The European Forest and Agricultural Sector Optimization Model

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1 Introduction

The agricultural and forestry sectors in the European Union may be at the onset of substantial structural changes. As natural resources are increasingly threatened, scientists and policy makers are searching for remedies. Major land use related environmental dilemmas include climate change, fresh water scarcity and pollution, air pollution, and the decline in biodiversity. Agriculture and forestry are connected to these environmental dilemmas in different ways. On the one hand, these two sectors contribute to the deterioration of environmental qualities through use of agrochemicals, irrigation, erosion promoting cultivation techniques, and diversification of natural ecosystems. On the other hand, agriculture and forestry have potential to remedy some of the negative environmental impacts. Carbon sink, wildlife habitat creation, and soil preservation are examples. How agriculture and forestry impact environmental qualities is foremost a matter of management and local soil and climate conditions.

Agricultural and forest management is mostly driven by incentives. Market incentives relate to the prices of various technologies and commodities, which are produced through these technologies. In addition, there is a long history of political support especially in the agricultural sector of the European Union. Historical support aimed foremost at domestic food security. Food security required to keep domestic farmers in business. Political regulations subsidized production and promoted higher production intensities. Higher intensities, however, often come at the expense of environmental qualities.

Currently, policy objectives regarding the agricultural and forestry sectors are changing. Several reasons have triggered this change. First, domestic food security is considered less important given today's international trade volumes and trade opportunities. Second, many European taxpayers resent the high support payments into the agricultural sector. This resentment is especially pronounced during times of budget deficits. Third, environmental interests gain more public support. Fourth, technical advances, i.e. in computing abilities and remote sensing as well as advances in agricultural and forest sciences decrease the transaction costs for regulations of environmental externalities in agriculture and forestry. Based on these developments, policy objectives in the European Union are moving away from domestic food security towards environmental goals. In short, farmers and foresters may only be supported in exchange for environmental services.

The European Forest and Agricultural Sector Optimization Model (EUFASOM) is a partial equilibrium model of the European Agricultural and Forestry sector, which has been developed to analyze changing policies, technologies, resources, and markets. Various policy designs and their consequences can be tested before implementation. For instance, the raise on carbon tax will influence the production on goods, plantation of different species, land use change etc. In addition, the model is well suited to examine the impact of new agricultural and forest technologies, which have not been used on a large scale outside experimental plots. The scientific value of the model also includes its link-ability to other models. Particularly, EUFASOM can provide input to the AROPAJ model from INRA, the AGRIPOL model from CIRAD, and land use models at IIASA. Through these models, EUFASOM results can be "processed" to obtain a higher spatial resolution or to increase the scope of the results.

2 Model structure

The model is regionalized at the EU country level (index r) and runs in 5-year steps from 2005 to a selected terminal period (index t)[1]. At the core of the model are agricultural and forest management options. Portrayed choices include many crop- and tree-species (index s) and alternative management choices (index m). Technologies require both physically limited resources (index n) and other inputs and yield one or several commodity outputs or growing resource stocks. Forest inventories are differentiated by age structure (index h) and ownership (index o). In addition, agricultural and forest activities also affect environmental qualities (index e). The individual members of the indicated indices and other not mentioned indices are listed in the Appendix of this document.

Figure 1 illustrates the basic structure of EUFASOM. Agricultural and forest production activities require inputs and natural resources, produce commodities and affect environmental qualities. Input supply and commodity demand parameters influence the optimal activity choice. The more commodities are supplied, the lower are prices. Similarly, the more inputs are required the higher are their costs. Governmental policies can influence agricultural and forest management directly or indirectly through agricultural inputs, agricultural commodities, or environmental qualities.
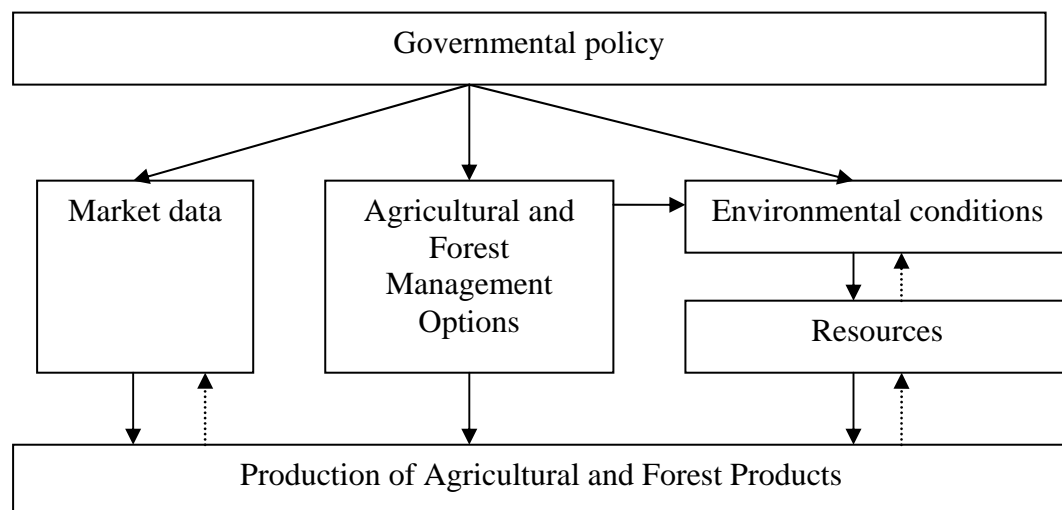

