Methodology underlying the CAPRI model

Contents

1 Introduction

The Common Agricultural Policy Regional Impact (CAPRI) model is an agricultural sector model with a focus on Europe (disaggregation into 280 NUTS2 regions, detailed activity data and coverage of Common Agricultural policies), but embedded in a global market model to represent bilateral trade between 44 trade regions (countries or country aggregates).

It is the outcome of a series of projects supported by European Commission research funds, the first one 1996-1999. Operational since more than a decade (1999), it supports decision making related to the Common Agricultural Policy (CAP) and, due to the development of environmental indicators, also environmental policies related to agriculture. In the following we will focus on the elements most relevant to the EUCLIMIT (Development and application of EU economy-wide climate change mitigation modelling capacity) project whereas the full documentation is online at http://www.capri-model.org/docs/capri_documentation_2012.pdf.

The CAPRI outlook systematically merges the information in historical time series with external projections from other models or independent expert knowledge while imposing technical consistency. In this application key external information came from the models PRIMES, GLOBIOM and AGLINK, together with national expert information on specific items. The key outputs (to GAINS) were the activity data in the livestock sector plus mineral fertilizer use in the crop sector.

CAPRI and GLOBIOM are both modelling the agricultural sector of EU countries and estimate the supply and demand of agricultural products as well as emissions from production and soil. There is thus an overlap of the models in terms of coverage but both have a quite different orientation and structure. Therefore they complement each other and give the user additional information when they are applied to the same scenarios.

The methodology report on CAPRI is structured in the following way. Section 2 briefly presents the general modelling suite as far as it is related to agriculture. Section 3 gives some details on the database where significant improvements have been achieved under EUCLIMIT. Section 4 explains the methodology to produce the CAPRI outlook and the improvements implemented under EUCLIMIT. Section 5 is devoted to "scenario mode" of CAPRI which has been used under EUCLIMIT to distinguish the "reference run" (with additional measures) from the "baseline" (only adopted measures). Three annexes complete this report. The first is a listing of the items available. Annex 2 gives some technical details on the animal sector of CAPRI that is most important for the role of CAPRI in the EUCLIMIT modelling chain. Annex 3 finally reports on the efforts to establish a database covering the complete area of countries. This helped to improve communication between CAPRI and GLOBIOM under EUCLIMIT.

2 Position in the agriculture related modeling suite of EUCLIMIT

To respond to the project tasks regarding emission projections, the models communicate as shown in Figure 1 below. The macro-economic outlook as well as economic activities and energy use by sector is captured by GEM-E3 and PRIMES. The biomass component of PRIMES provides bioenergy related information both to CAPRI and GLOBIOM, ensuring consistency in bioenergy related assumptions. However, due to the differences between CAPRI and GLOBIOM, different pieces of information are used as model inputs:

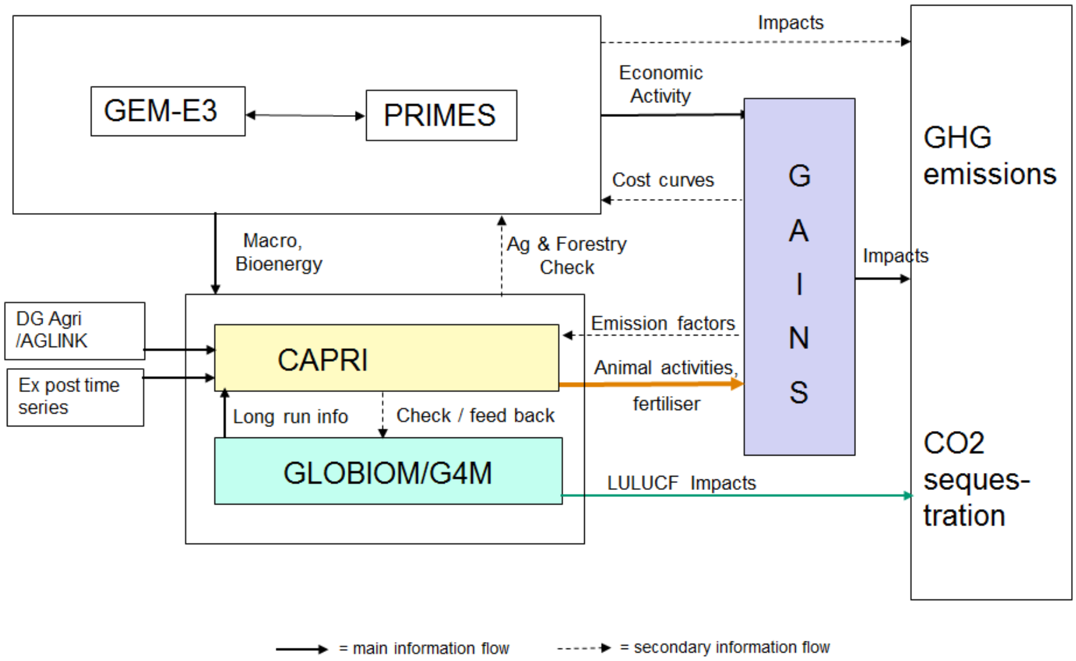
- GLOBIOM uses information on various types of bioenergy demand (heat, power, cooking, transport fuels of first and second generation) and biomass production of energy purposes (from crops, forestry, waste items) as lower bounds for the market equilibrium.
- CAPRI uses supply and demand of biofuels and the shares of first and second generation production. Furthermore the broad split of first generation agricultural feedstocks (cereals, oilseeds, sugar crop) as well as the areas for lignocellulosic crops are inputs from the PRIMES biomass component.

These differences reflect the endogenous coverage of forestry and lignocellulosic crops in GLOBIOM. Both models yield results on the complete area allocation and feed back to the PRIMES biomass components in case of questionable results, for example if a very high expansion of lignocellulosic crops would have dubious implications for the whole area allocation in a country.

GLOBIOM projects a long run market equilibrium for key agricultural (and forestry) products from basic drivers such as GDP, population, food consumption trends, productivity growth. It is interacting with the G4M model for supply side details on forestry. The CAPRI model uses these GLOBIOM projections as prior information for its own baseline. This means that they provide target values for the CAPRI baseline. At the same time CAPRI uses prior information from the AGLINK baseline, but due to the relative strength of these models the weight of AGLINK decreases relative to GLOBIOM along a longer-term projection horizon (2030-2050). The preliminary baseline results of CAPRI and GLOBIOM are compared and in case of surprising differences a feedback loop of information is initiated.

Relying on a considerable level of technical detail, the forestry and agriculture models may also supply projections of emissions and removals of GHGs. However, in the EUCLIMIT modelling suite it is only the LULUCF results from GLOBIOM on carbon releases and sequestration that enter the final reporting. Non-CO_2 emissions from agriculture (and other sectors) are calculated in GAINS, considering technical abatement options and their cost and using the agricultural activity information from CAPRI (animal herds, fertiliser use). The energy related emissions of CO_2 are directly provided by PRIMES.

Figure 1: Overview of EUCLIMIT model interactions.



Important model characteristics may be summarised as follows, highlighting the differences and complementarities.

2.1 CAPRI

CAPRI (for Common Agricultural Policy Regional Impacts) is a global agricultural sector model developed at Bonn University with a clear focus on Europe. The main characteristics are:

- Global multi commodity model covering about 60 agricultural and processed products and 80 world regions, aggregated to 40 trade regions.
- Supply modelling in Europe occurs in more detail (280 NUTS2 regions, potentially disaggregated into 2000 Farm Types) in nonlinear programming models. Both the behavioural function of the global market model as well as the nonlinearities in the European programming models ensure smooth responses to changes in economic incentives.
- Partial equilibrium, meaning that non-agricultural sectors are excluded but there are options and experience to link the CAPRI core model to CGEs.
- European agricultural land use is represented completely (including fruits, vegetables, wine etc), but some globally relevant crops (e.g. peanuts) and forestry are not modelled.
- The livestock sector is represented in great detail including feed requirements (energy, protein, fibre etc.) and young animal herd constraints (Annex A.4.2).

- CAPRI has a detailed coverage of CAP and agricultural trade policies (including TRQs), relying on the Armington approach for two way international trade.
- The model is not designed for stand alone outlook work but incorporates external prior information combined with a statistical analysis of its time series database
- It is comparative static and not suitable for very long scenario runs (>2050).

2.2 GLOBIOM

The Global Biosphere Management Model (GLOBIOM) has been developed and is used at the International Institute for Applied Systems Analysis (IIASA). The main characteristics are:

- Global land use model covering 53 world regions, including all EU28 Member States. The regional break down can be altered if needed.
- The methodology is the same for Europe and other regions. A maximisation of a social welfare function in a linear program simulates the market equilibrium. In small simulation units on the supply side strong specialisation may occur, but the aggregation to countries and larger regions and constraints at the simulation unit level tends to smooth out this feature to some extent.
- It is a partial equilibrium model with bottom-up design, not only in a strong disaggregation of supply regions into simulation units but also in the technological detail (detailed representation of cropland management (input and management systems), livestock sector (FAO system classification) and globally consistent GHG accounting)
- Substantive experience with linkages to other biophysical and economic models (EPIC, G4M, RUMINANT, PRIMES, POLES etc.)
- It covers the major global land-based production sectors (agriculture, forestry, bioenergy, other natural land) and different bioenergy transformation pathways, but some agricultural products (fruits, vegetables, wine etc) are neglected.
- Compared to CAPRI less details on agricultural policies as the focus is on global land use issues. Bilateral trade is modelled, but two way trade and TRQs are not explicitly represented.
- GLOBIOM is recursive dynamic as e.g. land use changes are transmitted from one period to the other and subject to certain inertia constraints.
- The model can relatively easily also be applied for scenarios up to the year 2100 but its short to medium run projections may not capture recent trends, as GLOBIOM does not calibrate its baseline to time series but to an average around the base year (2000). In addition, it is driven by long-term macro-economic driver such as GDP, population growth and productivity changes.

2.3 G4M

For the forestry sector, biomass supply is projected by the Global Forestry Model (G4M):

- Geographically explicit forestry model
- Estimates afforestation, deforestation and forest management area and associated emissions and removals per EU Member State
- Is calibrated to historic data reported by Member States on afforestation and deforestation and therefore includes policies on these activities. Explicit future targets of forest area development can be included
- Informs GLOBIOM about potential wood supply and initial land prices
- Receives information from GLOBIOM on the development of wood demand, wood prices and land prices

3 CAPRI database

The main characteristics of the CAPRI data base are:

- Wherever possible link to harmonised, well documented, official and generally available data sources to ensure acceptance of the data and the possibility of annual updates.
- Completeness over time and space. As far as official data sources comprise gaps, suitable algorithms were developed and applied to fill these.
- Consistency between the different data (closed market balances, perfect aggregation from lower to higher regional level etc., match of physical and monetary data)

Data are collected at various levels from the global, to the national, and finally regional (NUTS2) level. A further layer consists of geo-referenced information at the level of clusters of 1x1 km grid cells which serves as input in the spatial down-scaling part of CAPRI (not used in EUCLIMIT). Finally in the last CAPRI-RD project a layer of regional CGEs has been implemented that may be switched on for an analysis of rural development policies (not used in EUCLIMIT). As it would be impossible to ensure consistency across all regional layers simultaneously, the process of building up the data base is split in several parts:

- Building up the *global data base*, which includes areas and market balances for the non European regions in the market model (mostly from FAO) and bilateral trade flows.
- Building up the *European data base at national or Member State level* (not only EU but also Norway, Turkey, Western Balkan). It integrates the Economic Accounts data (valued output and input use) with market and farm data, with areas and animal herds (that are currently not covered for non European countries).
- Building up the data base at *regional or NUTS 2 level*, which takes the national data basically as given (for purposes of data consistency), and includes the allocation of inputs across activities and regions as well as consistent areas, herd sizes and yields at regional level.
- Given the extent of public intervention in the agricultural sector, policy data complete the database. They are partly CAP instruments like premiums and quotas

and partly data on trade policies (Most Favourite Nation Tariffs, Preferential Agreements, Tariff Rate quotas, export subsidies) plus data on domestic market support instruments (market interventions, subsidies to consumption) and rural development policies.

