Matière à débattre & décider

Land Use and Food Security in 2050: a Narrow Road

Agrimonde-Terra

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3. The GlobAgri-Agrimonde-Terra Database and Model

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Introduction

THE GLOBAGRI PLATFORM was set up by CIRAD and INRA to generate consistent databases and biomass balance models using data from FAOStat as well as data shared by colleagues from different institutions.[4] The databases generated are balanced and account for the links between products (through animal feed or oilseed crushing for instance). Biomass balance models provide a balance equation between resources (domestic production plus imports minus exports) and utilization (food, feed and other) for each region and each agri-food product. In each equation, imports are a linear function of total domestic use and exports are a linear function of the world market size. A world trade balance equation ensures that world imports equal world exports for each agri-food product. The system of balance equations can simulate land-use change in each region induced by changes in the use of agri-food products, provided hypotheses made on changes of a set of variables (such as plant and animal yields, maximum available cultivable land, trade conditions etc.).

The GlobAgri platform has been used to generate a database and a biomass balance model specifically customized for Agrimonde-Terra (specific product and country aggregation, specific rules for co-product handling and specific rules for model closure). The resulting tool is named GlobAgri-Agrimonde-Terra (GlobAgri-AgT). It encompasses 33 aggregates of agri-food products (25 plants, seven animal aggregates and a miscellaneous "Other products") and covers 14 broad regions.

4. These colleagues are warmly thanked as well as their institutions: the Center for Sustainability and the Global Environment (SAGE), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the International Institute for Applied Systems Analysis (IIASA), the Institute of Soil Science of the Chinese Academy of Sciences, the Joint Research Center (JRC), Princeton University, the World Fish Institute, the World Resources Institute (WRI) and the Woodrow Wilson School of Public and International Affairs.

We first detail the product and geographic nomenclatures of GlobAgri-AgT. Then we describe briefly how the biomass balance model functions. Finally, we examine the model's entry variables.

Product and country aggregation in GlobAgri-AgT

In GlobAgri-AgT the whole set of FAO's 'commodity balances' (CB) is aggregated into 33 agri-food aggregates (Table 3.1). As the FAO's CB do not cover some of the key ingredients fed to animals, such as grass and various forage plants, GlobAgri-AgT considers five additional aggregates. Corresponding data are from Herrero *et al.* (2013) and Monfreda *et al.* (2008). Table A1.1 (Appendix 1) details the composition of all the product aggregates considered. Oilcrop products are rather detailed in order to be able to account for the link between the oilseed and both crushing co-products, oil and cake, which is specific for each type of oilseed.

For each product in each country, the FAO's CB provide the resource-utilization balance where the utilization involves food, feed, other uses (biofuels, for example), waste and processing. The latter reports the quantity of the primary product which has been processed into derived products (sugars, sweeteners, alcohols, oils and cakes, for example). In GlobAgri-AgT, oils and cakes are explicitly accounted for as product aggregates and there is no need for specific computations. Sugars, sweeteners and alcohols, however, are not explicit product aggregates but are accounted for through their equivalent quantities in the balance of the parent product from which they are derived. In this case, the processing use in a parent product balance is replaced by the appropriate items of the balances of its derived products (import, export, various uses), in equivalent quantities using transformation coefficients. When the processing of a parent product into a derived product generates co-products, their import, export and various use quantities are also merged with the balance of the parent product, on the basis of their energy content. As a first step in these overall computations, one must be able for each derived product to disentangle the various sources of its supply or, equivalently, for each parent product to split the processing use between the various derived products produced. We achieve this by first assuming that the share of a parent product as a source of production of a derived product is correlated to the share of the processing use of this parent product in the total processing use of all parent products contributing to the production of this derived product (for example, if in a region sweeteners are produced from both wheat and maize, and wheat processing use accounts for one-third of the total processing use of wheat and maize, then one-third of the sweeteners produced will be considered to come from wheat). Secondly, as we must deal with cases where one parent product is used for the production of several derived products (taking the previous example, if wheat is also used for producing alcoholic beverages), the shares of this parent product in the production of each derived product need to be determined simultaneously. A minimization program (of the remaining processing use in the balance of the concerned parent product) is used to solve this problem.

The overall procedure is described in Dumas and Manceron (2014). But let's take a practical example in order to illustrate fully the general description of our computations given above. Suppose that in one region, alcoholic beverages are obtained from wheat, molasses and sugar cane. This means that in the wheat, molasses and sugar cane balances, one share of the processing use is dedicated to producing alcoholic beverages. The share of alcoholic beverages coming from wheat, for instance, is determined as the share of the processing use of wheat in the total processing use of wheat, molasses and sugar cane, considering simultaneously the shares of wheat in the production of all other derived products wheat is involved in. Then, import, export and the various use quantities of alcoholic beverages are transformed into import, export and other uses equivalent quantities of wheat, molasses and sugar cane. The equivalent quantities of wheat and sugar cane are added to the import, export and other uses quantities in the whole balances of wheat and sugar cane, while the corresponding processing use items are removed. In the same way, the equivalent quantities of molasses are added to the whole balance of sugar cane.