Figure 1 EUFASOM components

Technically, EUFASOM is a mathematical programming model containing millions of individual variables and equations representing a welfare maximizing objective function and technological, resource, and market restrictions. These equations and variables are entered as indexed blocks. All agricultural and forest production activities are specified as endogenous variables and denoted here by small letters[2].

EUFASOM's objective function maximizes total agricultural and forestry sector surplus (*WELF*) subject to a set of constraining equations, which define a feasible convex region for all variables. Feasible variable levels for all depicted activities range from zero to an upper bound, which is determined by resource limits, supply and demand balances or trade balances. Solving EUFASOM involves the task of finding the "optimal" level for all endogenous

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[1] The time steps and the time horizon can be adjusted (shortened or extended) to different specifications.
[2] A detail desciption of the variables you find in the appendix

variables subject to compliance with all constraining equations. By means of EUFASOM's objective function, optimal levels of all endogenous variables are those levels which maximize agricultural and forest sector based surplus, which is computed as the sum of total consumer surplus, producer surplus, and governmental net payments minus the total cost of production, transportation, and processing. Basic economic theory demonstrates that maximization of the sum of consumers' plus producers' surplus yields the competitive market equilibrium as reviewed by McCarl and Spreen[3]. Thus, the optimal variable levels can be interpreted as equilibrium levels for agricultural and forest activities under given economic, political, and technological conditions.

2.1   Objective function[4]

EUFASOM tries to emulate the market equilibrium under certain technical and political environments. Applying the McCarl and Spreen (1980) technique, EUFASOM uses a price-endogenous, economic surplus maximizing objective function as shown in (1)[5]. The total economic surplus equals the sum of the truncated areas underneath all commodity demand curves minus the sum of the areas underneath all factor supply curves minus the sum of all technological, transportation, and land use conversion costs. In addition, policy premiums are added while taxes are subtracted. The last term adds a terminal value for existing forests at the end of the modeling period. Note that all cost and benefits are discounted by the discount-factor δ_t.

$$(1) \qquad welf = \sum_{t \in T} DF_t \cdot \begin{bmatrix} + domd_t \\ - sspp_t \\ - ssur_t \\ - main_t \\ + subp_t \\ - recl_t \\ - luch_t \\ - emit_t \\ - tran_t \\ - term_t \end{bmatrix}$$

The left hand side of equation (1) contains the unrestricted total agricultural and silvicultural welfare variable (*WELF*), which is to be maximized. The right hand side of equation (1) contains several major terms, which will be explained in more detail below.

The first term *domd* adds the sum of the areas underneath the inverse domestic demand curves over all timber, crops, livestock products, and processed commodities. EUFASOM can employ four types of demand specifications: a) downward sloping demand curves, b) horizontal or totally elastic demand implying constant prices, c) vertical demand implying fixed demand quantities, and d) zero demand. Downward sloping demand curves are specified

[3] McCarl, B. A., Spreen, T. H., 1980. Price endogenous mathematical programming as a tool for sector analysis. Amer. J. Agr. Econ. 62, 87-102.
[4] The detailed mathematical formulation you find in the appendix
[5] In displaying the objective function, several modifications have been made to ease readability: a) the integration terms are not shown explicitly, b) farm program terms are omitted, and c) artificial variables for detecting infeasibilities are omitted. A complete representation of the objective function is available from the authors.

as constant elasticity function[6]. To prevent integrals underneath a constant elasticity function and thus consumers' surplus reach infinity, we use truncated demand curves. A truncated demand curves is horizontal between zero and a small quantity (truncation factor) and downward sloping for quantities above it[7].

