.

FSSIM-MP can be applied to individual (i.e. real) or representative farms (i.e. typical or average farms) as well as to natural (territorial) or administrative regions by considering the selected region as a large farm (i.e. if the heterogeneity

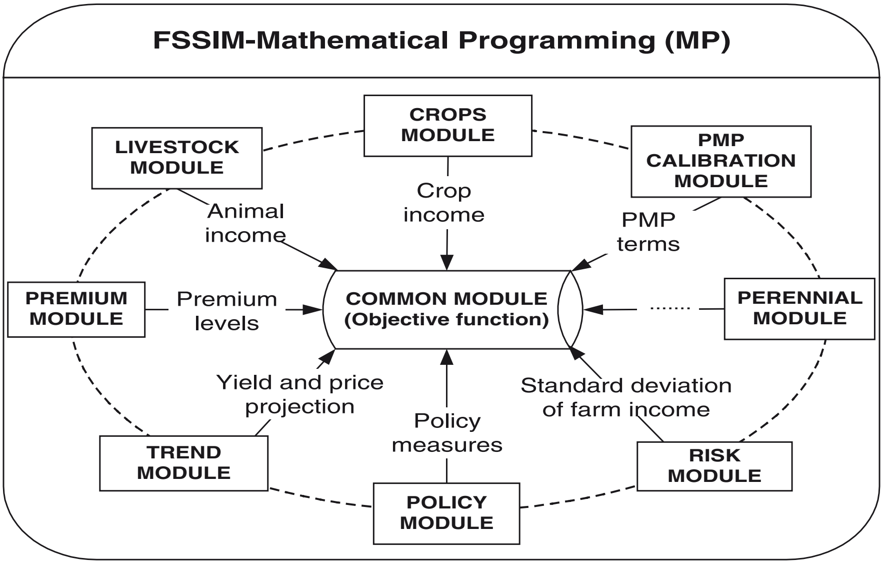

Fig. 5.2 Relationships between FSSIM-MP components

among farms inside the region is insignificant) or by aggregating the results of individual or representative farms (i.e. assuming the inter-dependencies between farms are minor).

FSSIM-AM: Agricultural Management

Aim of FSSIM-AM

Aim of the Agricultural Management Module is to describe, generate and quantify production techniques of current and alternative production enterprises which can be evaluated by APES (Chapter 4, this Volume), or other cropping/livestock system models, in terms of production and environmental effects. In this chapter, we focus on annual crop activities to describe FSSIM-AM, although the same methodologies have been used for livestock and perennial activities. The fully quantified activities i.e. the complete sets of agricultural inputs and outputs are assessed in FSSIM-MP on their contribution to the farmer's and policy goals considered. Alternative activities are new activities or currently not widely practised activities in the study area, and include technological innovations or newly developed cropping or husbandry practices (Van Ittersum and Rabbinge 1997; Hengsdijk and Van Ittersum 2002). Current activities are widely practiced in a sample region and their management operations and some of the associated outputs can be based on observed data and expert knowledge.