GlobAgri-AgT divides the whole world into 14 broad regions (Table 3.2).

Table A1.2 (Appendix 1) specifies the country composition of each region.

Table 3.1. Agri-food aggregates in GlobAgri-AgT*.

Aggregates from the FAO's CB			Aggregates from other sources
Aquatic animals Bovine meat Dairy Eggs Pork meat Poultry meat Small ruminant meat	Fibres etc. Fruit and vegetables Pulses Roots and tubers Maize Other cereals Rice Wheat Sugar plants and products Other plant products Other products	Other oilcrops Cake other oilcrops Oil other oilcrops Oilpalm fruit Palm product oil Palm kernel cake Rape and mustard seeds Rape and mustard cake Rape and mustard oil Soyabeans Soyabean cake Soyabean oil Sunflower seeds Sunflower seed cake Sunflower seed oil	Grass (grass from direct grazing and as silage of permanent pastures) Grass-like forages (mixed grass and ryegrass from temporary pastures) Other forages (alfalfa and fodder crops: beats, vegetables, sorghum, maize etc.) Occasional feeds (food leftovers, cut-and-carry forages and legumes, roadside grasses) Stover (crop residues)

* See Table A1.1 for the detail of the composition of each aggregate.

Table 3.2. Broad geographic regions in GlobAgri-AgT.

Brazil/Argentina	Canada/USA	China	North Africa
Rest of America	EU-27	India	West Africa
	Oceania	Rest of Asia	East, Central and Southern (ECS) Africa
Rest of the world	Former Soviet Union	Near and Middle East	

The GlobAgri-AgT biomass balance model

THE GLOBAGRI-AGT BIOMASS BALANCE MODEL is made up of a resource-utilization balance equation for each agri-food product in each region:

$$Prod_{ijt} + Imp_{ijt} - Exp_{ijt} = Food_{ijt} + Feed_{ijt} + Oth_{ijt} + Waste_{ijt} + VStock_{ijt}$$

Where i is the product ($i \in I$), j the region, t the reference year (here 2007/2009 named '2010' thereafter), *Prod* the domestic production, *Imp* imports, *Exp* exports, *Food* the domestic food consumption, *Feed* the domestic feed use, *Oth* the other domestic uses, *Waste* the waste and *VStock* the stock change.[5]

For all plant (vegetal) products ($v \in I$), domestic production equals harvested area (A) multiplied by per-hectare yield (Y):

$$Prod_{vjt} = A_{vjt} \times Y_{vjt}$$

For all products, the domestic feed use is a linear function of the domestic production of reference animal products ($a \in I$)[6]:

$$Feed_{ijt} = \sum_{a} \beta_{iajt} * Prod_{ajt}$$

Where β_{iajt} is the fixed transformation coefficient of product i into animal product a in region j for year t. β_{iajt} are thus what we call the feed-to-output ratios. For each animal product (*e.g.*, milk), they are a weighted average of the corresponding feed-to-output ratios observed in the various production systems co-existing in the sector concerned (*e.g.*, mixed, pastoral, urban and other systems co-existing in the dairy sector). For the five sectors under consideration (dairy, beef, small ruminants, pork and poultry), the various production systems are those suggested by Herrero *et al.* (2013). The way the

5. For Grass, Occasional feeds and Stover, there is no international trade and no stock change. The only utilization is feed. The *Feed* variable (linked to livestock production) determines alone, through the balance, the domestic production (*Prod*).

6. In the case of co-products, such as 'milk' and 'bovine meat' or 'oil' and 'cake', one co-product is chosen as a reference product while the other becomes a by-product (see Handling of co-products below for more details).

feed-to-output ratios are computed at the production system level and at the sector level is described in detail in Dumas (2014). One may notice that GlobAgri-AgT assumes that there is no substitution between feed ingredients within feed rations: when the animal product quantity increases, the feed demand of each ingredient increases proportionally while the composition of the ration remains unchanged.

Finally, for all products *i*, imports are written as a fixed share of total domestic use:

$$Imp_{ijt} = \alpha_{ijt} * (Food_{ijt} + Feed_{ijt} + Oth_{ijt} + Waste_{ijt} + VStock_{ijt})$$

Where α_{ijt} is the import dependence coefficient of region *j* for product *i* in year *t*. In other words, GlobAgri-AgT assumes that when total domestic use of one product increases in region *j*, a fixed share of the additional need is covered by imports from abroad, while the remaining share is covered by increased domestic production, provided that region *j*'s maximum cultivable area is not binding (see below).

