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**Documentation  
of the MEA-Scope tool prototypes  
with special focus on their capability to analyse  
multifunctionality policies**

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## 1 INTRODUCTION

### 1.1 Motivation

The Model of European Agriculture (MEA) views agriculture as the producer of agricultural goods and of such diverse outputs as landscape, environmental benefits, food security, rural employment, or cultural heritage. Multifunctionality refers to the fact that agriculture produces jointly commodity and non-commodity outputs (COs and NCOs) (BLANDFORD and BOISVERT 2002, BOISVERT 2001, LANKOSKI and OLLIKAINEN 2003, OECD 2001, PETERSON *et al.* 2002, VATN 2002). In view of the MEA, the recent reform of the first pillar of the Common Agricultural Policy (CAP) towards decoupled direct payments, modulation, and cross-compliance introduced significant changes to the European agricultural sector. Regarding the second pillar, the council regulation on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) (EC Council Regulation 1698/2005) for the programming period 2007-2013 shifts the focus increasingly towards rural development policy (SCHADER and STOLZE 2005, PIORR *et al.* 2005).

With the new enlarged priorities for the agricultural sector, new challenges for research also arise. To optimise the effectiveness and efficiency of the diverse CAP instruments towards getting closer to the above mentioned multifunctional MEA, it is required to assess the impacts of agricultural activities on the multiple functions in the wide range of European landscapes. The integration of socio-economics, environmental aspects and agronomy is needed to deliver information support that facilitates shaping the rural development policy in an effective way according to the respective needs and potentials of rural areas. Therefore, a substantiated knowledge of the site specific potentials and the characteristics of and conditions for CO production provide the basis for the identification of site specific potentials for NCO production and the development of feasible joint production techniques.

The FP 6 EU project MEA-Scope responds to this need for multifunctionality impact assessment. A key objective of MEA-Scope is to develop a tool that allows simulating important interactions between multifunctionality and policy instruments at farm and regional scale. The tool consists of three linked simulation models and it combines three existing distinct programming and simulation models (MODAM, FASSET and AgriPoliS) to capture different environmental, economic and social facets of multifunctionality. The models focus on different complementary aspects relevant to modelling the multifunctional aspects of agriculture. MODAM (ZANDER 2003) and FASSET (BERNTSEN *et al.* 2003) capture the farming processes and the joint production of non-commodity outputs in detail. They are complemented by AgriPoliS's (HAPPE *et al.* 2004) focus on modelling policy impact on regional structural change (HAPPE 2004) that adds an important dynamic dimension to policy impact analysis.

As the project represents a first step towards an operationalisation of multifunctionality impact assessment, it does not produce results which are generally applicable. Rather the tool is developed to the conditions and landscapes of seven case study areas across the EU with a focus on beef production. The application of the tool is done in Workpackages 4 and 5 (WP4 and WP5) of the project. Although the issue of multifunctionality concerns rural areas as a whole, the project's main focus is on the specific contribution of agriculture.

## 1.2 Objective of research and structure of the report

The aim of this report is to document the prototype of the MEA-Scope modelling framework. Specifically the potential for the combined model to analyse the effects of CAP policy options within the framework of multifunctionality will be presented.

A prototype is defined as

*"a first full-scale and usually functional form of a new type or design of a construction"* (Merriam-Webster online 2005).

Accordingly, by prototype we mean a version of the tool in which all three models are used together, but which is not yet fully operational with some questions and problems remaining to be applied to all case study landscapes in the project. The work presented is the result of Workpackage 3 within the MEA-Scope project.

The specific goal and scope of the MEA-Scope modelling framework is to

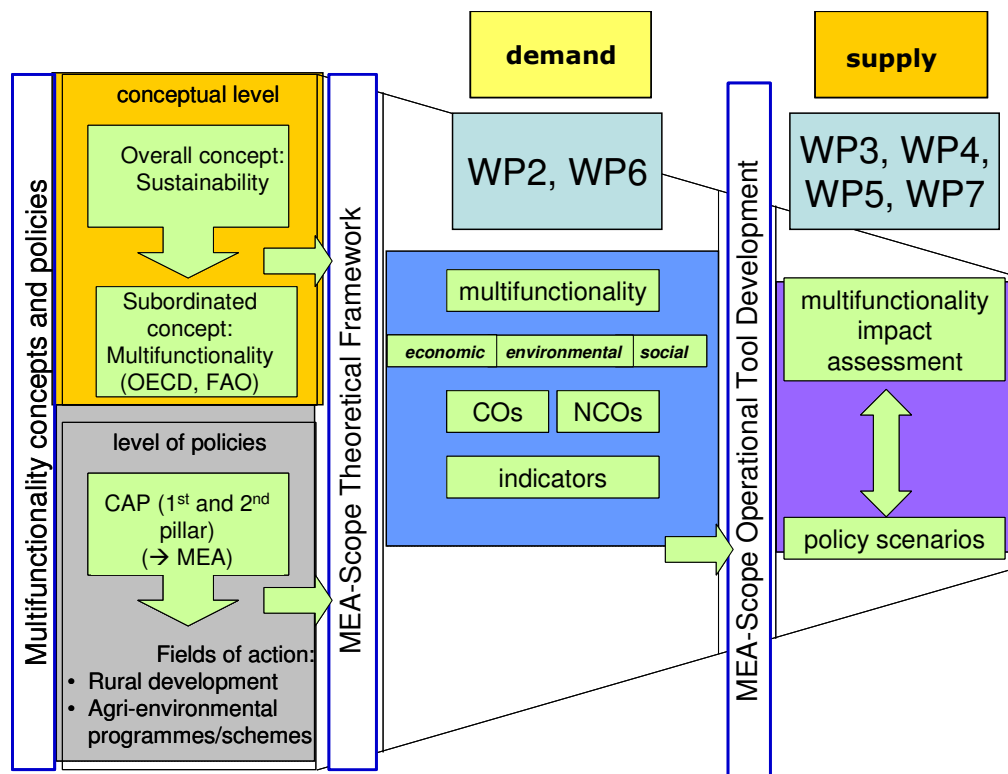
- incorporate different spatial and temporal dimensions in the same investigation,
- investigate a multifunctional set of parameters,
- be able to look at the whole region and at details of individual farms in the same analysis,
- create a common analysis methodology and analysis process which can be adapted to the study of the seven MEA-Scope case study areas.

In this report, we will proceed starting from a more general and abstract level towards a more in-depth presentation of specific data requirements and model adjustment to case study region. The approach implies the following structure: First, we present the individual models and their technical interrelations in the linked model (sections 2 and 3). Special focus is put on possible policy options which could be analysed using the tool as well as the tool's capability to analyse multifunctionality issues. Second, we will present further developments of the individual models which have been started as part of the development efforts within the project (section 4). Third, we will discuss the empirical adaptation of each individual model and the linked model to a case study region (section 5). Finally, we will discuss our results so far and lay out pathways for future developments within the MEA-Scope project and beyond.

## 1.3 Position of MEA-Scope tool prototype development within the MEA-Scope project

The MEA-Scope tool is part of the overall MEA-Scope conceptual framework, shown in Fig. 1 (PIORR et al. 2005). On the conceptual level, the MEA-Scope theoretical framework brings together the positive (joint production of CO and NCO) and normative views of multifunctional agriculture (social, environmental and economic function). The specific concept aims at integrating different multifunctionality concepts as well as the demand and supply side for multifunctionality and NCO, respectively. Regarding WP3 and the application of the framework in WP4 and WP5, the differentiation between the supply and the demand side for NCO is of particular relevance. The emphasis of the model development activity within the project is on representing the supply side of multifunctionality by creating the capability to model an extensive set of NCOs. Based on established conceptual frameworks on multifunctionality (OECD, FAO), and the given policy environment (1. and 2. pillar of the CAP), the demand

for multifunctionality as exemplified by NCOs and COs and the respective indicators for them, is determined as part of WP2 and WP6 (see WAARTS 2005, SCHADER and STOLZE 2005). The large number of indicators identified were further categorised by functions following the FAO approach to multifunctionality (WAARTS 2005). To match the NCOs identified on the demand side with those modelled, for each case study region, the indicator/NCO list developed in WP2, was balanced with the indicators included in the models.<sup>1</sup>



**Fig. 1:** The MEA-Scope framework integrating multifunctionality concepts, policies, and demand and supply (Source: PIORR et al. (2005), modified).

## 2 THE MEA-SCOPE TOOL PROTOTYPE – A HIERARCHICAL MODELLING APPROACH

### 2.1 Objective of the MEA-Scope tool prototype

The MEA-Scope modelling approach developed as part of WP 3 is based on three agronomic and economic simulation models. In the past, each model has been focussing on specific aspects of the agricultural system (Table 1). Each individual model covers some aspects relevant in the context of multifunctionality impact assessment. For example, whereas AgriPoliS explicitly aims at modelling the dynamics of structural change, it offers a rather limited range of production possibilities. MODAM is more detailed in its specification of production activities, but in a static context. FASSET, on the other hand, simulates nutrient flows on daily bases which neither AgriPoliS, nor MODAM are able to do.

Depending on the individual models' scope, linking the three models allows to extend the capabilities to model multifunctional aspects of agricultural systems into two directions:

<sup>1</sup> WAARTS (2005) describes the steps of this process and gives details on NCOs and indicators chosen.

1. to combine the individual strengths of each model and obtain a more complete model with regard to spatial, analytical and temporal aspects.
2. to cover a wide range of multifunctionality indicators which are simulated in the respective models and to analyse results with regard to these.

In doing so, we aim at providing more comprehensive results on multifunctionality impact assessment that span different levels of scale (region and farm level) as well as different domains (economics and environmental sciences). We consider our approach to be a first step in a process of a more integrated analysis of change in rural areas. The linked model is a basic tool, which enables us through a reduction and abstraction of reality to investigate patterns which may otherwise be undetected.

**Table 1:** Overview of key model characteristics

<b>AgriPoliS</b>	
<b>Original Scope</b>	Policy evaluation tool made to investigate structural change in the agricultural sector.
<b>Characteristics</b>	Spatial and dynamic agent-based model of regional agricultural structures. Rooted in agricultural Economics. Consist of a large number of individually acting autonomous farms. Indirect interactions through land market. Production activities at the farm level are aggregated.
<b>Multifunctionality dimension</b>	Socio-economic (Structural change, land markets, land use, farm income, labour use)
<b>Scale</b>	Regional scale (meso-level) with indirect interactions between farms
<b>Basic unit of time</b>	One period = one financial year.
<b>MODAM</b>	
<b>Original Scope</b>	Policy evaluation tool to investigate policy effects on the decision behaviour of farmers and the corresponding environmental effects.
<b>Characteristics</b>	A hierarchical specialist developed database structure able to generate linear programming farm models and through use of fuzzy-logics investigate trade-offs between economic and ecological goals. Disaggregated with regard to farm-level production activities.
<b>Multifunctionality dimension</b>	Environmental, socio-economic (e.g. groundwater recharge, nitrate leaching, habitats and biodiversity, ecological-economic trade-off)
<b>Scale</b>	Regional scale or farm level (aggregated level).
<b>Basic unit of time</b>	One period = one financial year
<b>FASSET</b>	
<b>Original Scope</b>	A dynamic whole-farm model that simulates the relationship between agricultural production, economics and pollution. Policy evaluation tool. Made mainly to investigate nutrient flows (N) and pollution including nitrate leaching, ammonia emission and the emission/absorption of greenhouse gasses.
<b>Characteristics</b>	Whole-farm model where farmers are maximising yearly income. Rooted in agronomy and soil science. Individual crop rotation plans are incorporated. Disaggregated model.
<b>Multifunctionality dimension</b>	Environmental (e.g. nutrient flows, nitrate leaching, greenhouse gas emission, hydrogeology (watershed analysis), pesticide and energy use)
<b>Scale</b>	Farm level.
<b>Basic unit of time</b>	One period = one day (however evaluated on a yearly basis).

At the outset of the project, two options for a common use of the three models were discussed. The first was to fully integrate the models and create an entire new model. The second option was to link the models in a consistent way but keep the capability to a) run the models independently from each other, and b) have the development tasks for each individual model with the groups that have been working with the models for years. We have chosen to follow the second path. This had several reasons. First of all, the researchers involved in WP3 had not worked together before; hence, a lot of time was spent during the first year to learn about each other's models and ways of thinking. This is also important because researchers in all groups had different scientific backgrounds. Moreover, if individual models are already highly complex, the merit of a fully integrated model at this stage of collaboration is questionable, considering the given resource limits, time constraints, and limited possibilities to work together at the same place. We hence chose to rather link the individual models and make them consistent with respect to the data used, and some model characteristics common to all three models such as crop shares. This offers enough flexibility to run each of the three models independently based on a common set of farm types and common input data, but also link model runs. Details of this will be given in sections 4, 5, and 6 of this report.