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The following table shows the elements of the CAPRI data base as they have been arranged in the tables of the data base.

Figure 2: Main elements of the CAPRI data base

	Activities	Farm- and market balances	Prices	Positions from the EAA
Outputs	Output coefficients	Production, seed and feed use, other internal use, losses, stock changes, exports and imports, human consumption, processing	Unit value prices from the EAA with and without subsidies and taxes	Value of outputs with or without subsidies and taxes linked to production
Inputs	Input coefficients	Purchases, internal deliveries	Unit value prices from the EAA with and without subsidies and taxes	Value of inputs with or without subsidies and taxes link to input use
Income indicators	Revenues, costs, Gross Value Added, premiums			Total revenues, costs, gross value added, subsidies, taxes
Activity levels	Hectares, slaughterings (flow data) and herd sizes (stock data)			
Secondary products		Marketable production, losses, stock changes, exports and imports, human consumption, processing	Consumer prices	

In 2012-13 there has been a thorough revision of the CAPRI **global database** which was motivated and financed from other projects, mainly to adjust to a different organisation and data availability from Faostat.

More important for EUCLIMIT are the European data which mostly rely on Eurostat and are compiled in two major modules, “COCO” (for complete and consistent at the national level) and “CAPREG” for the CAPRI (NUTS2) regions. The first one, the COCO module for the **national database**, is itself composed of two submodules:

- COCO1 submodule: This is the major step preparing the bulk of the national database for European countries, one country after the other. It involves three steps:
  - A data import step that collects a large set of very heterogeneous input files
  - Including and combining these partly overlapping input data according to a set of hierarchical overlay criteria, and
  - Calculating complete and consistent time series while remaining close to the raw data in an optimisation program.

  The data import and overlay steps form a bridge between raw data and their final consolidation step to impose completeness and consistency. The overlay step tries to tackle gaps in the data in a quite conventional way: If data in the first best source (say a particular Eurostat table from some domain) are unavailable, look for a second best source and fill the gaps using a conversion factor to take account of potential differences in definitions. To process the amount of data needed in a reasonable time this search to second, third or even fourth best solutions is handled as far as possible in a generic way where it is checked whether certain data are given and reasonable.

- COCO2 submodule: The second COCO module estimates consumer prices and some supplementary data for the feed sector (by-products used as feedstuffs, animal requirements on the MS level, contents and yields of roughage). Both tasks run simultaneously for all countries and build on intermediate results from the COCO1 submodule.

CAPRI is a policy information system regionalised at **NUTS 2 level** with an emphasis on the impact of the CAP. The core of the system consists of a regionalized agricultural sector model using an activity based approach. It is thus necessary to define for each region in the model, at least for the basis year, the matrix of I/O-coefficients for the different production activities together with prices for these outputs and inputs. Moreover, for calibration and validation purposes information concerning land use and livestock numbers is necessary. The key data are coming from various tables in the REGIO domain of Eurostat on land use, crop and animal production, and cow milk collection. For some data the Farm Structure

Survey (FSS) provides important data to regionalise the national data even though these data are not available on an annual basis.

3.1 Improvements in the CAPRI database under EUCLIMIT

The list of database improvements triggered by EUCLIMIT includes the following points

3.1.1 Standard database updates and outlier checking

A large scale modelling system such as CAPRI requires an extensive database that needs to be up to date and cleaned from data errors or gaps. Erroneous data are partly cleaned by automated routines in this context but frequently are also detected only in the process of analysing results. They are listed in detail in the log of the CAPRI versioning system SVN (e.g. for revision number 1544, 06.09.2012:" DK: correction of market balances for RICE to ensure that there is no MAPR", because processing of paddy rice is zero according to Eurostat in DK). This maintenance of the database may not be directly related to EUCLIMIT but it is essential for the functionality of the system (activating the behavioural function for processing of rice will give an error if there is no input into processing). Updates that have been directly related to EUCLIMIT include the biofuel data (bioethanol from http://www.epure.org, biodiesel from http://www.ebb-eu.org).

3.1.2 Improvement of land use database

For better communication with GLOBIOM, but also because this provides a natural constraint for modelling, the CAPRI database has been extended to cover the whole country area, see Annex 3.

3.1.3 Full integration of herd size data in all CAPRI modules

Before 2011 CAPRI largely disregarded the statistical information on animal herd sizes, that is the animals stocks counted at certain survey dates, in favour of the flow data, the slaughterings per year which were more closely related to meat market balances. An exception was the treatment of the female breeding herd (cows, sows, ewes, hens). Nonetheless the conceptual differences caused mapping problems to other modelling systems that use these animal stock data rather than the flow data, in particular GAINS and GLOBIOM operated at IIASA. To improve the fit of the databases, CAPRI has included the herd size data now as well, and where they were inconsistent with the flow data also reported by Eurostat, has implemented a compromise data set that meets the technical constraints linking animal herd size, slaughterings per year, process length, daily growth and final weight). A preliminary implementation for this integration of herd size data into CAPRI was achieved and rendered operational already in the context of a previous service contract involving the same consortium (Model based assessment of EU energy and climate change policies for post-2012 regime, Tender DG ENV.C.5/SER/2009/0036). Under EUCLIMIT this integration was fully integrated in all CAPRI modules from the feed requirement functions, the regionalisation step and the baseline modules to fully exploit the potential for additional consistency checks (see http://www.capri-model.org/docs/capri_documentation.pdf, pp 32-34, 40-41, 47-50, 101-102).

4 Baseline Generation

The purpose of a baseline is to serve as a comparison point or comparison time series for counterfactual analysis. The baseline may be interpreted as a projection in time covering the most probable future development or the European agricultural sector under the status-quo policy and including all future changes already foreseen in the current legislation.

Conceptually, the baseline should capture the complex interrelations between technological, structural and preference changes for agricultural products world-wide in combination with changes in policies, population and non-agricultural markets. Given the complexity of these highly interrelated developments, baselines are in most cases not a straight outcome from a model but developed in conjunction of trend analysis, model runs and expert consultations. In this process, model parameters such as e.g. elasticities and exogenous assumptions such as e.g. technological progress captured in yield growth are adjusted in order to achieve plausible results (as regarded by experts, e.g. European Commission projections). It is almost unavoidable that the process is somewhat intransparent. Two typical examples are AGLINK and FAPRI.

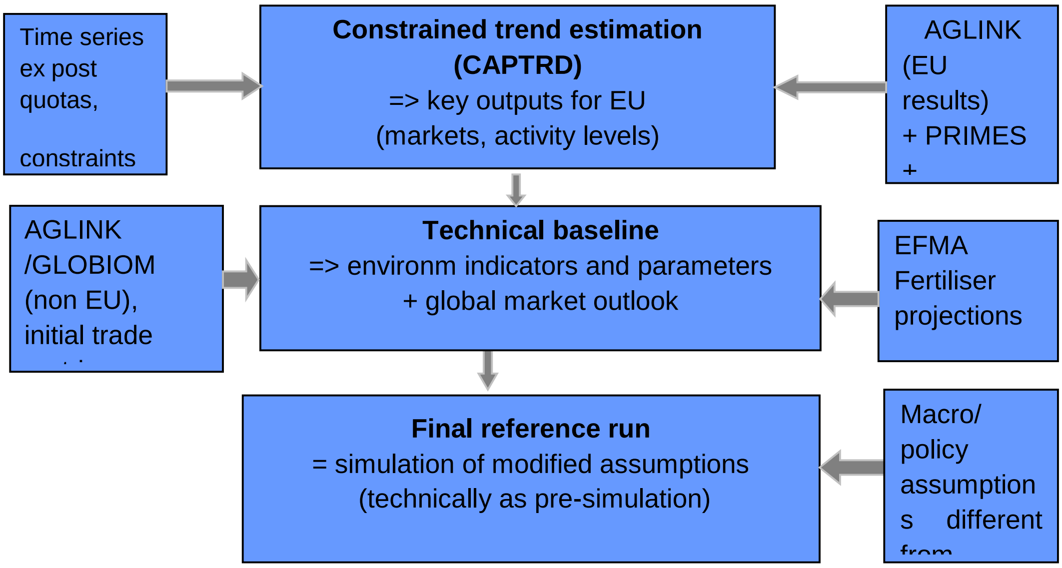
As is the case in other agencies, the CAPRI baseline is also fed by external ("expert") forecasts, as well by trend forecasts using the CAPRI database. The purpose of these trend estimates is, on the one hand, to compare expert forecasts with a purely technical extrapolation of time series and, on the other hand, to provide a 'safety net' position in case no information from external sources is available. The CAPRI module providing projections for European regions (CAPTRD) operates in several steps:

- Step 1 involves *independent trends* on all series, providing initial forecasts and statistics on the goodness of fit or indirectly on the variability of the series.
- Step 2 imposes *constraints* like identities (e.g. production = area * yield) or technical bounds (like non-negativity or maximum yields) and introduces specific *expert information* given on the MS level or for specific sectors (like PRIMES for bioenergy).
- Step 3 includes expert information on aggregate EU markets. Because this requires some disaggregation to single MS but also because it often the key information steering the outcome, it is treated in a step distinct from (2).
- Depending on the aggregation level chosen, the MS result may be disaggregated in subsequent steps to the regional level (NUTS2) or even to the level of farm types.

The constrained trends from CAPTRD are simultaneously subject to the consistency restrictions in steps 2 and 3. Hence they are not independent forecasts for each time series and the resulting estimator is a system estimator under constraints (e.g. closed area and market balances). Nonetheless it is to be acknowledged here that even constrained trends remain mechanical in that they try to respect technological relationships but remain ignorant about behavioural functions or policy developments[1].