Exports of product *i* by region *j* are written as a fixed share of the world market size of product *i*:

$$Exp_{ijt} = \sigma_{ijt} * \left(\sum_j Imp_{ijt} \right)$$

Where σ_{ijt} is the world export market share of region *j* for product *i* in year *t*.

Import and export specifications in GlobAgri-AgT imply some rigidity in international trade: each region imports a fixed share of its domestic use and regional world export market shares are constant. Such rigidity may result from several factors such as the slow change in regional comparative advantages, and slow change in transport infrastructures and commercial channels. However, such specifications are rather restrictive when dealing with mid- to long-term analysis. We should emphasize, however, that import dependence coefficients (α_{ijt}) and/or world export market shares (σ_{ijt}) may be changed exogenously as part of simulated scenarios (*e.g.,* the 'Regionalization' scenario) and may change endogenously as part of the scenario simulations in regions where the maximum cultivable land area is binding (see below). In both cases such adjustments of import dependence coefficients and world export market shares may figure changes in regional comparative advantages or transport or trade costs potentially implied by trade, agricultural and/or environmental policies for instance.

Finally, when replacing in the balance equations all variables by their respective expression in the additional equations, one realizes that, provided that *Vstock* is fixed, *Food*, *oth* and *Waste* are the model's exogenous variables while the area harvested (*A*) is the model's endogenous variable.

The handling of co-products

Among the 33 agri-food aggregates of GlobAgri-AgT, there are some sets of co-products, namely 'Bovine meat' and 'Dairy' in the dairy sector and 'Oil' and 'Cake' in the oilseed crushing sectors (Table 3.1). For these sets of co-products, the balance equations reported above apply for one of the co-products, which is chosen as the reference product, but they must be changed for the other, which is called the by-product.

In GlobAgri-AgT, we decided to choose 'Dairy' and 'Cake' as reference products. Balance equations were thereby adapted for 'Bovine meat' (in fact for the dairy by-product share of 'Bovine meat' only) and for all oilseeds 'Oils'. In these cases, the production variable (*Prod*) no longer freely adjusts following a change in utilizations, but is pre-set by the quantity produced of the reference product and one of the various uses (most often the *Food* use) becomes endogenous.

This modelling makes it possible to maintain the existing link between co-products. However, this creates some difficulties for simulating changes in food diets since it requires an exogenous setting of the quantities consumed of each product, including 'Bovine meat' and 'Oils', in each region. This problem is easily dealt with for 'Bovine meat' as there is another source of production unlinked to 'Dairy': the beef sector. As far as 'Oils' are concerned, there is no oilseed producing only oil but we circumvent the problem by ignoring the link between 'Palm kernel cake' and 'Palm product oil' in the model. Hence, in both cases we are able to calculate the food consumption shocks for the share of 'Bovine meat' produced by the beef sector and for 'Palm product oil' required for the overall changes in 'Bovine meat' and 'Oils' food consumption to correspond exactly to the changes in food diets which are to be simulated.

Model closure

The model is closed firstly adding a world trade equilibrium equation for each product and secondly adding an agricultural land constraint equation in each region.

For each product *i*, the world trade equilibrium equation is written:

$$\sum_j Imp_{ijt} = \sum_j Exp_{ijt}$$

While for each region *j*, the agricultural land constraint equation is:

$$\sum_v Surf_{vjt} \leq \overline{Surf_{jt}}$$

This agricultural land constraint may be defined for various sets of products *v* so that the *Surf* and $\overline{Surf}$ may have different meanings: the land constraint may be defined for the cropland area, for the pastureland area or for the total agricultural land area for instance, or for all other sets of products. In GlobAgri-AgT, because of the lack of data regarding the maximum pastureland area in each region, we defined the agricultural land constraint on the cropland area. Hence $Surf_{vjt}$ is the cultivated area devoted to crop product *v* in region *j* during year *t* and $\overline{Surf_{jt}}$ is the maximum cultivable area in region *j* in year *t*. Let's emphasize at this stage that defining the land constraint on the cropland area has important implications since it means that pastureland may adjust freely to all the shocks introduced into the model. This is one important limit of our Agrimonde-Terra quantitative analysis. This limit does not result from the GlobAgri-AgT model since the latter can very easily deal with other levels of agricultural land constraints. It results from the lack of data on potential maximum areas which could be shifted to permanent pasture in each region.