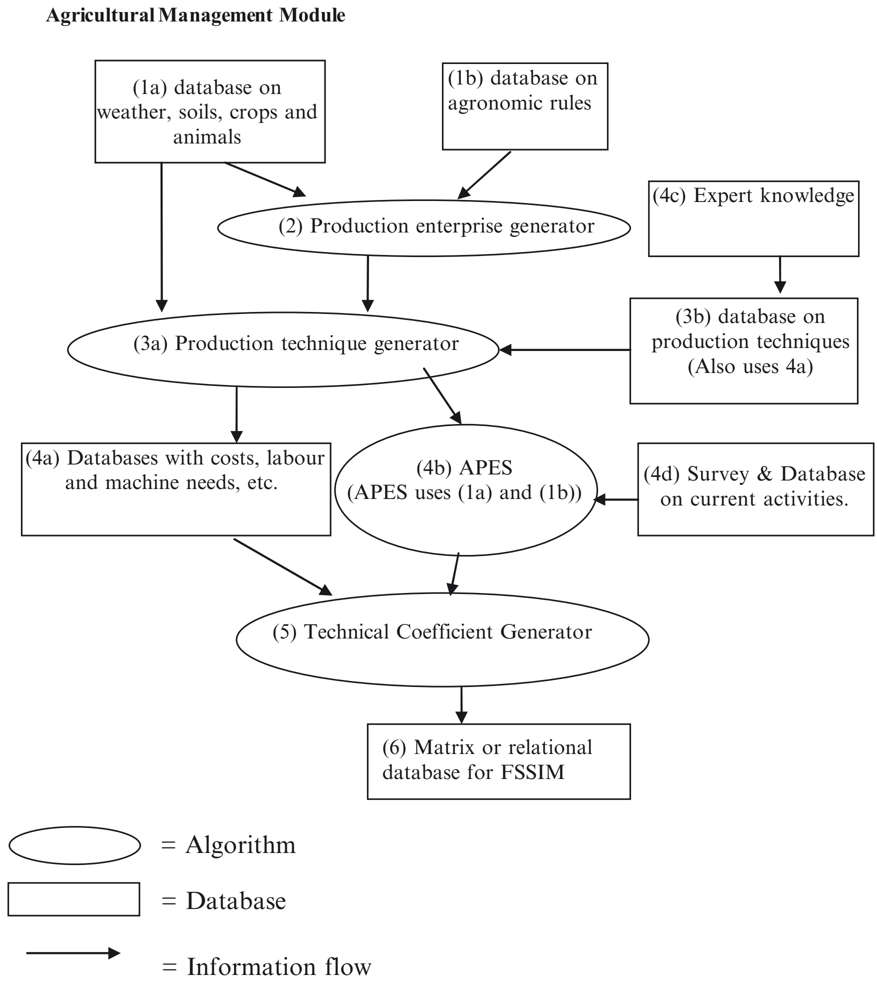

Fig. 5.3 Relationships between algorithms and database components in FSSIM-AM

The main components of FSSIM-AM are the Production Enterprise Generator (PEG), Production Technique Generator (PTG), Survey on Current Activities, and the Technical Coefficient Generator (TCG) (Fig. 5.3); FSSIM-AM is linked to a cropping system model, i.e. APES within SEAMLESS-IF. Relational databases are used to collect and store input and output information which is used in different components.

FSSIM and APES require information on the following items: yield of products, general management (sowing/harvesting), tillage/crop residue management, nutrient management, water management, weed, pest and disease management and the timing of different management events, while FSSIM-MP additionally requires information on costs of activities, price and yield variability, and different types of policies.

Deriving and Quantifying Current Activities

A current activity (CA) is an agricultural activity currently in use on farms. The biophysical assessment of these activities requires detailed information on the implements used in field operations and timing of all field operations to produce a product. This detailed management information cannot be extracted from aggregated databases such as FADN. In order to collect those data on current activities, two computer-based surveys were developed at different levels of detail.

Detailed Survey

A detailed survey includes detailed agronomic information on crop rotations and the field operations of each crop (Zander et al. 2009). This survey is completed by local experts with several years of experience in crop cultivation and knowledge about current agricultural practices. In order to limit the possible rotations, the number of potential crops in the survey is reduced on the basis of the crop distribution information in the FADN.

The survey's Graphical User Interface gives direct access to three windows containing all data entered:

(i) The crop rotations;
(ii) The field operations from tillage to harvest and their timing per crop; and
(iii) The resources related to field operations, differentiated per type of soil and climate.

Crops, field operations and resources have to be selected from predefined lists. The crop is defined by the botanical name, the growing period, the plant part used, the product quality aimed at and the production orientation (conventional or organic). Different intended usage and growing procedures for botanically the same plant species can be classified in a consistent way. For crop management, we tried to reduce complexity by identifying 70 different field operations which, in the case of seed and harvest, can have different economic and technical characteristics (e.g. harvest of sugar beet or cereals). In the case of fertilizers and pesticides, the survey offers no brand choice but the possibility to choose a certain type of fertilizer or pesticide – in the latter case only types of treatment are available (e.g. post emergence treatment of grass weeds in rape). The survey is designed to obtain the most complete information set on agricultural activities with a minimum effort. The tool includes a semi-automatic cost calculation procedure, which requires some economic information like machinery costs.