However it should be explained that the CAPTRD results are in turn only the first of several steps before a full CAPRI baseline is ready to use. There are at least one and often two steps following:

Figure 3: Overview on CAPRI baseline process



1. The constrained trend estimation merges the information in the ex post time series with external information (AGLINK, PRIMES, GLOBIOM, national expert information). The result of this first step is a first projection for the key variables in the agricultural sector (activity levels and market balances) of Europe.
2. The "technical baseline" calibrates missing parameters and in this context also calculates missing variables that are related to the key variables, in particular complete nutrient balances in the crop and livestock sectors and all non EU market balances and the bilateral trade matrix.
3. A third step may give the final reference run if some assumptions made in steps one or two need to be revised to obtain the desired starting point for further analysis. In some studies it turned out useful, for example to modify

[1] The only exception are the quota regime on the milk and sugar markets which are recognised in the trend projections.

the macro assumptions of the "agricultural" expert sources (AGLINK, GLOBIOM) but under EUCLIMIT the macro assumptions were aligned with each other.

4.1 Improvements in the CAPRI baseline procedure under EUCLIMIT

4.1.1 Improved alignment with PRIMES biomass

The earlier processing of PRIMES input suffered from some misunderstandings related to the interpretation of certain items ("Bioheavy") that have been clarified in the first phase of the project. Furthermore the new output format offers additional information such as the split of bioethanol production (rather than only production capacities) according to first and second generation production which facilitates a better link to CAPRI items.

Communication has also improved relative to ethanol beets where CAPRI has used in earlier projects the forecasts from industry sources because the PRIMES outputs appeared to be given in units not commensurate with CAPRI. Some discussion on single country results has further improved the alignment in the sugar sector.

4.1.2 Update of EFMA information of fertiliser outlook

In some earlier projects there was an intense communication with EFMA representatives that led to the use of some detailed EFMA projections also in CAPRI, at least for the medium term horizon. This detailed exchange was very fruitful, but also time consuming such that the EFMA projections used by CAPRI before the EUCLIMIT project were dating from the 2007 forecasting exercise. In the meantime the published EFMA reporting (see http://www.fertilizerseurope.com/fileadmin/user_upload/publications/agriculture_publications/Forecast_2012-final.pdf) has become more complete in terms of single country information such that it was feasible to update the EFMA forecasts for basically all EU MS without lengthy communication processes.

However it should be mentioned that beyond 2020, an increasing weight has been given to the CAPRI internal projection mechanisms as opposed to the EFMA projections (running to 2022 only). These internal mechnisms rely on a stable evolution of parameters describing farmer's behaviour, including their habit to apply a certain over-fertilisation above crop needs, even when acknowledging that a part of organic nutrients are considered not "plant available" (and thus expected to be lost to the environment).

4.1.3 Deepening of linkages to IIASA models

The key motivation for the extension of the CAPRI land use database to include non-agricultural land uses was the benefit in projections. While there is some uncertainty how single land uses might develop in the future (and how they have developed in the past) it is clear that the sum across all uses must remain constant. Under EUCLIMIT a total area balance has been added therefore to the set of CAPRI constraints used in the initial trend estimations (CAPTRD step in Figure 3).

Furthermore the consistent “double” accounting in the animal sector in terms of flow data (slaughterings) and stock data (animal herds counted at some point in time) has also been extended from the database routines to the projection routines with a few additional equations.

These adjustments increase the internal consistency of CAPRI projections but they also support the exchange of respective information between the models. In particular the GLOBIOM projections on forestry and “other natural land” may be included now as prior information and indirectly also support the alignment in terms of agricultural areas.

Furthermore there had been a discussion on the various concepts used to represent productivity gains in the models. It has been clarified that the GLOBIOM approach currently relies on the idea of neutral technological change. This implies that the input requirements of all inputs for a kg of milk are decreasing over time by the same percentage due to technological change. In reality, the number of cows required for a given quantity of milk also declines, because each cow receives more feed (energy). The reciprocal of the input requirement in terms of cows, that is the milk produced per cow (a partial factor productivity), therefore increases historically (and very likely also in the future) at a rate that exceeds the productivity gain from technological progress (measured by total factor productivity). The latter is sometimes called the “net productivity” change, whereas the total change in the milk yield per cow may be called a “gross productivity” change. In GLOBIOM, only net productivity gains due to increasing feed conversion efficiency (the input requirements for a kg of milk in terms of feed) are accounted for, but not the additional productivity gains by changing diets/increasing calorie intake per animal. In other words, the initial intensity of feed energy per cow is maintained during projections. However, this approach tends to overestimate total herd numbers compared to reality, if milk yields change faster than feed efficiency. The clarification of this point led to the conclusion that it is preferable to remove the GLOBIOM results in terms of animal herds from the input set for CAPRI and to align instead only the market balance information, including production quantities.

Finally it is worth mentioning that some technical details to deal with the transition from the medium run (up to 2020) to the long run (2030 and beyond) have been changed in the CAPTRD module. It is possible now to phase in the GLOBIOM information already before 2020 if this is useful for common applications. In the end it turned out that for EUCLIMIT it is not useful to increase the weight for GLOBIOM a lot up to 2020, but the initial discussion suggested that more flexibility might be needed.

In terms of the linkages to GAINS there have been no changes such that the outputs to gains continue to be

- animal herd data (dairy cows, other cattle, pigs fattened, piglets, sows, sheep, hens, other poultry)
- dairy cow milk yields including milk directly fed to calves
- nitrogen fertiliser use quantities

4.1.4 Update of MS level expert information

In Ireland several analyses have been carried out to assess the feasibility and consequences of the national "Food harvest 2020" plan (see e.g. from the FAPRI Ireland group http://www.teagasc.ie/publications/2011/67/67_FoodHarvestEnvironment.pdf), a private initiative involving both representatives from agriculture as well as from the downstream food industry and the government. The food harvest 2020 plan includes a target increase for the volume of milk production from 2009 to 2020 amounting to 50% which is almost twice the growth that might be expected otherwise. The final EUCLIMIT baseline assumes a modest effectiveness (25% of the planned impact) which reflects that so far there are no hard "measures" to support the plan but the creation of several communication platforms, supporting agencies and so forth with unclear impact. This is somewhat increased compared to the first implementation (10%) after considering an independent "industry note" of the dairy sector competitiveness by Rabobank (2012). As a consequence Ireland appears to be one of the most expansive countries in Europe in terms of milk production.

In addition the MS consultation process also led to some re-specification of the expert information related to some other countries (AT, NL, LU, HU).

5 Simulation mode

The CAPRI **global market module** breaks down the world into 44 country aggregates or trading partners, each one (and sometimes regional components within these) featuring systems of supply, human consumption, feed and processing functions. The parameters of these functions are derived from elasticities borrowed from other studies and modelling systems and calibrated to projected quantities and prices in the simulation year. Regularity is ensured through the choice of the functional form (a normalised quadratic function for feed and supply and a generalised Leontief expenditure function for human consumption) and some further restrictions (homogeneity of degree zero in prices, symmetry and correct curvature). Accordingly, the demand system allows for the calculation of welfare changes for consumers, processing industry and public sector. Policy instruments in the market module include bilateral tariffs and tariff rate quotas (TRQs). Intervention purchases and subsidised exports under the World Trade Organisation (WTO) commitment restrictions are explicitly modelled for the EU 15.

In the market module, special attention is given to the processing of dairy products in the EU. First, balancing equations for milk fat and protein ensure that these exactly exhaust the amount of fat and protein contained in the raw milk. The production of processed dairy products is based on a normalised quadratic function driven by the regional differences between the market price and the value of its fat and protein content. Then, for consistency, prices of raw milk are also derived from their fat and protein content valued with fat and protein prices.

The market module treats bilateral world trade based on the Armington assumption (Armington, 1969). According to Armington's theory, the composition of demand from domestic sales and different import origins responds smoothly to price relatives among various bilateral trade flows. This allows the model to reflect trade preferences for certain regions (e.g. Parma or Manchego cheese) and to explain the common feature of trade statistics that a country may export to another country and in the same period also import from this trading partner. As many trade policy instruments like TRQs are specific for certain trading partners, bilateral trade modeling is a precondition for accurate representation of trade policies.

For **European regions** the supply side behavioural function in the global market module approximate the behaviour of country aggregates of regional **nonlinear programming models**. In these models regional agricultural supply of annual crops and animal outputs are given as solutions to a profit maximisation under a limited number of constraints: the land supply curve, policy restrictions such as sales quotas and set aside obligations and feeding restrictions based on requirement functions.

The underlying methodology assumes a *two stage decision process*. In the *first stage*, producers determine *optimal variable input coefficients* per hectare or head (nutrient needs for crops and animals, seed, plant protection, energy, pharmaceutical inputs, etc.) for given yields, which are determined exogenously by trend analysis (data from EUROSTAT) and updated depending on price changes against the baseline. Nutrient requirements enter the supply models as constraints and all other variable inputs, together with their prices, define the accounting cost matrix. In the *second stage*, the *profit maximising mix of crop and animal activities* is determined simultaneously with cost minimising feed and fertiliser in the supply models. Availability of grass and arable land and the presence of quotas impose a restriction on acreage or production possibilities. Moreover, crop production is influenced by set aside obligations. Animal requirements (e.g. feed energy and crude protein) are covered by a cost minimising feeding combination. Fertiliser needs of crops have to be met by either organic nutrients found in manure (output from animals) or in purchased fertiliser (traded good). A nonlinear cost function covering the effect of all factors not explicitly handled by restrictions or the accounting costs – such as additional binding resources or risk - ensures calibration of activity levels and feeding habits in the base year and plausible reactions of the system. These cost function terms are estimated from ex-post data or calibrated to exogenous elasticities. Fodder (grass, straw, fodder maize, root crops, silage, milk from suckler cows or mother goat and sheep) is assumed to be non-tradable, and hence links animal processes to the crops and regional land availability. All other outputs and inputs can be sold and purchased at fixed prices. Selling of milk cannot exceed the related quota, the sugar beet quota regime is modelled by a specific risk component. The use of a mathematical programming approach has the advantage to directly embed compensation payments, set-aside obligations, voluntary set-aside and sales quotas, as well as to capture important relations between agricultural production activities. Not at least, environmental indicators as NPK balances and output of gases linked to global warming are easily represented in the system.

The equilibrium in CAPRI is obtained by letting the *regional supply and global market modules* iterate with each other. In the first iteration, the regional aggregate programming models (one for each Nuts 2 region) are solved with prices taken from the baseline. After being solved, the regional results of these models (crop areas, herd sizes, input/output coefficients, etc.) are aggregated to the country level, leading to a certain deviation from the baseline solution, depending on the kind of scenario. Subsequently the supply side behavioural functions of the market module (for supply and feed demand) are recalibrated to pass at the given prices through the quantity results from the supply models. The market module is then solved, yielding new equilibrium producer prices for all regions, including European countries. These prices are then passed back to the supply models for the following iteration. At the same time, in between iterations, premiums for activities are adjusted if ceilings defined in the Common Market Organisations (CMOs) are overshot.

In EUCLIMIT, the difference between the baseline (only adopted measures) and the reference run (assuming that the renewables targets are met and including the recent Energy Efficiency Directive) has been treated as a shock to be simulated with the CAPRI scenario mode. The exogenous shifts were limited to the shifts in the bioenergy sector as given by the PRIMES biomass component. The variation concerned mainly two types of variables: The changed production of biofuels (biodiesel and bioethanol) and the contributions from second generation technologies were modifications for the global market module. At the same time, the (exogenous) area use for lignocellulosic crops in European countries has been modified in the regional supply models, assuming that the regional allocation would not change from the baseline.