As mentioned above, to simulate the market equilibrium, EUFASOM's objective function maximizes discounted economic surplus over all regions and all time periods. Technically, this is done by maximizing the sum of the areas underneath all final product demand curves (*domd*) minus the sum of the areas underneath all production factor supply (*sspp, ssur*) curves minus the sum of all technological cost. Welfare theory has demonstrated that this indirect technique is equivalent to the direct maximization of consumers' and producers' surplus. Computationally, the indirect method is faster.

To implement separable programming, the whole range of possible processing intensities is discretized through a sequence of closely spaced grid points. The distance between grid points does not have to be constant. In contrary, small distances should only be used in the neighborhood of the expected optimal processing magnitude. Large distances save computing power but decrease the accuracy of the solution if the optimal processing magnitude falls between two widely spaced grid points.

Each of the q grid points is associated with a so-called step variable and with two data parameters. One parameter measures the distance from zero to the quantity of grid point q. The other parameter gives the integral underneath the inverse marginal cost curve. An idea of the approximation we have made is found in Figure 2.
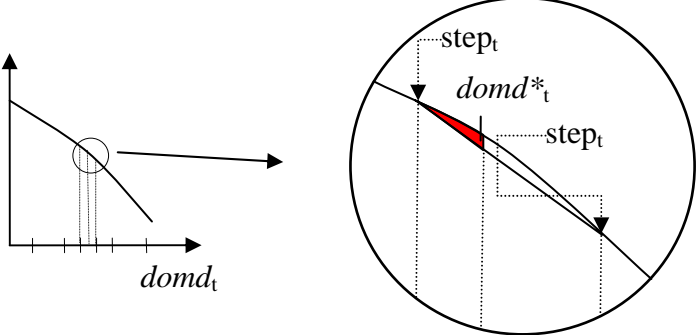

Figure 2: Approximation error in computing the area underneath the final product demand curve. Plotted on the left side is the integral of a linear inverse demand curve as a function of demand. On the right side, the approximation error is shown as filled area in red. Particularly, the convex combination of the area associated with the neighboring grid points leads to a very small underestimation of the integral.

The second right hand side term *sspp* subtracts the areas underneath the endogenously priced input supply curves for products and *ssur* the areas underneath the endogenously priced input supply curves for the resources like labor, water, land and animal grazing units.

Supply curves for these inputs are specified as upward sloping constant elasticity functions. The *ssur* supply variables are constraint by physical limits. Thus, when the physical limit is reached, the inverse supply curve becomes effectively vertical.

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[6] The GAMS version of ASMGHG contains a stepwise linear representation of constant elasticity supply and demand functions.
[7] A detailed description of the integral is written in the model documentation.

The areas underneath both curves are calculated in the similar was as the area of the demand curve.

The term *main* sums up the cost for planting, maintenance and harvesting of the forestry sector, cost for harvesting of the agricultural sector, cost for slaughtering life stock and cost for all processes of the forest product production.

subp represents the term for area based subsidies. *recl* takes into account the recycling process in the paper industry. In *luch* the costs of land use change for increasing or constant marginal cost are calculated. Emission payments or emission reduction credits are considered in the term *emit*. For transportation costs, the term *tran* sums over all in- and exports of one country to or from the other.

Since the program has a finite time dimension, one has to establish a final term, *term* to give the final standing forest a value. Otherwise it will get harvested in the last period.

2.2 CONSTRAINTS[89]

2.2.1 SEPARABLE PROGRAMMING RESTRICTIONS

For the linearization technique we need to have an identity and convexity restriction for demand, supply, resource and land-use-change. Together with the step-approximation in the objective function these constraints calculate the area under the particular functions.

2.2.2 EUFASOM DYNAMICS

Dynamic equations identify the inter-temporal relationships in EUFASOM. Because a finite time horizon is chosen, three types of restrictions need to be placed. First, initial resource conditions are needed to define a starting value for dynamic resources. Second, transition equations are needed for all dynamic components, which define the change between two adjacent periods. Finally, terminal conditions must be established to value relatively late investments, whose main returns occur beyond the model's last time period.

Generally, all exogenous parameters of EUFASOM have a time dimension and thus, potentially different values across time. The following list gives a brief overview about the dynamic parameter changes in EUFASOM:
- Physical resource endowments change based on population and resource projections
- Commodity demand functions change based on population projections
- Factor supply functions change based on industry projections
- Crop and tree yields change because of technological progress
- Cost and input use coefficients of agricultural and forest technologies change because of technological progress

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[8] A detailed description with all mathematical expressions is found in the EUFASOM documentation. Here we confine to the verbal description for efficiency and clarity reasons.
[9] The detailed mathematical formulation and additional constraints you find in the appendix

2.2.2.1   Initial conditions

Initial conditions are needed for all endogenous variables, which represent resource stocks. In EUFASOM, these variables include forest, crop and ecological inventories.