Simple Survey

The detailed survey requires a detailed knowledge about crop production, which is not easily accessible in a large number of regions. Consequently, a less demanding survey, e.g. Simple Survey was developed and implemented in a larger sample of regions. This survey concentrates on economic data for crop farming as well as on livestock and policy variables. Data needs for filling in the Simple Survey are limited, and required data can be readily derived from national or regional publications.

The Simple Survey's structure includes one part for each topic: livestock, crop farming and policies. Livestock is divided into one sheet each for beef cattle, dairy cattle, small ruminants for dairy, small ruminants for meat and grassland. Data for three intensities of livestock production can be entered. In the crop part, there is one variable list that must be filled in for all major crops based on regional FADN data. Crop rotations are entered in a separate survey sheet. The major difference compared with the detailed survey is that simple survey does not contain information on the timing of operations. The policy part consists of three single sub-parts with different structures, referring to CAP compensation payments, cross-compliance and agri-environmental measures as well as national subsidies.

Data Storage and Checking

Both surveys are server-based tools for which users only have to install a small application on their own computer. Entered data are directly stored in a PostgreSQL database server. Data from these databases are uploaded into the integrated database of SEAMLESS (Janssen et al. 2009). To facilitate error checking of entered data, there are several overviews provided in the surveys that can be opened from the graphical user interfaces.

Generating Alternative Activities

Purpose

Two components are used to define management operations of alternative activities:

(i) PEG generating rotations; and
(ii) PTG generating management operations and associated inputs for rotations.

Production Enterprise Generator

PEG is a tool to generate feasible sets of crop rotations of farms based on crop suitability filters, such as soil and climate characteristics and specific agronomic, rotation filters for annual arable crops. For example, timeliness rules avoid the generation of rotations in which crops are sown before the preceding crop is harvested. These pre-screening suitability filters limit the number of crop rotations for which production techniques need to be defined and the number of simulations to be carried out by APES.

Based on specific crop requirements (Russell 1990; Reinds and Van Lanen 1992; Wolf et al. 2004; Alterra and INRA 2005), ten crop suitability filters were developed. An example of such a filter is the altitude filter, which excludes crops from areas with unfavourable temperatures for crop production. The PEG contains an adapted version of ROTAT (Dogliotti et al. 2003). ROTAT is a tool to generate feasible crop rotations based on agronomic rotation suitability filters in a flexible and transparent manner. An example of a rotation suitability filter from ROTAT that was re-used in the PEG is the crop frequency filter, which limits the crop frequency in a rotation.

Production Technique Generator

The PTG is a tool to generate alternative production techniques for a feasible set of crop rotations. A production technique is a complete set of agronomic inputs characterized by type, level, timing and application technique (Van Ittersum and Rabbinge 1997). First, the PTG creates alternative management practices based on user defined parameters and agronomic expert rules. Second, the PTG combines different alternative management practices into production techniques. The complete set of inputs consists of the following management practices (Fig. 5.3):

– General management includes all operations that are mandatory for a successful harvest such as sowing, harvesting, clipping, pruning and field inspection.
– Water management includes rain fed or irrigated production; for irrigation, the method of application (sprinkler, furrow, etc.), timing rules and amounts must be described.
– Nutrient management includes a description of the level of application, type of nutrient, method of application and dose/timing of application of nutrient management.
– Weed pest and disease management includes packages that describe all operations required to achieve a well-defined control level of weeds, pests and diseases for a crop.
– Conservation management includes operations aimed at soil conservation and landscape and biodiversity management.

Technical Coefficient Generator

The TCG converts the agronomic input and output coefficients generated by the Surveys on CA, PEG and PTG in APES and FSSIM-MP compatible inputs. The TCG extracts data from the farm typology (Andersen et al. 2007) to define the farm types for FSSIM-MP. The result of the TCG is a fully quantified set of agricultural activities (Technical Coefficient Matrix) that can be transferred to FSSIM-MP.

The Technical Implementation Through an Integrated Modelling Framework (SeamFrame)

FSSIM is a collection of models, which are integrated into the modelling framework SeamFrame (Chapter 9, this Volume), have consistent inputs and outputs through an ontology and implement the OpenMI-standard to exchange data at runtime as components. SeamFrame is the software framework developed within the SEAMLESS project. The models of FSSIM are developed in different programming languages (e.g. C#, Java and GAMS), while data are stored in relational databases.