Annex 1 Activities and items in CAPRI

List of activities in the supply model

Group	Activity	Code
Cereals	Soft wheat Durum wheat Rye and Meslin Barley Oats Paddy rice Maize Other cereals	SWHE DWHE RYEM BARL OATS PARI MAIZ OCER
Oilseeds	Rape Sunflower Soya Olives for oil Other oilseeds	RAPE SUNF SOYA OLIV OOIL
Other annual crops	Pulses Potatoes Sugar beet Flax and hemp Tobacco Other industrial crops	PULS POTA SUGB TEXT TOBA OIND
Vegetables Fruits Other perennials	Tomatoes Other vegetables Apples, pear & peaches Citrus fruits Other fruits Table grapes Table olives Table wine Nurseries Flowers Other marketable crops	TOMA OVEG APPL CITR OFRU TAGR TABO TWIN NURS FLOW OCRO
Fodder production	Fodder maize Fodder root crops	MAIF ROOF

Group	Activity	Code
	Other fodder on arable land Graze and grazing	OFAR GRAS
Fallow land and set-aside	Set-aside idling Non food production on set-aside Fallow land	SETA NONF FALL
Cattle	Dairy cows Sucker cows Male adult cattle fattening Heifers fattening Heifers raising Fattening of male calves Fattening of female calves Raising of male calves Raising of female calves	DCOW SCOW BULF HEIF HEIR CAMF CAFF CAMR CAFR
Pigs, poultry and other animals	Pig fattening Pig breeding Poultry fattening Laying hens Sheep and goat fattening Sheep and goat for milk Other animals	PIGF SOWS POUF HENS SHGF SHGM OANI

Land use classes in CAPRI

OART	artificial
ARAO	(other) arable crops - all arable crops excluding rice and fallow (see also definition of ARAC below)
PARI	paddy rice (already defined)
GRAT	temporary grassland (alternative code used for CORINE data, definition identical to TGRA
FRCT	fruit and citrus

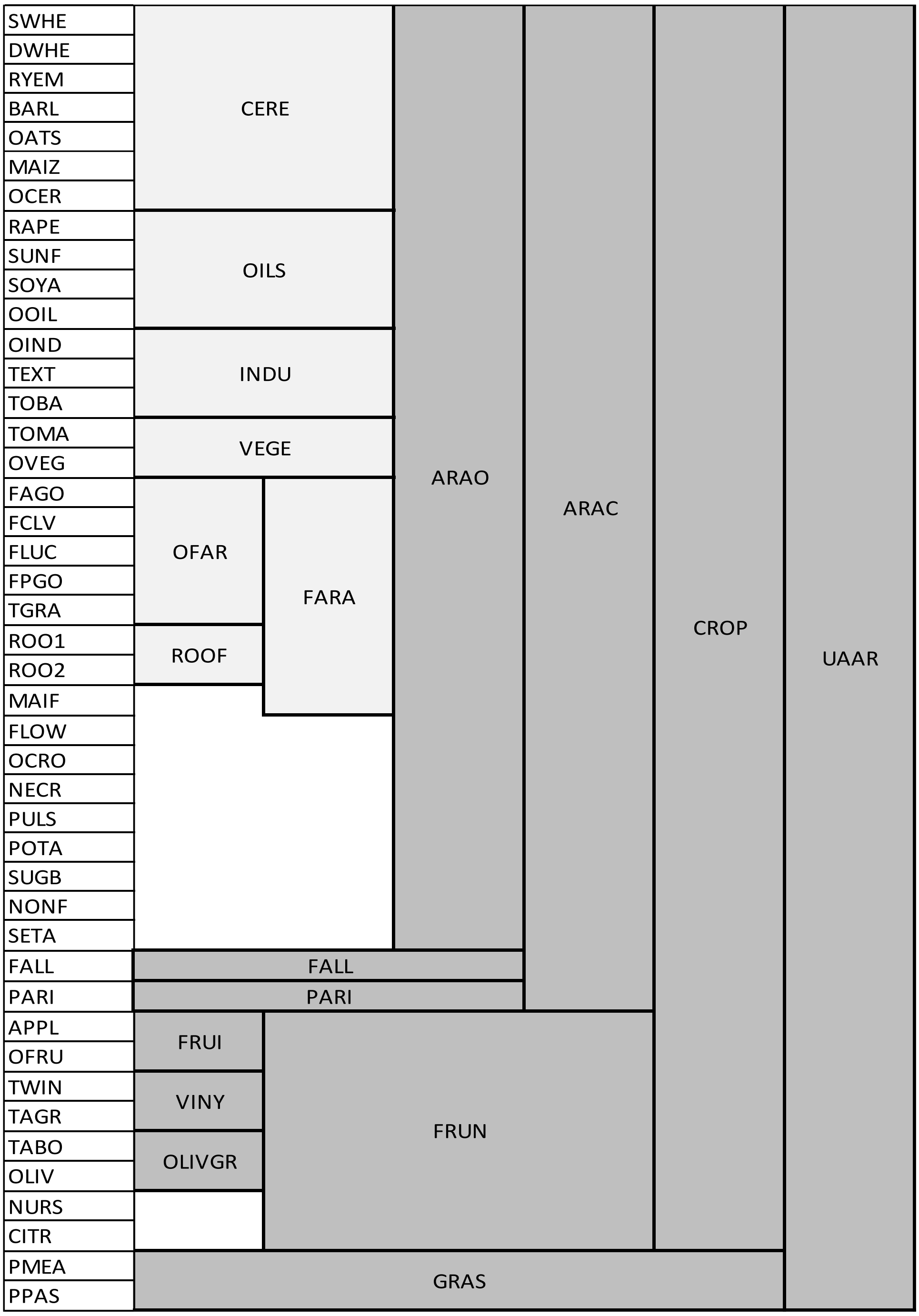
OLIVGR	Olive Groves
VINY	vineyard (already defined)
NUPC	nursery and permanent crops (Note: the aggregate PERM also includes flowers and other vegetables
BLWO	board leaved wood
COWO	coniferous wood
MIWO	mixed wood
POEU	plantations (wood) and eucalyptus
SHRUNTC	shrub land - no tree cover
SHRUTC	shrub land - tree cover
GRANTC	Grassland - no tree cover
GRATC	Grassland - tree cover
FALL	fallow land (already defined)
OSPA	other sparsely vegetated or bare
INLW	inland waters
MARW	marine waters

Land use aggregates in CAPRI

OLND	other land - shrub, sparsely vegetated or bare
ARAC	arable crops
FRUN	fruits, nursery and (other) permanent crops
WATER	inland or marine waters

ARTIF	artificial - buildings or roads
OWL	other wooded land - shrub or grassland with tree cover (definition to be discussed)
TWL	total wooded land - forest + other wooded land
SHRU	shrub land
FORE	forest (already defined)
GRAS	grassland (already defined)
UAAR	utilizable agricultural area (already defined)
ARTO	total area - total land and inland waters
ARTM	total area including marine waters
CROP	crop area - arable and permanent

Mapping primary agricultural activities to groups and land use in CAPRI



Mapping land use classes to aggregates in CAPRI

<table>
<tr><td>PARI</td><td rowspan="4">ARAC</td><td rowspan="8">CROP</td><td rowspan="10">UAAR</td><td rowspan="19">ARTO</td><td rowspan="20">ARTM</td></tr>
<tr><td>FALL</td></tr>
<tr><td>ARAO</td></tr>
<tr><td>GRAT</td></tr>
<tr><td>FRCT</td><td rowspan="4">FRUN</td></tr>
<tr><td>OLIVGR</td></tr>
<tr><td>NUPC</td></tr>
<tr><td>VINY</td></tr>
<tr><td>GRANTC</td><td rowspan="2">GRAS</td><td rowspan="3"></td></tr>
<tr><td>GRATC</td></tr>
<tr><td>OART</td><td>ARTIF</td><td rowspan="10"></td></tr>
<tr><td>BLWO</td><td rowspan="4">FORE</td><td rowspan="5">TWL</td></tr>
<tr><td>COWO</td></tr>
<tr><td>MIWO</td></tr>
<tr><td>POEU</td></tr>
<tr><td>SHRUTC=OWL</td><td rowspan="3">OLND</td></tr>
<tr><td>OSPA</td><td rowspan="4"></td></tr>
<tr><td>SHRUNTC</td></tr>
<tr><td>INLW</td><td rowspan="2">WATER</td></tr>
<tr><td>MARW</td><td></td></tr>
</table>

Output, inputs, income indicators, policy variables and processed products in the data base

Group	Item	Code
Outputs		
Cereals	Soft wheat Durum wheat Rye and Meslin Barley Oats Paddy rice Maize Other cereals	SWHE DWHE RYEM BARL OATS PARI MAIZ OCER
Oilseeds	Rape Sunflower Soya Olives for oil Other oilseeds	RAPE SUNF SOYA OLIV OOIL
Other annual crops	Pulses Potatoes Sugar beet Flax and hemp Tobacco Other industrial crops	PULS POTA SUGB TEXT TOBA OIND
Vegetables Fruits Other perennials	Tomatoes Other vegetables Apples, pear & peaches Citrus fruits Other fruits Table grapes Table olives Table wine Nurseries Flowers	TOMA OVEG APPL CITR OFRU TAGR TABO TWIN NURS FLOW

Group	Item	Code
	Other marketable crops	OCRO
Fodder	Gras Fodder maize Other fodder from arable land Fodder root crops Straw	GRAS MAIF OFAR ROOF STRA
Marketable products from animal product	Milk from cows Beef Pork meat Sheep and goat meat Sheep and goat milk Poultry meat Other marketable animal products	COMI BEEF PORK SGMT SGMI POUM OANI
Intermediate products from animal production	Milk from cows for feeding Milk from sheep and goat cows for feeding Young cows Young bulls Young heifers Young male calves Young female calves Piglets Lambs Chicken Nitrogen from manure Phosphate from manure Potassium from manure	COMF SGMF YCOW YBUL YHEI YCAM YCAF YPIG YLAM YCHI MANN MANP MANK
Other Output from EAA	Renting of milk quota Agricultural services	RQUO SERO
Inputs		
Mineral and organic	Nitrogen fertiliser	NITF

Group	Item	Code
fertiliser Seed and plant protection	Phosphate fertiliser Potassium fertiliser Calcium fertiliser Seed Plant protection	PHOF POTF CAOF SEED PLAP
Feedings tuff	Feed cereals Feed rich protein Feed rich energy Feed based on milk products Gras Fodder maize Other Feed from arable land Fodder root crops Feed other Straw	FCER FPRO FENE FMIL FGRA FMAI FOFA FROO FOTH FSTRA
Young animal Other animal specific inputs	Young cow Young bull Young heifer Young male calf Young female calf Piglet Lamb Chicken Pharmaceutical inputs	ICOW IBUL IHEI ICAM ICAF IPIG ILAM ICHI IPHA
General inputs	Maintennce machinery Maintennce buildings Electricity Heating gas and oil Fuels Lubricants Water Agricultural services input Other inputs	REPM REPB ELEC EGAS EFUL ELUB WATR SERI INPO
Income indicators	Production value Total input costs	TOOU TOIN