Initial forest equation

The initial forest condition determines the distribution of management options within the forest area in the first period. So the forest area depending on the forest management type will be chosen in this equation.

Initial mire equation

The initial mire equation determines the crop area in the first period and the ecological area in the first period, to be greater or equal certain base-area on peat soil. It will also be summed over the management index, which means, like in the initial forest condition, the initial distribution of the management type will also be chosen in this equation.

2.2.2.2   Transition conditions

Relative land use change balance condition

Agricultural and forestry activities in one period affect the state of connected resources. The land use can vary from one period to the other. This condition keeps track of to the change in forest-, agricultural- or economic land use.

Forest inventory equation

The forest inventory equation pursues the forest stand (forest variable) in the following way. The forest stand of a certain cohort in certain cannot exceed the forest area of the previous period of the previous cohort minus the harvested area.

Forest sequence restriction condition

The forest sequence restriction condition restricts which species can be planted after harvesting another (or the same species) in the previous period. A species equation map defines all possible combinations of species, i.e. the group of species which can succeed (planted) a certain species' which was harvested before. This depends on region, soil type etc.

Harvest inertia inequality for old trees

The harvest inertia equation for old trees (trees older than 30 years) limits the harvest of old trees from one period to the other for ecological reasons.

Stock inventory equation

This environmental impact equation concerns the deadwood and the final forest products. Under stock we understand all dead wood classes of wood waste and all forest products. So this equation actually incorporates two accounts, one for the dead wood pool (how much is

produced from one period to the other) depending on the decomposition rate, harvested volume, forest stand and the other for the product pool produced from one period to the other.

2.2.2.3 Terminal equations

Inventory of final forest products equation

EUFASOM portrays a finite number of periods. Without terminal conditions, all forests would be cleared before or during the last time period. Afforestation and reforestation activities would be zero in late periods of EUFASOM. However, life goes on beyond the horizon of EUFASOM. Consequently, we expect reforestation and afforestation activities also in late periods of EUFASOM. To allow these investments, we must place a terminal value on all incomplete investment projects, whose life spans multiple EUFASOM periods. This value is part of the objective function.

2.2.3 BALANCE EQUATIONS

Balance equations balance supply and demand for agricultural and forest production factors. In the Production equation, the total use of production factors by forest, cropping, livestock, land use change, and processing activities must be matched by total supply of these factors in each region.

Production equation

The product balance equation holds track of the demand, supply and production of the different products within a period. This includes the balance within a sector but also the balance of supply and demand of agricultural and forest commodities. Specifically, the commodity-volume sold domestically, processed, and exported, cannot exceed the commodity supply through forest harvest, crop production, livestock breeding, processing, and imports. Therefore in EUFASOM, trade activities are not implemented in a separate equation but inside this equation.

Resource equation

The resource balance equation pursues the resource inventory of all sorts of reserves. It takes care that the sum of all resources stays constant if one resource is shifted to another pool. Resources are e.g. land, labor, fuel etc.

Product inventory equation

The product inventory equation keeps track of the stock data. Stock which is produced in the previous periods and not yet transformed into carbon dioxide, plus the new produced stock has to be in balance with the exogenous stock data inventory according to the data base for each country, period and product (stock).

2.2.4 LIMITATION EQUATIONS

Resource limitation equation

For all resources, in each country and period we have a certain limit within the resource variable has to be.

Maximum land use change equation

The maximum-land-use-change-equation compares the change in land-use compared to the base period. The change of land use shall not exceed a certain amount which is compared to the first base area where the extent on forest, crop and eco land is defined.

Life stock conditions

Maximum and minimum feed intake by animal and nutrient is defined in these inequalities. So the optimal feed intake lies within a predefined scale - band.

Crop Area Mix constraints

Here the crop rotation is incorporated. The change of the crop species and the frequency of the change have an impact on carbon storage in the ground as well as the volume of crop harvested.

2.2.5 EMISSION ACCOUNTING

Emission accounting equations

The assessment of environmental impacts from agricultural and forest production, activities as well as political opportunities to mitigate negative impacts are a major application area for EUFASOM. To facilitate this task, EUFASOM includes environmental impact accounting equations. For each land use item, i.e. forest stands, perennial crops, annual crops eco land, animals and certain processes the amount on produced (or present) substance (carbon) is calculated, including the difference of the amount of stock from one period to the other. Negative values of greenhouse gas accounts indicate emission reductions.