In the following, we will briefly introduce the structure and core concepts of each model. As models generally represent an idealised perception of a defined part of reality, it is therefore necessary to clearly demarcate the part of the system investigated. Only hereby are we able to justify the ability of the combined model.

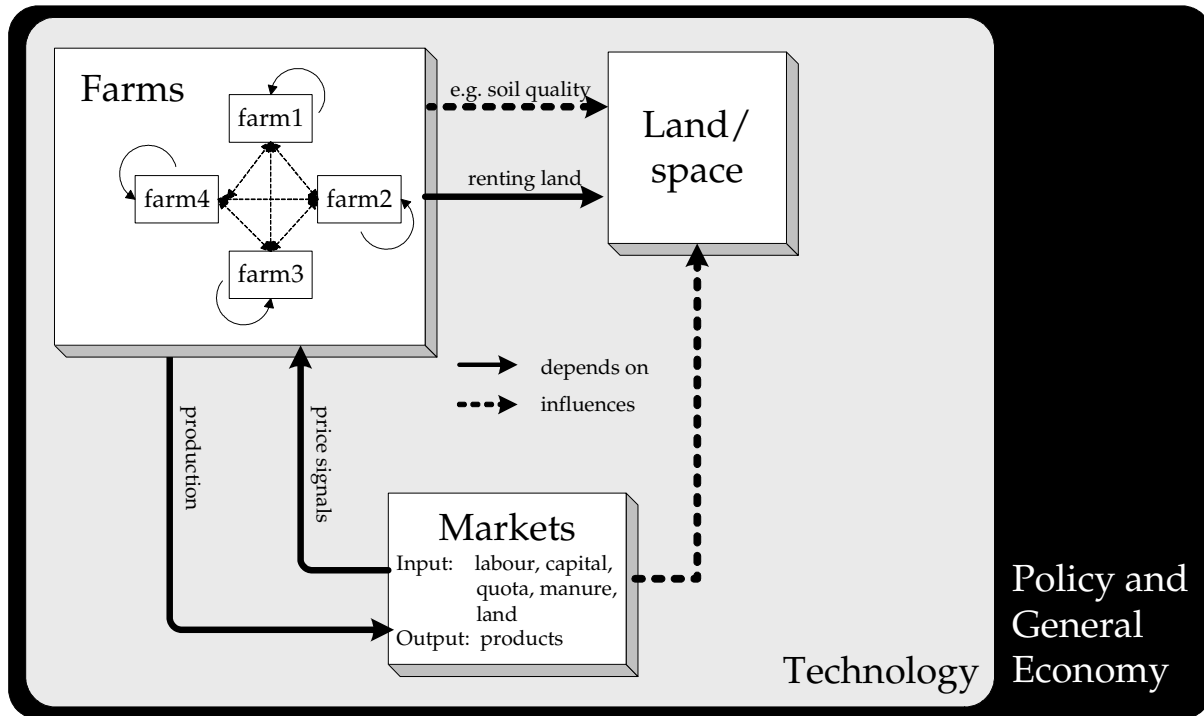
## 2.2 Description of the models

### 2.2.1 The agent-based model of regional structural change AgriPoliS

AgriPoliS (Agricultural Policy Simulator) is a spatial dynamic agent-based simulation model of regional agricultural structure. The core of AgriPoliS is the understanding and modelling of an agricultural system as an agent-based system (FERBER 1999, FRANKLIN and GRAESSER 1997, GILBERT and TROITZSCH 1999, JENNINGS et al. 1998, LUCK et al. 2003, RUSSEL and NORVIG 1995). The model, AgriPoliS, establishes a virtual model world of an agricultural region on the computer. The model comprises a large number of individually acting farms operating in a region as well as farms' interactions with each other and with parts of their environment. The modeller can fully control the rules of the model. AgriPoliS is a further development of a model originally developed by BALMANN (1997) to study path dependencies in structural change. Whereas the original model was based on an abstract agricultural region, AgriPoliS provides interfaces to adapt the model to empirical data on individual farms and regional agricultural structures. In the following, we present a basic overview of the model; HAPPE (2004) gives additional technical details and a more thorough description.

Figure 2 depicts the conceptual framework of an agent-based model of a regional agricultural system. In brief, an agricultural system can be described as consisting of the three key factors: the farms in a region, the landscape the farms are situated in, and the markets for factors inputs and outputs. For the purpose of AgriPoliS, each farm in the region is defined as an agent which can be described as an entity that acts individually, senses parts of its environment and acts upon it. Therefore, the farm agents are equipped with a behavioural model and with an internal state that describes typical attributes of a farm like age, location or factor endowments. According to the behavioural model, the individual farm agents evolve subject to their actual state and to changes in their environment. In AgriPoliS, this environment consists of

three parts: the direct environment of a farm consisting of other farms located in the same region, the landscape in which the farms are located and which at the same time serves as factor input for agricultural production, and markets for the necessary inputs and produced outputs of agricultural production. These three main groups of entities themselves are embedded in the general technological and political environment.



**Fig. 2:** Conceptual framework of AgriPoliS

The following section gives a more precise description of the single entities as listed above and describes the relationship between these entities.

### *The farm agent*

The main element of a farm agent is its behavioural model which determines the decision making process. It is therefore responsible for selecting a suitable action out of the available action space, according to the current state of the farm and the state of the farm's environment. The farm agent's behavioural model is founded in neo-classical production theory. The objective is to maximize household income. Farm agent's actions are strictly derived from this assumption which implies a normative behavioural foundation. In the core, this normative behavioural assumption is implemented in a mixed-integer programming model (cf. HAZELL and NORTON 1986). It allows the farm agent to simultaneously decide on the production and investments, and to derive shadow prices for scarce production factors. Each farm agent is equipped with a separate mixed-integer programme. At the end of each simulation period, a farm agent's production programme is recursively updated to account for the effect of new investments or divestments.

The production and investment programme calculated with the mixed-integer program forms the main part of the farm agent's action space. A farm agent can engage in a range of production activities, which are distinguished into livestock production (e.g. fattening pigs, turkeys), plant production activities (e.g. crops, sugar beets, grassland), short-term capital activities (e.g. short-term borrowing), short-term labour activities (e.g. short-term hiring), and 'addi-

tional' activities. Though MEA-Scope is focusing on beef production, all production types will be included. This is done in order to be able to replicate the study area as realistic as possible. Most livestock and plant production activities are marketable activities. grassland production activities and silage maize are exceptions which serve as intermediate products for livestock production.

In order to produce, the agent uses different production factors (land, buildings, machinery, liquid capital, labour) of different types and capacities. HAPPE (2004) gives a detailed description on the structure of production activities and production factors. Regarding the latter, we implemented the possibility to introduce economies of scale. AgriPoliS also aims to mimic the effect of technological progress by decreasing production costs by a certain percentage in case of re- (or new) investments. We assume that new investments affect production capacities for the operating lifetime of the investment. Accordingly, the salvage value of any fixed asset at any time during the simulation is zero. Thus, investment costs are sunk costs.

In addition to the standard production activities, there are a number of auxiliary activities: rental activities for land, production quotas, and manure disposal rights. A farm agent can hire labour on a fixed or on a per-hour basis; vice versa farm family labour can be offered for off-farm employment (for details see HAPPE (2004)). To finance farm activities and to balance short-term liquidity shortages, farm agents can take up long-term and/or short-term credit. Unused liquid assets are invested at the assumed savings rate.

The internal state of a farm agent changes as a result of the farm agent's actions. The internal state of a farm is organized as a balance sheet which keeps track of factor endowments, the farm's age, expectations about future prices along with a number of financial indicators. Based on these indicators, farm agents decide whether to exit or stay in the sector. It is rational for a farm agent to exit either if its equity capital is zero, the farm is illiquid, or if opportunity costs of farm-owned production factors are not covered. In the latter case, it would be more profitable, for the farm agent to use capital off-farm.

After a farm agent has reached a certain age, a generation change takes place. In case of such a generation change, we assume the opportunity costs of labour to increase. Accordingly, for a successor to take over, the farm has to generate at least as much income as a comparable job outside farming.

Even though we assume a normative behavioural foundation, the farm's decision-making is myopic or boundedly rational. This holds because of two reasons. First, a farm agent has no perfect foresight. Instead, expectations about future prices rely on an adaptive expectation formulation process. Merely the impact of major policy changes are anticipated one period in advance and included into the decision making process. Second, a farm agent does not act strategically. Whereas this assumption is normally unproblematic on markets where farms are price takers (which holds generally for agricultural product markets), this is not the case for local factor markets such as the land market which plays an important role in agricultural structural change.

### *Landscape*

AgriPoliS models space in a stylistic way to implement some, but not explicit, spatial relationships. In the current version of AgriPoliS, space is represented by a set of equally sized cells/plots assembled into a grid to form a kind of GIS-styled interface. GIS provide a way of organising spatial data and assigning certain properties to space. For example, this could be

the soil type, ownership, or ecological parameters like the nitrogen load. AgriPoliS, follows a more stylistic approach in that land of different types can be considered. The total land of a farm agent consists of both own and rented land. Land is heterogeneous with respect to its location in space and with respect to its quality. One individual plot or cell in the stylised GIS represents a standardised spatial entity of a specific size (initially 1 ha) that can take different states. In this representation, all factors that do not directly relate to agriculture and land use (roads, rivers, etc.) have been eliminated. AgriPoliS does not implement a spatially explicit GIS in which the exact location of farms and land as found in a real region is modelled. Nevertheless, this kind of an explicit spatial representation could also be used in the context of an agent-based model of agriculture as some recent examples show (e.g., BERGER 2001, PARKER et al. 2002)

### *Factor and product markets*

Agents in AgriPoliS interact indirectly by competing on factor and product markets. Market agents that explicitly coordinate the allocation of scarce resources such as land or the transaction of products organize the interactions. Direct interactions between agents, for example to directly negotiate on rental contracts, are not considered at this stage of the model development.

Market agents bring together supply of and demand for products and production factors. For products, capital and labour, prices are determined via an exogenously price function with a given price elasticity and a price trend factor for each product. The land market is an exception. The land market in AgriPoliS is organized as a sequential auction to allocate free plots in the region to farm wishing to rent the plots. In AgriPoliS, the land market is the central interaction institution between agents. In reality, the land market is of particular relevance, as – for example in Germany – farm growth is not independent of a farm's hectare base. Moreover, in regions with intensive livestock production, land provides the basis for fodder production or manure disposal. In AgriPoliS, extensions of a farm agent's hectare base takes place, like in reality, exclusively via renting land. Regarding land ownership, in AgriPoliS there are farm agent landowners and external non-farming landowners. The latter are not modelled explicitly but they rent out their land to farm agents. In the initial situation, all land is either owned or rented by farm agents. When AgriPoliS runs, land available for rent on the rental market stems from two sources: one is of farms that have quitted production and withdrawn from the sector, the other is land released to the market due to the termination of rental contracts.

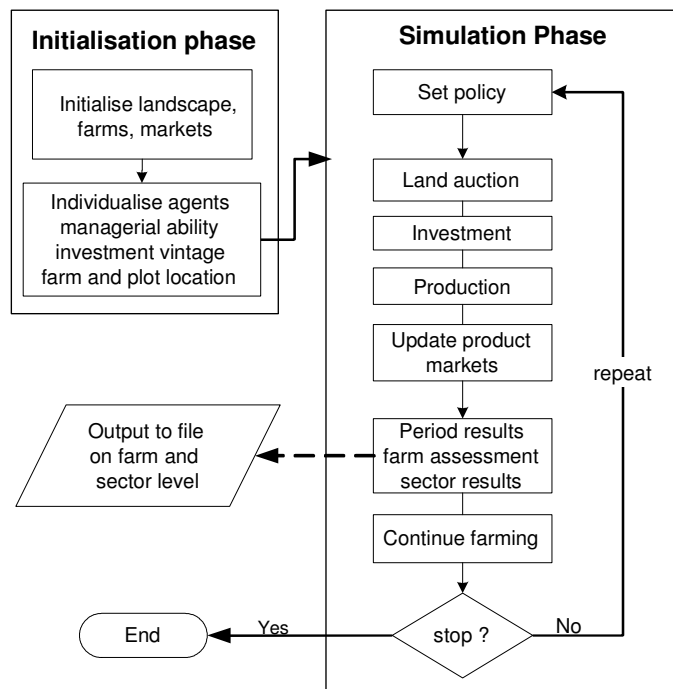
As a conclusion, the land allocation process works as follows. To allocate free land to farms, AgriPoliS implements an iterative auction during which an auctioneer (market agent) allocates free plots to farm agents intending to rent additional plots of land. First, each farm agent produces a bid for a particular plot of land. The bid depends on the farm agent's shadow price for land, the number of adjacent farm plots and the distance-dependent transport costs between the farmstead and the plot. Second, the auctioneer allocates a free plot to the farm agents with the highest bid. This procedure is repeated until all free land is allocated or if bids are zero.