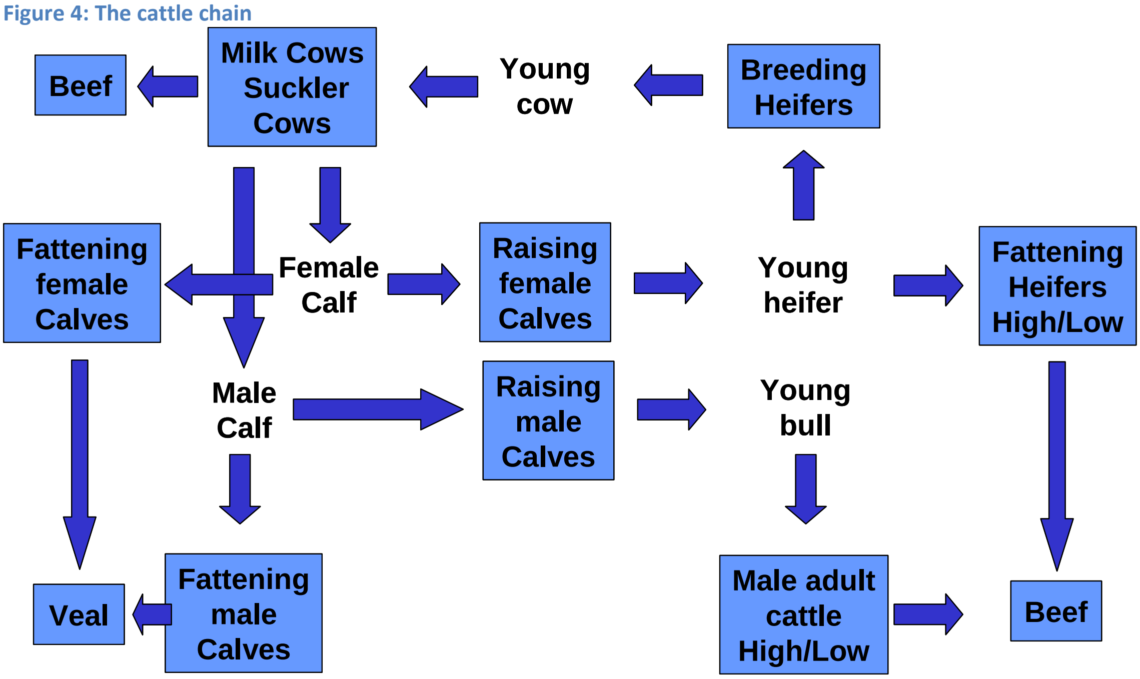
Group	Item	Code
	Gross value added at producer prices Gross value added at basic prices Gross value added at market prices plus CAP premiums	GVAP GVAB MGVA
Activity level	Cropped area, slaughtered heads or herd size	LEVL
Policy variables Relating to activities	Premium ceiling Historic yield Premium per ton historic yield Set-aside rate Premium declared below base area/herd Premium effectively paid Premium amount in regulation Type of premium application Factor converting PRMR into PRMD Ceiling cut factor	PRMC HSTY PRET SETR PRMD PRME PRMR APPTYPE APPFACT CEILCUT
Processed products	Rice milled Molasse Starch Sugar Rape seed oil Sunflower seed oil Soya oil Olive oil Other oil Rape seed cake Sunflower seed cake Soya cake Olive cakes Other cakes Gluten feed from ethanol production Biodiesel	RICE MOLA STAR SUGA RAPO SUNO SOYO OLIO OTHO RAPC SUNC SOYC OLIC OTHC GLUE BIOD BIOE

Group	Item	Code
	Bioethanol	PLMO
	Palm oil	BUTT
	Butter	SMIP
	Skimmed milk powder	CHES
	Cheese	FRMI
	Fresh milk products	CREM
	Creams	COCM
	Concentrated milk	WMIO
	Whole milk powder	WHEP
	Whey powder	CASE
	Casein and caseinates	FPRI
	Feed rich protein imports or byproducts	FENI
	Feed rich energy imports or byproducts	

Annex 2 Animal sector details in CAPRI

Without doubt the animal sector is the most complex topic in the CAPRI regional programming models because it includes various internal relationships as well as inter-linkages with the crop sector. Among the former are the various input-output relationships related to **young animals**. Figure 4 shows the different cattle activities and the related young animal products used in the model. Milk cows and suckler cows produce male and female calves. The relation between male and female calves is estimated ex-post in the "COCO module" that handles the data consolidation. These calves are assumed to weigh 50 kg at birth and to be born on the 1st of January. They enter immediately the raising processes for male and female calves which produce young heifers (300 kg live weight at the end) and young bulls (335 kg). These raising processing are assumed to take one year, so that calves born in t enter the processes for male adult fattening, heifers fattening or heifers raising on the 1st January of the next year t+1. The heifers raising process produces then the young cows which can be used for replacement or herd size increases in year t+2.

Figure 4: The cattle chain



Source: CAPRI Modelling System

Accordingly, each raising and fattening process takes exactly one young animal on the input side. The raising processes produce exactly one animal on the output side which is one year older. The output of calves per cow, piglets per sow, lambs per mother sheep or mother goat is derived ex post, e.g. simultaneously from the number of cows in t-1, the number of slaughtered bulls and heifers and replaced in t+1 which determine the level of the raising processes in t and number of slaughtered calves in t. The herd flow models for pig, sheep and goat and poultry are similar, but less complex, as all interactions happen in the same year, and no specific raising processes are introduced.

In most cases, all input and output coefficients relating to young animals are estimated in the database identical at regional and national level, projected by constrained trends and maintained in the simulations. For **slaughter weights** a certain regional variation is allowed in line with stocking densities. In reality farmers may react with changes in final weights to relative changes in output prices (meat) in relation to input prices (feed, young animals). A higher price for young animals will tend to increase final weights, as feed has become comparatively cheaper and vice-versa. In order to introduce more flexibility in the system, the dairy cow, heifer and bull fattening processes are split up each in two versions that may substitute against each other in scenarios as shown in the following table.

Table 1 Split up of cattle chain processes in different intensities

	Low intensity/final weight	High intensity/final weight
Dairy cows (DCOW)	DCOL: 75% milk yield of average, variable inputs besides feed and young animals at 75% of average	DCOH: 125% milk yield of average, variable inputs besides feed and young animals at 125% of average
Bull fattening (BULF)	BULL: 20% lower meat output, variable inputs besides feed and young animals at 80% of average	BULH: 20% higher meat output, variable inputs besides feed and young animals at 120% of average
Heifers fattening (HEIF)	HEIL: 20% lower meat output, variable inputs besides feed and young animals at 80% of average	HEIH: 20% higher meat output, variable inputs besides feed and young animals at 120% of average

For all regions it is assumed that ex post and in the baseline the shares for the high and low yielding variant (e.g. DCOL, DCOH) are 50% for each. As so far no statistical information on the distribution of intensities has been used, the category "intensive" has been *defined* to represent the upper 50% of the historical and baseline distribution. In scenarios however, these shares may change in response to incentives.

For fattening activities the process length DAYS, net of any empty days (EDAYS, relevant for seasonal sheep fattening in Ireland, for example) times the daily growth DAILY should give the final weight after conversion into live weight with the carcass share *carcassSh* and consideration of any starting weight *startWgt*.

Equation 1
$$X_{r,yield,t}^{maact,Trend} / carcassSh_{maact} = startWgt_{maact} + X_{r,DAILY,t}^{maact,Trend} \cdot \left(X_{r,DAYS,t}^{maact,Trend} - X_{r,EDAYS,BAS}^{maact,data} \right)$$

The process length permits to convert between the CAPRI activity levels for fattening activities (activity level LEVL = one finished animal per year, flow data) and the animal herds (HERD) that may be observed in animal countings at some point in time (stock data, used in GLOBIOM and GAINS).

Equation 2
$$X_{r,HERD,t}^{maact,Trend} = X_{r,LEVL,t}^{maact,Trend} \cdot X_{r,DAYS,t}^{maact,Trend} / 365$$

The process length is fixed to 365 days for female breeding animals (activities DCOL, DCOH, SCOW, SOWS, SHGM, HENS) such that the activity level is equal to the herd size there.

The **input allocation for feed** describes which quantities of certain feed aggregates (cereals, rich protein, rich energy, processed dairy feed, other feed) or single fodder items (fodder maize, grass, fodder from arable land, straw, raw milk for feeding) are used per animal activity level.

This input allocation for feed takes into account nutrient requirements of animals, building upon requirement functions from the animal nutrition literature. In the case of cattle they have been taken from the IPCC (2006) manual on emissions accounting according to a "tier 2" methodology. For other animals the requirement functions are using other sources and are typically simpler. The crude protein needs are not only used to steer feed demand but they also determine the N content of excretions and therefore the fertiliser value of manure, but also the risk of emissions.

The feed allocation and hence input coefficients for feeding stuff are determined in the solution of the supply models to ensure that energy and protein requirements cover the nutrient needs of the animals while respecting maximum and minimum bounds for lysine, dry matter and fibre intake. Furthermore, ex-post, they also have to be in line with regional fodder production and total feed demand statistics at the national level, the latter stemming from market balances. And last but not least, the input coefficients together with feed prices should lead ex post to reasonable feed cost for the activities.

Historical data do not always meet these consistency relationships. In fact a frequent problem is that nutrient intake is implausibly exceeding the requirements from the literature. A certain luxury consumption is perfectly plausible, just reflecting that observed data usually do not meet the high efficiency laboratory situations in the literature. Nonetheless without further corrections the measured excess would often attain 50% or more, at least for protein. A number of remedies have been introduced therefore in CAPRI to reduce the number of odd cases:

- Grass and other fodder yields have been estimated (in COCO already) as a compromise of statistical and expert information (from Alterra, O. Oenema, G. Velthof)
- Losses of straw have been permitted to vary according to the surplus situation in the region
- A luxury consumption embedded in the sectoral data on feed input and animal products has been steered mainly towards the less intensive (sheep, cattle) activities as opposed to more intensive production chains (pigs, poultry).

This excess „luxury" consumption is treated as a parameter characterising farmer's behaviour, just like the "over-fertilisation parameters" related to fertiliser use. The requirements from the literature are therefore adjusted (upwards) to permit a balance of feed use and requirements in the historical period. Subsequently they are maintained in simulations apart from some moderate gains in feed efficiency over time.

Organic fertliser is another link to the crop sector. Given the feed allocation, the nutrient contents of manure may be calculated. In the historical period the mineral fertiliser use is also known and allows to calculate the above mentioned parameters characterising nutrient availability in organic fertilisers and the over-fertilisation on the part of farmers. In the baseline, prior information for mineral fertiliser use may be available from external projections (EFMA) or trend extrapolations. This prior information as well as the behavioural parameters are adjusted to yield consistency in nutrient availability from organic and mineral fertilisers on the one hand, and nutrient use in the crop sector on the other (acknowledging gaseous losses).

