FOODSECURE
FOR POLICIES THAT MATTER

Assessment Framework and Operational Definitions for Long-Term Scenarios

David Laborde (IFPRI)
Simla Tokgoz (IFPRI)
Lindsay Shutes (LEI)
Hugo Valin (IIASA)

FOODSECURE Working paper no. 14
September 2013

INTERDISCIPLINARY RESEARCH PROJECT
TO EXPLORE THE FUTURE OF GLOBAL
FOOD AND NUTRITION SECURITY

SEVENTH FRAMEWORK PROGRAMME

Assessment Framework and Operational Definitions for Long-Term Scenarios

David Laborde (IFPRI), Simla Tokgoz (IFPRI), Lindsay Shutes (LEI), Hugo Valin (IIASA) [1]

Abstract:

To navigate among the long term challenges for global and national food security, policy makers cannot only rely on qualitative analysis. They also need quantitative tools to measure and rank the different issues that they will face and the policy responses that can be designed. FOODSECURE proposes state-of-the art simulation models that will give both researchers and policy makers the capacity to study these issues in a comprehensive framework. This paper is aimed at providing an overview of the different modeling solutions proposed in the FOODSECURE toolbox and defines a strategy for using the different models in a consistent manner. First, the different models are briefly described and compared. Next, we see how these models tackle key food security indicators and drivers and translate different assumptions about the future within their framework. We then discuss the relative strengths and weaknesses of the different models to address different policy questions. Finally, we discuss how to combine these models and which optimal level of model integration should be used for analysis.

FOODSECURE deliverable 7.1

The research leading to these results has received funding from the European Union's Seventh Framework Programme FP7/2007-2011 under Grant Agreement n° 290693 FOODSECURE.

[1] With contributions from Tom Kram, Marijke Kuiper, Gerdien Meijerink, Martine Rutten, Elke Stehfest, Ewa Tabeau-Kowalska, Michiel van Dijk, Hans van Meijl

Table of Contents

List of Tables

List of Figures

1 Introduction

Achieving food and nutrition security (FNS) is increasingly part of the global agenda. In 2000, UN members adopted Millennium Development Goals that include the eradication of extreme poverty and hunger. Recent tight agricultural markets and food price spikes have increased the debate on how to improve FNS in developing countries and the methods with which to achieve this goal. There are various factors that impact FNS since this is a complex issue with both qualitative and quantitative components. Laborde, Tokgoz and Torero (2013), as part of work package (WP) 1 (specifically, Deliverable 1.3), propose a systematic framework to analyze the role of key long term drivers of FNS and show that FNS depends on complex interactions between the supply and the demand sides, prices and income, households and global markets. The demand factors include rapid growth in demand for bioenergy (biofuels, biogas and bioelectricity), increased demand for meat, dairy, livestock feed, and cereals due to rapid economic growth and urbanization, particularly in Asia and Africa. The supply constraints include bad weather (short-term yield shocks), increase in world energy prices (energy intensive agriculture, higher transportation costs from exporters to importers) and increase in agricultural input costs (fertilizers, seeds, etc.). In the longer term, climate change and growing water scarcity will be major challenges to agricultural production and food security. The authors also show that many policies (e.g. trade liberalization) will have contrasting effects on FNS and careful quantitative assessment will allow us to draw some conclusions regarding the impact of these policies on FNS.

Our focus in the FOODSECURE project is to discuss FNS within a quantitative framework and utilize state-of-the art quantitative tools to address these complex issues. Therefore, we will rely on a set of diverse economic and biophysical models that can give us quantitative indicators pertaining to FNS. Specifically, we include three families of models: partial equilibrium (PE), computable general equilibrium (CGE), and biophysical (impact assessment framework) models. Tongeren et al. (2001) and Robinson et al. (2013) discuss the differences and similarities between PE and CGE models. Table 1 provides the list of the models included in this project and discussed in this paper. Together these models form the FOODSECURE modeling toolbox for long term projections, hereafter referred to as the FOODSECURE toolbox. Although all models include agricultural and food sectors, the focus and the methodologies of these models differ greatly. Thus, each model has relative advantages which make them complementary in terms of providing a full picture of the FNS issues. For example, bio-physical models can provide detailed analysis on the supply side, whereas CGE models can provide household level demand analysis. Therefore, the whole set of models provides a complementary framework in the analysis of drivers for FNS. Furthermore, including these quantitative tools in an “integrated modeling” framework by linking the models will allow us to analyze a wider range of scenarios that pertain to FNS where an individual model would be limited in analyzing these issues and allows both first and second order effects to be included. For example, a shock to the productivity of crops not only affects supply, but also has a second order effect through a change in biofuels supply that responds to crop prices. Finally, many changes happening in agricultural and food markets are the result of long-term dynamics (such as urbanization and climate change) where only models can capture the impact of these dynamics, since they allow analysts to deal with counter-factual situations and examine alternative futures and policies.

The FOODSECURE toolbox plays a central role in the FOODSECURE project. The interaction between WP7 and other work packages is shown in Figure 1. The selected models and the specific efforts that will be done within WP7 to improve their ability to tackle FNS aspects rely on the work done in WP1 that identifies the drivers that impact FNS as well as the indicators needed to monitor it. WP3 will provide critical inputs in terms of technological evolution. WP5 will provide the long term vision that will feed the models’ baselines and the work on long term projections that will take place within WP7. Furthermore, the toolbox will be used in WP4 for measuring the impact of existing policies conducted by leading economies and in WP9, WP10 and WP11 to guide the design for the future EU policies in various domains (climate change, bioenergy, foreign aid, trade, research and development, and agricultural policies). The aim is to promote a pro-FNS agenda for each policy but also show the need to achieve consistency among this large set of policies that can interact and therefore should not be assessed individually.WP13 is the data vault of the project and will therefore be a critical partner for WP7 to facilitate data exchange between the models and compare and visualize results. Last but not least, intense dialogue between WP6 and WP7 research teams will try to bridge the gap between the short and long term challenges of FNS.

The paper is organized as follows. In section 2, the different models are briefly described and compared. Then, we discuss the relative strengths and weaknesses of the different models to address different questions. Next, section 3 summarizes how these models tackle key food security indicators and drivers and translate different assumptions about the future within their framework. Section 4 discusses the relative strengths and weaknesses of the different models to address different policy questions followed by a discussion of how to combine these models and which optimal level of model integration should be used for analysis in section 5. Finally, we conclude.

2 Description and Comparison of the models

In this section, we will provide a brief description of each model included in the toolbox and compare and contrast the approach taken by each model. All of the models are (recursively) dynamic, multi country/regions, and multi product models. Please note that all models have different product and country coverage, as well as base years and data inputs. In addition, this coverage will evolve during the lifetime of the FOODSECURE project.

The toolbox includes two partial equilibrium (PE) models: GLOBIOM and IMPACT. The first model, developed by IIASA, is a linear programing model based on a highly detailed bottom up approach in which production decisions are taken at the production unit level (unit of land where a homogenous supply response can be defined based on biophysical features). The second model, developed by IFPRI, is a log linear supply and demand commodity market model with additional specialized modules (e.g. water management). These two economic models are traditionally linked to biophysical crop models to assess changes in effective or potential yields (EPIC in the case of GLOBIOM and DSSAT in the case of IMPACT).

The toolbox also includes two general equilibrium models: MIRAGE and MAGNET. The MIRAGE model, developed by IFPRI, includes two variants pertinent to FNS issues: the MIRAGE-Biof version focusing on biofuels and land use changes, and the MIRAGE-HH model that allows a full bottom up analysis of household level effects. The MAGNET model , previously known as LEITAP, is a GTAP-based model developed by LEI that has a modular structure and is flexible in regional and commodity aggregation that allows the model to be tailored to a particular research question such as the impact of the biobased economy (by including the biofuel and land modules), impact of Common Agricultural Policy (by including CAP module) and household level impacts (by including the household module).The models share similar structure and input data, having a canonical structure for global CGE, and are similar to other global CGE models such as Envisage (World Bank, OECD, FAO) or GTAP, even though they both have their own specificities and innovation. Finally, the IMAGE model, developed by PBL, is an impact assessment model with a strong biophysical component, which can be used independently or in conjunction with a global CGE model such as MAGNET or a PE model such as IMPACT.

A summary of the main characteristics of the models included in the toolbox in terms of regional aggregation and time dimension is provided in Table 2. It is clear from this table that even models of the same modeling type, PE or CGE for example, differ in the level of detail and focus. All of the models used in the toolbox are continually evolving; they all have a rich history with different versions and evolutions and an even richer future. This paper can therefore only provide a snapshot of these models at one point in time and the reader should consult the model documentation managed by each development team for the most recent information (see the link to the most recent documentation in the table). In the following discussion, we will present the main pillars of each model (international trade, domestic supply, and domestic demand) focusing on both similarities and differences.

Finally, it should be indicated that all the economic models can provide results in terms of relative changes of prices and volume consumed, at least by a representative agent at a country/regional level. These outputs will be the basis for computing the most of the FNS indicators. An important caveat is the fact that any price is associated to a given physical unit. The choice of the physical unit is dependent on not only the commodity, but also the level of product aggregation. The CGEs employing a higher level of aggregation – on average – will use a system of units, in most of the cases an “efficient” unit and not a physical unit that allows normalization of the prices in the base year. For instance, due to heterogeneity of workers, CGEs do not explicitly consider “people” in the labor market, but an efficient unit of labor for a given level of productivity. It helps to define a single representative wage rate, when the reality is quite different. For food products, for instance, if a model aggregates pork meat and chicken meat into one commodity, that have quite different nutritional values, it will also define a system of unit for this “white meat” aggregate and an associate price. Now, even if PE models use “physical” units and concrete prices to operate, it should not mean that PE models are about “real” quantities as soon as the aggregate products into representative commodities. A PE having only one type of wheat, or corn, aggregates in reality different varieties (feed wheat and durum wheat, yellow corn and white corn) that have very different yields, uses and even nutritional values. Therefore they create a “virtual” commodity called “wheat” or “corn” with an average yield, an average price and average nutritional values. This latter aspect is very important when addressing FNS issues.

Fundamentally, it is quite similar to the CGEs approach since the PE models will create an "efficient" normalized unit of wheat/corn as soon as some aggregation is introduced in the model. At the opposite, the more disaggregated the model is, the fewer differences exist between real world unit and model unit.

By combining PE and GE models with different levels of aggregation, the FOODSECURE toolbox also offers a great opportunity for the users. Indeed, having a highly disaggregated model is not always the best solution, even neglecting the important issue of cost/time consumption of processing large datasets and running large scale models. Indeed, all economic analysis has to deal with three aggregation challenges: longitudinal (or spatial), temporal, and contemporaneous (related to different indicators or variables). Each research question and modeling option may be associated with an optimal level of aggregation. The interests of having a highly disaggregated model are obvious: avoiding aggregation and obtaining better precision. At the same time, the risks are also high: misspecification, measurement errors, and non-linearity. The main issue can be summarized by the quote of John Maynard Keynes: "it is better to be roughly right, than precisely wrong". The issue is particularly important when long term projections are considered. Most long term projection models (climate, economic growth, demographic) tend to operate at a relatively high level of aggregation, or at least will display the results at a high level of. The further we go from our calibration point, , the higher the risk of divergence between the simulated local conditions and the projected ones (very high non-linearity of behavior for a specific individual, location or product). For instance, in recent years, a country like Nigeria has partially shifted its domestic production of bread from a 100% wheat flour composition to a 50% wheat and 50% cassava flour, partially as a response to strong policies in favor of the cassava expansion and the reduction of import dependency. A model initially calibrated on data displaying consumers eating bread made from wheat will not be able to capture this evolution and will wrongly assess the effects of a change in trade policy on FNS. At the opposite, a model considering a broad commodity defined as "starchy crops" and aggregating several real world crops will perform much better.