### *Technological and political environment*

The technological environment is given by technologies of different vintages and technological standards. We assume technologies to undergo technological process over time. This is created in the up-stream sector, but not on the farms themselves. Farm agents can benefit from

technological progress by way of realizing additional cost savings when adapting new technologies. General economic framework conditions such as interests for capital and agricultural policies define the farm agents' political environment. Agricultural (and environmental) policies affect the farm at different instances such as prices, stocking density, direct payments, whereas general economic framework conditions enter AgriPoliS via interest rate assumptions.

To understand how the agents and their actions interplay as well as the way in which this process is synchronized, Fig. 3 provides an overview about the dynamics of the model and the course of events during one simulation period.



**Fig. 3:** Model dynamics and course of events during one period

### 2.2.2 The multi-objective decision support tool MODAM

The bio-economic modelling system MODAM has been developed for the analysis of relations between economic and ecological objectives in agricultural land use by evaluating a broad number of agricultural production practices regarding their effects on the environment, both negative effects, e.g. nitrate leaching, water erosion, as well as positive ones, e.g. providing habitat functions for certain animal species on agricultural fields (cp. SATTLER and ZANDER 2004) as well as their economic performance.

For example, the different ways of producing wheat by using different tillage techniques, or applying different amounts of fertilizer or pesticides affects jointly produced non-commodities. Compared to conventional tillage by ploughing, reduced tillage or zero tillage techniques will lower the risk of water erosion; or, the increase of nitrogen fertiliser input will increase the risk of nitrate leaching to the groundwater. These are both unwanted negative externalities. As a positive externality, respectively, the total omission of pesticide application will improve the habitat quality for sensitive species, like some beneficial insects.

Thus, agricultural production techniques and technologies play a major role in the maintenance of agro-ecosystems, and at the same time, affect their dynamics. Farmers' decisions on

the type of production practice applied on a certain field are generally based on economic and crop-production criteria. Hence, a farmer - given the restrictions of limited resources and a certain type of farm organization - will select a combination of production technologies that leads to maximum economic return of the farm. There are two assumptions at the basis of the MODAM modelling approach: (i) farmers' behaviour is always economically rational neglecting the fact that a farmer has objectives other than just maximising his profit (SCHULER and KÄCHELE 2003), and (ii) major ecological effects of farm activities can be directly derived from cropping practices, even if they are based on long-term average technical coefficients. In particular, the first assumption is clearly not always true, but it represents a generally accepted simplification of the complex reality that farmers have to cope with.

In order to show the jointness of production as well as the cross-relationship between different externalities, MODAM makes use of trade-off functions. A „trade-off“ function describes a negative mutual dependence between two goals, a goal conflict, illustrating how many units of one goal have to be sacrificed to gain one unit of another. They are of interest as they define the solution space, specify what is possible (transformation curve) and indicate the societal costs associated with different levels of goal attainment (ZANDER 2003). „Goals“ in this context refer to either the promotion of positive externalities or the mitigation of negative ones. Evaluating trade-offs, when done carefully and systematically, involves comparing the advantages and disadvantages of available alternatives. Decisions based on information such as provided by trade-off functions are not all-or-nothing decisions, rather they enable decision makers to find out compromises involving changes at the margins - a little more of this at the cost of a little less of that. These efforts may result in a mix of all those externalities that are of interest for the decision-makers - individually or on behalf of a certain community at the regional or national level. Trade-off functions can also show where a multitude of aims can be obtained in combination (positively correlated externalities) and where conflicts have to be resolved (negatively correlated externalities).

MODAM allows two kinds of scenarios (i) incentive oriented scenarios to assess the consequences of policy instruments like subsidies or taxes and (ii) regulation oriented scenarios to assess the effects of legislative policy options like environmental restrictions.

#### *Model structure*

MODAM is hierarchically structured into three levels (cf. ZANDER and KÄCHELE 1999, ZANDER 2003). The first level (Data organisation) contains a detailed description of a variety of production alternatives for agricultural crop, fodder and livestock production. Agricultural production practices are divided into single operations in sequence of application: tillage, sowing, application of fertilisers, application of plant protection agents, mechanical weeding and harvesting, the yield expectation is calculated for four different soil qualities. Livestock production practices are aggregated into production units include the production of milk, pork, chicken/eggs, horses and sheep at different levels of performance, i.e. milk can be produced at annual levels from 5.000 up to 10.000 l/cow. To facilitate adaptation of farm models, various farm modules were defined that may be combined with any farm model. Each of the defined livestock modules covers the production or purchase of progeny and requires satisfaction of feed requirements through production or purchase of fodder. Required data are derived from standard data tables (e.g. KTBL) or expert knowledge.

At the second level (Partial analysis), and the economic and ecological evaluation of the production alternatives takes place. For the economic evaluation, costs are calculated depending

on the given set of prices for inputs and outputs, applied farm machinery, energy consumption, required labour, etc. At the third level (Integrated analysis), linear programming (LP) farm models are generated for the integrated economic-ecological analysis to simulate decision-making behaviour when farmers produce economically under the conditions of different policies.

### *Ecological evaluation*

The ecological evaluation in MODAM is done by means of a fuzzy-logic-based environmental impact assessment-tool (SATTLER and ZANDER 2004). The approach relies on expert knowledge, which means the experts' perception of the potential environmental effects of different agricultural production practices. The use of fuzzy-logic distinguishes this model from other bio-economic models (e.g., BARBIER and BERGERON 1999, DONALDSON et al. 1995, DEYBE and FLICHMAN 1991), where the biophysical portion is generated by other independent sub-models, such as the Erosion Productivity Impact Calculator (EPIC) (WILLIAMS et al. 1987). Expert knowledge-based fuzzy-logic tools rely on less complex assessment algorithms and can be run with comparatively fewer data. Hence, the advantage of such an approach is a more flexible introduction of additional ecological indicators into the model without running a set of different biophysical models, e.g. SWIM (KRYSAKOVA et al. 1998) or WEPP (LAFLEN et al. 1991) thereby causing a high data demand. Fuzzy-logic has been applied in a number of studies dealing with environmental impact assessment (e.g. MERTENS and HUWE 2002, MITRA et al. 1998, VAN DER WERF and ZIMMER 1998). So far, 10 different environmental NCO-related indicators have been assessed using MODAM (cf. SATTLER and ZANDER 2004).

### **2.2.3 The ecological assessment tool FASSET**

The FASSET model simulates dynamically the nutrients flow and production which results from specific farm management. In FASSET a farm is assumed to have two biological components: livestock and fields. These components interact indirectly through the stores, which may contain animal manure, feeding stuffs etc. Management of fields is an input and is implemented annually on August 1st and thereafter simulated according to climate data, actual farm characteristics and external factors. The results from these simulations are stored as a set of environmental and economic indicators.

The simulation module simulates the outcome of the production plan using daily climate data. The state variables of each module and the flow of products and information between module entities are updated daily.

The storage, transformation and flows of several products are simulated in the module. These include both simple products, such as N, C and water, and more complex products such as manure, meat and various forms of energy. The most detailed modelling concerns N. N is imported to the farm as livestock, artificial fertiliser, manure or feeding-stuff, and is exported in plant or animal products. The N from feedstuffs is partitioned between faeces and urine, and animal growth. The faeces and urine cause gaseous losses from the animal housing, predominantly as ammonia. The remainder is transferred to the manure storage. Additional losses as ammonia, dinitrogen and nitrous oxide occur from this storage. On field application, a further volatilisation loss from the manure occurs (volatilisation from mineral fertilisers are ignored). This loss is taken from standard Danish application losses, where the fraction of N lost depends on the application date and crop cover. The remaining inorganic N enters the soil surface directly, while the organic part is added to the soil organic matter. Further N input comes

via atmospheric deposition. The N concentration in precipitation is assumed to have a constant value, which is set according to the general load of the region in question, and is assumed all to be in the form of ammonia. The growth of leguminous crops leads to an additional N input by atmospheric fixation.

Turnover of soil organic matter causes both mineralisation and immobilisation of N, which influences the soil content of ammonium and nitrate. The mineral N in the soil is lost by denitrification, predominantly as free N<sub>2</sub> and N<sub>2</sub>O and primarily when the soil water content is high. The remaining mineral N is either taken up by the crops or lost by leaching. Leaching results from water mediated N transport. Part of the crop N uptake is returned to the soil by rhizodeposition and via above-ground crop residues. The harvested N is either sold, or used on the farm for animal feed.

### *Fields*

The crop simulation sub-model calculates dry matter (DM) production from the light interception and a radiation use efficiency that depends on temperature, crop nitrogen status and water availability. Radiation use efficiency is furthermore affected by carbon dioxide concentration, following the principle from OLESEN et al. (2000). Light interception is calculated from leaf area, which in turn is simulated using expansion rates depending on crop phenological stage, temperature, N uptake, above-ground DM and drought stress. Thermal age and daylength govern the phenological development.

The soil sub-model has a one-dimensional vertical structure, and is divided into a number of layers. The hydrological processes considered include accumulation and melting of snow, interception of precipitation by the crop canopy, evaporation from the canopy and soil surfaces, infiltration, water uptake by plant roots, transpiration and vertical movement of water in the soil profile. Soil temperature is calculated according to the principles in JANSSON (1996). Soil water and N movements follow the description of ADDISCOTT and WHITMORE (1991). The crop-soil subsystem is described in further detail in JACOBSEN et al. (1998b) and OLESEN et al. (2002).

Irrigation decisions are made according to OLESEN and PLAUBORG (1995), and are performed with an optional time-delay that is intended to mimic limited irrigation capacity.

### *Livestock*

Within a given year, the pig production is modelled as a steady state i.e. the day-to-day variation is not modelled. The pig herd is divided into production sows and their piglets (up to 30 kg) and finishers (from 30 kg to sale weight of 100 kg). Any imbalance between the numbers of piglets born and finishers produced is adjusted by selling or buying piglets. Feed plans for pigs can consist of the feed items defined in the system. Each production sow and finisher is assumed to accumulate 17 and 1.58 kg N per year, respectively. N not accumulated is partitioned into urine and faeces according to the feed digestibility, such that N associated with apparently indigestible protein is assumed to be excreted in faeces, and the remainder is excreted in urine.

The modelling of cattle differs from pigs. For pigs, the feed consumed and production achieved are inputs; the main function of the pig submodel is to simulate the production of urine and faeces. For cattle, the feed ration is input but the feed consumed, weight gain, milk production and production of urine and faeces is then simulated. The reason for treating the

two types of animals in a separate way is that the management of cattle varies considerably from farm to farm e.g. extensive v intensive feeding, much or little/no grazing, whereas the management of pigs varies much less. The model used to simulate production and excretion of manure is based on the system used by the Danish farm advisors. This is a factorial system that calculates feed intake, the energy and protein provided by the feed and how the energy and protein are partitioned between maintenance, pregnancy, lactation and body growth. As for pigs, the protein nitrogen that is not partitioned to body growth or to milk produced, is excreted. The partitioning of excreted nitrogen between urine and faeces depends on the apparent digestibility of the feed consumed.