GHG emissions and emission reductions are accounted for all major sources, sink and offsets from agricultural, forest and ecological activities, for which data were available or could be simulated. Generally, EUFASOM considers:

- Direct carbon emissions from fossil fuel use in tillage, harvesting, or irrigation water pumping as well as altered soil organic matter (cultivation of forested lands or grasslands),

- Indirect carbon emissions from fertilizer and pesticide manufacturing,
- Carbon savings from increases in soil organic matter and from growing trees,
- Carbon emissions from harvested timber products,
- Nitrous oxide emissions from fertilizer usage and livestock,
- Methane emissions from livestock and rice cultivation, and
- Methane savings from changes in livestock management.

Future development of EUFASOM, i.e. within the European Non-Food Agriculture project will add biofuel production opportunities and their impact on emission levels.

2.3 CALIBRATIONS

Generally, mathematical programming models do not automatically replicate a base situation. Possible reasons include incorrectly specified or missing data as well as incorrectly specified or missing equations. Several techniques have been developed to address these shortcomings and calibrate models. Positive mathematical programming (PMP) uses nonlinear cost functions, where the coefficients of these functions are endogenously determined. A second technique involves restrictions, which force the solution to form a convex combination of historically observed or expert estimated states. EUFASOM uses the latter technique.

3 Details on Data – Linkage to other Models

EUFASOM is data intensive. Many input data are simulated by other models or are directly taken out of some data base. These processes are automated to allow easy replication and update. Below is a short description of these procedures describing the use and linkage to other models.

3.1 FORESTRY SECTOR

The forest sector module of EUFASOM needs period specific input data, which are the biophysical data (OSKAR data), forest lent rent data (data base), forest industry data (FAO data), forest process data (forest sector GTM data), forest product data and also FAO wood data for import and export of each country. All other exogenous data for the forest sector are calculated out of these data sets (and for a certain extent also out of the agricultural input data)

3.1.1 BIOPHYSICAL DATA and LOGS

The biophysical data, including "raw" – products like logs, are produced by the OSKAR Model[10]. The OSKAR Model simulates all "potential" data of each region[11], each period, each species, each cohort, each forest management, according to biophysical grow curves, the standing biomass, tree number, amount of carbon, decomposition rate, cost for either planting or maintenance, labor for either planting or maintenance, potential harvested biomass, potential labor for harvesting, potential fuel for harvesting, potential cost for harvesting, potential logs and stem biomass.

They are starting from FAO data and model all these items according to the assumed functions. All simulated data have time dimension. In EUFASOM they are used as input data as well as for the constraints.

3.1.2 FOREST MARKET, FOREST PROCESS DATA, FOREST PRODUCT DATA

From the OSKAR Model, EUFASOM receives the "raw" (primary) product yields like round wood or pulp wood for different harvest times, management regimes, tree species, and regions. These primary products serve as input for different processing alternatives. Other inputs for these processes, like labor and energy etc. are explicitly computed. The processing results are intermediate and final products. Intermediate products serve for further processing and final products face a demand function and can be traded.

Intensity in this context refers to the amount to which a certain forest industry technology is used

Forest industry processing technologies are described for each region, time, process and program alternative. Each process data contain the quantity of major inputs, the quantity of outputs and the costs of the process excluding the costs of (producing) inputs, which are quantified explicitly (OSKAR Model). The sign associated with a process quantity distinguishes inputs from outputs. Variable cost data associated with a process identify expenditures in addition to wood input, labor, and energy.

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[10] See description there

[11] The OSKAR Model portrays several regions per country.

Forest market data (FAO) contain regional specific demand curve parameters for final products, current price and demand levels (quantity). It is important that the law of demand is satisfied. This law requires a weak monotonic decrease in demand as function of the own price. Demand functions are classified in three types: a) perfectly elastic demand (constant prices), b) downward sloping demand functions, and c) total inelastic demand (fixed demand quantities). Commonly used downward sloping demand functions are linear or constant elasticity functions.

3.2   AGRICULTURAL SECTOR

In the agricultural sector, data of the biophysical model Environmental Policy Integrated Climate (EPIC) and FADN, FAO, and EUROSTAT data are used. They provide the crop, feed and land data, crop supply, average crop emissions and for the distribution of the available peat land, the amount of wetland, mire and annual crop land for each country.