By combining PE and CGE models with different levels of aggregation, the FOODSECURE toolbox ensures that the questions of interest for the project will be tackled at the most adequate level of detail. Indeed, each economic problem has an optimal aggregation level to be investigated, both from a theoretical and applied point of view (see Lutero, 2010, for an overview of this issue in the literature). Three aggregation dimensions in particular need to be addressed: longitudinal, or spatial, temporal and contemporaneous (related to different indicators or variables). The issue is particularly important when long term projections are considered, considering that uncertainty range increase when going further in the future and challenge any attempt to provide robust results at detailed level.

In the following subsections, we focus on a few key features of the different models that play an important role in defining global and regional FNS.

2.1 Representation of Trade and International Price Transmission

The way in which trade is modeled is a critical aspect of any global modeling attempt as it defines how countries can rely on world markets to address their food security challenges and how imbalances between domestic production and consumption will be absorbed in the future.

Both MAGNET and MIRAGE are bilateral trade models with heterogeneous products that use the standard CGE assumption of trade in products differentiated by country of origin (Armington 1969). Nested CES functions are used to reflect preferences among varieties originating from different countries. Therefore, countries can export and import the same product at the same time due to consumer preferences for different varieties. The price transmission between domestic and international market is imperfect and highly dependent on the choice of the CES trade elasticities and the initial share of trade. The values of elasticities in both models are mainly based on the parameters of the GTAP database.

IMPACT includes a pooled net trade model with homogeneous goods that does not include spatial differentiation. Only net unilateral trade flows are considered and represent at any period in time, the gap between domestic supply and demand. The algorithm used aims to minimize the sum of global trade flows since trade costs generate a waste of resources in this framework. Minimizing global trade is therefore the best solution to ensure both global efficiency and commodity market balance in each market. In contrast, GLOBIOM follows spatial equilibrium model specifications (Takayama and Judge, 1971) of trade for homogenous goods between individual regions. Therefore, it has the possibility to represent bilateral, but not reciprocal trade flows. Trade costs are incorporated in the model objective function beside production costs and consumer surplus.

These different assumptions will lead to different degrees of price transmission from the “global” market to domestic markets where they are the strongest in the case of IMPACT (one world price with full price transmission in percentage terms between world market and domestic producers and consumers with the policy wedges) and the lowest in the case of the CGE models (imperfect price transmission, existence of *n* prices for a given commodity within a country, where *n* is the number of regions producing the good). In addition, the PE models display a more flexible pattern of international trade (after a shock or in dynamics) compared with the CGE models that are more conservative due to the role of the CES function in conserving initial trade patterns.

Two important caveats follow for long term projections from the specification of trade in the toolbox models. First, pure trade creation is not possible in the two CGE models since a zero trade flow in the dataset used for the model calibration will force this specific trade flow to remain equal to zero at all points in the future. Second, the type of trade model also determines the trade policy components of each model and how trade policies are represented and constrains how trade policy reform can be simulated in each model. The different ways of handling trade may cause different results obtained from similar policy shocks.

2.2 Representation of Production

Production is a key aspect in FNS with food production forming the core of the availability dimension of FNS. PE and CGE models differ strongly in their approach to modeling production. Since CGE models include both commodity and factor markets, these models can employ a more detailed production structure. CGE models specify the technology underlining the production function with producers maximizing profits with respect to both input and output prices. CGE models also differentiate between intermediate goods and primary inputs (land, labor, etc.) in their representation of production. They are often calibrated on social accounting matrices (SAM) and for relatively aggregated sectors (e.g. cattle sector without differentiated information for dairy cow and beef subsector), and thus their cost structure may be less accurate than in some PE models.

In contrast, PE models rely on reduced form specifications and include supply functions for agricultural commodities with different input and output coefficients. The link to input markets are tentative, with some models including fertilizer prices or wages in their crop yield functions. PE models rely on distinguishing area and yield separately in their production module. This allows PE models, with their focus on agricultural markets, to use a more detailed production module. For example, GLOBIOM includes water as a resource and differentiates management systems for crops. In IMPACT, area and yields are disaggregated with respect to water basins in a region for each crop.

Being calibrated on SAMs (or data that can be arranged as a SAM), MAGNET and MIRAGE, in their standard use, will not have shadow price for all technologies and all crops in all countries as only existing production pattern can be calibrated. In contrast, a PE model such as GLOBIOM has shadow prices for all goods, under some assumptions, that explain the existing/missing productions in the base year.

In the next subsections, we will focus on two key aspects related to agricultural production: land use and yields.

2.2.1 Land allocation

The way in which land allocation is modeled differs between the two CGE models in the toolbox. Total land supply in MAGNET is modeled based on biophysical outcomes from the IMAGE model. Important information to construct the land supply curve concerns the total amount of land that is potentially available for agriculture in a country and the yield per grid cell. Different land types are distinguished in a flexible nested CET structure (the user determines the number of nests and how they relate to each other), with the relative evolution of land rents determining how land is reallocated from one use to another. Versions of MAGNET in which land use is defined at the AEZ level and forestry is included in the nested CET structure are available. In MIRAGE, land use is defined at the AEZ (18 agro-ecological zones as defined by FAO-IIASA) level within each region or country, and a 4 level CET (first nest among similar crops, second between different crops, third between crops and pasture land, fourth between plantation and crop plus pasture) defines how land is allocated between all farm and forestry economic activities.

The two partial equilibrium models also differ in their representation of land markets. The GLOBIOM model includes detailed land use representation with forests (unmanaged forest, managed forest, short-rotation tree plantations), cropland, grassland and other natural vegetation. Land cover is converted between these types depending on the relative profitability of the individual activities (18 major crops, 7 animal products, and 5 forest products) and on the land conversion costs and constraints. Land is divided into about 200,000 Simulation Units[2], which are aggregates of 5 to 30 arcminute pixels based on same altitude, slope and soil classes within a country. IMPACT includes area under cultivation for 25 main crops where area is divided into irrigated and rainfed components based on the Spatial Production Allocation Model (SPAM). Crop area and yields are further divided into Food Production Units, where crop area encompasses 115 geopolitical regions and 126 hydrological basins in the world. The intersection of these two geographical layers creates 281 food production units (FPUs). Harvested area is specified as a response to the crop's own price, the prices of other competing crops, the projected rate of exogenous (non-price) growth trends in harvested area, and water.

Thus, even if the four models will reallocate land among different agricultural activities based on relative prices/rents/profitability, the land response to a given shock will be quite different. In addition, the use of the CET function in the CGE models requires additional treatment to get a consistent economic response and physical constraints and yields.

2.2.2 Yield and Land Productivity

Yields grow according to an exogenous factor in all models: technical progress. None of the models currently includes endogenous R&D in agriculture (or in other sectors). The rate of technical progress will be a key aspect of the assumptions made for the baseline projection. It can be specified to impact only land productivity, total factor productivity or even both input and factor productivities.

In CGE models (both MIRAGE and MAGNET) the quantity of factors (capital, skilled and unskilled labor) combined with land in the value added tree of the model will also directly impact land productivity (standard neo-classical behavior under declining marginal factor productivity and constant returns to scale to production). Therefore, in CGE, yields will be impacted by the evolution of relative factor prices. In addition, some models have additional specificities about endogenous yield response:

- MIRAGE-BIOF includes specific modeling for intensive and extensive production systems for crops and livestock based on a logistic approach of land productivity when combined with different inputs (fertilizer for cropland, feedstuff for pasture). In this framework, relative prices of fertilizer (or feedstuff) and land prices will have a direct impact on yields;
- GLOBIOM offers a very specific way to have endogenous yield response through shifts in agricultural production system. For cropland, 4 management systems are included (high input irrigated, high input rainfed, low input rainfed and subsistence) and management changes and yields evolve with changes in output prices (and/or exogenous input prices). To estimate the different management systems, GLOBIOM utilizes crop yields, fertilizer and irrigation rates information from the EPIC model that is run for each Simulation Units of the global grid. In addition to management switches, yields in GLOBIOM are also affected by the quality of land where crops are allocated: most profitable crops will receive the most fertile land, but if their returns decrease, they are moved to more marginal land and their yield become lower.
- In the IMPACT model, crop yields are directly expressed as a function of crop prices, the prices of inputs (wages and fertilizer), available water, and a projected non-price exogenous trend factor. In the traditional

[2] For model runs at the global scale, a compromise between precision and computation time is often found by aggregating Simulation Units at lower resolution (up to 2°). Usual aggregation corresponds in that case to calculation over about 10,000 units.

implementation of IMPACT, fertilizer price projections from GTEM are used as an explanatory variable in crop yield equations.

- MAGNET uses exogenous yield improvements based on FAO projections, calculates an endogenous yield response as a result of the substitution between land and other input factors, and their supply and relative price elasticities. A recent development is the explicit introduction of fertilizer sectors and the substitution possibilities between land and fertilizers in crop sectors and therefore also affecting the yields. Additionally. MAGNET takes into account information from the IMAGE model on yield changes due to climate change and due to agricultural expansion. In the future, the representation of resource constraints in crop production will be improved, e.g. by taking into account water availability for irrigation.

2.3 Representation of Demand

The demand for food products is a key component of the access dimension of FNS. Both PE and CGE models include final consumption from households that depend on household income and the vector of prices (food and non-food) faced by the households. In addition, the models include intermediate consumption of goods from firms that depend on the relative prices of different inputs and the production of each sector of the economy, for both raw and processed foods.

PE models include raw agricultural products with a few processed ones such as sugar or vegetable oils (Valin et al. 2013). CGE models generally include fewer raw products compared to PE models. However, some model modifications can be done to extend the crops covered (e.g. MIRAGE-BioF version and MAGNET). All models include non-food demand for agricultural products, both from traditional activities such as textiles and new ones such as bioenergy.

CGE models rely on well-defined utility functions to derive demand, specifically CDE (constant differences in elasticities) or LES in MAGNET and LES-CES in MIRAGE. This limits the flexibility that CGE models have for income and price elasticities used in the model. In addition to the standard GTAP CDE specification, MAGNET also allows a CDE utility function based on GTAP data and parameters but with the addition of changing income elasticities over time to capture falling shares of food expenditure as income grows. To this end, MAGNET calculates income elasticities with a function where income elasticities depends on real-PPP corrected GDP per capita and thus they are updated iteratively when the model is run.

PE models rely on a reduced demand form that allows more flexibility in adjusting and using price and income elasticities. IMPACT includes cross-price elasticities in food demand equations, whereas GLOBIOM does not have cross price effects (Valin et al. 2013). Regarding income and demand relationship, IMPACT allows income elasticities to change over projection period. GLOBIOM defines income elasticities as functions of GDP per capita and calibrates them with respect to different scenario of future food diet evolution.

Both MIRAGE-HH, a specific version of the MIRAGE model, and the MAGNET model depart from the generic assumption on one single representative agent for the final demand by country or region i.e. a group of countries. Up to 500 categories of household are included in MIRAGE for selected regions with each category having its own demographic weight, represent the final demand having different preferences and income constraints, facing potentially different prices (market access costs). In this context, aggregate demand can have richer behavior, for instance displaying aggregated negative income elasticity for some commodities even if each household demand is represented with functional form authorizing only positive income elasticities. The MAGNET model will also be extended along this dimension with several household categories and wider country coverage.

For long term projections, it is important to note that all the models include non-homothetic preferences[3], but have heterogeneous ways to deal with the paths that elasticities (income and/or prices) should follow. In addition, the cross price effects in the model are weakly represented. The IMPACT model offers more flexibility, whereas

[3] This implies that consumption has a non-unitary income elasticity; when the consumer's income is augmented by x percent, the consumption of each good is not systematically raised by x percent, other things being equal.

GLOBIOM excludes such cross-price effects. The CGE models have cross-price effects, but they are mainly driven by the choice of the functional form (CES-LES or CDE) instead of being calibrated on realistic pair-wise elasticities. It is important to keep in mind that, to the exception of GLOBIOM, none of the models discussed here are based on a linear programing approach. Therefore, the consumer behavior is not solved under nutritional constraints and the consistency of the food demand simulated will be mainly reached through adjustments of key parameters (elasticities). The two closure (endogenous adjustments or multiple nutrition requirement constraints) are however usual features in GLOBIOM, even if scenarios with a nutrient constraint at a more refined level than total vegetal or animal calorie constraints have not been explored so far with the model.

