A generic bio-economic model for integrated assessment of agricultural and land use policies at farm and regional levels

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Introduction

Assessing the impact of policy on agriculture and sustainable development has become a central issue for researchers, stakeholders and policymakers in both developed and developing countries. It represents a systematic and careful attempt to shed light on the possible effects of policy proposals and plays an important role in the implementation of the sustainable-development strategy. Several governments have introduced regulatory impact assessment procedures for their own policy-making processes and others are being encouraged to do the same. Science has contributed largely to such governmental demands and an increasing body of literature and models is being developed. However, most of existing models are mono-dimensional, monolithic, and targeted to answer specific problems. Approaches that allow flexible impact assessment for a range of issues and functions are scarce. 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.

The aim of this paper is to present an integrated approach developed within the European SEAMLESS project (Van Ittersum *et al.*, 2008) that attempts to overcome some of the limitations of earlier impact assessment models. Based on the link of biophysical and economic models, this approach seeks to assess the ex-ante impact of European agricultural and environmental policies and technological innovations on farm's performance and sustainability at multiple scales. In this paper we focus mainly on the bio-economic farm model FSSIM (Farm System SIMulator) since it can be easily adaptable and reusable in the context of developing countries. Thanks to its generic and modular setup, FSSIM can be used to assess a wide range of agricultural, environmental and land use policies under various socio-economic conditions and for different agricultural systems. Here we define generic as being useful for a range of agrienvironmental zones, different farm types, different innovations or policy questions and applications that require different level of detail in input or output data.

Methods

The main objective of SEAMLESS is to deliver an integrated and operational framework for ex-ante assessment of the impact of policy changes and technological innovations in agriculture and agro-forestry at multiple scales (from field, farm, region to EU and global). To achieve this goal a SEAMLESS-Integrated Framework (SEAMLESS-IF) was developed based on a set of models linked and integrated automatically (Figure 1): the general equilibrium model GTAP used to asses the consequences of policy change at the global level. The agricultural sector model SEAMCAP (Britz *et al*, 2007) that simulates supply-demand relationships in the EU-25 for agricultural commodities. The bio-economic farm model FSSIM (Louhichi *et al*, 2009b) which simulates farm behaviour using agricultural activities (e.g. crop rotations) assessed through a mechanistic simulation model for agricultural production and externalities (APES; Donatelli *et al.*, 2009), working at field scale. The meta-model EXPAMOD (Bezlepkina *et al*, 2007) used to extrapolate economic results from sample of farms to all EU25 farms by means of econometric approaches.

To apply this model chain a farm typology was developed within SEAMLESS since modeling all individual farms within EU25 is not plausible due to data, manpower, financial and computer software limitations. The SEAMLESS farm typology was created by extending the EU farm typology, which mainly classifies farms according to their income, with environmental criteria related to the land use and intensification of farming (Andersen *et al.*, 2006). A spatial allocation procedure was used to add a spatial dimension to the farm types and make it possible to aggregate model's results at farm type level to both natural (territorial) and administrative regional level (Elbersen *et al.*, 2006). The "average farm", which is a virtual (not observed in reality) farm derived by averaging historical data from farms that are grouped in the same farm type, is used to represent all farms that belong to the same farm type.

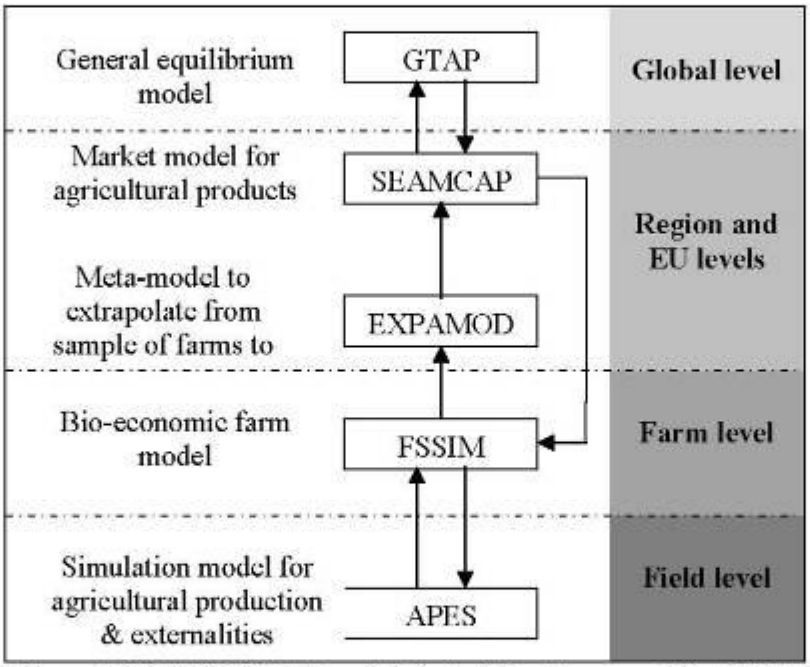

Figure 1: SEAMLESS-IF model chain (Van Ittersum et al., 2008)