By contrast in scenarios the behavioural parameters are fixed. Nutrient supply has to be adjusted to nutrient need that follows from crop yields. Animal activities therefore have manure as a secondary output, valued at a shadow value that is related to the mineral fertiliser price. However, in scenarios that constrain emissions directly in the regional supply models, this value might also become negative.

Annex 3 Complete area database

I. Background

Land use data are a surprisingly contentious issue, given that it should be an easy question to answer how a particular parcel of land is being used. In addition there are several statistical sources available that provide information on this issue. However, this multitude of potential statistical sources can be used in different ways to set up a database for modelling purposes and indeed this choice has been answered in different ways in CAPRI (for '**C**ommon **A**gricultural **P**olicy **R**egionalised **I**mpact analysis') and GLOBIOM (for '**Glo**bal **Bio**sphere **M**anagement Model'), two modelling systems that are applied in parallel in EUCLIMIT, see http://www.euclimit.eu/, (and other) projects[2]. The differences are mainly due to the different needs of the systems with GLOBIOM requiring spatially explicit land use data for certain pixels, but limited to the base year 2000, whereas CAPRI only requires NUTS2 level data, but these in annual time series back to 1985, if possible. Nonetheless for joint model application differences in the data base should be small or at least attributable to clear differences in definitions or procedures. Due to the frequent data exchange with GLOBIOM it is useful to include in this CAPRI land use documentation also some comparisons and explanations related to GLOBIOM.

[2] Annex 3 draws heavily on Witzke P, Zintl A, Kempen M, Boettcher , Frank S (2013): CAPRI land use documentation (including a comparison with GLOBIOM land use data), Bonn-Laxenburg 2013.

II. Specific data sources related to land use

While the general problem to establish a complete and consistent database for land use is similar as in many other areas there are some particularities related to land use:

- In general, the cases of conflicting raw data on agricultural variables are rare (for example to take production from Eurostat production statistics or from the market balances) and the different sources do not diverge a lot. This does not hold for land use data: There are often several possible sources and the differences can be large.
- Agricultural time series (from Eurostat) are often rather complete and evident statistical breaks are exceptions. Again this does not hold for land use data: Observations are typically given for a few years only or time series show evident breaks.
- Whereas many agricultural series show a high volatility (prices, trade, yields, production, single crop areas) land use data for aggregate area categories tend to change only slowly. As a consequence a land use observation for 2010 may have some informational content to assess land use in 1990, whereas such inference would be hazardeous for price or trade data.

The first two points are specific problems, the latter more an additional option that suggested to modify the typical strategy to establish a consistent and complete database on time series of land use data. The typical strategy applied in the CAPRI system was to decide on a reasonable expectation for variables on the basis of a ranking in terms of presumed data quality and to leave to a mechanical data consolidation procedure only the problem to resolve inconsistencies between related data (possibly initialised from different sources). So variables like meat production are initialised preferably with the value from the Eurostat market balances in CAPRI, but if that was missing, a second best estimate based on the Eurostat slaughtering statistic is used.

A preferable strategy, adjusted to the multitude of competing sources, possibly on land use at different points in time, it to consider all of them simultaneously but to define weights that reflect the presumed quality of these weights. The data sources considered are the following.

1. **Estat_NatLU**: Eurostat national land use data (Eurostat table: “apro_cpp_luse”). As these data are annually available since the 80s and give importand land use categories (total area ARTO with inland waters INLW[3], arable land ARAC, permanent grassland GRAS, forest land FORE, etc) this would be our preferred source if all series were complete and reliable.

[3] See Annex 1 for a complete list of codes.

2. **Estat_RegLU**: Eurostat regional land use data (Eurostat table: “agr_r_landuse”). Inspite of using the same codes as for the national data, the national totals, aggregated from the NUTS2 regions are not always in line with CAPRI_natLU. Furthermore a few categories are missing (no inland waters, no other wooded land). However there are few alternative annual series avaialble to regionalise the national data in a later step of data processing.
3. **Estat_LandCov**: Eurostat land cover data for 2009 at the MS level. Agricultural land is only distinguished into cropland CROP and grassland GRAS, but 5 nonagricultural areas are neatly aggregating up to the total country (Artificial ARTIF, shrubland (considered similar to “other wooded land” OWL), bare land & wetlands (mapped to “other sparcely vegetated or bare OSPA) and waters WATER.
4. **Estat_Envio**: Eurostat land cover data from the environment section (table “env_la_luc1”[4]). Total area is classified into about 40 categories, but data are only given for a number of years (1950, 1970, 1980, 1985, 1990, 1995, 2000) and with many gaps, in particular for the subcategories.
5. **Estat_FSS**: Eurostat farm structure survey data (table “ef_lu_ovcropaa"). Gives a very detailed and reliable description of agricultural area use, but only for the survey years (1990, 1993, 1995, 1997, 2000, 2003, 2005, 2007). As CAPRI_regLU these data are also used in the subsequent regionalisation steps of the CAPRI data consolidation because NUTS2 data are offered. The main disadvantage for our purposes is the complete lack of nonagricultural data coverage.
6. **FAO**: Land use data from the resource FAOSTAT domain[5] with annual time series on agricultural land use but also some non argicultural area categories (forest, inland waters, other land, total area).
7. **MCPFE**: Year 2007 version of the Ministerial Conference on the Protection of Forests in Europe C&I database for quantitative indicators. This gives validated data on the forest sector (forest land FORE, other wooded land OWL) and some non forestry data (inland waters INLW, total country area ARTO), but data were only given for 1990, 2000 and 2005[6].
8. **CAPRI_CLC**: Corine Land Cover (44 classes, aggregated to the NUTS2 level[7] by JRC, Ispra (contact: Sarah Mubareka) for 1990, 2000, 2006. To link the Corine information to the CAPRI land use classes (Table A2) NUTS2 contingency tables[8] from Corine to

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[4] Apparently these data are currently under revision because they are not accessible on the Eurostat website anymore since about June 2012. However they are still accessible (in July 2012) via http://eu22.eu/land-use.2/land-use-by-main-category/.

[5] See http://faostat3.fao.org/home/index.html#DOWNLOAD.

[6] http://www.foresteurope.org/filestore/foresteurope/Publications/pdf/state_of_europes_forests_2007.pdf. In November 2011 the year 2011 report has beome available, including year 2010 data, but the updated numbers have not yet been used in CAPRI.

[7] Data for some countries and years affected by evident problems have been removed. For example the 2006 CLC data only covered parts of Greece, hence are no usable to calculate totals at the MS level.

[8] An EU level contingency table and a discussion of problems in assessing the accuracy of CORINE is avaialble at http://agrienv.jrc.ec.europa.eu/publications/pdfs/LUCAS_CORINE.pdf. See also

LUCAS categories have been used as a interim step which were provided by JRC Ispra based on LUCAS 2006 and 2009 (new MS) data. This allowed to map the Corine classes (like complex cultivation patterns – "complexCultiv") to the most probable land cover class from the LUCAS survey (typically for "complexCultiv" => annual crops) which may be aggregated then to the CAPRI land use classes (annual crops[LUCAS] => arable crops[CAPRI], code ARAC). This procedure has many disadvantages, for example, that certain LUCAS categories like "fallow land" are not mapped at all because they are not the most probable matching LUCAS category for any of the Corine classes. But the procedure preserves the original Corine information as much as possible while still yielding transparent rules for mapping to CAPRI.

9. **CAPRI_CLC_LUCAS**: To acknowledge that the Corine Classes may be mapped to *several* LUCAS categories they may be multiplied with the "profiles", giving the distribution of each Corine category according to the LUCAS classes. In the case of the "complexCultiv" area and for the EU level, only 27.6% are be mapped to annual crops, but 5.5% are mapped to "permanent grassland with sparse tree cover", 35.2% to "permanent grassland without tree cover" and so forth. Currently the Corine data have been used by CAPRI in this transformed form. The transformed Corine data often give the most detailed area coverage and thus assume a role as a kind of fall back information in case that other information is missing.
10. **GLOBIOM_CLC**: For use in GLOBIOM the Corine data are used in the spatially explicit format. They have been aggregated from the disaggregate pixel information to the country level using a different methodology than used by JRC staff to prepare the NUTS2 tables for CAPRI. Furthermore the mapping to the GLOBIOM area categories relied on other rules than using the most probably LUCAS category. As a consequence the aggregate CLC data from the GLOBIOM database yields different national totals than given by CAPRI_CLC. This illustrates the sensitivity of land use data sets to various methodological issues.

The electronic annex[9] to this documentation reproduces the observations from these sources of "raw data" in the period 1985-2010 for EU27 Member States (Belgium and Luxembourg aggregated), together with the CAPRI final consolidated results (**CAPRIdata**) as well as the land use data from GLOBIOM for year 2000 (**GLOBIOMdata**).

III. Methodology of data consolidation for the CAPRI Data Base

The key procedure of data consolidation applies to all levels (national, regional, global) of the CAPRI database:

Javier Gallego, Catharina Bamps (2008) Using CORINE land cover and the point survey LUCAS for area estimation, International Journal of Applied Earth Observation and Geoinformation 10 pp 467–475.

9 The excel file "Appendix B.3._land_use_data_docu.xls" collects time series of raw data and results at the MS level for land use aggregates. This excel file is delivered as a separate file along with this report.

- Collect a possibly large set of heterogeneous input files and map them to the definitions of the system.
- Define expected values ("supports") for each variable (quantities, areas, etc) based on the available "raw data".
- Calculate complete and consistent time series that minimise the distance to the expected values.

Furthermore, the following principles are applied:

- Accounting identities – like the identity that production follows from activity levels times yields - constrain the estimation outcome.
- Relations between aggregated time series (e.g. total permanent crop area) and single time series are used as additional restrictions in the estimation process.
- Bounds for the estimated values based on engineering knowledge or other sources constrain the estimation results
- As many time series as technically possible are estimated simultaneously to use the full extent of the informational content of the data constraints (1) and (2).

The first three points neatly conform to the Bayesian Highest Posterior Density (HPD) approach proposed in Heckelei, Mittelhammer, Britz 2005. The second point, consistent aggregation to higher levels, is particularly valuable for land use data because the total country area is typically reported unanimuously in all sources and may be considered one of the few really "hard" data. Even though the CAPRI land use database will be is mainly used for its agricultural content, the coverage of total country area is expected to provide a valuable constraint in the light of different allocations of this total area to land use classes in the original sources.

The estimation is carried out as part of the CAPRI module "COCO" and the following explanations heavily draw on http://www.capri-model.org/docs/capri_documentation.pdf, section 2.2. We may distinguish the following steps:

1. Estimate independent trend lines for the time series.
2. Estimate a Hodrick-Prescott filter using given data where available and otherwise the trend estimate as input.
3. Define 'supports' which are (a) given data, (b) the results from the Hodrick-Prescott filter times R^2 plus the last $(1-R^2)$ times the average of nearest observations.
4. Specify a 'standard deviation' for each data point which is different for given data and gaps.