Finally, the main difference between the PE and the CGE models is the explicit representation by the latter of the intermediate demand and the inter-sectoral linkages as well as the determination of household income (endogenous in a CGE, exogenous in a PE).

2.4 Constraints in models

The models included in this analysis incorporate several types of constraints in model structure, reflecting economic closures (the mechanisms by which goods, factor and savings/investment markets clear) or biophysical limits on processes and resources. Depending on their theoretical background, each model puts more emphasis on the one or the other, but no model appears to be able to include all relevant constraints in one unique setting. This limitation reinforces the value of the FOODSECURE toolbox for tackling long run FNS challenges. For example, a CGE model which assumes that trade follows an Armington plus CES specification will impose strict constraints on the long term evolution of trade flows, especially when models are run with a high level of disaggregation. Similarly PE models face a conceptually important challenge of their own: how to simulate long term changes and shocks (agricultural transformation, yield shocks to climate change) that are considered to be important for FNS since these will introduce important effects for developing countries with a large share on GDP tied to agriculture, without considering effects on income, investments and the feedback on market labor of changes in agricultural productivity.

2.4.1 Economic closures

In MAGNET and MIRAGE, as CGE models,[4] every economic agent balances income and expenditures: income of households equals to spending of households (consumption, savings and transfers), firms' spending (including payment to capital) equals firms' revenue. At a global level, savings must be equal to investment. At the country level, a gap between the two variables can occur due to international capital movements. Nevertheless, constraints on current account surplus or deficits are also considered, leading to real exchange rate adjustments (determining relative international prices among economies). Furthermore, supply equals demand for all commodities and factors in the economy.

The closure between income and production is lacking in PE models that consider consumer and producer surplus separately. For this reason, evaluating the feedback from production shock on the demand can require iterative resolution of the model, as these effects may not be second order in the case of developing countries where income and food demand rely heavily on agricultural revenue. Another closure missing in PE models concerns factor markets for capital and labor. These models therefore assume an exogenous price of capital and wages, constant in GLOBIOM, or following a CGE derived trend in IMPACT. PE models also exclude feedback from the evolution of exchange rates which is mainly determined in CGE models by the evolution of TFP and the current account closures.

[4] Beyond the accounting constraints, the utility based demand system for households also include constraints on the different elasticity values in the model (direct and cross price elasticities, income elasticities).

2.4.2 Biophysical production constraints

Agricultural and other land use based sectors require several natural resources inputs and their production is subject to some biophysical constraints with respect to crop cultivation, livestock rearing, and forest production. Models representing the best these types of constraints are models that incorporate biophysical accounts either expressed as harmonized quantities (e.g. N stock, water) or with a high level of disaggregation for heterogeneous physical units (yield by unit of land). In the case of GLOBIOM, the consistency on resource constraints is pushed even further as the model embeds several activity models (EPIC for crops, RUMINANT for livestock and G4M for forestry) into its depiction of production.

On the supply side, three biophysical constraints deserved to be tackled specifically:

a. **Land**: Land in CGE models is mainly represented through the purchase value of the land factor. In MIRAGE and MIRAGE-HH, a simplified iso-elastic land supply curve is assumed for all land rents supporting agricultural activities. In MIRAGE-Biof, a richer setting is developed to capture all land used in anthropic activities (cropland, pasture and forestry) and a non-isoelastic land supply is included for each country, calibrated on an explicit land availability constraint, based on the amount of land suitable for agriculture. In this case, declining yields on new land are assumed. Furthermore, in the case of crops, these land rents are harmonized to obtain a consistent mapping with cultivated areas at the AEZ level according to the M3 database. The MAGNET model also relies on a land rent description and assumes a land supply function with a vertical asymptote calculated using data on land availability from IMAGE. The shape of the asymptote is determined by the current land use, the current land price, and the current price elasticity (based on data from literature and, if not available, the biophysical suitability in IMAGE). Substitution between land use types is then managed through CET functions. GLOBIOM has an explicit representation of land use. In GLOBIOM, land availability is described at the pixel level, which contains information on the land cover based on Global Land Cover 2000. Land suitability in each pixel is determined for crops by the EPIC model under different management systems. Land supply is the result of the matrix of possible conversions across the different land uses in the model, whose costs are specific to each region. GLOBIOM also represents the constraint on production of livestock products depending on grassland needs, through a spatially explicit representation of grass production. Forest harvest potentials are determined by a specific forestry model, G4M. In contrast, IMPACT does not include land constraints.

b. **Water:** A water constraint is only represented in PE models. IMPACT includes a quite developed representation of the water availability constraint for irrigation on crop yields through its link to the Water Simulation Model, a feature not available in other models. In GLOBIOM, water is also an important input and water scarcity constrains the possible development of irrigated systems. However, no water availability limit is set to the potential water use and water supply is represented in each region with an isoelastic supply function. In IMAGE, the newly coupled LPJmL model provides a fully coupled crop and hydrological model, and allows assessment of the potential contribution of (additional) irrigated land to food production. In allocating new irrigated area, water availability is taken into account. More generic information on the potential of irrigation per region is derived by calculating a series of scenarios by stepwise increasing the irrigated area in a region, and analyzing the resulting increase in crop production. This yields a supply function for additional irrigated production, which is leveling off as available water is limited.

c. **Agronomic constraints:** None of the economic models discussed here, either PE or CGE, includes a physical constraint on crop nutrients. However, thanks to the data provided with EPIC, nutrient cycle information is represented in GLOBIOM for the different management systems and could potentially be used as an indicator for long term assessment. Rotation constraints for crops are also not developed in any of the participating models at the world level.

3 How the models can tackle key FNS indicators and drivers?

At the World Food Summit of 1996 food security was defined as existing "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 1996). This definition makes it clear that available food supply is not enough for achieving food security and requires other conditions to be met. FAO's definition encompasses four key dimensions: food **availability and accessibility**, **stability** of food supply and **utilization** of food (FAO 2006, 2008). It also involves both the quantity of food and its quality, linking the concept of food security to nutrition and food safety. This definition shows that, first, FNS is a criteria defined at the individual and household level. Even within a specific household, we can find people being food secure and food insecure at a given point in time. Secondly, FNS depends on elements affecting the market conditions in which a given person will make his/her choices in terms of food consumption. So, long term drivers of food security needs be discussed in two steps: at the individual level and at the market level. These drivers also provide key entry points for the scenarios that will be run using the "model integration" framework to analyze FNS in a quantitative framework.

3.1 Key variables that influence FNS

Laborde, Tokgoz and Torero (2013), as part of WP1 (deliverable D1.3), identified key long term drivers of FNS and proposed a systematic framework to analyze the role of these drivers on FNS. Below we summarize these drivers.

3.1.1 Income

One of the most significant drivers of FNS at the individual and household level is the real income of households and the distribution of income among and within households in an economy. With a higher level of income, households are able to meet their basic needs and in cases of short-term disruptions, can reduce the consumption of other goods (manufactured goods and services) without lowering their food intake. In other words, an increase in the level of income allows not only a higher purchasing power, but also a decrease in the share of income spent on food products making households less vulnerable to price volatility thereby promoting both the accessibility and stability dimensions of FNS. Although households are more food secure with higher income, economic growth is not a sufficient condition for FNS improvement. Any increase of national income should also be well distributed among and within households in a country.

3.1.2 The Role of Prices

Relative prices between food and non-food commodities will affect the level of real income that households have and its distribution among different categories of goods. In this context, any alteration of relative prices will change the optimal allocation of consumption between food and non-food products, and depending on preferences – the relative income vs. substitution effects – the household may become more or less food secure. Nevertheless, under a normal demand structure, and for a given level of income, a decrease in the prices of non-food products will be translated to an improvement in the accessibility dimension of the FNS situation of the household.

3.1.3 Sanitary Conditions

The sanitary conditions in which food products are consumed or prepared at the household level are significant in determining the overall quality of the food intake of a person. Higher income households will be better equipped (e.g. fridge, water filtering system) to create sanitary conditions and this will improve the quality of the food prepared. In addition, higher level of income will be associated with safer behavior (where household will discard potentially corrupted food as a precautionary measure whereas poorest households may not have this opportunity). Furthermore, better infrastructure in terms of access to electricity, water quality, and sewages will provide better conditions for the consumption of food products. Improved sanitary conditions therefore contribute to the utilization dimension of FNS.

3.1.4 Education

Better education and better dissemination of information especially for women in a country where they continue to play a key role in the household's food production system have positive consequences on food safety. It would also shift households' consumption towards healthier products and should contribute to the reduction of obesity, malnutrition and cardio-vascular diseases (e.g. ongoing legislation and information on transfats). Education therefore also contributes to improvements in the utilization dimension of FNS.

3.1.5 Transaction and market access costs

As discussed, prices play a significant role in FNS at household and individual level. However, a clear distinction needs to be made among global, country level, and local prices since households may face different distortions in the prices they pay for food. For both food and non-food products, the prices faced by a specific consumer is a combination of market wide conditions, called here market prices, and specific market access costs paid by a household or a group of households. These costs can be the consequence of infrastructure, market structure, or domestic policies. For example, a household in a remote area will pay a higher transaction cost to access food (both in terms of monetary cost or time cost). In this case, improvements in infrastructure will help reduce the food costs for this category of households and improve its access to food. Similarly, if due to regulatory or non-regulatory measures, the food distribution system within a country or a region is inefficient (e.g. concentration in the market structure), specific efforts could be made to reduce the mark-up behavior of some agents and improve the FNS situation of consumers. It should be noted that most of these measures will affect both food and non-food prices and in turn will generate real income gains that will benefit FNS both directly and indirectly.

3.1.6 Market equilibrium drivers

As we have seen, market prices play an important role in the individual FNS situation, both through the income channel and the consumption (price of food) effect. Since everyone is a price taker on the food market as they do not have the power to influence market prices, we now focus on the drivers affecting the market conditions that define these prices.

Global vs. domestic prices

One of the critical drivers of FNS at the aggregate market level in a country is the difference between global prices and the domestic prices that consumers and producers face. The first source of this difference is the evolution of the real exchange rate in an economy. Secondly, trade policy measures, such as import or export restrictions and tariff rates determine the level of domestic prices. Non-tariff measures, including Sanitary and PhytoSanitary measures (SPS) and Technical Barriers to Trade (TBT), may create additional costs for the exporter (or the importer) and increase food prices. Another important component of this gap between the domestic and international markets is transportation costs.

Drivers of aggregate food demand

Demographic dynamics will lead to increased demand for food and higher food prices. The accelerated increase in the global population has increased the number of mouths to feed and the demand for agricultural commodities. A significant portion of this population growth is projected to come from low-income countries that have limited potential to increase domestic supply of food, and thus would turn to world markets to meet their demand through food imports. However, projections of total population are only a first starting point. To better capture the implications of demographic changes we need to consider changes in the distribution of gender and age as well.

The expansion of income per capita will increase the demand for food per capita. Even if income elasticities of food products decline with income level, they remain positive for most products for the range of income changes faced by most of the world population. Higher incomes combined with urbanization trends will cause a change in dietary preferences, specifically a shift towards meat and dairy products, and latterly, towards fruits and vegetables and away from staples such as cereals.

Drivers of aggregate food supply

Three key drivers of aggregate food supply can be identified: the amount of land available for food production, the normalized average yield and the share of waste/losses generated by the food system. An increase in the overall amount of available agricultural land will allow a shift in agricultural supply, reduction of food prices, and easing of FNS constraints. Agricultural area increases with higher agricultural commodity prices in real terms, investments in irrigation, improvement of transport and trade infrastructure. At the same time, land degradation and desertification, forest conservation policies and urbanization will lower available agricultural area for food production.

Yields are positively impacted by prices received by farmers which will lead to more intensification efforts, better land management practices that increase overall quality of land and more use of inputs such as water, seeds and fertilizers. R&D efforts and extension services that improve agricultural practices also positively impact yields, increasing aggregate supply, and improving FNS.