As stated above, in this paper we focus mainly on the bio-economic farm model FSSIM (Farm System SIMulator) as it is the only one from the SEAMLESS model chain which can be easily adapted and reused in the context of developing countries to simulate the impact of policy and market changes at farm and regional levels.

FSSIM is a bio-economic farm model which integrates biophysical processes, farm decision making and resource endowment. 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 can be used for two purposes: (i) to allow detailed regional impact assessment of policy decisions, market change and technological innovations on farming practices and sustainability of the different farming systems; (ii) to facilitate the link of micro and macro levels in integrated way through the estimation of supply-response functions that can be integrated in a partial equilibrium market model.

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 (Janssen *et al.*, 2009). 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 (Louhichi *et al*, 2007). 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 2).

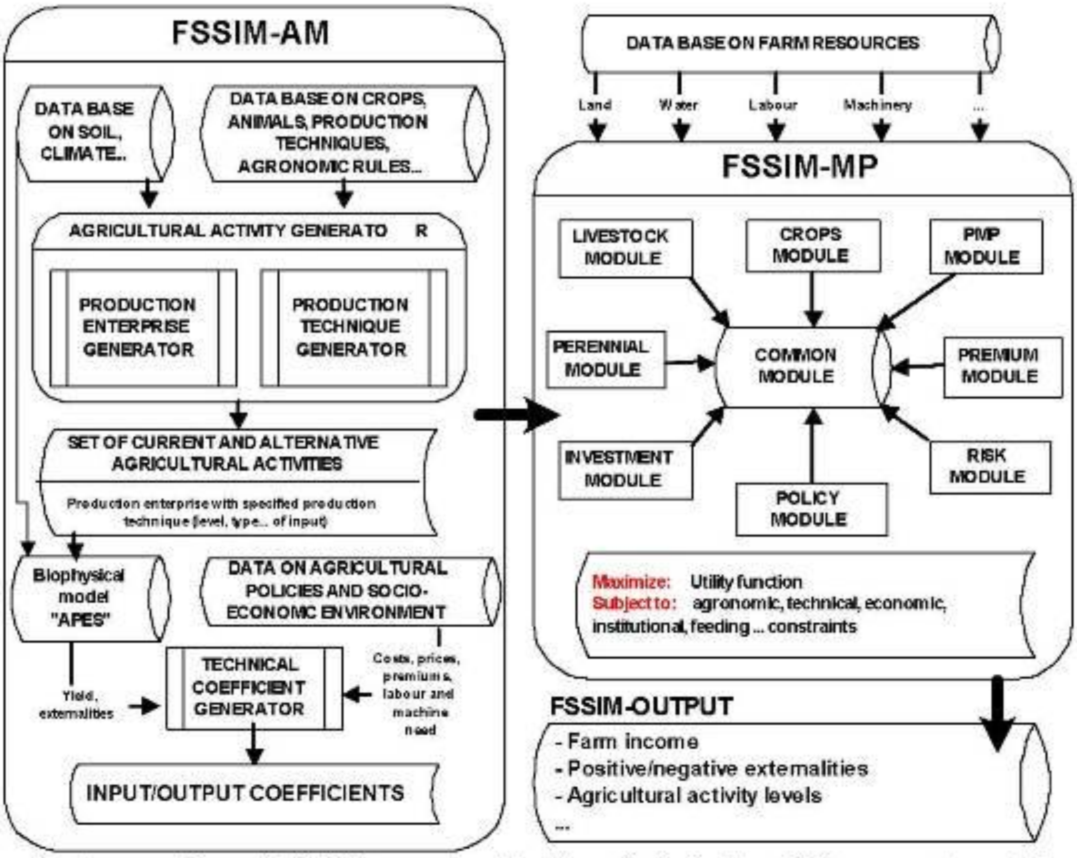

Figure 2. An overview of FSSIM as a combination of Agricultural Management module and Mathematical Programming module (Louhichi et al., 2009b).

FSSIM 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 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 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 include text files, provided that they are structured in the required format.