### **2.3 Target capabilities of the MEA-Scope tool with regard to multifunctionality indicators and policy options**

AgriPoliS, MODAM and FASSET produce an exhaustive set of data and indicators, some of which may be relevant for multifunctionality impact assessment.<sup>2</sup> To match model indicators with the multifunctionality indicators relevant in the project the following steps were pursued in collaboration with WP2 (WAARTS 2005). First, a literature study of existing indicator systems was conducted in WP2, to identify possible multifunctionality indicators. Redundant indicators and indicators irrelevant for the project were reduced out. The abbreviated list was compared to the list of indicators that the three models are able to produce as well as the requests of the end-users. At the end of the process, regional partners selected multifunctionality indicators most relevant in their respective region. This resulted in the so-called MEA-Scope integrated indicator list. The choice gives a guideline for modellers in which direction to carry out subsequent analyses. Table 2 gives an overview on the main indicator groups and indicator groups covered by the models.

Besides the identification of important multifunctionality indicators by regional partners, there is also an exchange on indicators with end-users as part of the end-user workshops carried out in WP6. Until mid-term of the project only one end-user workshop has taken place, such that the matching of the supply of indicators and data from models with demands from end-users will be an ongoing process during the remainder of the project.

In addition to multifunctionality indicators, the analysis of policy impacts is an important part within MEA-Scope. Fig. 4 shows a range of policy scenarios which the models allow to implement. Due to the specific background of the models, most policies can be implemented in AgriPoliS and MODAM. AgriPoliS puts an emphasis on the decoupling policies and cross-compliance options; MODAM's strength is in agri-environmental payments and specific cross-compliance regulations.

For the actual simulation of CAP policy options within WP4 and WP5, a selection of policies, particularly relevant for the respective case study regions will be simulated. It is planned to analyse up to four different scenarios.

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<sup>2</sup> A detailed listing of model indicators can be obtained from the authors upon request.

**Table 2:** An overview of the main indicator groups and the models best covering the particular group

Indicator groups	AgriPoliS	MODAM	FASSET
<b>Economic</b>			
General, including costs	X		
Generation of income	X <sup>1)</sup>		
Rural entrepreneurial activities			
<b>Social</b>			
Cultural heritage			
Social infrastructure (age of farmer)	X		
Non-farming activities (pluriactivity)			
Employment	X <sup>2)</sup>		
Healthy food/food safety			
Animal welfare			
<b>Environment</b>			
Management practices		X	X
Energy use			X
Environmental quality, abiotic			
Pesticide use		X	X
Air quality		X <sup>3)</sup>	X
Soil quality		X <sup>3)</sup>	X <sup>4)</sup>
Water quality		X <sup>3)</sup>	X <sup>4)</sup>
Water availability		X	
(Agro)Biodiversity and habitats, biotic			
Biodiversity		X <sup>3)</sup>	
Habitats		X <sup>3)</sup>	
Landscape and land use	X		
Landscape management	X	X	
Landscape pattern	X		
Farming systems (in Protected Areas)		X	
Grassland management	X		
Abandonment of farmland	X		
Landscape amenities			

Notes: Category is marked where models cover one or more indicators in indicator group, detailed list in WAARTS (2005). <sup>1)</sup> includes income from off-farm activities <sup>2)</sup> employment in agriculture and of farm families off-farm, <sup>3)</sup> expert knowledge based fuzzy models <sup>4)</sup> mechanistic models of water and soil process

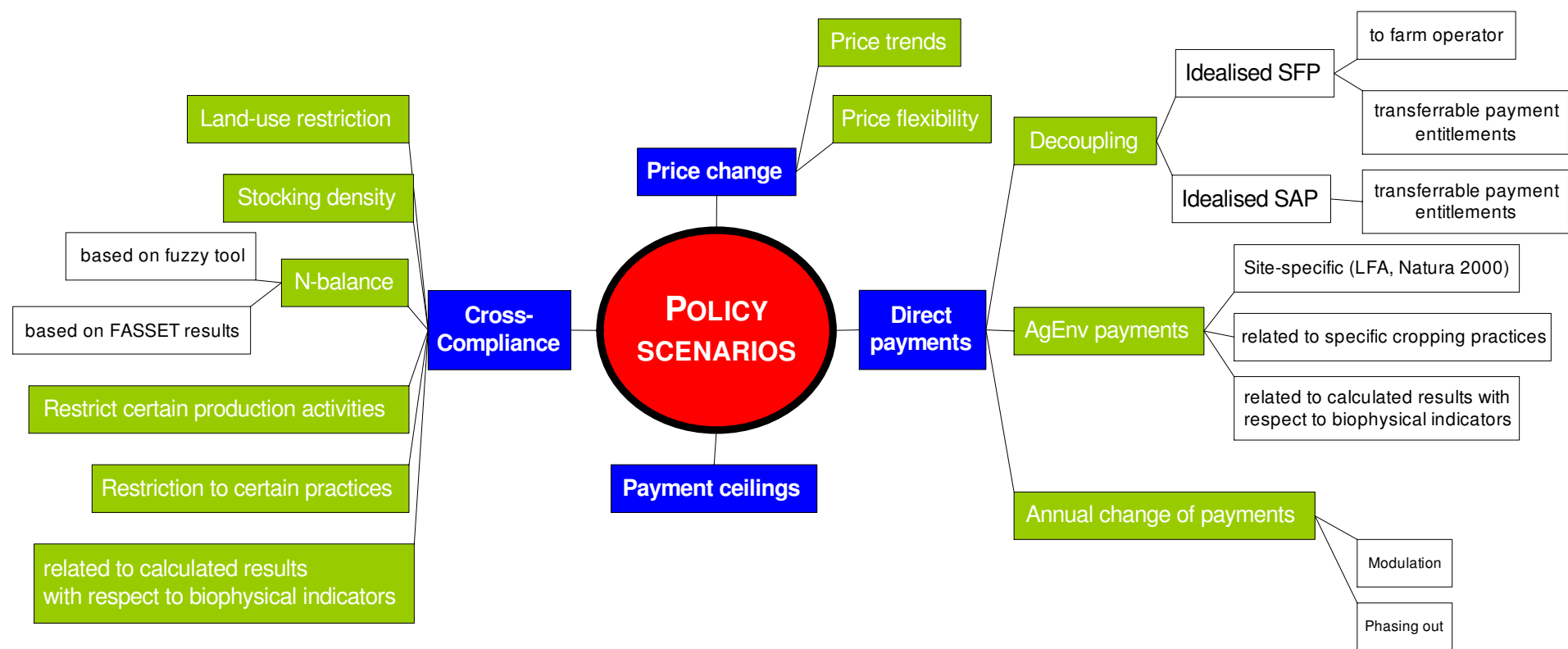


Fig. 4: Possible policy scenarios in AgriPoliS and MODAM



## 2.4 Linking the models: the MEA-Scope tool prototype

As mentioned in section 2.1, linking the three individual models in a consistent and meaningful manner is central for the realisation of the MEA-Scope prototype and the later tool. We have chosen to link the models in a hierarchical manner that allows the analysis of multifunctional indicators at different analytical levels. As agriculture on the one hand is a long-term activity and on the other hand has to react to short-term events on markets or with respect to the weather, it encompasses different temporal levels. At the same time, spatial interactions are of importance at different levels: e.g. matter flows depend strongly on specific site conditions, while the survival of the stork depends on the management of a landscape and the development of a farm depends on the regional possibilities to hire labour and rent land. To examine multifunctionality aspects of agriculture these different temporal and spatial aspects need to be addressed. The hierarchical modelling approach is a top-down modelling approach combining large scale and long-term analysis with the ability to investigate results of an individual farm's daily actions.

The hierarchical modelling approach is constructed in such a way that the temporal and spatial dimensions change down through the linked models, however without changing in the individual farms which link the models together. This is illustrated in Fig. 5, starting with AgriPoliS (running at IAMO), down to MODAM (at ZALF) and FASSET (at DIAS).

In the modelling framework, the individual farm is the unit, which combines the three models. AgriPoliS recreates the regional farm structure in a region. The model simulates the development of a large number of individually acting farm agents which were derived from real-farm data. Thereby each farm evolves due to its initial conditions, the local competition for land and the regional economic framework conditions. During a simulation run of, for example 15 time periods, at various time steps (e.g. every 5 time periods), either all farm agents or a subset of them is transferred down through the hierarchical modelling structure. More specifically, for each selected farm agent, MODAM receives from AgriPoliS data on land use and production (more details in section 3.3). Based on these specifications, MODAM calculates detailed optimal land use patterns for each farm. Moreover, an environmental impact assessment is carried out. To simulate the consequences of specific management practices for matter flows, MODAM transfers the farm specifications to FASSET. MODAM produces output that details the area of different crops and the field operations performed upon them (e.g. ploughing, sowing, fertilisation and harvesting).

Simulation is done using daily time-steps and actual weather data. The short-term and small-scale simulation allows temporal peaks of nutrient flows in the soil to be detected. Fig. 5 depicts this procedure. On the left side, an exemplary real study area is shown. On the right, the three models are shown in their hierarchical order. Each red star represents an individual farm.

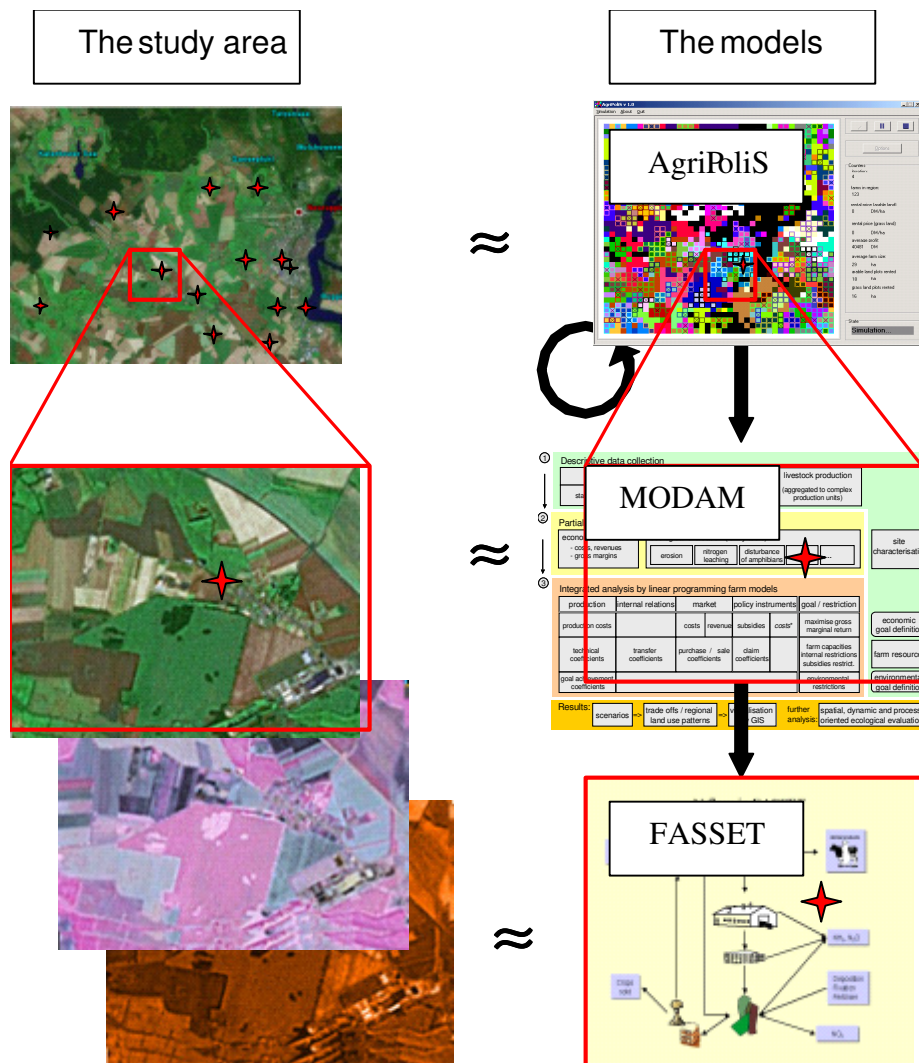


Fig. 5: Modelling procedure (Source: Google Earth 2005. Own figure)

### 3 THE TECHNICAL INTERRELATION BETWEEN THE MODELS

In this section, we describe the interrelationship of the three models. The linkage mainly takes place via a common use of data and a data exchange between models.

#### 3.1 Common input data and data flow

Fig. 6 shows a schematic representation of the data flow within the MEA-Scope tool prototype. The input data is shown at the same level as the team responsible for them. The white arrows illustrate the data flow in the hierarchical modelling approach. At the same time as the individual farm data is part of the output created by AgriPoliS and MODAM they are also the common denominator linking the two models together.