A key long-term driver of yields is climate change. Climate change adds further pressure to the dramatic transformation of global agricultural markets, due to its effect on local temperature and precipitation conditions. In addition to the temperature and water channels, climate change may bring new pests and diseases to some regions, and remove them from others. A first conclusion of the potential scenarios on climate change is that it will have uneven effects among crops and among countries, generating winners and losers. Studies that combine Global Circulation Models (GCM) with economic models show that climate change has an impact on agricultural productivity, on commodity prices, and on factor prices. Using current technology (crops, practices, locations), climate change will reduce average yields during the transition period but may also generate large opportunities of increased biomass production since higher temperatures, a wetter climate and higher concentration of CO_2 can support increased photosynthesis.

3.2 Exogenous and endogenous variables: how models can tackle FNS drivers?

CGE models are economy-wide models that present a complete view of the national economy either as a single country or global model. CGE models include all agents and sectors in an economy, although these sectors might be aggregated into more general categories (such as including an aggregate agricultural and food industry rather than specifying crop sectors individually). Therefore, many of the FNS drivers discussed above are endogenous to the models, but not all of them. PE models, on the other hand, focus on a subset of sectors, most commonly agricultural markets, and take a large portion of the economy as given. In this context, these exogenous variables can be a part of the scenario building process, generated independently of the model, or critical macroeconomic variables can be passed from the CGE models to the PE models in a model integration exercise. These variables include GDP levels or GDP growth rates, real exchange rates, and various energy prices and demand for energy sources and factor prices. In this way, the model integration process enables analysts to endogenize the previously exogenous variables of the PE model by linking it to a CGE model. At the same time, it allows the analysis to take place at a more detailed sectoral level through the PE framework, which a CGE model cannot capture as a standalone model. A full discussion of model integration is presented in section 5 but it is important to first review the exact status of key FNS drivers in the different models.

3.2.1 Exogenous drivers in both PE and CGE models

Demographic variables including total population, ageing of population, gender balance are exogenous in all the economic models in the toolbox. Similarly, labor productivity changes related to change in health status or access to improved nutrition are not considered in their current versions. International migration is also exogenous in these models and “embedded” in the demographic projections. Urbanization and/or changes in preferences are also considered as exogenous, even if they can be updated in the baseline to reproduce the pre-defined evolution of demand elasticities.[5]

Waste and stockpiling behavior are not represented explicitly in any of the models. For some models, fixed coefficients will represent the share of production (or consumption) stored, and the waste is translated by lower input efficiency along the supply chain or lower yield (expressed as sold output on the market). Therefore, even if the models can have variables related to these drivers, their dynamics are not responsive to price changes.

Food safety and food quality are not explicitly considered in these models, which implies that the nutrition/utility granted by the consumption of one unit of a food-related product does not improve over time by default. If some of these parameters can be shocked, it will be done in an exogenous way.

Policy variables are also assumed to be exogenous in the normal closures of all these models. In the standard closure of both the MAGNET and MIRAGE model, the surplus or deficit of the current account is fixed in an exogenous way, leading to an endogenous real exchange rate. PE models will assume simply an exogenous exchange rate. Finally, all R&D (private or public) expenditures and therefore the technological trend – their outcome - is assumed to be exogenous.

3.2.2 Endogenous in the GE models and exogenous in the PE models

In a CGE model, all prices – goods and factors – are in principle endogenous. These models allow each market to clear in each period. In addition, the supply of land and capital can be endogenous. Therefore, income at a country, but also household level will be endogenous.

On PE model side, income and most factor prices are usually exogenous. Similarly, all non-farm based inputs also have exogenous prices (fertilizers, insurance services etc.). Some specific factors and input markets can, however, be represented in a detailed way. GLOBIOM and IMPACT with its integrated water availability module both represent endogenous price for water access. GLOBIOM also includes a full land market price.

At the macro-economic level, the (real) exchange rate is endogenous in CGE models but exogenous in PE models. Levels of public resources, and potentially the scope of public investments, are endogenous in the CGE framework.

3.2.3 Endogenous in the PE models and exogenous in the GE models

The PE models can generate, directly or indirectly, endogenous behavior for agricultural productivity or nutritional values, whereas CGEs cannot, or require significant investment to achieve. We will focus here on how PE can capture technological changes and improvement. First, technological change can appear in a PE like GLOBIOM where discrete changes in land management at a disaggregated level will lead to endogenous technological change at the farm level, and aggregated changes in average land productivity at a country/region level. Second, water management (in GLOBIOM as previously described, or in IMPACT through the water module) in PE models may change endogenously and cause the ratio between irrigated and non-irrigated land to endogenously evolve. Third, thanks to their considerable disaggregation in terms of crops, average land productivity will evolve as the relative size of different crops evolves. Therefore, in a PE model, if the relative productions of sorghum vs. maize evolve in a region, the value/nutrition output per ha will change whereas the CGE model will miss this effect as it assumes constant yield at the level of the “coarse grains” sector.

3.3 Summary of FNS Drivers and Indicators in the FOODSECURE toolbox

As discussed above there are multiple drivers of FNS in the long-term. The FOODSECURE toolbox will address most of them in an exogenous or endogenous way. Table 3 summarizes the current status of the models and their projected evolution. Indeed, the models will be individually adapted during the project to cover new aspects (e.g.

[5] In fact, to reproduce a dynamic path for demand elasticities (income and/or prices) underlying preference parameters of the demand function should be modified, the latter implying a modification of the preferences.

endogenous R&D), to improve existing features (e.g. climate change) or will be linked to other models in the toolbox to compensate their individual limitations.

Some of these drivers affect individuals and households only and some have broader implications. These drivers also provide us entry points to build and run various scenarios using the "model integration" framework discussed in section 5. These scenarios, defined around critical FNS drivers, will allow us to generate a quantitative depiction of alternative visions of the future (as specified in WP5). Furthermore, a "model integration" set up allows us to run a wider array of scenarios and generate more detailed results that can be accomplished in a single model framework. For example, an income shock that is analyzed using a CGE model would give us results at a more aggregate sectoral level. If the same scenario is run in combination with a PE model, detailed results on agricultural production by crop can also be obtained. As we have seen, different models have different exogenous and endogenous variables as shown in Table 3, yet the toolbox should not be seen as a collection of models, separated from one another, but has a consistent analytical tool that considers different levels of interactions and linkages among them. Therefore the set of drivers and their interactions considered in the toolbox is richer than the sum of model features. This aspect is discussed in more detail in section 5.

The FOODSECURE toolbox already captures key drivers of FNS in terms of income evolution and the determination of food prices through supply and demand effects. Nevertheless, the different models will be extended to better capture the mechanics of the FNS drivers and their evolution, integrating where possible the findings of WP1 and WP2. Table 3 indicates such changes for each model, including those that will be achieved through model linking. To summarize the main direction of improvements:

1. Better modeling of the demand system through disaggregation (household modeling), diet evolution, improved functional forms etc.;
2. Improved representation of the yield dynamics, in particular driven by endogenous changes as R&D or exogenous impacts (climate change);
3. Increase commodity disaggregation where relevant.

Next to covering a large set of drivers and expanding the models to improve their modeling approach, the toolbox will also make significant efforts to fine tune outputs of the models to deliver relevant FNS indicators. Indeed, if the models generate a large amount of information, it has to be processed in specific ways to address the research questions at stake. Therefore, an important effort is made to adapt the models to compute key FNS indicators as summarized in Table 4. As shown in the table, all of the models already have the key elements needed to define FNS indicators, that is, the evolution of food and agricultural supply and consumption, prices and income. Nevertheless two main efforts will be done by nearly all the models, some being already more advanced than others:

1. Move from quantity (tons) and value of commodities to (macro) nutrient contents (calories, proteins and fats) to measure availability and intake per capita. Where possible, indicators concerning the evolution of food rich in micro nutrients (but poor in calories, fats and proteins) such as fruits and vegetables will also be tracked;
2. Disaggregate national indicators into different household categories. Indeed, even if FNS indicators should ideally be analyzed at the individual level, having set of indicators at the household level will already be a great achievement of the FOODSECURE project based on the current state of the art in the modeling field.

Other indicators relevant for the policy makers will also be included since they are a critical component of ongoing debate: the role of trade and therefore the ratio of self-sufficiency, to make the distinction between food security and self-sufficiency, and the role of volatility and food supply instability.

4 Using the toolbox to tackle key policy questions related to FNS

As discussed in the previous section, all the FOODSECURE toolbox models capture all the key drivers of FNS that can be reasonably quantified in the current state of science. The challenge is now to adequately apply the toolbox in the policy space. This involves two stages: first, to create the proper baseline projection or one or more reference scenarios and second, to translate the different policies into quantitative variables in the models. As with any tool, the quality of the output will depend as much on the quality of the tool as the way in which it will be used. We conclude this section by discussing some important recommendations on the implementation strategy.

4.1 How will the toolbox fit the policy space?

The first stage of WP7 is to use the different models of the toolbox to build long term projections of the FNS situation at the global, regional, country, and household levels. This exercise will use inputs from WP5 and different visions of the future (reference scenarios) that include alternative assumptions on demographic, technological – with a specific focus on yields – and economic growth (with alternative specifications among and within countries). In addition, new constraints on natural resources, including those linked to climate change will be introduced. This step is quite important since it will define the different reference scenarios in which policy scenarios will be introduced. It is quite important to understand that the same policy will lead to different effects depending on the environment into which it is introduced. For instance, an EU CAP reform will have different consequences for Africa FNS in 30 years' time if the EU is still a key food provider to this region, compared to the situation where it is not. Similarly, the role of foreign aid in the future will be directly linked to the level of income and development of the beneficiaries. Even the ranking of technological options will depend of the state of the world: in a world of scarce inputs (water, fertilizer), input saving technologies will be preferred to yield improvements. Finally, this stage will be used to build robust, meaningful and contrasting reference scenarios and to test the different models, including the new developments that will take place in WP7, and compare their results and performance.

When the proper reference scenarios having been defined, then the assessment of policy options can start[6]. The different models can translate most of the policies of interests (agricultural policies, foreign aid, trade, biodiversity, sustainability) through two channels:

- Changes in exogenous parameters or variables that directly represent the policies such as rate of subsidies, tariffs and quota levels. These changes are mainly grouped into two categories: price wedges e.g. the price gap between a producer and a consumer introduced by a tax or subsidy, and the level of a binding constraint e.g. a minimal level of biofuel use or an income constraint shift due to changes in international transfers;
- Changes in exogenous parameters or variables representing the effects of the success of the policy such as the introduction of new technology e.g. yield improvement, improvement in food system legislation e.g. reduction of a waste parameter in the food distribution, or the implementation of a new forestry code e.g. reduction of available forested area for agricultural expansion;

In both cases, the policy will have direct and indirect effects that impact FNS, depending on the model scope and design. This work in policy implementation and analysis will be performed in WP4 (measuring impact of existing policies on FNS) and WP9 to 11 (designing new pro-FNS policies). Based on the current status of the models, including their team expertise, and the expected developments, Table 5 proposes a mapping between models and policy questions for the FOODSECURE project.

[6] It has to be clearly acknowledged that the reference scenarios already include policies and assumptions in their evolution. In most of the cases, a "status quo" assumption will be considered, meaning that existing policies are maintained over time.

The complex information generated by the model(s) should be summarized into a selection of key indicators to measure the effects of the policies and to communicate the results to a wider audience, including policy makers. In addition to the indicator list provided in Table 4, it is important in each case to present the impacts of the policy in the right way. First, the goal of using such models is to achieve better designed policies regarding their FNS outcomes which suggested that different policy options should be compared and ranked. The main lesson from models results will therefore be obtained by comparing different scenario outcomes, not by considering model results separately. Second, the level of uncertainty, especially for long term projections, necessitates the use of extensive sensitivity analysis, both in terms of modeling uncertainties (parameter values, etc.) and baseline uncertainties (different baselines) to check the robustness of the policy ranking or to provide a better navigation system for the policy makers ("if the world go in this direction then the best policy appears to be"). Third, the indicators provided should include information on:

i. The primary goals of the policy, a policy aimed to support wheat production in Europe will be first assessed in terms of its impact on EU wheat production;
ii. The secondary effects of the policy for the key variables related to the primary goal. In our previous example: the impact on global wheat production, wheat prices in Europe and in world markets, and farm income in Europe;
iii. The relevant FNS indicators (see Table 4);
iv. The welfare and budgetary costs of the policy (where available in the model).