FSSIM can be applied to individual (i.e. real) or representative farm (i.e. typical or average farm) as well as to natural (territorial) or administrative region by considering the selected region as a large farm (i.e. if the heterogeneity among farms inside the region is insignificant) or by aggregating the results of individual or representative farms (i.e. if the inter-dependencies between farms are minors).

The mathematical programming module of FSSIM (FSSIM-MP) is a constraint optimization model which maximizes an objective function at given prices and subsidies subject to a set of resource and policy constraints. It consists of a static, non-linear programming model, which maximizes the farm's utility defined as the expected income minus risk, according to the Mean-Standard deviation method. FSSIM-MP is referred to as a positive mathematical programming (Howitt, 1995) model which integrates a large number of crop and animal activities to facilitate the endogenously matching between feed availability and feed requirements in mixed farming system. The principal specifications of FSSIM-MP are (Louhichi *et al.*, 2007): (i) 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[1]” rather than individual crops and animals; (ii) a positive model in the sense that its empirical applications exploit the observed behaviour of economic agents to reproduce the observed production situation as precisely as possible; (iii) an activity based model to make suitable integrated assessment of new policies which are linked to activity (i.e. production process) and not to product; (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 discrete based model to integrate easily the engineering production functions generated from biophysical models and to account positive and negative jointness in outputs (i.e., joint production) associated with the production process. These specifications enable FSSIM to explore the impacts of policy changes and technological innovation not only on the relationship between market and nonmarket goods, but also on the production process.

The general mathematical formulation of FSSIM is presented below:

Maximise: $\boldsymbol{U = Z - \phi\sigma}$

Subject to: $\mathbf{Ax \leq b,\ x \geq 0}$

Where U is the utility function to maximise, z is the expected income, **x** is the nx1 vector of the simulated levels of the agricultural activities, $\boldsymbol{\phi}$ is the risk aversion coefficient, $\boldsymbol{\sigma}$ is the standard deviation of income due to price and yield variation, A is a n×m matrix of technical coefficients, and b is a n×1 vector of available resources and upper bounds to the policy constraints.

The farm’s expected income is defined as total revenues including sales from agricultural products and compensation payments (subsidies) minus total variable costs from crop and animal production. Total variable costs include accounted linear costs for fertilizers, irrigation water, crop protection, seeds and plant material, animal feed and cost of hired labour as well as unaccounted cost due to management and machinery capacity reflected by the quadratic term of the cost function. Using mathematical notation, the non-linear income function can be presented as follow:

$$Z = r'x - d'x - 0.5xQx'$$

Where Z is the expected income, **r** is the n×1 vector of total revenues per activity, **d** is a n×1 vector of activity linear costs of activities, **Q** is the n×n matrix of quadratic terms of the cost function and **x** is a n×1 vector of the simulated levels of the agricultural activities. Q and d parameters are estimated using a variant of the Positive Mathematical Programming approach which guarantees exact reproduction of activity levels observed in the base year.

Results and conclusion

FSSIM has been applied to 11 regions to assess supply responses for EU, to 4 regions for a more comprehensive regional analysis, to both arable and livestock systems and to one region (Mali) outside the EU (Table 1). The distinction between two different purposes, the subdivision of FSSIM in different modules and the coupling to the different user interfaces has proven to be useful for achieving an appropriate configuration of the model with respect to data availability, research question and location.

This large number of application has demonstrated the capacity of the model to simulate different farming system under various socio-economic conditions and policies. It has illustrates also its potentials to integrate technical, economic and environmental knowledge and to make the policy debate on the CAP reforms more transparent thus contributing to well-informed decision-making.

In order to facilitate the use of FSSIM by policymakers and reduce the burden on scientists, an automated interface is being developed.