Coordinated by WP4, three broad categories of data were collected for each case study regions: data describing the structural characteristics of agriculture including total production and information on individual farms (responsibility IAMO-AgriPoliS), data on livestock and crop production (responsibility ZALF-MODAM), and regional soil data (responsibility DIAS-FASSET). Technically, an Excel form has been used to collect the structural characteristics of the regions. Two databases input structures have been developed to ease the collection of

technical and production related data. One input structure for the animal production and one for crop production. A video instruction has been attached to each of these data survey forms.

In the following, for each model we describe what takes place at each model stage, how and which information is passed on from one stage to the next:

### Interface 1 MODAM → Agripolis (Before the first period)

- economic coefficients of production activities

### Interface 2 Agripolis → MODAM (After each 5 periods in AgriPolis)

- farm capacities and prices for typical farms at specific locations.

### Interface 3 MODAM → FASSET (After each period in MODAM)

- production system and size
- ecological coefficients of production activities (timing, work step, amounts ...)

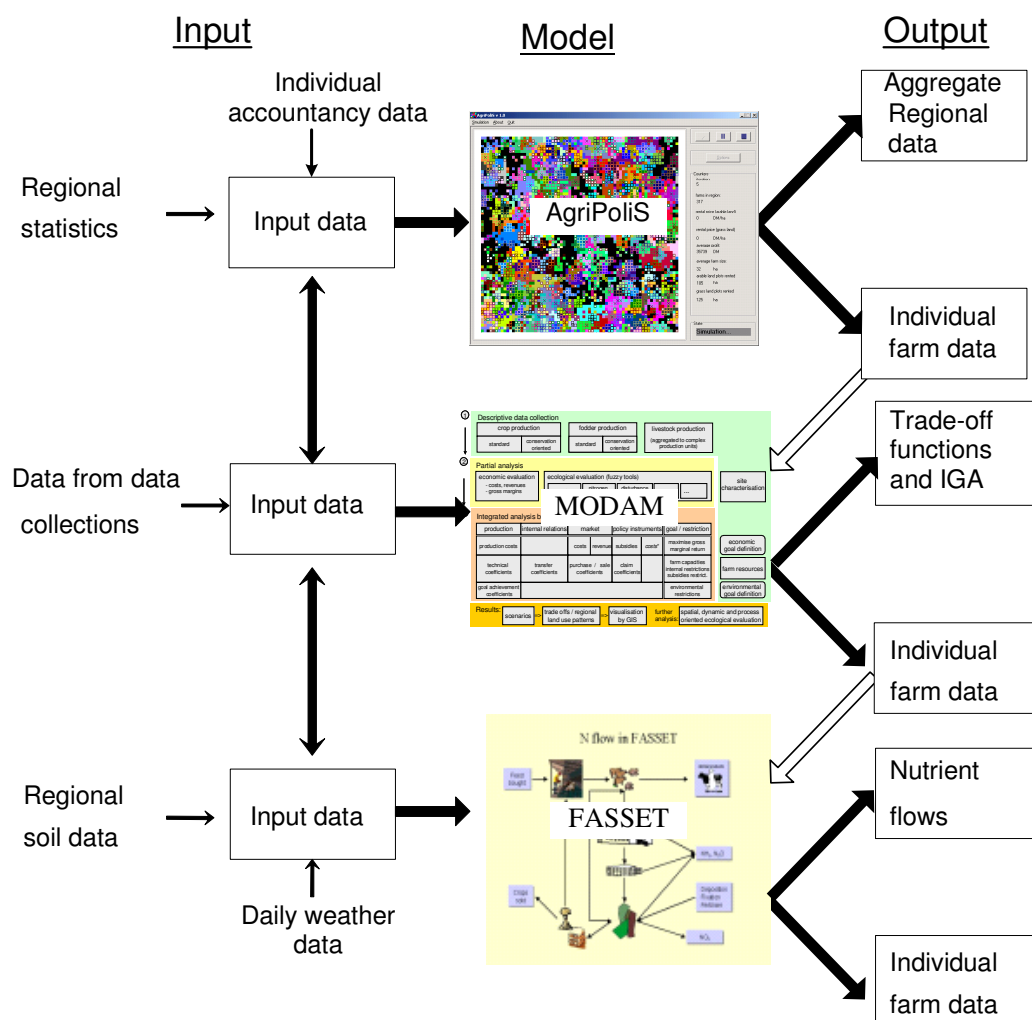


Fig. 6: Schematic representation of the inputs and outputs in the combined model.

### 3.2 From MODAM to AgriPoliS

Before the actual simulation, AgriPoliS is adjusted to the same economic and technical coefficients of the production activities as found in MODAM. Table 3 lists the common data. Additional data needed by AgriPoliS is directly provided by the regional partners.

**Table 3:** Data coming from MODAM

For each plant production activity	For each livestock production activity	Other
Gross margin (€ per dt)	Gross margin (€ per year)	Rotational restrictions
Total variable costs (€ per dt)	Total variable costs (€ per year)	
Total labour demand (h)	Total labour demand (h)	
Variable costs bounded during a production period (%)	Variable costs bounded during a production period (%)	
Revenue (€)	Revenue (€)	
Premium (€)	Premium (€)	

### 3.3 From AgriPoliS to MODAM

The scenario-specific information used in AgriPoliS is transferred to MODAM before each simulation. Before the actual simulation, AgriPoliS and MODAM agree on common market prices projections, support programs as well as other policy instruments.

As indicated in section 2.4, AgriPoliS simulates a multitude of individual farms of different types. At defined time steps (e.g. period 0, 5, or 9), the specification of a selection of these farms is passed on to MODAM for more detailed analysis. More specifically, for each selected farm the information shown in Table 4 is transferred.

**Table 4:** Data passed from AgriPoliS to MODAM

Parameter	Unit
Farm number	-
Organic farming	yes/no
Total labour input	Hours
Total Utilised Agricultural Area (UAA)	Ha
Arable land	Ha
Grassland	ha
Male cattle 12-24 months	animals
Dairy cows	animals
Other cows	animals
Ewes	animals
Other sheep	animals
Breeding sows	animals
Pigs for fattening	animals
Premiums	€
Other policy instruments	-

Currently, the data exchange between AgriPoliS and MODAM is still solved in a manual way, but first endeavour has been made to create an automatic transfer of output files.

### 3.4 From MODAM to FASSET

Most of the production specific data required to run FASSET (e.g. livestock housing and manure storage facilities, number and type of animals, fodder plans etc.) can either be derived

from MODAM's databases or from MODAM's simulation output tables. Table 5 contains the parameters that are passed from MODAM to FASSET.

**Table 5:** Data passed from MODAM to FASSET

Information	Description
<b>General Information</b>	
Region	Region
ShortCut	Shortcut for the Farm (ID)
AnimalGroup	Animalgroup ID
NumberOfAnimals	Number of Animals in the group
AverageWeight	Average body weight
WeightGain	Weight gain
PastureAreaPerAnimal	Pasture area
GrazingPerDay	Average hours of grazing during grazing season
StartGrazing	Start of grazing period in day-of-year
EndGrazing	End of grazing period in day-of-year
GroupDuration	Days in that category
ManureInsideDuration	Time the manure remains inside the stable
Offspring	Number of surviving offspring
OffspringFemale	Percent female offspring
OffspringWeight	Offspring weight at birth
PeriodsPerYear	How often are the animals repaced per year
ValueOfAnimal	Value of the animal
DirectSubsidies	Subsidies per head
<b>Fodder</b>	
UtilityNumber	UtilityNumber
Unit	Unit
UsedPerYear	Amount used per year for all animals in that group
<b>Livestock husbandry</b>	
LabourMilk	Labour for milking
StableAreaPerAnimal	Stable area
StableCapacity	Stable capacity for animals in that category
AnimalsInTiestalls	Proportion of animals in tiestalls
AnimalsOnDeepLitter	Proportion of animals on deep litter
AnimalsOnSlats	Proportion of animals on slats (slurry)
LitterRequirements	Litter required
StableCosts	Average investment costs for stable, including equipment
<b>Products</b>	
Milkproduction	Average milk production
PriceOfMilk	Price of milk
MilkFatPercent	Average milk fat
MilkProteinPercent	Average milk protein
<b>Field Production</b>	
Crop	Crop ID
Area	Ha
Operations	Field operations

Developing methods to transfer parameter values between the two models has been time-consuming. This process required each FASSET input to be related to a MODAM output, with conversion of units where necessary. The process has been most complete for field operations. Field production in MODAM is recorded as the (crop and ha) grown on each soil type in each year, whereas FASSET requires information on a field-by-field basis. The crop mixture information is obtained from MODAM and then a linear programming optimisation

model (Detlefsen, 2004) is used to construct individual fields and calculate the rotation of crops between them. The crop-specific field operation data from MODAM is also converted to FASSET format and used to create the input files for FASSET.

The livestock categories currently available in FASSET are pigs and cattle. For pigs, the correspondence between the two models is quite close; in both models, both the feed ration and production are inputs. Data transfer therefore consists of linking the MODAM feed and animal type classes with the corresponding classes in FASSET. Conversely, cattle production in MODAM is handled in a different way than in FASSET. FASSET takes the feed ration as input and then simulates milk and meat production (as output) whereas MODAM takes the milk and meat production as input and then calculates feed ration required to achieve that production. To circumvent this problem, we decided to alter FASSET to enable it to use the milk and meat production used in MODAM as a target. FASSET then adjusts the cattle feeding to obtain a closely as possible this level of output.

In addition to input from MODAM, FASSET needs soil and weather information. Soil information is default retrieved from the JRC soil classification whereas weather information is default obtained from the MARS weather database. By now, except for minor problems relating to the livestock sector, the data transfer between MODAM and FASSET is working and nearly completely automated.

## 4 EXTENDING THE MODELS' CAPABILITIES

### 4.1 Introducing site characteristics into AgriPoliS

The AgriPoliS model constitutes the first step in the hierarchical modelling approach. It models regional structural change in agriculture. This makes the model's capability to reproduce the different regional landscapes in a realistic way important. As the model has previously been used for economic analyses, the model's ability to simulate landscape characteristics has been less developed. The indicator list developed in WP2 showed the importance of site and landscape characteristics for multifunctionality. In addition, in order to be able to model multifunctional agricultural production in cooperation with the two more agronomical founded models FASSET and MODAM, improvements on this point were needed. In the original version of AgriPoliS, the spatially heterogeneous land qualities were reduced down to two land types, namely grassland and arable land. The frequency of the two land types was empirically founded, yet randomly distributed in the region. Although this may be sufficiently accurate for economic simulations, it did not provide the degree of precision we aimed for within MEA-Scope given the importance of landscape. We hence introduced a higher diversification of the model landscape to account for site differences. This constituted the main area of improvements for AgriPoliS.

First, the original AgriPoliS model underwent a thorough inspection with regard to where all references to the two original landscape types were located. The maximum site characteristics influencing the economic variability of the simulated farms in AgriPoliS were determined. The determination was based on the empirical data accessible, the combined models capabilities (to insure consistency in the simulated data should the landscape types be in agreement with all models) and the theoretical request. Based upon these preliminary findings a standard input file for AgriPoliS is being developed. Second, we changed data output into a vector structure to allow for 2-dimensional data output. Third, we introduced the functionality to de-

fine a number of landscape characteristics through the input file.<sup>3</sup> This means that the number of possible site characteristics no longer are restricted to arable and grassland but can be defined according to regional needs. Each landscape characteristic introduced into AgriPoliS can describe both bio-physical qualities such as the soil-type and slope as well as human determined characteristics such as administrative borders (e.g. Natura 2000 areas). The landscape characteristic has to be articulated through its economic influence on the farms choices.

Once the regional landscape is reproduced, the farms are distributed in the area in such way that their empirically founded spatial character such as location in a Natura 2000 area, is reproduced in the model. The creation of 2-dimentional output files allows to investigate simulation results more easily. This stylistic GIS interface could be recreated into GIS input data if further spatial explicit information could be added. A description of the created 2-dimentional output files is listed in Table 6.