Indeed, policy design must be informed by the right level of information concerning the policy effects on the "central" variables i.e. why the policy is implemented in the first place as well as those directly linked to the political economy of the policy design and implementation and the direct and indirect costs of the policy for the government (i.e. taxpayers) and the collective (welfare). It is only in comparing these different metrics and the FNS outcomes that a meaningful ranking can be done for a specific policy or across policies[7].

Considering the set of constraints in policy design is essential for the navigation system proposed in the FOODSECURE framework and large scale models offer a great contribution in being able to include these constraints. In many cases, the policies analyzed are not aimed at addressing FNS concerns directly, e.g. bioenergy policy, but can have serious FNS consequences. Therefore, the goal of the toolbox is not to define the best policy in terms of FNS outcome in absolute, but to show what will be the FNS consequences under the main political economy constraints in order to feed the broader debate and to identify which specific design will maximize the positive FNS outcomes or minimize FNS losses.

4.2 Guidelines for using the toolbox

Including different models in the toolbox offers great opportunities but also leads to important challenges. Indeed, the risk of producing conflicting messages using different models can weaken the credibility of the toolbox if not properly addressed and explained. In this context, it is critical to define a consistent analytical framework capable of generating useful and credible conclusions, but also to see how combining the models optimally can improve the overall research outputs as well as the credibility of the toolbox. Three concepts will guide the use of the models of the toolbox.

First, it is important to associate the right model to the right question, see Table 5 that links models and research questions and shows how the toolbox can be applied in different work packages. Even using the different models independently, it will avoid suboptimal use of resources and weak conclusions if the right model is selected to address the right policy question. In addition, it is very important to stress that models are tools managed by teams of experts. Beyond the features of the model, the quality of the research is directly linked to the level of

---

[7] For instance, harmonized indicators on FNS changes related to the cost for EU taxpayers of different types of policies, help to define which policies are the best way to achieve FNS goals and tackles the important question of the rate of return of public policies.

expertise of the team using it. Since each team has its own knowledge, experience and expertise, the model features are just an element in the decision to match models with research questions. The strength of the FOODSECURE toolbox is not only to gather and combine different models specially updated to tackle FNS questions, but also to link teams and build a unique network of experts.

Second, we propose to use the right combination of tools to answer a specific question. This requires definition of the optimal level of model linkages. A detailed discussion on different methodologies to link models is provided in Appendix B. As we discuss in the next section, more integration is not always recommended. A holistic approach of the linkage issue should be considered, with integration efforts done at different stages: upstream (data and modeling choices), midstream (soft and hard linkages at the simulation stages) and downstream (results and conclusions).

Third, using toolbox models that share the same domain of research independently to answer the same question is an excellent opportunity to discuss the results and generate robustness in conclusions. This approach will increase the overall credibility of the toolbox, assuming that enough efforts for linking the models, at least upstream and downstream, have been done to generate the a similar starting point and a transparent presentation of the results, including the causes of different findings. A good illustration of such an exercise is the AGMIP model comparison project of global models (von Lampe et al. 2013). Model comparison based on using identical scenario assumptions lead also to many model improvements by comparing and discussing results and discussing the causes (data, parameter, methodology) behind differences in model outcomes.

5 Towards an optimal model linking strategy for FOODSECURE toolbox

Model linking, as well as modeling team linking, is a key element of the FOODSECURE project and model toolbox. Nevertheless, linking models should be considered in a holistic way, keeping in mind the goals that researchers want to achieve during the process. Linkages are complex to implement and can be a source of inefficiencies (see Appendix B on the risk of inadequate linking strategies). Therefore, such approaches should be done in an optimal way, in the light of the objectives.

We can list three main advantages to model linkages:

i. more consistent assessments: feeding model A which is well suited to address the research question at stake with inputs generated by model B. It allows us to use all the information of the toolbox, which is guaranteed of to be of high quality and developed in a consistent way, and avoid relying on third parties;

ii. more integrated analysis: linking allows to address issues that two models taken independently would not be able to address properly, the total being greater than the sum;

iii. more robust and credible analysis, by ensuring internal peer reviewing through model interactions and dialogue, and increasing consistency of results and conclusions.

The following subsections begin by discussing what can be done at an early stage of the project in terms of model linking upstream (model inputs, data, and parameters) and midstream during the simulation process. We, then, discuss how model integration could take place in an organic and natural way within the life cycle and evolution of the models. Finally, we focus on the need to ensure consistent – not identical - model results and conclusions.

5.1 Linking FOODSECURE models: upstream approach

A first step in creating model linkages is to generate a joint effort in consolidating the databases of each model. Achieving integrated datasets can appear to be a reasonable goal in the medium term since all the models are using similar sources: GTAP, FAOSTAT and in some cases the SPAM dataset (to provide spatially disaggregated datasets). Improvement and data cleaning done by one team could benefit the whole consortium. Potential synergies and more importantly, significant economies of scale can be achieved on this data component alone. Similarly, merging information on key parameters (elasticities, cost structures, carbon stock or land fertility index) is a critical first step. Later, having an integrated database (one value for one parameter) could be a final target.

Thus, sharing data and other model inputs is the first meaningful way to link models and to obtain consistent answers. Indeed, discrepancies in initial datasets are natural sources of diverging conclusions (quantitatively and qualitatively). It is also very difficult to make two models interact in a meaningful way if they start from different descriptions of the world (e.g. the level of yields, or the share of global production for one country). Even if hard/soft model linkages remain limited, having access to a library of different model datasets and parameters remains a key aspect of the internal peer reviewing process and a core element of the “credibility” strategy that we would like to enforce for the toolbox. Therefore, without this stage, any other type of model integration will be like “putting the cart before the horse”.

As part of WP 13, the FOODSECURE project will develop a data management system for storing the primary data, modeling results, and project documents to increase efficiency and effectiveness of research. This system will be used to provide a store of primary and secondary data for use in multiple work packages, to compare data across different sources, and for the interfacing data with the modeling tools applied. Therefore, it will play an important role in the “upstream” linking stage. We discuss potential features of such a database for this stage in appendix C.

5.2 Linking FOODSECURE models: a midstream approach

As discussed above, it is important to find the optimal way to link models and maintain a pragmatic approach to reach the goals of the project. Figure 1 shows the overall structure in terms of model interaction possibilities in FOODSECURE. However, each research question both in terms of topics and specific indicators will lead to different recommended linkage solutions. As a general rule, all the exchange of information should go through the data sharing platform of FOODSECURE (WP13), with each batch of results being clearly identified and archived. The relevant variables should be provided (prices and quantities) in their original nomenclature and unit for the baseline and any alternative scenarios for each year and a vector or matrix of relevant weights should be provided for additional aggregation if needed.

Due to their similarities, it is expected that the two CGEs (MIRAGE and MAGNET) will not enter in soft or hard linkages at the midstream level and they will mainly benefit from upstream and downstream linkages (i.e., a comparison of data and results). The CGE models will however provide inputs, in a top-down fashion, on factor and input prices as well as income and real exchange rate to the other models. CGE baseline simulations for all these key variables will be stored online through the services of the data management WP and will be available for all the other teams.

PE models and IMAGE can deliver to the CGEs information such as yield changes, fertilizer application rates/demand and land use changes and constraints. Some of the economic models can be linked in a top down way to a household survey-based model to get disaggregated results. Nevertheless, using the feature of MIRAGE-HH, available only for a limited number of countries, will generate the projections of household heterogeneity in the baseline. However, to address FNS challenges at the household level in 2050, it cannot be used as it is a household survey from 2008.

Finally, an interactive linking strategy can take place for a limited number of cases, using an iteration approach. Beyond the top down exchanges discussed above, it will be useful to get adjustment (e.g. updating elasticity values) on the supply side of the agricultural sectors of the CGE models and allow for preferences to change in the PEs (after taking into account the income changes) to reach a converging solution in both models.[8] Iterations should be performed until the two models (the PE and the CGE) reach a well-defined point of convergence, described in qualitative terms (increase vs. decrease of indicative variables), and then in quantitative terms (percentage changes) for the more advanced exercises. Due to the focus of the project on FNS indicators *in fine*, it is recommended to focus on produced and consumed quantities for food products in each country/region. Due to the strong differentiated approach of modeling for trade flows, we do not recommend targeting trade related variables or international market indicators. Finally, since all models are highly monotonic in their temporal dynamics in their current versions, focusing on the final year during the iteration process is the best approach, even if each model will change the key parameters during the full simulation periods. To facilitate implementation of such a convergence algorithm, models can compute the production/consumption elasticities for the CGEs/PEs to harmonize the parameters that will be updated iteratively.

5.3 Linking the research agenda

Another upstream linkage between models and modeling teams is the definition of a joint research initiative to tackle ongoing problems in modeling. This activity can deliver a high level of synergy benefiting all the modeling teams of the consortium but also deliver important public goods for the global research community which is consistent with the underlying motives of the FP7 framework.

It is also, from a dynamic point of view, the best way to bring convergence in modeling techniques and approaches, by encouraging the use of shared data and parameters, instead of seeking artificial harmonization strategies through quick but dysfunctional linkages.

---

[8] Maintaining the demand parameters in the CGEs is critical for all the welfare analysis done traditionally in these models.

In practice, the WP7 toolbox participants will define joint research topics that benefit each model (PEs or CGEs). After a list of research priorities has been defined, each modeling team will pick up a research area and will lead the activities on this topic. The activities will include:

- Investigation of literature on the topic;
- Organization of workshops and / or online discussions to inform their partners and brainstorm with them;
- Investigation of alternative modeling solutions including the pros and cons;
- Ranking of the modeling solutions, recommendations and data/parameter sharing

Defining the specific research questions and narrowing data/model challenges to be tackled in WP7 will be decided on and prioritized during the second year of the project and will generate outputs and recommendations by the end of FOODSECURE. Topics of relevance for several modeling teams involved in WP7will be favored. Some proposals currently include: trade modeling in the long run (Armington and beyond), nutrition, health and labor productivity: a new feedback in existing models, the dynamics of demand systems: from ad hoc solutions to a rigorous framework, endogenous R&D decisions: how to implement in a recursive model, short term volatility and long term production decisions: toward path dependent FNS outcomes.

5.4 Linking the model conclusions: FOODSECURE toolbox downstream consistency

Finally, the FOODSECURE modeling team will need to compare and explain the key sources of differences when the different models simulate the same, or similar, scenarios and/or baselines; This is an important challenge to demonstrate the robustness and the usefulness of the FOODSECURE toolbox. A full discussion of model validation and verification is available in Laborde and Tokgoz (2013).

A part of this task will be performed in the setting of the WP7 since it is the place where model developments, comparisons and simulations of the “visions” (alternative baselines) take place. At the same time, other simulations will take place in other work packages. Thus, at the project level, we may also face cross-work package comparisons where simulations of similar policies may lead to different outcomes for global FNS and require comparative analysis. (e.g. policy 1 assessed in WP A lead to a decrease of EU wheat production in model I, policy 2 assessed in WP B has a similar effect in model II, but both models have different conclusions in terms of global FNS since global reallocation of wheat production due to different effect on world wheat prices for instance).

6 Conclusions

In this document, we identified key variables that influence FNS through different mechanisms. These include income (and its distribution), prices (and its transmission), sanitary conditions and infrastructure, education and dissemination of information, and transaction and market access costs. We also identified market equilibrium drivers that affect FNS in a country. These are exchange rates, trade policy measures and NTB that generate a difference between global prices and the domestic prices that consumers and producers face. Furthermore, factors that affect aggregate supply and demand conditions in a country and in global markets affect FNS and these are also added to the discussion. The document also summarizes the current status of the models and their projected evolution to improve the modeling of the key indicators.