The architecture of SeamFrame is shown in Fig. 5.4. SeamFrame links the models to the data in the database and requires that models adhere to the ontology. The models are left in their original programming language and wrappers translate between the programming languages of the different models, the framework and the database (Fig. 5.4). A model wrapper provides the four functionalities. First, it wraps the model to a processing environment compliant interface and defines the exchange items (model inputs and outputs). Second, it initializes the model as component right after the start of the execution of the workflow. Third, it prepares for *each* run of the model dynamically the meta-models describing the model specifications (e.g. modules and equations to be used, sets definitions, how selected modules are structured, etc.). Fourth, it prepares the model input data in an exact format the model needs for each run of the model and retrieves model outputs of each run to be stored or communicated with other linkable model components.

Although the architecture leaves the models relatively untouched, the models lose their direct link to the database or data-source. The development of the wrappers is a tedious, difficult and time-consuming task. Each wrapper is specific to a model and

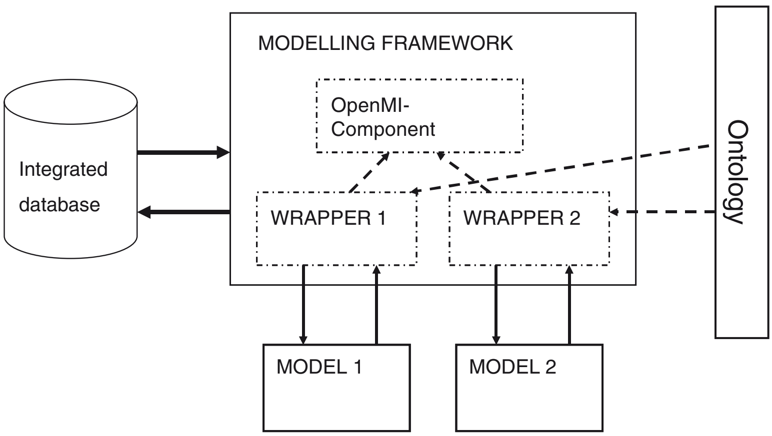

Fig. 5.4 The modelling framework SeamFrame with the wrapped models referring to a common ontology and database schema

therefore requires updates if the model is updated, which is difficult for maintenance. Such wrappers are not required for the FSSIM-AM models, as these have been developed in Java^{tm}, which is also the programming language of SeamFrame.

The Open Modelling Interface and Environment (OpenMI; Moore and Tindall 2005) was used in the SEAMLESS modelling framework to link the models at run time into a model chain. OpenMI is based on a pull-approach in which the last model in the chain pulls its outputs from other models in the chain by calling "getValues()"-methods, which means requesting outputs from a model or data source. The model can set its outputs as inputs to other models through a "setValues()"-method. The model components (Fig. 5.4) are developed as OpenMI-components. If a model is wrapped, then the wrapper needs to be developed as an OpenMI-component, which implies that the models are not aware of OpenMI or affected by OpenMI. The definition of data exchanged in setValues() (e.g. inputs) and getValues() (e.g. outputs) forced modellers to be specific about the inputs and outputs of a model and facilitated linking of the models in a model chain. Wrapping the model as an (OpenMI) component facilitated the definition of models independently of each other, of data sources and of the graphical user interface.

Model assumptions, interfaces and available data sources need to be clearly and explicitly specified, so that the models can be linked to each other. The FSSIM model interfaces in terms of inputs, outputs, states and parameters have been defined explicitly in an ontology, which is a collection of all concepts and relationships between concepts relevant to the domain (Antoniou and Van Harmelen 2004) and which functions as a dictionary. It sets up clear definitions for loosely integrating models in an open environment, facilitated by the knowledge manger for knowledge processing (such as reasoning and consistency checking) and by the domain manager (such as automatic generation of code templates for models and domain classes, accessing an instance of a domain class at runtime to supply the model component with the appropriate data).