**Table 6:** Description of 2-dimensional output file

Name of output file	Description	Data
DistanceCostMap	Displays for each plot the transportation cost the owner of the plot has by using it.	For each period
LandRentedByAgentMap	Display the farm number of the farm utilising the individual plot (for plots nobody utilises and non-agricultural areas the value is = -1)	For each period
Ownership	Display the farm number of the owner of the plot (if the plot is rented or non-agricultural area the value is =-1)	For the first period only
RentMap	Display the rent paid for the individual plot (rent for owned land and non-agricultural area is = 0)	For each period
SoilMap	Displays for each plot its type of landscape characteristics.	For the first period only
StateMap	Display the non-agricultural area (-1), the idle plots (0), the rented plots (1), the farmstead (2) and the owned plots (3)	For each period

By combining the information from the different output files, detailed spatial analysis of the structural development in the region can be made. The spatially heterogeneous land qualities and socio-economic aspects of the area introduced through the initialisation of the modelled region in AgriPoliS also allow the two following models to be more spatially explicit. Therefore the coordinates of the location of the farmstead will be included in the dataset passed on to MODAM.

<sup>3</sup> Note that we do not implement a fully spatially explicit landscape based on GIS, but we introduced the possibility to create artificial landscapes which resemble some characteristics of GIS-maps, yet, without expensive GIS data and software.

## **4.2 MODAM**

### **4.2.1 Data management and interfaces**

For the requirements of MEA-Scope, MODAM had to be adopted to new tasks. The database containing basic information on production techniques is currently redesigned under consideration of new data from KTBL and the requirements coming out of the need to cover 7 regions with different farm types and production techniques simultaneously (see also section about data collection). The interfaces to FASSET and AgriPoliS have been tested, the automating process has still to be edited. Parameters exchanged between the three models were harmonized. The testing of already received data from the case study region is in progress, for Ostprignitz-Ruppin the model testing could be finished, first results for different policy scenarios are presented in this report.

### **4.2.2 Capacities and simulation of policies**

Further, MODAM's capacities have been extended to run a broader range of farms simultaneously as well as to implement different policy scenarios. So far cross compliance requirements can be modelled as well as agri-environmental measures such as extensive grassland or organic farming. First endeavour has been made to easily integrate other agri-environmental programmes into the MODAM linear programming matrix.

### **4.2.3 Environmental impact assessment**

Concerning the environmental impact assessment, additional assessment modules are under consideration depending on the indicators that are of interest in the different case study regions. So far, environmental indicators are available only for Ostprignitz-Ruppin. For this region, additional modules for energy input, greenhouse gas emissions, wind erosion, soil organic matter content, animal welfare and habitat potential for cranes (*Grus grus*) are in preparation complementing the previous list of indicators (see Table 2,).

## **4.3 FASSET**

MODAM has been reprogrammed to output a database that contains both results from running the MODAM model and information obtained directly from the regions. An interface has been built to transfer data from the database to almost all input files for FASSET. Since MODAM defines the timing of field operations according to a period whilst FASSET requires them to be allocated to a specific date, FASSET has been developed to calculate the date of field operations according to temperature sums. This means that the timing of field operations can respond to inter-annual variations in the weather. MARS weather data has been retrieved and are ready to be used for the seven regions.

## **5 ADAPTING THE MODELLING FRAMEWORK TO THE MEA-SCOPE REGIONS**

### **5.1 Introduction**

The overall modelling framework has to be adapted to seven representative European landscapes, the case study areas. The adaptation of the models to the individual regions has to reflect the needs defined by the models; the partners' wishes to the models' analytical abilities and the overall aim of the MEA-Scope project. Finally, the data requirements for the individ-

ual regions should not exceed what is realistic for the regional partners to provide within the framework of the project. This work is therefore made in collaboration with other WPs, and in particular with WP2, WP 4, and WP5.

To reduce the amount of data demanded from partners and to establish a common database, specific input requirements of the three models were collected and compared. Fig. 7 gives a schematic representation of the process towards finding a common input data set. Ideally, the range of desirable data for the models is bigger than what has actually been collected. Given partners' limited resources, and limited data availability in some case study areas, the common input data set represents the minimum data needed for the three models to simulate the regions in a consistent and satisfying manner. The list of required input data was then compared and any doubles was reduced out. Additionally input data was added to the list by comparing the modelling abilities to both the regional and the MEA-Scope specified needs. The combined list constitutes the common input data.<sup>4</sup>

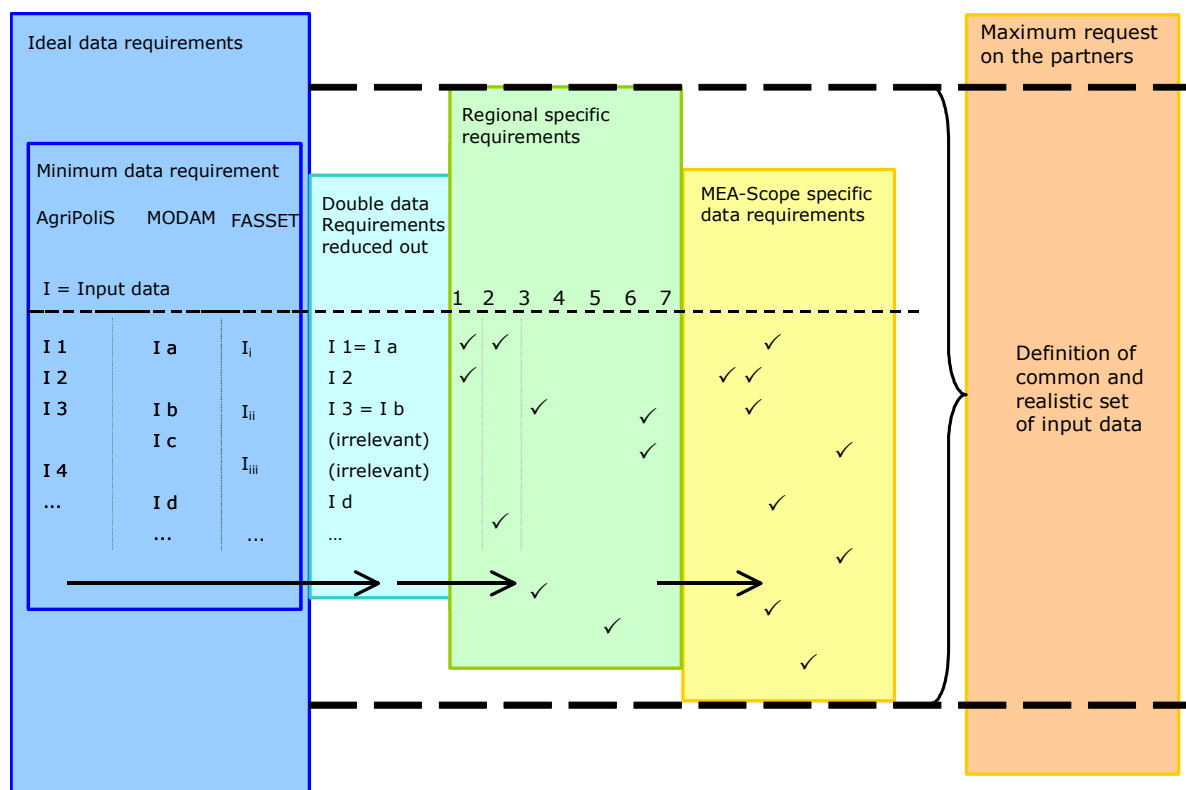


Fig. 7: Schematic diagram of the process towards finding the input data set

Ideally, the three models draw on the same pool of empirical data from which the models are adapted to the regions. As the focus and degree of detail differs between the models, there is also a need for model specific input data. To insure the best use of the data, each modelling team has had the responsibility to build the most suited input data to their model. Some of the data could directly be used by all the models (e.g. interest rate) however other had to be first pre-processed in one model before being passed on to the other (e.g. individual accountancy data and regional statistics into "typical farms")

<sup>4</sup> A full list of model input data requirements can be obtained from the authors upon request.

In the following, we present the detailed data requirements of each individual model. By presenting the empirical foundation for the simulation models, one can have a good impression of the degree of detail the combined MEA-Scope model will operate with can be obtained.

## 5.2 Representing the regional agricultural structure based on typical farms

### 5.2.1 The procedure to derive typical farms and to adapt AgriPoliS to a case study area

AgriPoliS has to be adapted to the reality as much as possible each time it simulates the structural changes of a region. The objective of the methodology presented here is to create an input data set to initialise AgriPoliS with a virtual farming structure that provides a close approximation of the observed real farming structure in a base year. This requires to represent the region's key structural indicators such as the number of farms, farm size distribution, types of farming, herds structures.

The method aims at representing the structure of the study region based on a number of "typical farms". By "typical farms", we mean a set of individual farms selected from empirically observed farms in the region. Each of them will be given a frequency factor so that each important real regional characteristic is represented best by the sum of the same characteristics at the individual level multiplied by the farm's frequency factor. To do so, statistical information on the regional agricultural structure and its production capacities in a base year is needed (regional data). However, the recreation of heterogeneity among farms in the region requires a detailed description of individual farms (farm data). A useful data source for deriving typical farms is the FADN database. But if no databases are available, the use of expert knowledge or interviews can be an alternative option. Then, the farm data should list variables in coherence with the ones calculated in the FADN database.

The method we use to re-build the regions has been created by KIRSCHKE et al. (1996) and further developed as described in BALMANN et al. (1998). This is a quadratic optimization model which finds the optimal combination of individual farms by matching the sum of their individual capacities multiplied by their corresponding frequency factor to the real regional capacity, and this simultaneously for all the selection criteria chosen. However, this method had initially been used to assign frequency factors to a sample of *already* selected typical farms.

The problem appeared with the use of much more extended samples of farms belonging to a region: how to avoid huge losses of time by feeding the quadratic optimisation model with different farm selections consecutively to check whether they could represent the region best? SAHRBACHER (2003) developed the procedure in use before in order to simultaneously (i) reduce the number of farms from a given individual data sample, and (ii) assign each farm its frequency factor. The procedure finds the optimal combination of individual farms by matching the sum of their individual capacities multiplied by their corresponding frequency factor to the real regional capacity, and this simultaneously for all the selection criteria chosen. Then it has become possible to run the procedure until 10 to 30 weighted farms remain to represent the regional characteristics best.

In mathematical terms, the selection procedure and the assignment of frequency factors can be explained as follows:

Let  $\mathbf{b}^k \in \mathfrak{R}^m$  be the vector of  $m$  farms in region  $k$  and let  $\mathbf{y}^k \in \mathfrak{R}^n$  be the vector of weights for  $n$  statistical goal criteria in the region. Furthermore, let  $v_{i,j}$  be the contribution  $j$  of farm  $i$ , and  $V \in \mathfrak{R}^{m \times n}$  the matrix of contributions of all farms. From this we derive the vector of all goal criteria  $\hat{\mathbf{y}}^k$  for the virtual region  $k$

$$\hat{\mathbf{y}}^k = \mathbf{b}^k \mathbf{V} .$$

Now we can construct a normalized matrix  $\mathbf{X}^k \in \mathfrak{R}^{m \times n}$  with

$$\mathbf{X}^k = \left[ \begin{array}{c} a_j^k \frac{v_{i,j}}{y_j^k} \\ \vdots \\ a_j^k \frac{v_{i,j}}{y_j^k} \end{array} \right]_{\substack{i=1,\dots,m \\ j=1,\dots,n}}$$

and  $a_j^k$  as the priority level of criterion  $j$  in region  $k$ , or  $\mathbf{a}^k \in \mathfrak{R}^n$  as the vector of weights of all criteria in region  $k$ . The vector of weights  $\mathbf{b}^k$  then results from the minimisation problem

$$\min_{\mathbf{b}^k} \left\{ (\mathbf{X}^k \mathbf{b}^k - \mathbf{a}^k)^T (\mathbf{X}^k \mathbf{b}^k - \mathbf{a}^k) \right\} \quad \text{with } \mathbf{b}^k \geq \mathbf{0} .$$

This problem can be solved with a quadratic programming algorithm. All farms with  $b_i^k > 0$  are then considered to represent the region. We call these farms “**typical farms**”. All other farms for which  $b_i^k = 0$ , are not considered any longer and removed from the sample. In this way, it is possible to automate the selection of typical farms if more than 25 to 30 farms are in the farm sample.

The second step is to represent the internal organisation of typical farms, that is to say, their main production activities, asset and capital endowments. Suitable data sources for the second step are standard farm management norms as provided, for example by KTBL for Germany. In MEA-Scope, data on production activities have been collected by MODAM and are used in AgriPoliS.