The FOODSECURE toolbox offers several state-of-the-art models to address a wide range of research questions associated with the future of FNS. This unmatched collection of tools gathered in one place not only offers great opportunities, but also generates challenges for the researchers and the final users. Indeed, the different models have their own specificities and used independently they may deliver different messages. Therefore, efforts will be made to link the models through data, variable values and comparison of results, to reinforce the credibility and the quality of the research outputs. The most important elements to keep in mind are:

- Many models try to address issues pertaining to FNS. However, the complexity of the issues as discussed in section 3 requires a toolbox since a single model is not sufficient. The FOODSECURE toolbox introduced in this document is a major step towards analyzing this issue;
- Models used in this project have different domains of expertise. This document provides important guidelines and illustrations for a well-designed toolbox that combines these models, since all models have their weaknesses and strengths. Used independently, they will deliver their own conclusions based on their own limitations. Using the right combination of models will help to overcome some of their individual problems;
- Efficient use of the toolbox will be ensured through different synergy approaches: upstream, midstream, downstream. Also, a trade-off will be found between model combinations and tractable and credible analysis. To this end, different sets of models will be used for different questions and in some cases comparison will be preferred over too complex model integrations;
- Hard- linking the different models is not a reasonable solution due to the initial structure of the different models and the limited resources of the project. A significant effort to harmonize the different datasets and the baseline assumptions and then comparing the implications of different model structures will yield more useful insights in the scope the FOODSECURE project;
- Using different models, managed independently by different teams, is a critical part of building the toolbox credibility. No simulation model in economics can be validated in absolute terms. Using different models help policy makers to compare and contrast results and conclusions. It forces each model to question itself and show that there is no black box. By showing consistent answers and/or the availability of each model to clearly explain the source of the results and the differences between several models is an important source of credibility for each model individually and the toolbox as a whole;
- A final, but critical linkage, for the different models will be to address ongoing modeling issues through joint research efforts to develop innovative solutions that will be implemented in each model in its own way but will be based on common understanding and methodology.

Table 1 List of models reviewed for the toolbox

Model Name	Methodology	Institution and contact person	Focus	Dynamics	Links to documentation
IMPACT	Partial Equilibrium	IFPRI Siwa Msangi	International agricultural markets with a water simulation module	Recursively Dynamic	ww.ifpri.org/book-751/ourwork/program/impact-model
GLOBIOM	Partial Equilibrium	IIASA Petr Havlik	International agricultural, bioenergy, forestry sectors	Recursively Dynamic	www.globiom.org
MIRAGE, MIRAGE BioF, MIRAGE-HH	General Equilibrium	IFPRI David Laborde	Global economy with an agricultural, biofuels and energy focus	Recursively Dynamic	http://www.ifpri.org/book-5076/ourwork/program/mirage-model
MAGNET	General Equilibrium	LEI Lindsay Shutes	Global economy with an agricultural, biofuels, biobased chemicals and energy focus	Recursively Dynamic	www.magnet-model.org
IMAGE	Biophysical	PBL Elke Stehfest	Integrated assessment model, provides MAGNET with land supply, crop yields, climate change and environmental impacts.		www.pbl.nl\image

Source: Authors' communication

Table 2 Modelling details

Model Name	Regional Aggregation	Time Frame (Base Year-Outlook period)	Trade Modeling
IMPACT	115 regions with supply divided into 281 units	Base Year is 1999-2001 avg. Outlook period is 2001-2050	Pooled Trade with Homogenous Goods
GLOBIOM	30 economic regions, >200,000 Simulation Units to represent land spatial heterogeneity	Base Year is 1999-2001 avg. Outlook period is 2000-2050 years	Bilateral Trade with spatial equilibrium Homogenous Goods
MIRAGE	Up to 129 regions (GTAP nomenclature). Average utilization: 30-40	Base Year 2007. Outlook period is 2007-2050	Bilateral Trade with Armington
MAGNET	Up to 134 regions (GTAP nomenclature). Average utilization: 30-40	Choice of base year: 2001, 2004 or 2007. Outlook period base year up to 2100	Bilateral Trade with Armington
IMAGE	24 regions	Historic period 1970-2005, outlook period 2006-2100	Trade according to MAGNET

Source: Authors' communication

Table 3 Models coverage of FNS drivers

Driver	MIRAGE (and subversions)	MAGNET	GLOBIOM	IMAGE	IMPACT
Exogenous national **income**	✓	✓	✓	✓	✓
Endogenous national **income**	✓	✓	E+L	L	L
Heterogeneous household **income**	✓	E			
Exogenous **technological** change	✓	✓	✓	✓	✓
Endogenous **food prices**	✓	✓	✓	✓	✓
Endogenous non-food prices	✓	✓	L	L	L
Endogenous **technological** change	✓+E	✓+E	✓		
Exogenous **population** growth	✓	✓	✓	✓	✓
Climate change effects	L	L	✓	✓	✓
Change in **diets** (including preferences, education, ageing)	✓+E	✓+E	✓+E	✓+E	
Land availability	✓+L	✓+L	✓	✓	
Other **farm inputs** availability	✓+E	✓		✓	
Urbanization effects				E	
Sanitary effects					
Food **waste**	✓+E	✓+E	✓+E		
International market access Costs	✓	✓	✓	✓	✓

Note: ✓ currently included in the model, **E** planned to be developed during the FOODSECURE project, **L** in the model through model linkages with other components of the FOODSECURE Toolbox.

Table 4 Models coverage of FNS Indicators

	MIRAGE (and subversions)	MAGNET	GLOBIOM	IMAGE	IMPACT
Income per capita (country level)	✓	✓	✓	✓	✓
Income per capita (Household level)	✓	E			
Share of food in total consumption (country level)	✓	✓	✓	✓	✓
Share of food in total consumption (household level)	✓	E			
Domestic supply of food (nutrition indicators, total, per capita)	E	E	✓		✓
National self-sufficiency ratio	✓	✓	✓	✓	✓
Total consumption of food (nutrition indicators, total, per capita)	E	E	E	E	
Household consumption of food (nutrition indicators, total, per capita)	E	E			
Proxy for consumption of micro-nutrients: evolution of per capita consumption of dairy products, meat products, vegetable and fruits	E	E	E	E	E
Volatility of food supply (quantity, prices)	E				
Agricultural and food productions	✓	✓	✓	✓	✓
Agricultural and food Prices	✓	✓	✓	✓	✓

Note: ✓ currently included in the model, **E** planned to be developed during the FOODSECURE project, **L** in the model through model linkages with other components of the FOODSECURE Toolbox.

Table 5 Models suitability related to research questions addressed in FOODSECURE

Research topics	Relevant WP	MAGNET	MAGNET and IMAGE	MIRAGE[1]	GLOBIOM	IMPACT
Long term projections of FNS under alternative baselines	7	***	***	***	***	***
Impact of agricultural policies on FNS	4,9	***	**	***	*	*
Relations between FNS, land use and natural resources in the context of sustainability policies	9	**	***	**	***	**
Assessing science and technology policies and improved R&D priority setting	9	***	**	**	***	**
Assessing coherence of EU aid and development policies with local FNS strategies.	10	***	*	***	*	*
Reforming trade policies towards more coherence with food security objectives	11	***	**	***	*	*
Designing renewable energy policies in order to improve coherence with FNS objectives	11	**	***	***	***	*
Designing climate and environmental policies more consistent with global FNS objectives	11	**	***	**	***	*

[1] Including MIRAGE-HH or MIRAGE-Biof based on the relevant case

Note: * indicates low suitability, ** medium suitability, *** high suitability.

As a matter of fact, two models with high suitability can still have comparative advantages and benefit from interactions. For instance, GLOBIOM has a clear advantage compared to a CGE like MIRAGE-Biof for tracking land use changes at a detailed level but it will underperform regarding the demand substitution patterns (in particular regarding intermediate uses by the industry of some agricultural inputs) or the macroeconomic consequences of a policy shock (such as the impact of bioenergy policy on the current account).

Figure 1 Overview of interactions between WP7 and other work packages

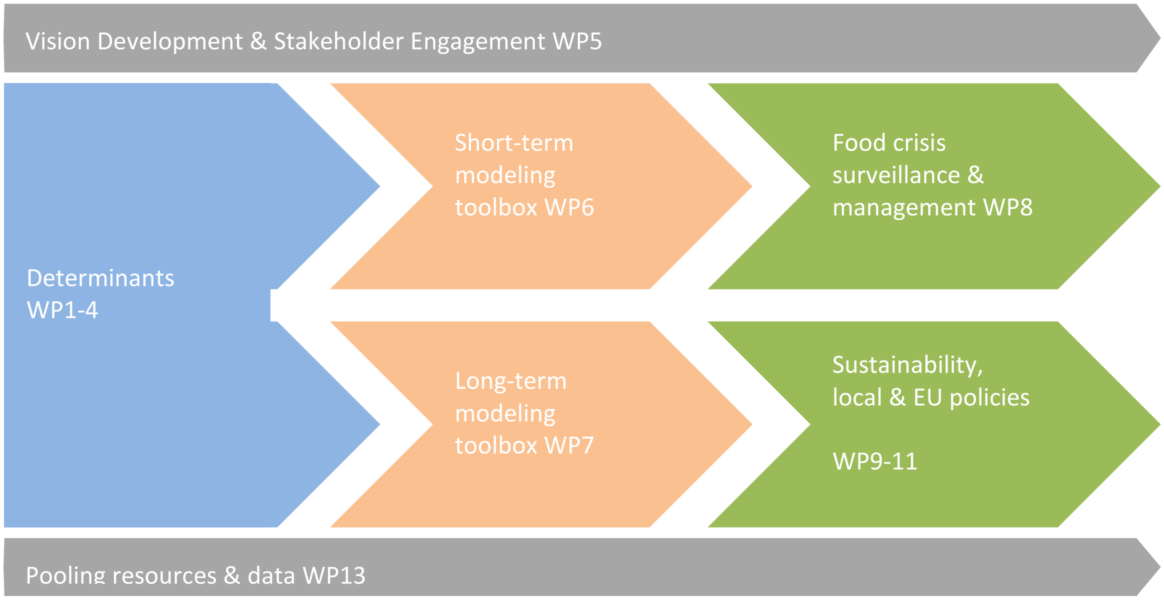
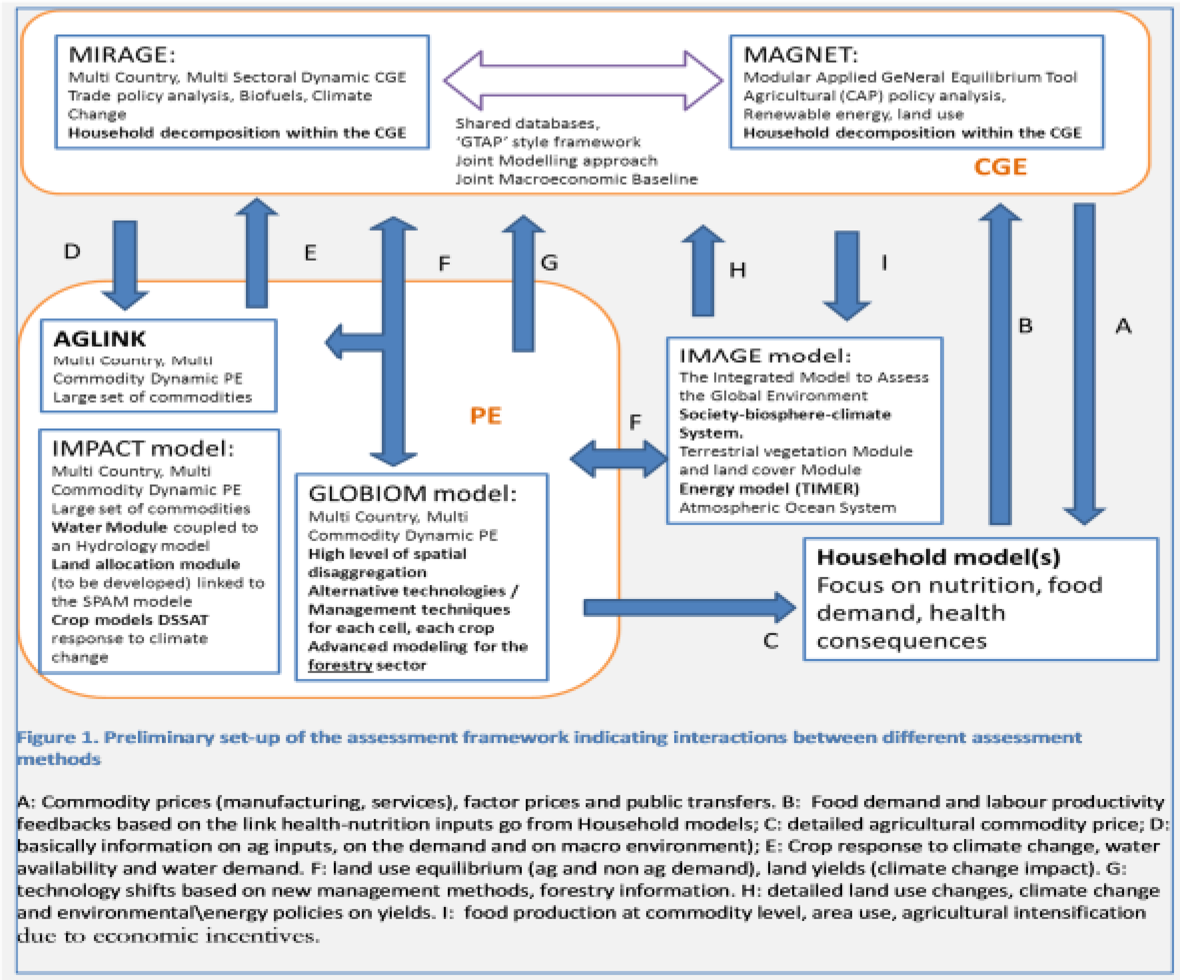


Figure 2 Initial set-up for models linkages



Source: FOODSECURE FP7 Grant Agreement

7 References

Argent, R. (2004). “An Overview of model integration for environmental applications- components, frameworks, and semantics.” *Environmental Modelling and Software.* Vol. 19, pp: 219-234.