FSSIM Application: Detailed and Simple Applications

Through the first application of FSSIM to a few regions it appeared that the data requirements of the models (FSSIM/APES) are too high (i.e. good data on farm management are extremely scarce). For this reason, it was decided to allow two variants of FSSIM: one that uses detailed data an agro-management and one that uses less detailed (simple or summarized) data on agro-management. The simple version can be more easily used for a larger number of applications necessary for up-scaling to the EU level (cf. Pérez Domínguez et al. 2009), whereas the detailed application is useful for application to specific regions. The principal differences between the two versions of FSSIM are summarised in Table 5.4.

The purpose of this section is to describe the results of a detailed and simple application of FSSIM to explain the followed procedure for running the model and to assess its capacity to reproduce the current situation and forecast the future.

Table 5.4 FSSIM application to regions with detailed or summarized data availability

FSSIM with detailed data	FSSIM with summarized data
– Use APES with observed input data	– Use APES with generated input data
– Use detailed survey	– Use simplified survey
– Includes current and alternatives activities	– Includes current and alternatives activities
– Use all FSSIM-MP modules	– Use only some FSSIM-MP modules
– Use semi-automatic procedure for calibration based on risk and/or Positive Mathematical Programming	– Use automated procedure for calibration based on risk or/and Positive Mathematical Programming

Detailed Application of FSSIM

FSSIM was tested for a range of detailed applications with the aim to analyse the current situation and to anticipate the impact of new, alternative scenarios and policy changes. In this chapter, results of Midi-Pyrénées (France) are presented as an example of the test application.

An overview on the selected components, modules and calibration procedure used in the detailed application as well as the tested scenario is described (Fig. 5.5) below:

- Components: the selected components are: (i) the farm typology; (ii) the detailed computer-based survey for agro-management and FSSIM-AM; (iii) the biophysical model APES; and (vi) the mathematical programming model FSSIM-MP.
- FSSIM-MP modules: the selected modules are the crops, premiums, risk, PMP, perennial, policy and common modules.
- 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. The model assigns automatically a value to the risk aversion coefficient[1] 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[2] (PAD). The aim of this step is to ensure that the model produces acceptable results before going to the second step.

[1]The chosen value can vary from 0 to 1.65, as suggested by the literature.

[2]Percent absolute deviation (%):

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

where $\hat{X}_i$ is the observed value of the variable *i* and X_i is the simulated value. The best calibration is reached when PAD is close to zero.

To do this test, the following assumptions were used: 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 specification must be improved before applying the second step. In the second step, we apply the Positive Mathematical Programming according to the Röhm and Dabbert (2003) approach in order to calibrate the model exactly to the observed situation.

– Tested scenario: The policy test case 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 the EU. This scenario was implemented at the market level (i.e. inside the market model, CAPRI) and the generated prices from CAPRI 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 Ittersum et al. 2008) (Fig. 5.5).