Ultimately the concept is a constrained minimisation of normalised least squares:

$$
\begin{aligned}
(1.1)\quad \min_{y_{i,t}} & \sum_{i,t\in obs} wgt^{dat}\left((y_{i,t}-y_{i,t}^{dat})\big/abs(y_{i,t}^{trd}-y_{i,t}^{dat})\right)^2 \\
& +\sum_{i,t\notin obs} wgt^{ini}\left((y_{i,t}-y_{i,t}^{ini})\big/s_{i,t}\right)^2 \\
& +\sum_{i,t} wgt^{hp}\left(\left((y_{i,t+1}-y_{i,t})-(y_{i,t}-y_{i,t-1})\right)\big/s_{i,t}\right)^2 \\
& +\sum_{i,t} wgt^{up}\left(\left(\max(y_{i,t}^{up},y_{i,t})-y_{i,t}^{up}\right)\big/abs(y_{i,t}^{up})\right)^2 \\
& +\sum_{i,t} wgt^{lo}\left(\left(\min(y_{i,t}^{lo},y_{i,t})-y_{i,t}^{lo}\right)\big/abs(y_{i,t}^{lo})\right)^2
\end{aligned}
$$

$$
\begin{aligned}
& s.t. \\
& (1.2)\quad y_{i,t}^{LO}\le y_{i,t}\le y_{i,t}^{UP} \\
& (1.3)\quad \textit{Accounting identities defined on } y_{i,t} \\
& (1.4)\quad \textit{Identity of land use from different sources}
\end{aligned}
$$

where *i* represents the index of the elements to estimate (e.g. crop production activities or groups, etc.), *t* stands for the year, wgt^x are weights attached to the different parts of the objective, and

$y_{i,t}$	=	the fitted value for item i, year t
$y_{i,t}^{dat}$	=	the observed data for item i, year t
obs	=	$\{(i,t) \mid y_{i,t}^{dat} \neq 0\}$, the set of data points with nonzero data
$y_{i,t}^{trd}$	=	the trend value of an initial trend line through the given data
$y_{i,t}^{ini}$	=	initial supports for gaps: preliminary Hodrick-Prescott filter result (from step 2) times R^2 plus the last $(1-R^2)$ times the average of nearest observations
$s_{i,t}$, $(i,t)\notin obs$	=	$0.1\cdot y_{i,t}^{ini}+s_{i,t}^{trd}$, weighted sum of the initial support for gaps and the standard error of the initialising trend
$s_{i,t}$, $(i,t)\in obs$	=	$0.1\cdot y_{i,t}^{dat}+s_{i,t}^{trd}$, weighted sum of given data and the standard error of the initialising trend
$y_{i,t}^{lo}, y_{i,t}^{up}$	=	‘soft’ bounds, triggering a high additional penalty if violated
$y_{i,t}^{LO}, y_{i,t}^{UP}$	=	‘hard’ bounds, defining the feasible space

The general weighing of the different terms evidently reflects the acceptability of certain types of deviations which is lowest (= 1) for deviations of the fitted value from the HP filter initialisation as these are considered quite poor, preliminary estimates (derived from independent trends). The weights are 10 times higher for deviations from given data and for the smoothing HP filter term. Finally there are extra penalty terms for fitted values moving beyond plausible 'soft' bounds $y^{lo}_{i,t}, y^{up}_{i,t}$. The 'hard' bounds $y^{LO}_{i,t}, y^{UP}_{i,t}$ are constraining the feasible space for a number of solution attempts. However, if it turns out that certain constraints would persistently preclude feasibility of the data consolidation problem, they are relaxed in a stepwise fashion, but this widening of bounds is monitored on a parameter to check.

The denominators used to normalise the different terms are 'standard deviations' of the prior distribution in the framework of a HPD estimation but they are specified in view of practical considerations. Essentially they provide another weighting for particular (i,t) deviations depending on their acceptability, but these weights are specific to the particular data point. All denominators are derived from the variable in question such that they acknowledge the fact that the means of the time series entering the estimation deviate considerably. The normalisation hence leads to minimisation of relative deviations instead of absolute ones which could not be summed in a reasonable way.

It should be mentioned that the above representation of the objective function is a quite simplified one: It is evident that the above lacks safeguards against division by zero or very small values which are included in the GAMS code. Furthermore there are different types of gaps which are not reflected above to avoid clutter (Are there gaps in a series with some data or is the series empty? Is the mean based on data or estimated from $y^{lo}_{i,t}, y^{up}_{i,t}$?)

Equation (1.3) indicates that accountancy restrictions are added. These restrictions can be balances, aggregation conditions, definitions for processing coefficients and yields etc.

In case of land use there are various sources reporting data on the same item. In technical terms each of them provides a support for a different variable, say "arable cropland in FAO definition" and "arable cropland in CAPRI definition". Equation (1.4) ensures that only a single definition applies in the consolidated land use database.

Based on this identity all other land related accounting restrictions only have to be checked for the item "activity level in CAPRI definition", while the objective functions minimizes deviation from supports of all sources. Accounting restrictions thus ensure consistency of crop activities with land use classes and their aggregates (see the annex).

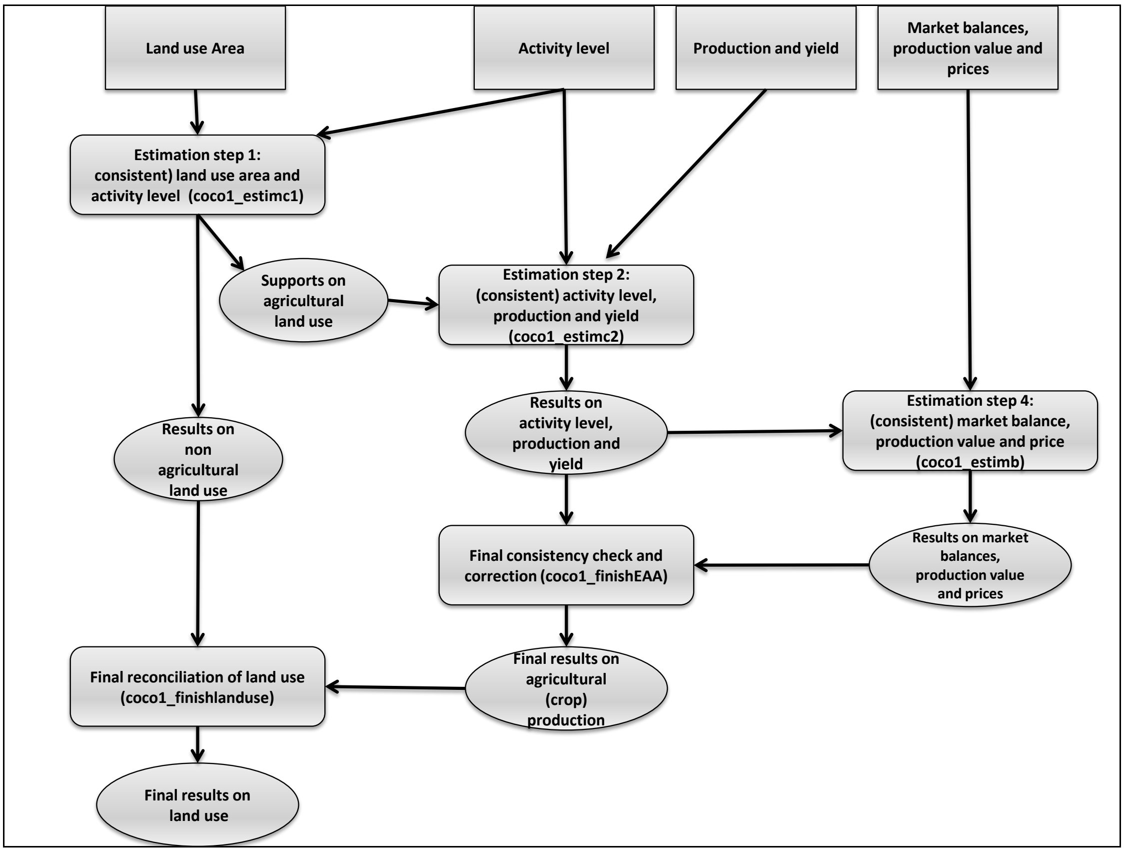
It should also be explained that Equation 1 is not applied simultaneously to the whole dataset because the optimisation would take too long. Instead it is applied to subsets of closely related variables:

1. Land use and land balance (Estimation step 1)
2. Crop production (land balance + yields) for all crops simultaneously (Estimation step 2)

3. Production, yields, EAA, market balances for groups of animals like “cattle” (Estimation step 3)
4. Crop EAA + market balances for groups of crops, taking production from (1.) as given (Estimation step 4).

This procedure has developed as a path dependent compromise between computation time and presumed quality. It starts with an estimation of land use in combination with agricultural land balance. This determines the utilisable agricultural area (UAA) and non-agricultural land use. Step 2 distributes crop areas within the fixed UAA from step 1 and estimates crop production and yields. Step 3 only tackles the complete animal sector data (activities, markets, EAA). The crop production is taken as given, when market balance and EAA are estimated for the crops and derived processed products (step 4). However, with all steps completed some final checks may modify the results (e.g. delete tiny activity levels, set activity level zero if there is no EAA). This may slightly change the UAA as well and and the accounting identities ensured in steps 1 are not necessarily fulfilled in a strict sence anymore. Hence a final reconciliation of land use is added for full consistency. The crop sector data processing may be summarised as follows:

Figure 5: Crop sector data consolidation in CAPRI: steps, inputs and outputs



IV. Results

The results are presented in detail in an electronic annex[10]. Here we will only comment on two examples, starting with the arable crop area in Denmark, a country that will not be considered in general as having shaky statistics.