Armington, P.S. 1969. A Theory of Demand for Products Distinguished by Place of Production. IMF Staff Papers 16(1): 159-178.

Burniaux J. -M. and Truong T. P., 2002. GTAP-E: An energy-environmental version of the GTAP Model. GTAP Technical Paper n.16.

FAO. Food and Agriculture Organization of the United Nations. 1996. *Declaration on world food security.* World Food Summit. Rome: FAO. Available Online <http://www.fao.org/docrep/003/w3613e/w3613e00.htm>

FAO. Food and Agriculture Organization of the United Nations. 2006. *Food security: policy brief*. Issue 2. FAO Agricultural and Development Economics Division. Rome: FAO. Available Online <http://www.fao.org/es/esa/>

FAO. Food and Agriculture Organization of the United Nations. 2008. *An introduction to the basic concepts of food security*. Food Security Information for Action Practical Guides. EC - FAO Food Security Programme. Rome: FAO. Available Online <http://www.fao.org/docrep/013/al936e/al936e00.pdf>

FAO. Food and Agriculture Organization of the United Nations. 2011. “FAOSTAT Database.” Available Online <http://faostat.fao.org>

FAO. Food and Agriculture Organization of the United Nations. 2012. “FAO Food Price Index” Available Online <http://www.fao.org/worldfoodsituation/wfs-home/foodpricesindex/en/>

Fischer G, M Shah, FN Tubiello and H van Velhuizen 2005. “Socio-economic and climate change impacts on agriculture: an integrated assessment.” Philosophical Transactions of the Royal Society B, Vol. 360, pp. 2067-2083. Available Online <http://rstb.royalsocietypublishing.org/content/360/1463/2067.full>

Laborde, D. and S. Tokgoz (2013) From model validation to model credibility: how will it be approached in FOODSECURE? FOODSECURE technical note.

Laborde D., S. Tokgoz and M. Torero, Long-Term Drivers of Food and Nutrition Security by David Laborde, Simla Tokgoz, Maximo Torero (IFPRI). FOODSECURE working paper no. 6. February 2013. Available Online <http://www3.lei.wur.nl/FOODSECUREPublications/06_Laborde%20Tokgoz%20Torero_FNS%20drivers.pdf>

Lutero, G. 2010. The aggregation problem in its hystorical perspective: a summary overview. Methods development of quarterly national accounts. ISTAT, National Accounts Directorate (2010).

Muhammad, A., J. Seale, B. Meade, and A. Regmi. 2011. International Evidence on Food Consumption Patterns: An Update Using 2005 International Comparison Program Data (Technical Bulletin 1929). USDA-ERS.

Nelson, G., M. Rosegrant, A. Palazzo, I. Gray, C. Ingersoll, R. Robertson, S. Tokgoz, T. Zhu, T. Sulser, C. Ringler, S. Msangi, and L. You. 2010. "Food security, farming, and climate change to 2050". IFPRI Research Monograph. Available Online
<http://www.ifpri.org/publication/food-security-farming-and-climate-change-2050>

Robinson, S., van Meijl, H., Willenbockel, D., Calvin, K., Dietrich, J., Fujimori, Sh., Havlik, P., Mason d'Croz, D., Masui, T., Sands, R.D., Schmitz, Chr., Tabeau, A., Kavallari, A., Valin, H., van der Mensbrugge, D., von Lampe, M., Wise, M. (2013). Different Supply-Side Specifications in Models of the Global Food System, *Agricultural Economics*, Special Issue on Global Model Intercomparison (forthcoming)

Robinson, T., P. Thornton, G. Franceschini, R. Kruska, F. Chiozza, A. Notenbaert, G. Cecchi, M. Herrero, M. Epprecht, S. Fritz, L. You, G. Conchedda, and L. See. 2011. *Global livestock production systems*. Food and Agriculture Organization of the United Nations (FAO) and International Livestock Research Institute (ILRI), (152 pp).

Seale, J., A. Regmi, and J. Bernstein. 2003. International Evidence on Food Consumption Patterns. ERS/USDA, Technical Bulletin No. 1904, Washington, DC.

Smith, L, and L, Haddad, 2000. "Explaining Child Malnutrition in Developing Countries: A Cross-Country Analysis." Washington, D.C.

Thornton, P. K. & Herrero, M. (2010). Potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics. *Proceedings of the National Academy of Sciences* **107** (46), 19667-19672. (Doi: 10.1073/pnas.0912890107.) Retrieved from <http://www.pnas.org/content/107/46/19667.abstract>.

Tongeren, F.W., H. van Meijl and Y. Surry, (2001), Global models of trade in agriculture and related environmental modelling: a review and assessment, *Agricultural economics*, Vol 1493, p.1-24.

United Nations (UN). 2011. World population prospects: The 2010 Revision, United Nations, New York. Available Online <http://esa.un.org/wpp/Documentation/publications.htm>

United Nations (UN). 2012. Department of Economic and Social Affairs, Population Division, Population estimates and Projections Section. World Population Prospects, the 2010 Revision, Updated June 2011. Available Online <http://esa.un.org/wpp/Excel-Data/population.htm> (Accessed December 16, 2012)

U.S. Department of Energy (DOE). 2009. "The National Energy Modelling System: An Overview 2009." Available Online <http://www.eia.gov/oiaf/aeo/overview/>

U.S. Department of Energy (DOE). 2012. Energy Information Administration. "Petroleum and Other Liquids Spot Prices" Available Online <http://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm>

U.S. Department of Agriculture (USDA). 2001. National Survey of WIC Participants. Report No WIC-01-NSWP. Available Online <www.fns.usda.gov/ora/MENU/Published/WIC/FILES/WICSurvey.pdf >

Valin, H., Sands, R.D., van der Mensbrugghe, D., Ahammad, H., Bodirsky, B., Hasegawa, T., Havlík, P., Kyle, P., Mason-D'Croz, D., Paltsev, S., Tabeau, A., Blanc, E., Fujimori, S., Heyhoe, E., van Meijl, H., Rolinski, S., Willenbockel, D., von Lampe, M., Nelson, G. D., forthcoming. Global Economic Models and Food Demand towards 2050: An Intercomparison Exercise. *Agricultural Economics*

von Lampe, Martin, D. Willenbockel, K. Calvin, S. Fujimori, T. Hasegawa, P. Havlik, P. Kyle, H. Lotze-Campen, D. Mason d'Croz, G. Nelson, R. Sands, C. Schmitz, A. Tabeau, H. Valin, D. van der Mensbrugghe, H. van Meijl (2013). Why Do Global Long-term Scenarios for Agriculture Differ? An overview of the AgMIP Global Economic Model Intercomparison, *Agricultural Economics,* Special Issue on Global Model Intercomparison (forthcoming)

World Bank. 2012. GEM Commodities. Available Online
<http://data.worldbank.org/data-catalog/commodity-price-data>.

8 Appendix A. List of Key Publications

IMPACT

Rosegrant, M. W., S. Tokgoz, and P. Bhandary. 2013. “The New Normal? A Tighter Global Agricultural Supply and Demand Relation and its Implications for Food Security.” American Journal of Agricultural Economics, Vol. 95, pp: 303-309.

Tokgoz, S., W. Zhang, S. Msangi, and P. Bhandary. 2012. “Biofuels and the Future of Food: Competition and Complementarities” Agriculture, Vol. 2: 414-435.

Nelson, G., M. Rosegrant, A. Palazzo, I. Gray, C. Ingersoll, R. Robertson, S. Tokgoz, T. Zhu, T. Sulser, C. Ringler, S. Msangi, and L. You. 2010. “Food security, farming, and climate change to 2050”. IFPRI Research Monograph. Available Online at <http://www.ifpri.org/publication/food-security-farming-and-climate-change-2050>

MIRAGE

Bouet, A. and Laborde D, 2010,. “Assessing the potential cost of a failed Doha Round.” World Trade Review, 9, pp 319-351. doi:10.1017/S1474745609990267.

Bouet, A., Laborde, D. 2012. “Food crisis and export taxation: The cost of non-cooperative trade policies” Review of World Economics. Springer, Vol. 148(1), pp: 209-233.

Laborde, D. 2011. “Assessing the land use change consequences of European biofuel policies”. European Commission. Report for the EC DG Trade. Atlass Consortium. http://www.ifpri.org/sites/default/files/publications/biofuelsreportec2011.pdf

Laborde, D. & Hugo Valin, 2012. "Modeling Land-Use Changes In A Global Cge: Assessing The Eu Biofuel Mandates With The Mirage-Biof Model," Climate Change Economics (CCE), World Scientific Publishing Co. Pte. Ltd., vol. 3(03), pages 1250017-1-1.

GLOBIOM

Havlik, P., Valin, H., Mosnier, A., Obersteiner, M., Baker, J.S., Herrero, M., Rufino, M.C. and E. Schmid. 2013. “Crop Productivity and the Global Livestock Sector: Implications for Land Use Change and Greenhouse Gas Emissions” American Journal of Agricultural Economics. Vol. 95, pp: 442-448

Havlik, P., Schneider, U.A., Schmid, E., Bottcher, H., Fritz, S., Skalsky, R., Aoki, K., De Cara. S., Kindermann, G., Kraxner, F., Leduc, S., McCallum, .I., Mosnier, A., Sauer, T., Obersteiner, M. 2011. “Global land-use implications of first and second generation biofuel targets” Energy Policy, Vol. 39(10), pp: 5690-5702

Schneider, U.A., Havlik, P., Schmid, E., Valin, H., Mosnier, A., Obersteiner, M., Bottcher, H., Skalsky, R., Balkovic, J., Sauer, T., Fritz, S. 2011. "Impacts of population growth, economic development, and technical change on global food production and consumption" Agricultural Systems, Vol. 104 (2), pp: 204-215.

MAGNET/LEITAP

Banse, M., H. van Meijl, A. Tabeau and G. Woltjer, 2008. Will EU Biofuel Policies affect Global Agricultural Markets? European Review of Agricultural Economics, 35: 117-141.

Nowicki, P., Goba V., Knierim A., van Meijl H., Banse M., Delbaere B., Helming J., Hunke P., Jansson K., Jansson T., Jones-Walters L., Mikos V., Sattler C., Schlaefke N., Terluin I. and Verhoog D., 2009., Scenar 2020-II – Update of Analysis of Prospects in the Scenar 2020 Study – Contract No. 30–CE-0200286/00-21. European Commission, Directorate-General Agriculture and Rural Development, Brussels.