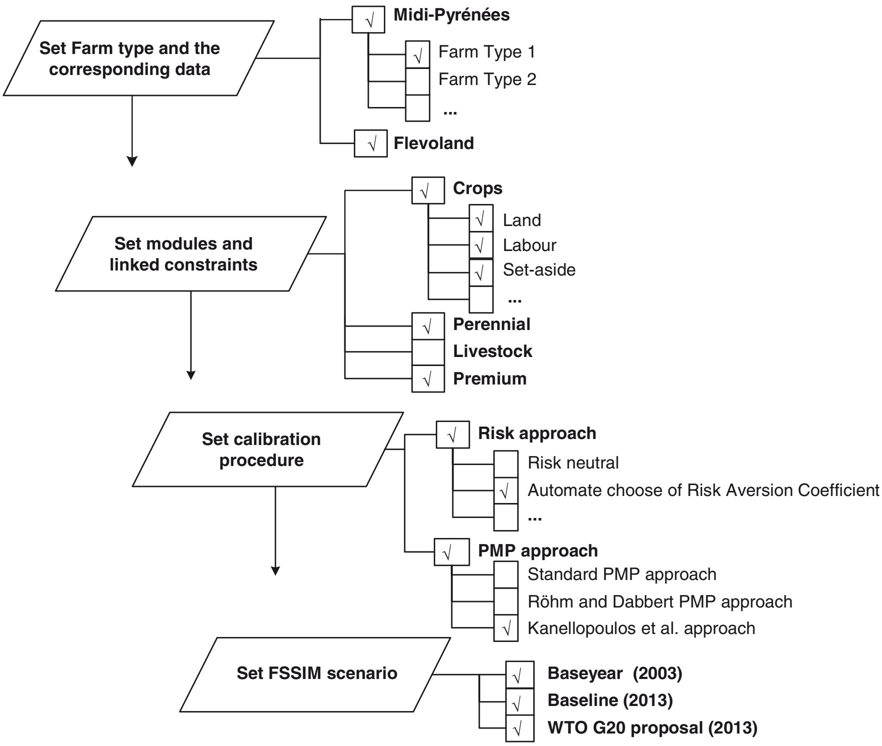

Fig. 5.5 Modules and calibration procedure selected in the detailed application

Table 5.5 Simulation of the WTO G20 proposal (policy scenario) for some economic and environmental aspects of the farm types of the Midi Pyrénées region

	Farm Type 1			Farm Type 2		
	Base year (2003)	Baseline scenario (2013)	WTO G20 proposal (2013)	Base year (2003)	Baseline scenario (2013)	WTO G20 proposal (2013)
		% change to baseyear	% change to baseline		% change to baseyear	% change to baseline
Farm income (k€)	86.3	65.8	62.0	81.9	65.4	63.5
		−24.9%	*−4.3%*		*−20.1%*	*−3.0%*
Premiums (k€)	39.9	29.9	29.8	35.3	27.4	27.4
		−23.3%	*−0.1%*		*−22.4%*	*−0.1%*
Nitrate leaching (kg N-NO_3/ha)	50.8	43.6	43.9	47.1	43.4	45.3
		−14%	*1%*		*−8%*	*5%*
Soil erosion (t/ha)	2.0	1.9	1.8	2.9	3.3	2.7
		−6%	*−7%*		*13%*	*−19%*
Pesticide use (kg/ha)	2.2	2.0	1.9	2.0	1.9	1.8
		−7%	*−4%*		*−3%*	*−10%*

Table 5.5 shows how two different farm types respond to the policy and baseline scenario, in comparison with the base year. Compared to the base year 2003, the farm income decreased in the baseline 2013 for the two farm types respectively with ca. 25% and 20%, mainly because of reduction of premiums. The environmental impacts in terms of nitrate leaching, soil erosion and pesticide consumption (average at farm level weighed by area per crop) seem positive due to the drop in the area devoted to cereals (mainly durum wheat and irrigated maize) and the increase in area of protein crops which are more efficient from an environmental point of view. The policy scenario tested in this example had a modest impact on farm income and nitrate leaching, in comparison with the baseline scenario, due to the limited impact of the policy proposal (G20) on the price of the major arable products as simulated by the market model.

Simple or Summarized Application of FSSIM

To enable upscaling of farm type analysis to the EU through the assessment of price-supply relationships (Pérez Domínguez et al. 2009), FSSIM is used with simple or summarized data. The data needs of FSSIM for the simple survey regions should be restricted to what is available in EU wide databases and the simple survey of current activities which was conducted within SEAMLESS to identify the currently used activities and the corresponding technical coefficients.

The purpose of this section is to describe a simplified version of FSSIM that can be used for analysis at EU level and to illustrate the type of analysis by presenting some preliminary results from application to Flevoland.

An overview on the components, modules and calibration procedure of the summary version of FSSIM-MP used for EU25 level analysis is described below:

– Components: the selected components are: (i) the farm typology; (ii) the simple computer-based survey; and (iii) the mathematical programming model FSSIM-MP.
– FSSIM-MP modules: the selected modules are the crops, premiums, PMP, trend, policy and common modules.
– Calibration procedure: The calibration procedure used in the detailed version of FSSIM-MP is also used here with minor adjustments.
– Tested Scenario: The model was calibrated for the base year and used to predict changes in the baseline scenario. Sensitivity of crop product quantities to prices changes was simulated to assess price supply relationships at higher levels. The price of each crop product was changed iteratively to 60%, 80%, 120% and 140% of the original price keeping the other product prices constant. The effects on supply were assessed in each iteration.