3.2.1   FADN DATA

Farm Accountancy Data Network (FADN) survey results are processed to represent European agricultural technologies in terms of inputs, outputs, and expenditures. EUROSTAT information is used to depict aggregate agricultural markets in the EU. FAO data are used to set up international trade and production in non-EU regions.

3.2.2   EPIC DATA

For each agricultural technology in each EU-HRU, soil carbon and other environmental impacts are assessed with the EPIC model. In addition, relative yield differences on different land qualities are used to adjust basic yields from FADN and EUROSTAT.

4   Results

Below are preliminary selected results from hypothetical carbon price scenarios and their intermediate impact on the agricultural and forest sector. These results illustrate that carbon sinks are competitive with each other and with traditional production and that economic potentials are generally smaller than technical potentials.

4.1   Strategy competition

The figure below shows the mitigation contribution of different strategies under different incentive levels. Lower incentive levels promote tillage based soil carbon sinks. At higher levels carbon sinks from growing trees dominate. As more and more lands are afforested, tillage based soil carbon sinks diminish for two reasons: a) less land remains in agriculture and b) increasing commodity market prices increase the opportunity cost of reduced tillage options.
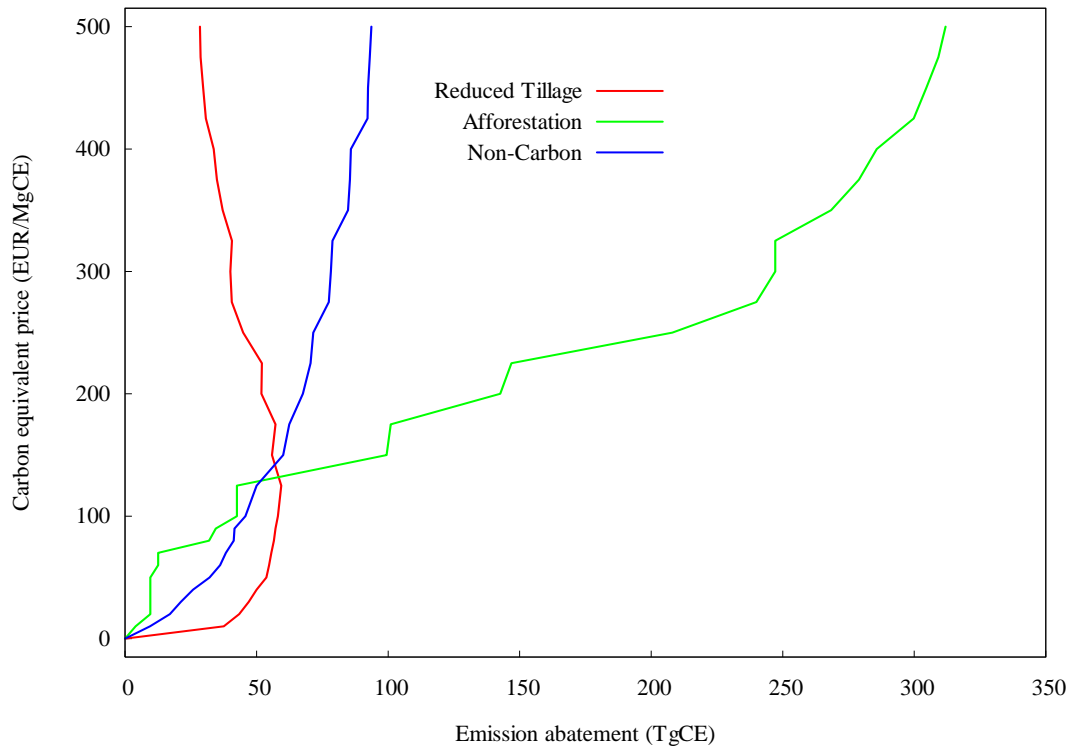
4.2   Traditional prices