Rutten, M., L. Shutes and G. Meijerink (2013), Sit Down at the Ballgame: How Trade Barriers Make the World Less Food Secure, Food Policy, 38: 1–10.

Verburg, P.H., Eickhout, B., van Meijl, H. 2008. A multi-scale, multi-model approach for analyzing the future dynamics of European land use. *Annals of Regional Science*, 42(1): 57-77

Woltjer G, Kuiper M, van Meijl H (2011) Chapter 2. MAGNET. The agricultural world in equations: An overview of the main models used at LEI. LEI, De Hague.

IMAGE

MNP (2006). Integrated modelling of global environmental change. An overview of IMAGE 2.4. Bilthoven, the Netherlands, Netherlands Environmental Assessment Agency (MNP).

van Vuuren, D., Stehfest, E., den Elzen, M., Kram, T., van Vliet, J., Deetman, S., Isaac, M., Goldewijk, K. K., Hof, A., Beltran, A. M., Oostenrijk, R., van Ruijven, B. (2011), RCP2.6: Exploring the possibility to keep global mean temperature increase below 2°C, Climatic Change, 109(1), 95-116.

Stehfest, E., vd Berg, M., Woltjer, G., Msangi, S., Westhoek, H. (2013) Options to reduce the environmental effects of livestock production – Comparison of two economic models. Agricultural Systems 114 (2013) 38–53.

PBL (2012), Roads from Rio+20, PBL Netherlands Environmental Assessment Agency.

9 Appendix B. Methodologies to link models

Integrated modeling in global food system analysis is becoming more important for decision making because of the complex nature of some of the grand policy challenges we face in an environment of continuous demand growth for food, fuel and fiber. It is difficult for any one modeling type to answer all the questions in a policy framework. Therefore, a model integration exercise that combines different research areas would allow researchers to conduct interdisciplinary research and to undertake scientific challenges in innovative ways.

B.1 Hard linking vs. soft linking

In terms of linking different models, there are various methodologies that can be utilized. The first one is “soft linking” between two models. In this type of linkage, first a scenario that takes advantage of each model’s relative strength is defined. Next, one model is shocked based on the scenario definition, and a data exchange is set up between the two models. This can either be a one-time data exchange from one model to the other or a series of successive iterations between the two models that continue until a convergence is reached. For example, if a CGE model is linked with a PE model, a scenario that takes advantage of the macroeconomic drivers in a CGE model or a scenario that takes advantage of the disaggregated agricultural production nature of a PE model could be used.

The second type of linking is more of a “complete integration” that we can label as “hard linking”. In this type of linkage, a JOINT baseline between the two models is generated. This type of linkage requires a detailed coordination of data exchanges between the two models, coordination of policy assumptions, and evaluation of technological change in each model. For the complete integration, analysts also need to make the decision which exogenous variables in the respective models would be changed to endogenous variables in the linked models. This joint baseline can then be used to run various scenarios using both models. This type of “complete integration” allows a more detailed analysis of the question at hand.

Both approaches have pros and cons, more integration does not necessarily mean better results.

B. 2 Challenges in linking models

Whichever methodology is chosen when linking different models, there are various common issues to consider before the linkage. First of all, different base years and different regional aggregations make data exchange between models difficult. Thus, the geographic coverage (countries and regional aggregation) of each model for demand and supply needs to be compared and contrasted before data exchange starts. Secondly, the regional resolution for the land use, crop area, and crop yields components of each model may differ, requiring further aggregation or further disaggregation in models and/or in the data exchanges between the models. Thirdly, the calibration year and the projection horizon (as well as time frequency of the solution) may differ between the two models. In this case, coordination of historical data may be considered. In terms of projection periods, if one model solves annually and one model solves in 10-year intervals, a linear interpolation can be used for the data exchanges in the projection period. Finally, sectors included in each model may overlap. In this case, a careful analysis of model projections for that sector needs to be conducted and necessary coordination for technological, economic, and policy assumptions need to be completed. It should also be noted that linkages for a baseline and linkages for scenario analysis are different procedures and may generate different problems for analysts. The “complete integration” of two models creates additional challenges. In this case, we need to make sure we have ONE equilibrium in linking the models for a baseline and for scenario analyses. Furthermore, convergence to that equilibrium has to be defined specifically.

The first step in both methodologies for linkage is to decide on a baseline projection path and baseline assumptions. The baseline assumptions include agricultural and trade policy assumptions, economic growth path for CGE models, and the commodity price projection path for all types of models. The second step is to decide on a scenario definition. Finally, the starting model for the scenario shock needs to be chosen.

B3. Pragmatic gains of soft linking

Hard linking and more integrated solutions may appear to be a richer framework. Nevertheless, they also require significant efforts and have several challenges. Three arguments usually invite to moderate the apparent benefits from hard-linkages.. First, forcing two models coming from two different horizons to be linked “at all costs” is the best way to face dire problems . On one hand, it may place severe demands on coordination and technical adjustment to link models, and be unduly time-intensive. On the other hand, it may threaten the integrity of each model. Indeed, each model has its own internal consistency and logic. For instance, the strength of a global CGE model comes from its being internally fully consistent with respect to Walras’ law, a strong argument in favor of such models. Opening a part of such a model to another one may violate its consistency. Second, combining different models using a modular approach can create an overly complex and intractable modeling architecture, giving the impression of a black box to users and making the detection of inconsistencies or errors more and more difficult. Both will weaken the credibility of the modeling framework. Last, linking models can appear as a cheap and incomplete solution when the right solution should be to merge some mechanisms/data in the main model of the secondary model. For instance, if a PE needs information on fish farming or fisheries to provide a complete picture of nutrition, linking the PE to a GE featuring this sector may not be as efficient as modeling it directly in the PE. Similarly, if a GE needs to generate a result for a few additional commodities, the best solution may not be to get them disaggregated within a PE but bear the cost of additional disaggregation within the CGE.

In contrast, a soft linkage approach may present three critical advantages: using lightly linked or no linked models managed by different teams, allows more planning flexibility and time efficiency when a request is addressed to the toolbox: the more models that are linked and the more people involved, the more difficult it is to react quickly to requests for new scenario analyses. In addition, it allows generating independent analysis on parallel tracks – without cross model contaminations - that will be compared to each other and help to build the toolbox credibility and provide an indication of the robustness of results.

10 Appendix C. Database(s) features for model linkages

An important component of the model linkages strategy is to share information between among models to:

- Benefit from positive externalities in their datasets;
- Understand the structural (behavioral parameters) differences;
- Analyze the different outputs and be informed of the divergences/convergences in effects;
- Increase transparency and favor a smooth peer-review of models (inputs and outputs).

To achieve these different goals, a consolidated data platform is needed and WP13 will provide such a tool.

We propose that four datasets, in addition to a metadata table that will gather information on the different models, are designed and fed into the data platform during the life of the project:

1. **Mapping tables.** Since the different models in the toolbox use different nomenclatures and these nomenclatures evolve over time and studies, these mapping tables cannot be seen as a static element. Therefore we need to cover both regional(country) and product classifications :
    a. One table defining the nomenclature:
        i. Type of nomenclature: Region or Product
        ii. Related model, e.g. MIRAGE
        iii. Code of the nomenclature, e.g. MIRCO01 for a first country nomenclature used in the Mirage model
        iv. Description
        v. Date of issue
    b. One table displaying the nomenclature:
        i. Code of the nomenclature e.g. MIRCO01
        ii. Code of the item e.g. EU27
        iii. Label of the item e.g. European Union
        iv. Description of the item e.g. the European Union with 27 members.
    c. Different tables indicating the mapping with international references when available (potentially 1-n or n-n mapping).

For countries/regions:

i. Code of the nomenclature e.g. MIRCO01
ii. Code of the item e.g. EU27
iii. UN ISO code 3 letters of the country
iv. Flag indicator: A for indicating that this code is an aggregate of different UN countries, D for indicating that this code is a sub-region of the UN country.

For products, two symmetric tables should be done to have mapping with GTAP and FAOSTAT nomenclatures.

2. **Initial Dataset.** Assuming that the different teams agree to share key parts of their initial dataset, the following information should be shared at the country (or AEZ-country) and product level (in the model nomenclature) when available:
    a. Description table
        i. Model code
        ii. Version

        iii. Base year
        iv. Dataset code
    b. Data table
        i. Dataset code
        ii. Item code [Income, Population, Production, Price, Factor use (water, land), Total consumption, Exports, Imports, Final Consumption, Intermediate consumption for Bioenergy, Intermediate consumption for Livestock]
        iii. Country code
        iv. Product code
        v. Unit [current Dollars, constant Dollars 2007, Tons, Ha, MJ, Kcal, %…]
        vi. Value

3. **Behavioral parameter tables.** These tables should gather information on behavioral parameters, namely demand and supply elasticities. However, for many models they are not constant or even explicit parameters. They are implicit values coming from the functional forms used, or even the combination of different functions in a CGE. Therefore a joint methodology will need to be written and agreed on to define properly each concept. The associated tables will be:
    a. Description table
        i. Model code
        ii. Version
        iii. Dataset code
    b. Data table
        i. Dataset code
        ii. Item code [Supply Elasticity, Yield Elasticity, Land demand elasticity, Final Demand Elasticity, Total demand Elasticity, Import Demand Elasticity, Export Supply Elasticity]
        iii. Year
        iv. Country code
        v. Product code (including for aggregates: total food supply and total food demand elasticity)
        vi. Value

4. **Scenario results tables.** The final set of information provides a transparent way to browse the results of the different models and studies. At minimum, the final year should be shared but intermediate periods will be useful too. All policy scenarios as well as the baseline have to be provided.

    a. Description table (additional tables for metadata for fields iv to vii will be needed)
        i. Model code
        ii. Version
        iii. Dataset code
        iv. WP-Tasks
        v. Study code
        vi. Baseline Code
        vii. Policy Scenario code
        viii. Single ID (primary key)
    b. Data table

i. Single ID
ii. year
iii. Item code [Income, Population, Production, Price, Factor use (water, land…), Total consumption, Exports, Imports, Final Consumption, Intermediate consumption for Bioenergy, Intermediate consumption for Livestock and all FNS indicators specific to the model or the study.]
iv. Country code
v. Product code
vi. Unit [currentDollars, constantDollars2007, Tons, Ha, MJ, Kcal,…]

In practice, different Excel templates can be designed, or some txt or SQL extraction protocols should be defined to retrieve the information from the different modeling teams.

Finally, based on all this information, standard routines will be implemented to produce results (e.g. in terms of relative changes) and comparison tables.

The FOODSECURE project in a nutshell

Title	FOODSECURE – Exploring the future of global food and nutrition security
Funding scheme	7th framework program, theme Socioeconomic sciences and the humanities
Type of project	Large-scale collaborative research project
Project Coordinator	Hans van Meijl (LEI Wageningen UR)
Scientific Coordinator	Joachim von Braun (ZEF, Center for Development Research, University of Bonn)
Duration	2012 - 2017 (60 months)
Short description	In the future, excessively high food prices may frequently reoccur, with severe impact on the poor and vulnerable. Given the long lead time of the social and technological solutions for a more stable food system, a long-term policy framework on global food and nutrition security is urgently needed. The general objective of the FOODSECURE project is to design effective and sustainable strategies for assessing and addressing the challenges of food and nutrition security. FOODSECURE provides a set of analytical instruments to experiment, analyse, and coordinate the effects of short and long term policies related to achieving food security. FOODSECURE impact lies in the knowledge base to support EU policy makers and other stakeholders in the design of consistent, coherent, long-term policy strategies for improving food and nutrition security.
EU Contribution	€ 8 million
Research team	19 partners from 13 countries

FOODSECURE project office
LEI Wageningen UR (University & Research centre)
Alexanderveld 5
The Hague, Netherlands

T +31 (0) 70 3358370
F +31 (0) 70 3358196
E foodsecure@wur.nl
I www.foodscecure.eu

This project is funded by the European Union under the 7th Research Framework Programme (theme SSH) Grant agreement no. 290693