### 5.2.2 Regional data

The regional dataset should roughly describe the main structural characteristics of the region and the main productions which can be found there. As regions differ one from the other, the corresponding datasets will be different. The following Table 7 is an example of possible regional characteristics, the region being a German one in this case. The cooperation with local representatives allows building the most suitable dataset for the corresponding region. It can be then decided that other characteristics are more relevant to describe the region: other animal species (e.g. no ewes in the region, presence of poultry, etc.), other classes of farm size, other legal forms, or other farm types. When possible and especially regarding the aim of the project, different beef productions systems can be distinguished, depending on the sufficient number of farms in each of them.

**Table 7:** Example of a list including regional characteristics

	Value	Source	Year
<b>General characteristics</b>			
Number of farms			
Utilized agricultural area (UAA)			
Beef cattle older than a year			
Dairy cows			
Other cows			
Ewes			
Other sheep			
Breeding sows (>50 kg)			
Pigs for fattening (>20 kg)	<i>Each case study area is particular. These very general characteristics should change from one region to another.</i>		
<b>Structural characteristics</b>			
<b>Number of:</b>			
Individual farms			
Partnerships			
Others			
<b>Total UAA of all the farms belonging to the following category:</b>			
Individual farms			
Partnerships			
Others			
<b>Area</b>			
Arable land			
Grassland			
<b>Number of farms specialized in:</b>			
Field crops			
Milk			
Grazing livestock			
Granivores			
Mixed (crops and livestock)			
<b>Total UAA of all the farms specialized in:</b>			
Field crops			
Milk			
Grazing livestock			
Granivores			
Mixed (crops and livestock)			
<b>Number of farms in different size classes</b>			
10 - 50 ha			
50 - 100 ha			
Etc.			
<b>Total number of pigs for fattening for all the farms of the following category:</b>			
Below 50 heads per farm			
50 - 200 “			

200 - 500 “	<i>categories as mentioned on the left column; and finally add all the pigs for fattening owned in total by all the farms of the considered category. Once again, the classification should fit the reality.</i>
500 - 1000 “	
1000 - 2500 “	
Above 2500 “	
<b>Total number of sows for all the farms of the following category:</b>	
Below 100 heads per farm	<i>It helps to appreciate the regional structure of cattle breeding, and the animals chosen to do this have to be the more representative of the region, as listed in the "General characteristics" part of this table.</i>
100 - 200 “	
200 – 500 “	
500 – 1000 “	
Above 1000	
<b>Total number of dairy cows for all the farms of the following category:</b>	
Below 50 heads per farm	<i>Same as above, but for dairy cows, if present in the region and representative of its breeding cattle structure.</i>
50 – 150 “	
150 – 250 “	
250 – 500 “	
500 – 1000 “	
Above 1000	

### 5.2.3 Farm data

A second dataset, at the individual level, is then to be filled in. In previous applications of AgriPoliS farm data could be derived from the Farm Accountancy Data Network (FADN) or IACS. However, in MEA-Scope, the possibility was offered to use data from the EU-FADN database. A set of farms is derived from this individual dataset (see Table 8), whose size/breeding cattle structure/farm type fits the best the main regional characteristics described above (. The method used to select these “typical farms”, a method which we call “upscaling”, is described above. For some regions, it was not possible access the corresponding FADN database, or FADN data for the region was not sufficiently available. Then, the regional partners delivered a sample of farms considered as typical for the case study area. The farms had to be described by variables identical to those calculated in the FADN database.

The two data sources, the regional and the individual ones, must be consistent one with the other to produce decent results.

**Table 8:** Farm data characteristics

<b>General information on the farm</b>	<b>Costs</b>
Organisational form of the holding	Total farming overheads
Type of farming	Machinery & building current costs
Organic farming	Energy
Irrigated area (UAA)	Contract work
Altitude zone	Other direct inputs
Structural Funds area	Depreciation
Areas with environmental restrictions	Total external factors
	Wages paid
<b>Structure and yield</b>	Rent paid
Economic size in European Size Units	Interests paid
Total labour input	
Labour input	<b>Subsidies</b>
Unpaid labour input	Total subsidies - excluding on investments
Unpaid labour input	Total subsidies on crops
Total Utilised Agricultural Area (UAA)	Compensatory payments/area payments

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UAA in owner-occupation	Total subsidies on livestock
Rented UAA	Other subsidies
Arable land	Environmental subsidies-c.u.
Grassland	LFA subsidies-c.u.
Cereals	
Other field crops	<b>Balance sheet</b>
Vegetables and flowers	Total assets
Vineyards	Total fixed assets
Permanent crops	Agricultural land
Orchards	Land, permanent crops & quotas
Olive groves	Permanent crops
Other permanent crops	Buildings
Forage crops	Machinery
Set aside	Total liabilities
Male cattle 12-24 months	
Dairy cows	<b>Income</b>
Other cows	Total output
Ewes	Gross Farm income
Other sheep	Family Farm Income
Breeding sows	Farm Net Value Added
Pigs for fattening	
	<b>Financial indicators</b>
	Net worth
	Change in net worth
	Gross investment
	Net investment

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### 5.3 Collecting data on the regional production practices for MODAM

#### 5.3.1 Data requirements for region-specific production activities

The economic and ecological evaluation modules of MODAM require a detailed description of production activities by numerous technical and economic coefficients.

MODAM is fed by four sources of information: (i) standardised or surveyed crop and live-stock production practices are combined with (ii) farm-specific information on capacities and (iii) site-specific information, e.g. soil-quality, restricted areas etc. Finally, (iv) scenario-specific information, e.g. on premiums can be added.

Within the MEA-Scope project, the coefficients for crop and livestock production practices stem either, from standardized technical data collections data (e.g. KTBL in Germany), or they were derived by expert valuation using computer based survey forms.

The other three sources of information are covered by the AgriPoliS/MODAM interface, in fact structural data concerning the capacities of typical farms at the base year and at certain time points, site-specific information as well as scenario definitions in the form of market prices and assumptions on policy instruments (see Fig. 4).

The following two figures illustrate the data needs of MODAM for an appropriate description of the production practices. For crop and fodder production data on the different kind of work steps, their timing, the applied machinery and the kind of in- and outputs are needed (see Fig. 8).

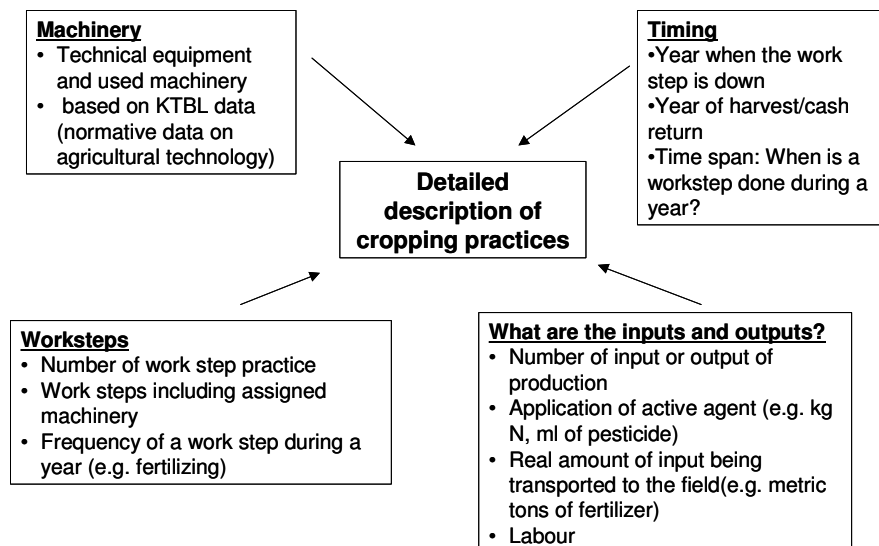


Fig. 8: Data needs for the description of the crop and fodder production activities in MODAM

MODAM's livestock production activities have a different structure. They describe animal husbandry systems throughout the year on the basis of herd size and composition, stables and their equipment as well as feeding activities. The data needs for their description are shown in Fig. 9.

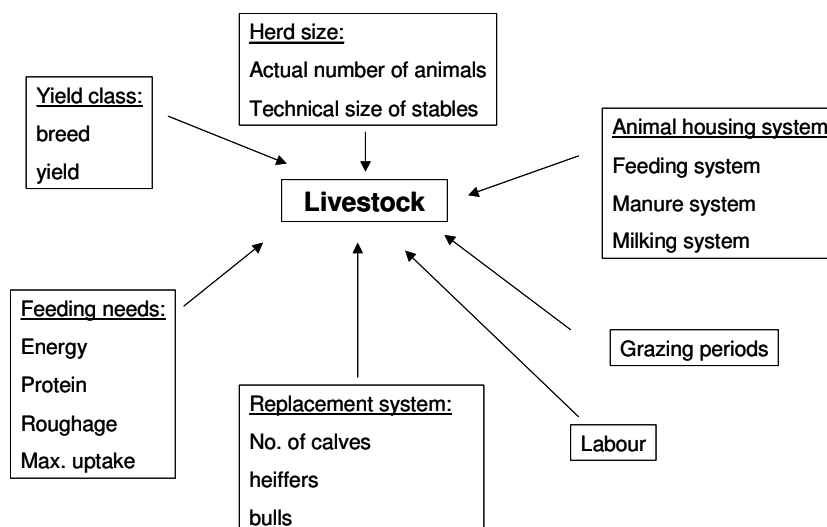


Fig. 9: Data needs for the description of livestock production systems in MODAM

### 5.3.2 Data collection on region-specific production activities

In order to collect and structure the data for the description of the MODAM production activities, MS ACCESS database supported survey forms for plant and livestock production were developed and tested by the ZALF team. In order to simplify the data handling, the database forms directly store the data in a useful computer readable format and additionally assist the user by suggesting values or creating lists to choose from. All forms are available for download on the MEA-Scope server: Plant and livestock production forms were sent to the regional partners in April 2005, following parameters were surveyed for the definition of crop /fodder production practices and livestock production systems (Table 9).

**Table 9:** MODAM - Data requested from the regional partners on crop, fodder and livestock production

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*Crop and fodder production practices*

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- Intensity, Scale and Orientation of the production
- Soil fertility index
- Crop grown

And for each combination of the above that exists in the respective region:

- Working steps required (e.g. seeding, ploughing, etc.); selectable from predefined
- Frequency of each working step
- Time span of each working step
- Amount and type of utilities applied (fertiliser, manure, etc.); selectable from predefined
- Amount and type of product yield (grain, straw, etc.); selectable from predefined

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*Livestock production system*

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- **Livestock branch** ( e.g. dairy cattle, fattening pigs); selectable from pre-defined.
  - Inner structure of the livestock branch; selectable from predefined **animal groups** (dairy cows, heifers, bulls, etc.)
  - Intensity, scale and orientation of the production
- For each **animal group** :
- Average number of animals in that category (daily head count averaged over one year)
  - Value of the animal
  - Weight gain
  - Average milk production
  - Labour for milking
  - Total labour required for this livestock branch, excluding on field fodder production and pasture management
  - Average body weight
  - Stable area
  - Pasture area
  - Litter required
  - Other products, like wool, eggs, etc., not meat or milk
  - Value of other products produced by that animal
  - Price of milk
  - Average milk fat
  - Average milk protein
  - Average investment for stable, including equipment
  - All other animal related costs (Not!: feed, stable, labour, quotas, purchase of animals)
  - Proportion of animals in tie-stalls
  - Number of surviving offspring
  - Offspring weight at birth
  - Percent female offspring
  - Days in that category
  - Subsidies per head
  - Cost of electric energy consumed for this Livestock Branch, excluding on field fodder production
  - Proportion of animals that belong to threatened breeds
  - Start of grazing period in Julian days
  - End of grazing period in Julian days
  - Average hours of grazing during grazing season
  - Proportion of animals on deep litter
  - Proportion of animals on slats (slurry)
  - Stable capacity for animals in that category
  - Cost for fossil fuels consumed for this livestock branch, excluding on field fodder production
  - Time the manure remains inside the stable
-