Running FSSIM for all farm types of the regions with summary information on agro-management requires some adjustments of FSSIM to restrict the data requirements to what is available in FADN and the simple survey. Those adjustments are:

1. In the first phase of PMP the observed crop levels are used as upper bounds to the added calibration constraints. In FADN there is no information on single crop levels, instead there is information on groups of crops (e.g. fresh vegetables which refers to the area of a number of crops such as area of onion, carrot and cabbage). In the detailed version of FSSIM, expert knowledge is used to transform the observed levels of FADN crop groups to observed levels of single crops. Finding experts in all sampled regions would be a resource demanding process. To avoid this process it was decided to evaluate and calibrate the reduced version of FSSIM directly on FADN crop groups.
2. In some cases, the observed cropping pattern of some farm types included crops that are not part of any rotation identified in the simple survey. This implies that it is not possible to simulate such crops. To avoid this problem it wad decided to treat the area of these crops as fixed land and it was subtracted from the total available farm land.
3. Finally, in order to ensure that there is at least a linear combination of activities that reproduces the observed cropping pattern, we decided to include some mono-crop activities, defined as rotations of a single crop; this is justified because this represents rented land (e.g. from dairy farms) on which specific crops are grown for 1 year.

An example of the sensitivity analysis of prices performed for one of the farm types in Flevoland is presented in Table 5.6. Note, that spring wheat substitutes winter wheat when prices of spring wheat are high or those of winter wheat are low. These farm level results are used to estimate price-supply relationships at regional level and subsequently they will be extrapolated with advanced econometric procedures (EXPAMOD) to non-sampled regions (Pérez Domínguez et al. 2009).

Table 5.6 Simulated supply response (tonnes per farm) to price changes for farm type 3303 in Flevoland

		Supply response (tonnes)					
	Price (€/t)	Maize (silage)	Onions	Potatoes	Sugar beet	Wheat spring	Wheat winter
Maize (silage)	21	23	671	1,219	628		132
	28	29	671	1,217	626		131
	35	35	670	1,216	624		131
	41	41	669	1,215	622		130
	48	47	669	1,214	620		129
Onions	66	39	526	1,237	660		143
	89	37	598	1,227	642		137
	111	35	670	1,216	624		131
	133	33	742	1,206	606		124
	155	31	814	1,195	588		118
Potatoes	45	41	684	1,055	672		147
	60	38	677	1,135	648		139
	75	35	670	1,216	624		131
	89	33	663	1,297	600		122
	104	30	655	1,376	585		113
Sugar beet	27	36	673	1,222	585		134
	36	36	673	1,222	585		134
	46	35	670	1,216	624		131
	55	33	662	1,201	724		122
	64	30	655	1,187	824		113
Wheat spring	86	35	670	1,216	624		131
	115	35	670	1,216	624		131
	144	35	670	1,216	624		131
	173	35	670	1,216	624	119	
	202	33	662	1,201	599	126	
Wheat winter	94	38	677	1,231	649	111	
	125	38	677	1,231	649	111	
	156	35	670	1,216	624		131
	187	32	661	1,199	594		140
	218	28	651	1,178	585		148

Conclusions

This chapter presented a detailed description of the bio-economic farm model (FSSIM), especially its specifications, structure, model linking and component integration. The original contributions of FSSIM to bio-economic farm modelling are the integrative approach, the modular setup and the generic features. The integrative approach of FSSIM makes the complex relationship between biological processes and economic decisions more transparent and allows a correct integration of technical economic and environmental issues, enabling the simulation of the different type of policies. The multidisciplinary framework facilitates synthesis of scientific knowledge in the domain of agriculture and its environment. The generic features allow the application to the broad variation of farming systems inside and outside the EU. The modular setup provides the possibilities to activate and de-activate modules depending on regions and conditions, to consider different types of policy instruments (subsidies, regulation, taxes, etc.) and to choose different methodological approaches, that are consistent with the data availability for a specific application. This includes different approaches concerning the representation of risk, different calibration approaches and different representations of agricultural activities.

FSSIM targets to be applied by different types of users such as (i) researchers with the purpose of testing different approaches; (ii) policy experts having the purpose of making ex-ante assessment of policies; and (iii) other stakeholder groups with the purpose to anticipate the effect of new policies.

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