Afforestation and associated land shifts from agriculture to forestry affect forestry and agricultural markets. This is illustrated in the figure below. As the forest base increases, agricultural production and net exports decrease, while prices for crop and livestock products increase.
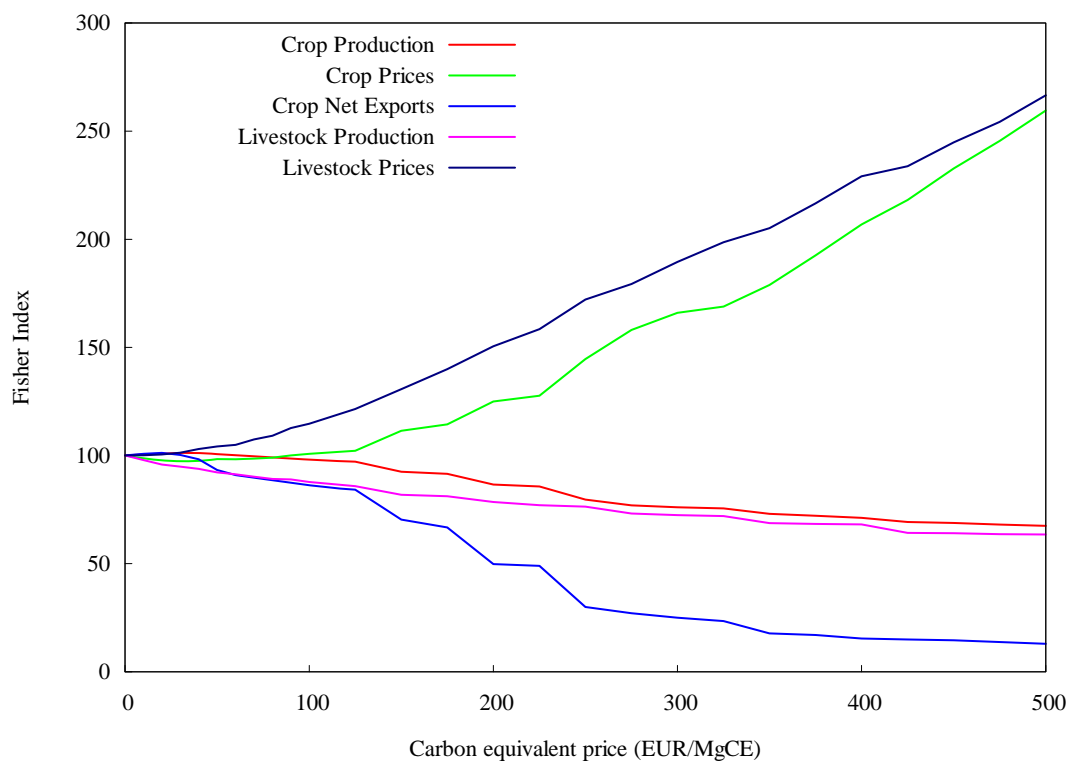
4.3   Economic vs. Technical Potential