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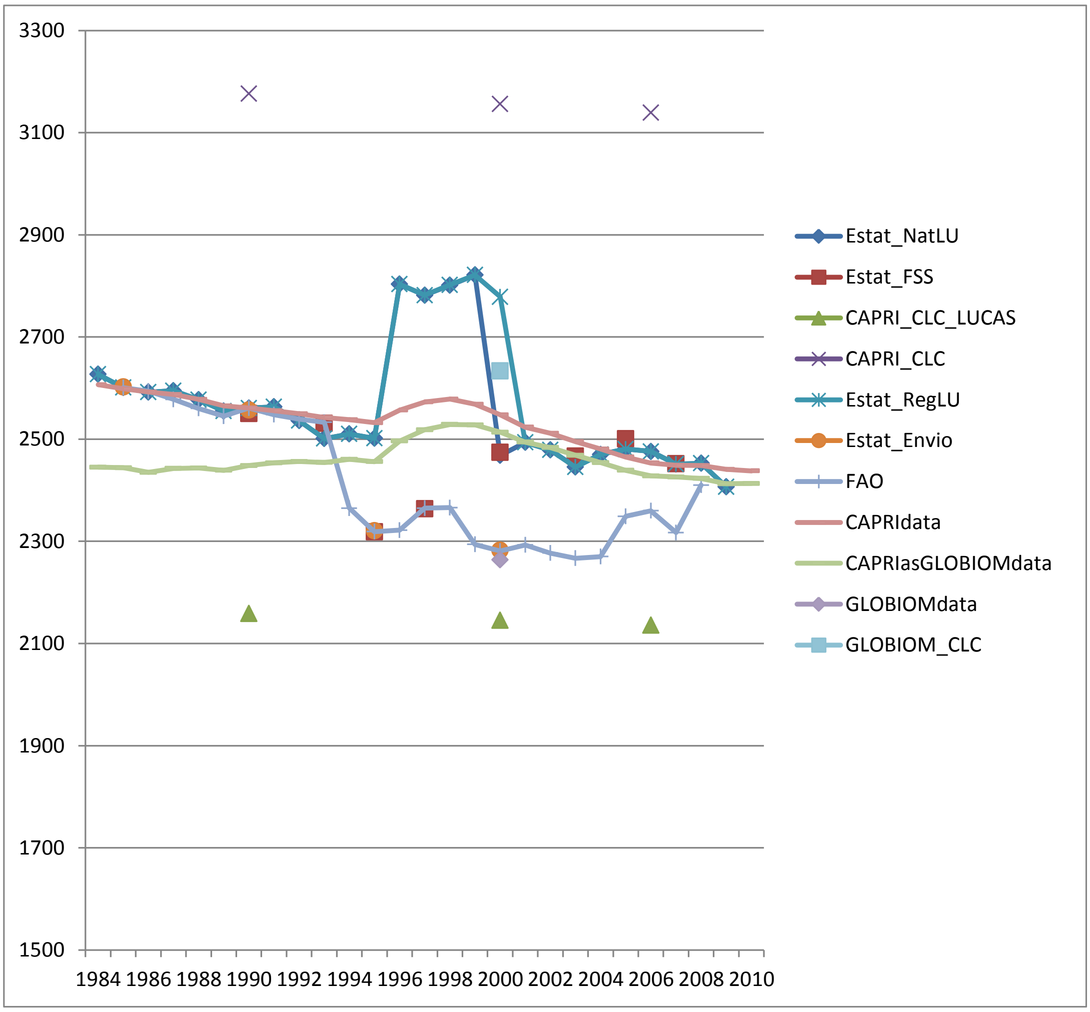
10 The excel file “Appendix B.3._land_use_data_docu.xls” collects time series of raw data and results at the MS level for land use aggregates. This excel file is delivered as a separate file along with this report.

Figure 6: Arable crop area [kha] in Denmark (1984-2010), according to various sources



- Figure 6 shows that the Eurostat land use series show evident statistical breaks from 1995=>1996 and from 1999=>2001. However these are not synchronised between Estat_natLU and Estat_regLU such that the arable crop area in 2000 may be taken to be 2.8 or 2.5 million hectares from Eurostat's land use statistics.
- The Eurostat data from the environment section (Estat_envio) and the farm structure survey data (Estat_FSS) seem to agree with FAO that arable cropland declined from 1993 towards year 1999, in contrast to the information from the Eurostat land use statistics (affected by statistical breaks).
- FAO seems to rely on Estat_FSS and Estat_Envio up to 1997. As of 1999 when Estat_FSS and Estat_Envio depart from each other, FAO first adopted Estat_Envio and then applied their own estimates.
- The untransformed Corine data (CAPRI_CLC) give considerably higher arable cropland than all other sources whereas the data transformed with the LUCAS

contingency table (CAPRI_CLC_LUCAS) seems to be "biased" downwards compared to most other sources. It may be noted that the CORINE data confirm some decline of arable crop area, but the decline is weaker than according to other sources.

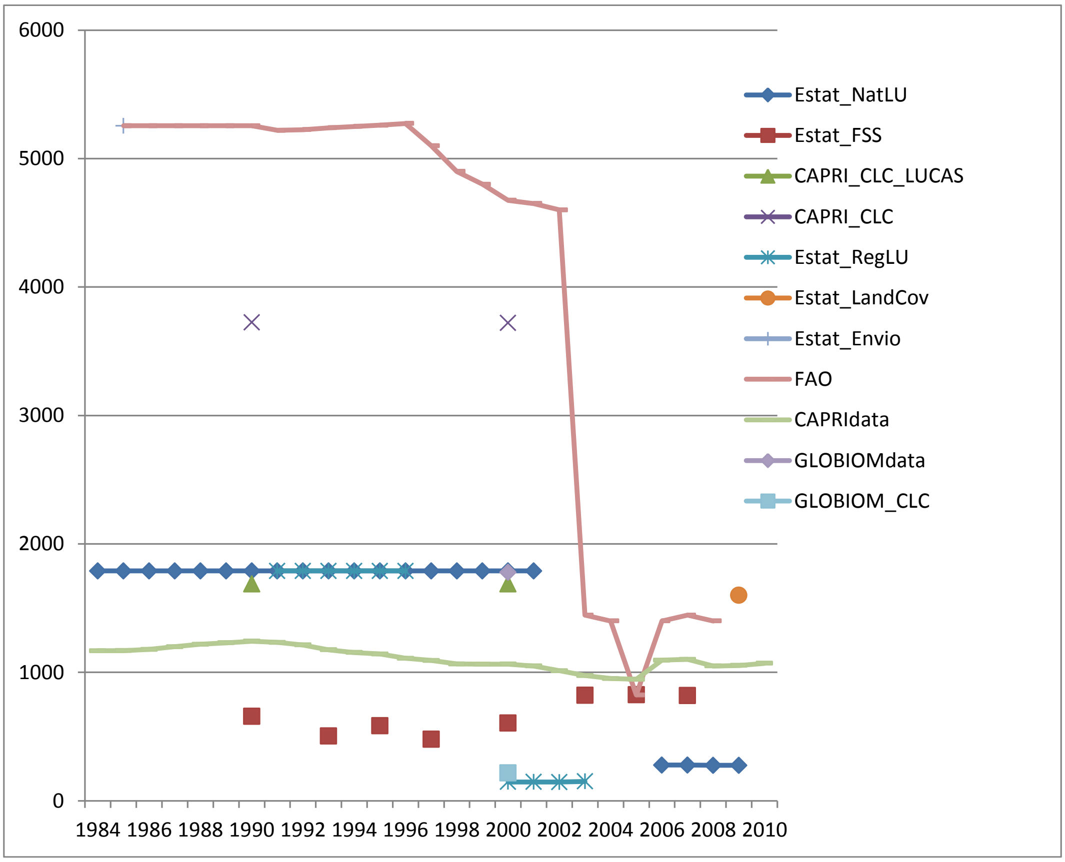
- The details of data processing matter considerably in Denmark: Whereas the CORINE data used in CAPRI (aggregated by JRC to the NUTS2 level) give an area for arable cropland of NUTS2 data of about 3.2 million ha, the CORINE data aggregated in GLOBIOM from pixel information give only 2.6 million ha (GLOBIOM_CLC).
- The consolidated GLOBIOM area (GLOBIOMdata ~ 2.25 million ha) is close to the FAO information and clearly smaller than the CAPRIdata (~ 2.55 million ha) which can be attributed to a smaller crop coverage only to a certain degree. The arable crop aggregate CAPRIasGLOBIOMdata (~ 2.50 million ha) defined from the crop list covered by GLOBIOM is still larger than the area given as GLOBIOMdata, mainly because the GLOBIOM database excludes "unproductive" fodder areas[11]. In fact this leads in many (but not all) cases to smaller fodder areas (grassland or fodder on arable land) being reported in GLOBIOM than in CAPRI.
- The estimated CAPRIdata are evidently "biased upwards" by the information from Estat_natLU and Estat_regLU in the years affected by the break (1996-2000), but the specification seems to ensure a reasonable compromise (in this example). The effect of the Eurostat land use data is unavoidable as these sources are usually the main information to rely on such that the CAPRI data cannot be immune against statistical problems in these sources.

The second example shows a number of remarkable breaks in the statistical information on grassland in Greece.

- The FAO series may be seen to show the most impressive statistical break from 2002 to 2003. It is not evidently derived from other statistical information but in 2005 the FAO number is identical to that from the Eurostat FSS that was related to the FAO information on arable crop area in Denmark in several years as well.
- The two annual series offered for land use by Eurostat for grassland (Estat_NatLU and Estat_RegLU) may be observed to drop from the value of 1.789 million ha, invariably given for years before 2000, to much lower values, about 150 kha according to Eurostat's regional land use statistics and about 275 kha for the national land use data. This information is inconsistent with each other and over time.

[11] The GLOBIOM area for „other fodder" (other than gras and fodder maize) in year 2000 is about 460 kha, whereas the corresponding area is in CAPRI 640 kha.

Figure 7: Grassland area [kha] in Greece (1984-2010), according to various sources



- The Eurostat farm structure survey (Estat_FSS) gives a grass land area of 500-800 kha for the survey years, but is likely to cover only the more intensively used grassland areas.
- Corine data are given only for 1990 and 2000. They are close to the earlier values reported in NatLU if the Corine data are mapped to the CAPRI land categories using a contingency table between Corine and LUCAS (CAPRI_CLC_LUCAS). Using the Corine data without this transformation gives a considerably higher area of about 3.7 million ha (CAPRI_CLC), almost as high as the older FAO data. The reason is that in Greece it turned out that the important Corine classes “complex cultivation patterns” and “agriculture with natural vegetation” are predominatly identified in LUCAS to be “permanent grassland without tree cover”.
- Again it is interesting to note that the methodology to aggregate the CORINE data to the country level matters considerably. The area aggregated from pixels according to the GLOBIOM routines (GLOBIOM_CLC) clearly falls short of the corresponding area mapped to grassland according to the CAPRI rules (CAPRI_CLC). In fact it is also smaller that the NUTS2 value for the CORINE class “natural grassland” as aggregated by the JRC with a different methodology.

- The land cover statistic by Eurostat (Estat_LandCov), unfortunately only given for a single year (2009) gives a value of about 1.6 million ha.
- The CAPRI consolidated series may be seen to settle between 1.0 and 1.3 million ha as a compromise of this conflicting raw data information while preserving the stability of grassland that will be considered plausible for this area category.
- It is interesting to note that in this case the GLOBIOM area is larger than the CAPRI data and very close to the Eurostat information for this year. So the earlier finding of smaller fodder areas being included in GLOBIOM than in CAPRI does not hold in all cases.

V. Concluding remarks

In many cases the CAPRI estimates for a complete area balance of EU countries appears to be more convincing than single sources that often show unbelievable statistical breaks and are in conflict with each other.

However this statement is merely confirming that a statistical procedure is able to minimise the deviations from observations within a given sample (data from various sources). A more difficult test would be a comparison with an independent, high quality information source on land use developments over time in one or better several countries. As such information has not been identified yet, it is difficult to assess whether the CAPRI estimates are "accurate" or not. Validation of the whole procedure must be considered pending therefore. A selective comparison with the GLOBIOM database also does not resolve the issue as the findings are quite heterogeneous.

Documenting the procedure and results in view of potential feedback is therefore one of the most promising options to achieve further progress in the future.