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

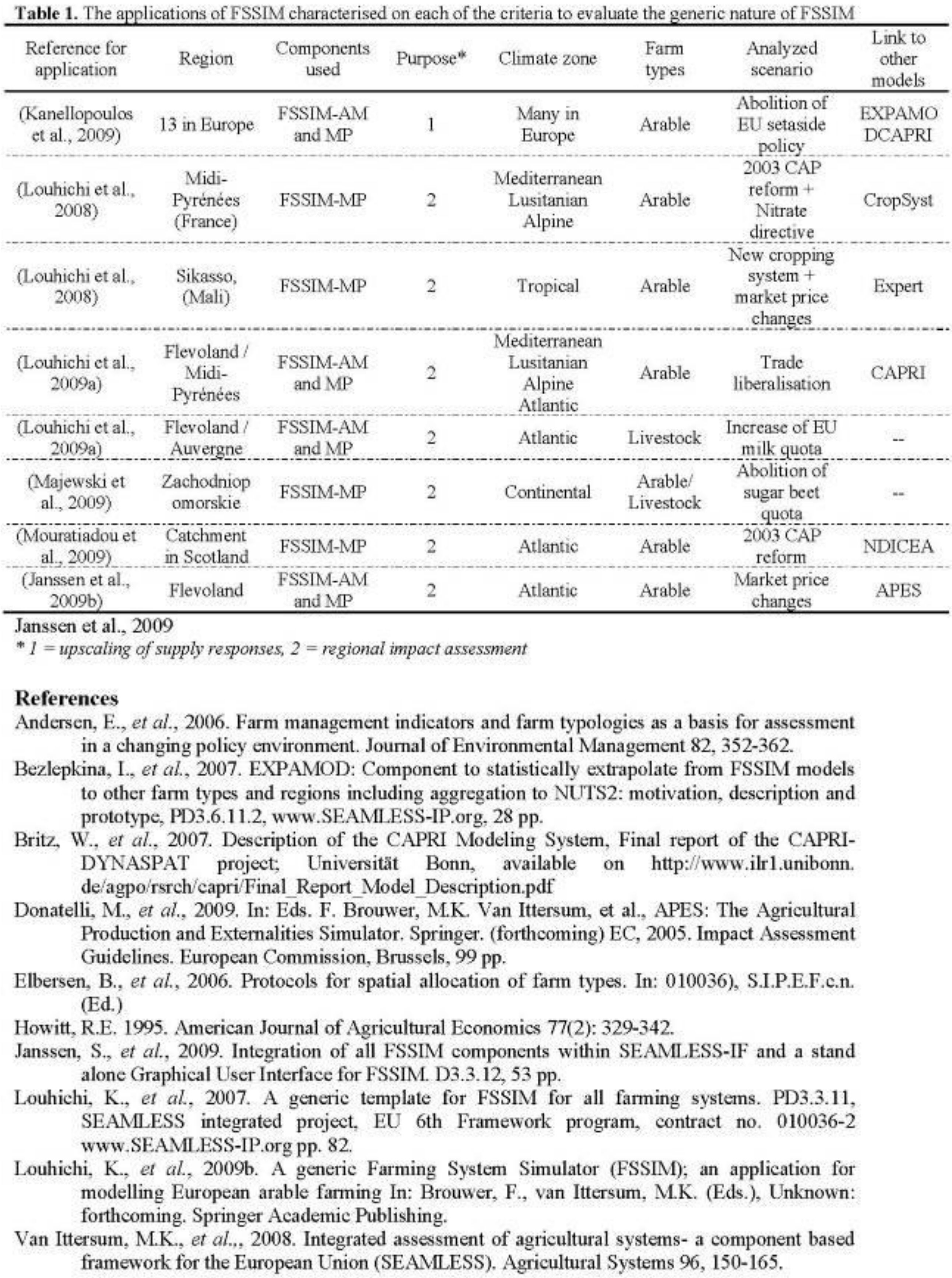

Table 1. The applications of FSSIM characterised on each of the criteria to evaluate the generic nature of FSSIM

Reference for application	Region	Components used	Purpose*	Climate zone	Farm types	Analyzed scenario	Link to other models
(Kanellopoulos et al., 2009)	13 in Europe	FSSIM-AM and MP	1	Many in Europe	Arable	Abolition of EU setaside policy	EXPAMO DCAPRI
(Louhichi et al., 2008)	Midi-Pyrénées (France)	FSSIM-MP	2	Mediterranean Lusitanian Alpine	Arable	2003 CAP reform + Nitrate directive	CropSyst
(Louhichi et al., 2008)	Sikasso, (Mali)	FSSIM-MP	2	Tropical	Arable	New cropping system + market price changes	Expert
(Louhichi et al., 2009a)	Flevoland / Midi-Pyrénées	FSSIM-AM and MP	2	Mediterranean Lusitanian Alpine Atlantic	Arable	Trade liberalisation	CAPRI
(Louhichi et al., 2009a)	Flevoland / Auvergne	FSSIM-AM and MP	2	Atlantic	Livestock	Increase of EU milk quota	--
(Majewski et al., 2009)	Zachodniopomorskie	FSSIM-MP	2	Continental	Arable/ Livestock	Abolition of sugar beet quota	--
(Mouratiadou et al., 2009)	Catchment in Scotland	FSSIM-MP	2	Atlantic	Arable	2003 CAP reform	NDICEA
(Janssen et al., 2009b)	Flevoland	FSSIM-AM and MP	2	Atlantic	Arable	Market price changes	APES

Janssen et al., 2009

** 1 = upscaling of supply responses, 2 = regional impact assessment*

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