For the two main land use based carbon sink strategies (below ground carbon sequestration i.e. through reduced tillage and above ground carbon sequestration i.e. through increasing the forest base) different measures of potential are computed. The lines labeled "competitive potential" correspond to the lines in section 4.1. The first graph shows the technical, economic (single strategy based), and competitive potential of carbon emission mitigation from reduced tillage. The technical potential is obtained by substituting the welfare maximizing objective function with a soil carbon sink maximizing function. The single strategy economic potential (middle line) shows the cost efficient abatement assuming that afforestation is not eligible for carbon credits. Clearly, the economic potential falls considerable short of the technical potential.
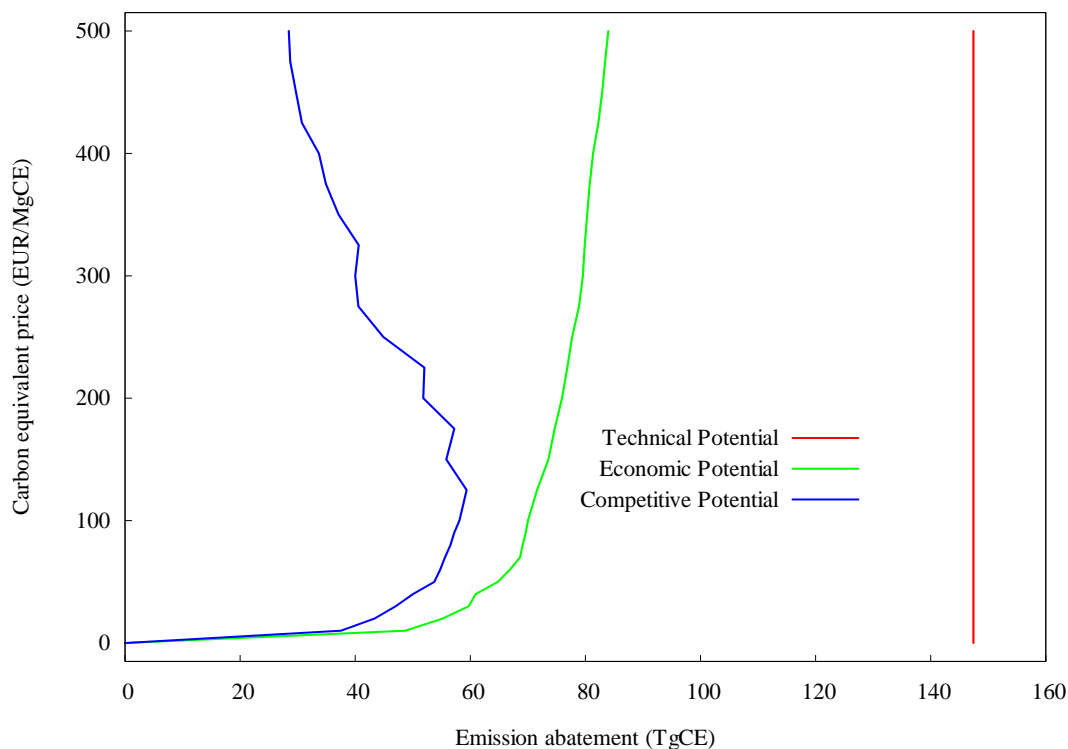
Potentials of above ground carbon sequestration i.e. through increasing the forest base are illustrated below. Again, the technical potential is substantially above the economic potential. Differences between the single strategy and competitive economic potential are relatively small. However, introduction of biofuels as additional mitigation option could increase the differences.
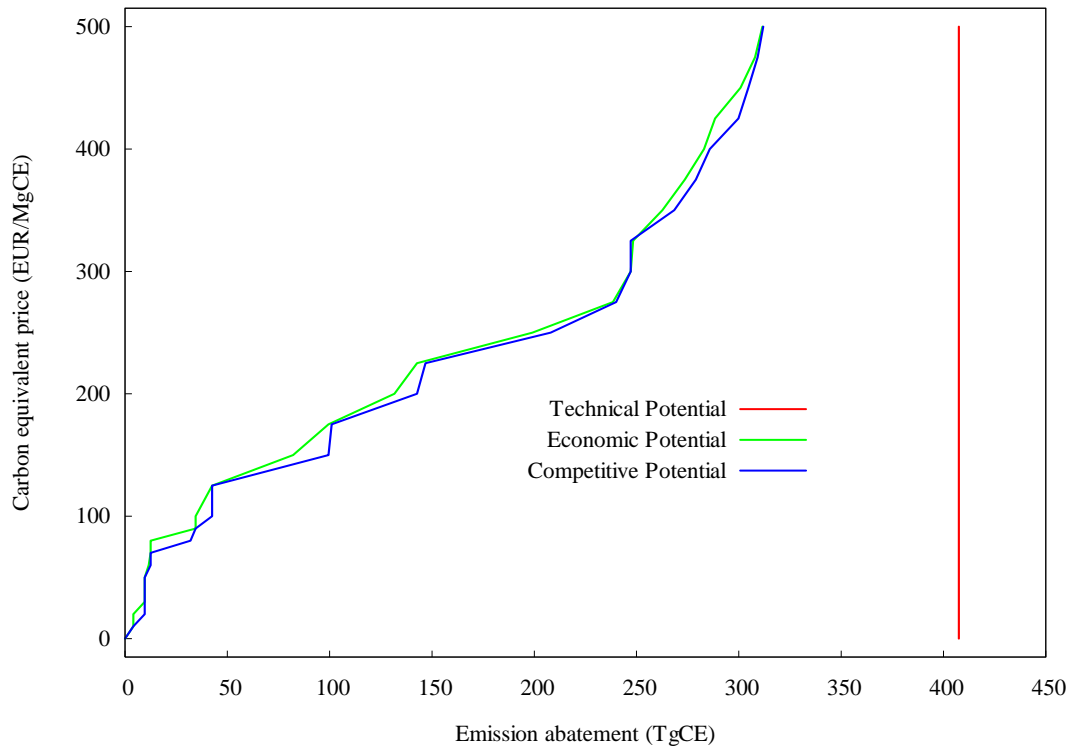
5 Outlook

EUFASOM has been successfully developed within INSEA. However, to be used as a quantitative tool for international policy negotiation, several steps must still be completed in the next weeks and month. Particularly, all main results must be verified and the core model should be peer reviewed. FADN data for EU+10 need to be integrated to better represent EU25 responses to policies. The additional data are expected to be available in September 2006. Through the above mentioned ENFA project, bioenergy chains will be added to EUFASOM within 2006/2007. Linked model scenarios could be performed through the whole network of INSEA tools to analyze the impacts of greenhouse gas mitigation through agriculture and forestry in a highly integrated manner.