Finally, as in the balance equations the domestic production of each crop *v* in each region *j* is linked to the harvested area and the per-hectare yield of corresponding products and regions, we need an additional equation linking the harvested area to the cultivated area for each crop in each region:

$$\sum_{v} Surf_{vjt} = e_{jt} * (\sum_{v} A_{vjt})$$

Where e_{jt} measures the ratio of total cultivated area over total harvested area in region *j* for year *t*. This ratio is lower than one when the cultivated area is lower than the harvested area, indicating the extent of multi-cropping (or the level of cropping intensity) in the concerned region. In contrast, the cropping intensity coefficient is greater than one when the cultivated area is greater than the harvested area, indicating the extent of fallow land or of harvest abandonment due to difficult climatic, economic or geopolitical conditions.

Model solving

In the initial '2010' situation, domestic resources-utilizations and world trade are balanced for all products and the observed cropland area is lower or nearly equal to the maximum cultivable area in all regions.

Let's assume that food consumption of product *i* increases in region *j*. According to our model specification, this increase is covered partly by rising imports and partly by expanding domestic production. This results in an expansion of cropland and, possibly, pastureland areas in region *j*. At this stage two situations may arise:

– Region *j*'s cropland area is still lower than region *j*'s maximum cultivable area, then the resolution of the model stops.

– Region *j*'s cropland area becomes greater than region *j*'s maximum cultivable area, then two stages are considered:

1. Region *j*'s exports are first evenly reduced (through equi-proportional decrease in its world export market shares σ_{ijt}) until the domestic cropland area falls below the maximum cultivable area. At this stage, the resolution of the model stops.
2. If, even with zero exports, region *j* still needs more cropland area than its maximum cultivable area, then region *j* starts increasing its imports (through increases in import dependence coefficients α_{ijt}). In other words, region *j* increases the share of its food needs which is covered by imports in order to reduce the required rise in domestic production and save some cropland area. As initial regional import dependence coefficients vary widely across products, we defined intervals of initial levels upon which the α_{ijt} coefficients are increased evenly, making it possible to differentiate the level of increase by band.

Therefore, in the last case, the world export market shares and import dependence coefficients of regions constrained by their maximum cultivable land area become endogenous.

The entry variables of the model

TABLE 3.3 below reports the entry variables of the GlobAgri-AgT model. These are the variables and the parameters of the model which can be exogenously altered for simulating scenarios.

Table 3.3. The entry variables of the GlobAgri-AgT model.

Variables	Definition	Examples of quantitative hypotheses of simulated scenarios
$Food_{ij}$	Food consumption of product *i* in region *j*	Population change in region *j* Food diet change in region *j*
Oth_{ij}	Other uses of product *i* in region *j*	Change in non-food use of agricultural biomass in region *j*
$\overline{Surf_j}$	Maximum cultivable land area in region *j*	Land degradation or land restoration in region *j* Expansion or reduction of irrigated land area in region *j* Impact of climate change in region *j*
Y_{vj}	Per-hectare yield of crop *v* in region *j*	Technical change and/or change in cropping systems in region *j* Expansion or reduction of irrigated land area in region *j* Impact of climate change in region *j*
Parameters		
β_{iaj}	Feed-to-output coefficient for feed product *i* and animal product *a* in region *j*	Technical change and/or livestock system change in region *j*
e_j	Ratio of total cultivated area over total harvested area in region *j*	Change in cropping intensity in region *j* Change in fallow land in region *j*
α_{ij}*	Import dependence coefficient for product *i* in region *j*	Change in trade policy in region *j*
σ_{ij}*	World export market share of region *j* for product *i*	Change in trade policy in region *j*

* Both parameters may become endogenous in regions exceeding their maximum cultivable area.

Conclusion

GlobAgri-AgT is a biomass balance model accounting for physical flows under physical constraints. It is thus different from a market and trade economic model relying on economic behaviors of agents and functioning with prices. It is obvious that our model is more rigid and implies less smooth adjustments than an economic model, due to the fact that we have no prices, which absorb part of the needed adjustment in an economic model, and no substitution possibilities between products, which contribute to smooth the needed adjustment across products in an economic model.

Despite the limits of a biomass balance model such as GlobAgri-AgT, we chose this kind of model for tractability and simplicity reasons. First of all, in a biomass balance model, many variables are exogenous, thus implementing long-term scenarios in this type of tool is rather easy. This is not the case with market and trade economic models, in which most of the variables are endogenous (especially in computable general equilibrium models). For example, in the case of long-term changes in food diets, the modeler can directly introduce alternative future diets into the biomass balance model (through shocks on the food quantities of the various products) while with a market and trade model this is not possible since the food quantities are endogenous. In the latter case, the modeler can only indirectly implement the long-term changes in food diets through shocks on consumers' income and preferences. Secondly, the use of a biomass balance model seemed more appropriate for this present exercise. It appeared like a simpler, a more transparent, and above all a better pedagogic tool compared to economic models, making discussions about the results and their main insights easier across economists and non-economists and across scientists and other stakeholders.