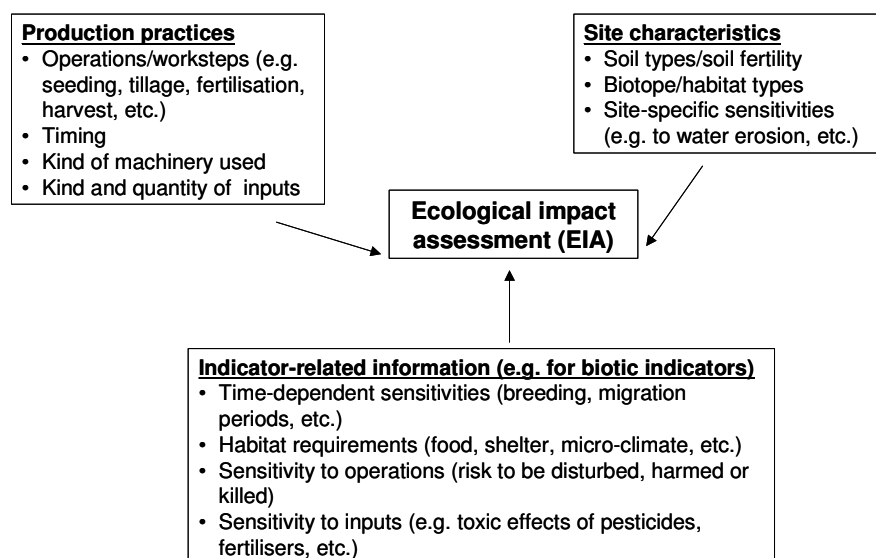
### 5.3.3 Data requirements for the environmental impact assessment (EIA)

The environmental impact assessment (EIA) of the MODAM production practices is indicator-based and implemented in a fuzzy logic tool, relying on expert knowledge. Up to now, assessment modules are available for 5 abiotic and 5 biotic indicators (Table 10):

**Table 10:** MODAM: Current list of environmental assessment modules

<i>abiotic:</i>
<ul style="list-style-type: none"> <li>– risk of nitrate leaching to groundwater,</li> <li>– risk of nutrient entries into surface waters,</li> <li>– risk of pesticide entries into groundwater and surface waters,</li> <li>– ground water recharge potential,</li> <li>– risk of water erosion.</li> </ul>
<i>biotic:</i>
<ul style="list-style-type: none"> <li>– impact on the habitat potential for skylarks (<i>Alauda arvensis</i>)</li> <li>– impact on the habitat potential for field hares (<i>Lepus europaeus</i>)</li> <li>– impact on the habitat potential for amphibians (Red belly toad, <i>Bombina bombina</i>)</li> <li>– impact on the habitat potential for hover flies (Syrphidae)</li> <li>– impact on the habitat potential for wild flora species (fall germinating)</li> </ul>
<i>Additional assessment modules under consideration:</i>
<ul style="list-style-type: none"> <li>– energy input</li> <li>– greenhouse gas emissions</li> <li>– wind erosion</li> <li>– soil organic matter content</li> <li>– animal welfare</li> <li>– habitat potential cranes (<i>Grus grus</i>)</li> </ul>

In order to run the indicator-based ecological assessment modules of MODAM data giving information on the agricultural production practices, the regional site characteristics and indicator-related data are needed (see Fig. 10).



**Fig. 10:** Data needs for the Environmental impact assessment (EIA) in MODAM

### 5.3.4 Data collection for the Environmental Impact Assessment (EIA)

According to the required data for the EIA (Fig. 10) a further survey form was developed and tested by the ZALF team. It was sent to the partners by the end of July and asks for the following information:

1. Choice of indicators being relevant in the respective region
  - a) Three abiotic and 3 biotic indicators of already implemented indicators
  - b) Two indicators out of the indicators under consideration
  - c) Suggestion for new indicators
2. Crop-related habitat potential (only important for biotic indicators): The partners are expected to select those crops being relevant for their region and to value the crops' habitat potential according to Table 11. In case that certain region-specific crops are not listed, new ones can be added.

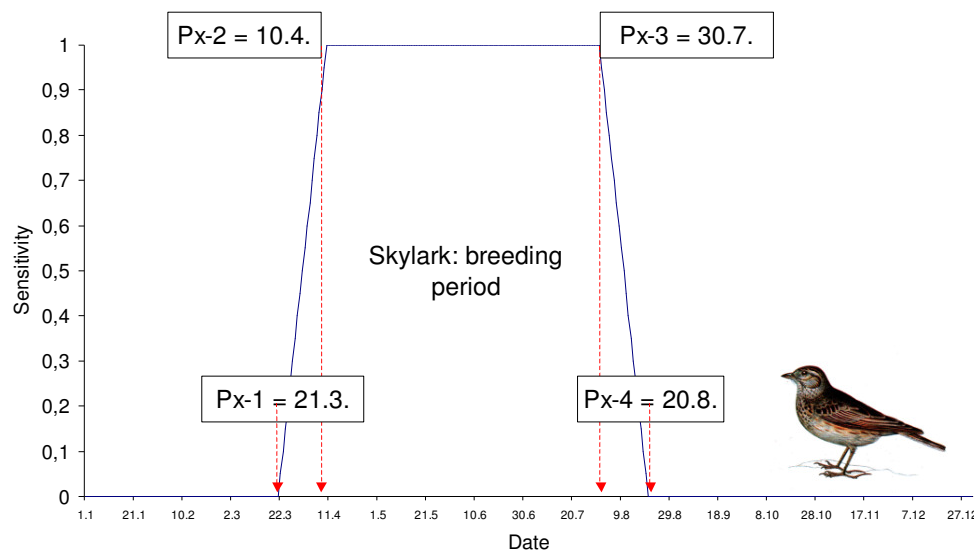
**Table 11:** EIA - Crop-related habitat potential (legend)

<i>Value</i>	<i>Description</i>
1	optimal habitat quality, long-term stable populations
2	partly optimal, partly good habitat quality, mostly stable populations
3	partly good, partly sufficient habitat quality, instable populations, high fluctuations possible
4	only partly sufficient habitat quality, instable populations, high risk of annihilation
5	unsuitable habitat quality, indicator is incapable of surviving

3. Crop-related data: Selected crop activities have to be specified by the following list of parameters. The partners are expected to check the predefined values and to adapt them to their region if necessary.
  - Production system/intensity of production
  - Dry matter [%]
  - Share of by-product [%] of whole crop biomass
  - Share of main-product [%] of whole crop biomass
  - N-content in main-product [kg/dt TM=dry matter]
  - N-content in by- product [kg/dt TM=dry matter]
  - P2O5-content in main-product [kg/dt TM=dry matter]
  - P2O5-content in by- product [kg/dt TM=dry matter]
  - N-retention in root zone over winter [kg N/ha]
  - Crop-related risk of lower yields over years (e.g. sensitivity to droughts, extreme weather conditions) [%]
  - Vegetation cover (spring/summer); 1=high, 2=low, 3= insufficient soil coverage
  - Vegetation cover (autumn/winter); 1=high, 2=low, 3= insufficient soil coverage
  - C-factor of the USLE (Universal soil loss equation) after Wischmeier & Smith

4. Sensitive periods (only important for biotic indicators): To define sensitive periods for biotic indicators 4 dates: Px-1, Px-2, Px-3 and Px-4 (Fig. 11) have to be described of which:

- Px-1 indicates the beginning of the transition phase before the core period where the sensitivity is gradually increasing.
- Px-2 and Px-3 define the core period where the highest sensitivity of the indicator is assumed
- Px-4 gives information about the end of the transition phase after the core period where the indicator's sensitivity is decreasing.



**Fig. 11:** Example definition of the sensitive period "breeding season" for the biotic indicator "Skylark"

5. Operation-related risk potential (biotic indicators): All operations relevant for the respective region have to be selected and their effects on the selected indicators have to be evaluated according to Table 12.

**Table 12:** EIA - Operation-related risk potential (legend)

Value	Description
0	no effects assumed
1	effects assumed only for single individuals of the population; negligible impact on the population as a whole
2	effects assumed for many individuals of the population; weakening of the population
3	heavy effects assumed for the majority of individuals of the population; impairment of the population
4	heavy effects on population level assumed; annihilation of the population possible

### 5.3.5 Current data availability

Table 13 displays the status quo of data availability regarding the description of crop, fodder and livestock production as well as the EIA (October 2005).

**Table 13:** Data availability for crop, fodder and livestock production (October 2005)

	Denmark	France	Germany	Hungary	Italy	Poland	Slovakia
Crop	X	announced	x	x*	x	x	x*
Forage/grassland	X	announced	x	x*	announced	x	x*
Livestock	announced	announced	x	x*	x	announced	x*
Environmental impact assessment	announced	announced	x	announced	x	x*	x*

x – available, \*data need to be completed

#### 5.4 Specific regional features needed for FASSET

All the data that FASSET needs as input is available either from MODAM or from other publicly available databases (weather and soil information). If the partners are not satisfied with the weather and/or soil information that can be retrieved through the JRC soil database and the MARS weather database, then they will have to provide this information themselves.

## 6 FUTURE STEPS

### 6.1 From prototype to the MEA-Scope tool

This paper has reported on the activities towards developing the MEA-Scope model prototype. The focus of the efforts were on linking three independently operating simulation models each of which is specialised on certain aspects related to multifunctionality. As described in the paper, the linkage takes place predominantly via a common data base and the analysis of the same farms in all three models.

As a prototype is not yet a fully functional model, further developments, adjustments and checks are required in order to be able to actually apply the framework to all case study regions in the MEA-Scope project. For this, a number of questions need to be solved. These mainly relate to the following points:

The **transfer of data** between models needs to be further developed. Regarding the link between AgriPoliS and MODAM data on a selection of typical farms is currently transferred with the use of specially created AgriPoliS output files, which include the types of data listed in Table 4. As site characteristics have been introduced into AgriPoliS, additional information such as the spatial location of the farms needs to be included. Moreover, the current transfer procedure requires however human interventions for the selection of typical farms to be analysed with MODAM and the creation of the output files containing information on these farms. As the number of farms set for further investigation (in test runs with the prototype we've only looked a four different typical farms) will certainly increase, the selection of farms from the large number of farms simulated in AgriPoliS must be thought further, tested and documented. A clustering algorithm may be an option here. Moreover, the transfer of data between the two models must be automated. This is likely to include adaptations of both AgriPoliS and MODAM.

Regarding the link between MODAM and FASSET, FASSET will include new animal groups, which are necessary in this project (particularly sheep). Another future task is to parameterise the operations with respect to temperature sums. We also anticipate that when we start running the model complex in the regions in southern Europe, we will have to include other crops in FASSET.

An important issue regarding the prototype is to find criteria for **making models and results consistent**. Results should be consistent both at the individual model level and across all three models. Especially the later will require attention as the scarce number of runs until now means that the likelihood to find inconsistencies between the models is rather large. This could happen in spite of the time and effort which has been used in calibrating the models with the same data and insuring consistency in scaling of the parameters. Once, results have reached a satisfactory level of consistency, the combined model needs to be validated, both technically by way of sensitivity analysis. If applied to the case study regions, validation of results can only take place in close collaboration with regional partners and end-users, focusing on the plausibility of results in the respective regional context.

## 6.2 Possible directions for further developments after MEA-Scope

It is obvious that the MEA-Scope tool under development represents only a first try to combine simulation models for policy impact assessment regarding multifunctionality. It has to be born in mind that the models have some limits. These are either set by the models' path-dependence stemming from previous applications and the scientific backgrounds of the modellers, or by the fact that certain issues relevant for multifunctionality of rural areas such as cultural heritage, tourism and recreation cannot be sensibly modelled within the given framework. Regarding the latter, it will only be possible to carefully draw some qualitative implications from model results. Accordingly, many issues which may be important from the perspective of multifunctionality cannot be tackled; at least not at this stage of development. These points create starting points for further developments beyond the scope of MEA-Scope.

The most important issue for further developments is to define and implement **feedback mechanisms** from the other models in the hierarchical structure. However, going from the detailed level and back to the aggregated level has a number of in-built obstacles. The modelling approach will not be able to generate detailed data for all farms in all the selected regions and it is therefore to be tested whether we will be able to generate conversion rules.

Modelling the **conversion** of conventional farms into organic farms is a very demanding task in a dynamic model when the optimisation is done on a yearly basis. This requires a longer range of perception for the individual farms. At the moment, AgriPoliS, therefore does not include the switch from conventional to organic production (or vice versa). The support for environmental friendly production is however often mentioned in connexion with multifunctional agriculture.

Another possibility is to extend the **socio-economic specifications** of the regions. An example could be to extend the current age structure in the model with demographic projections. The demographic structure in the rural areas in Europe is likely to influence the structural development of the agricultural sector. However the models do include ageing of the farmer as well as generation change, so it is debateable how much new such projections could add to the model.

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