A New Methodology for Incorporating Nutrition Indicators in Economy-Wide Scenario Analyses

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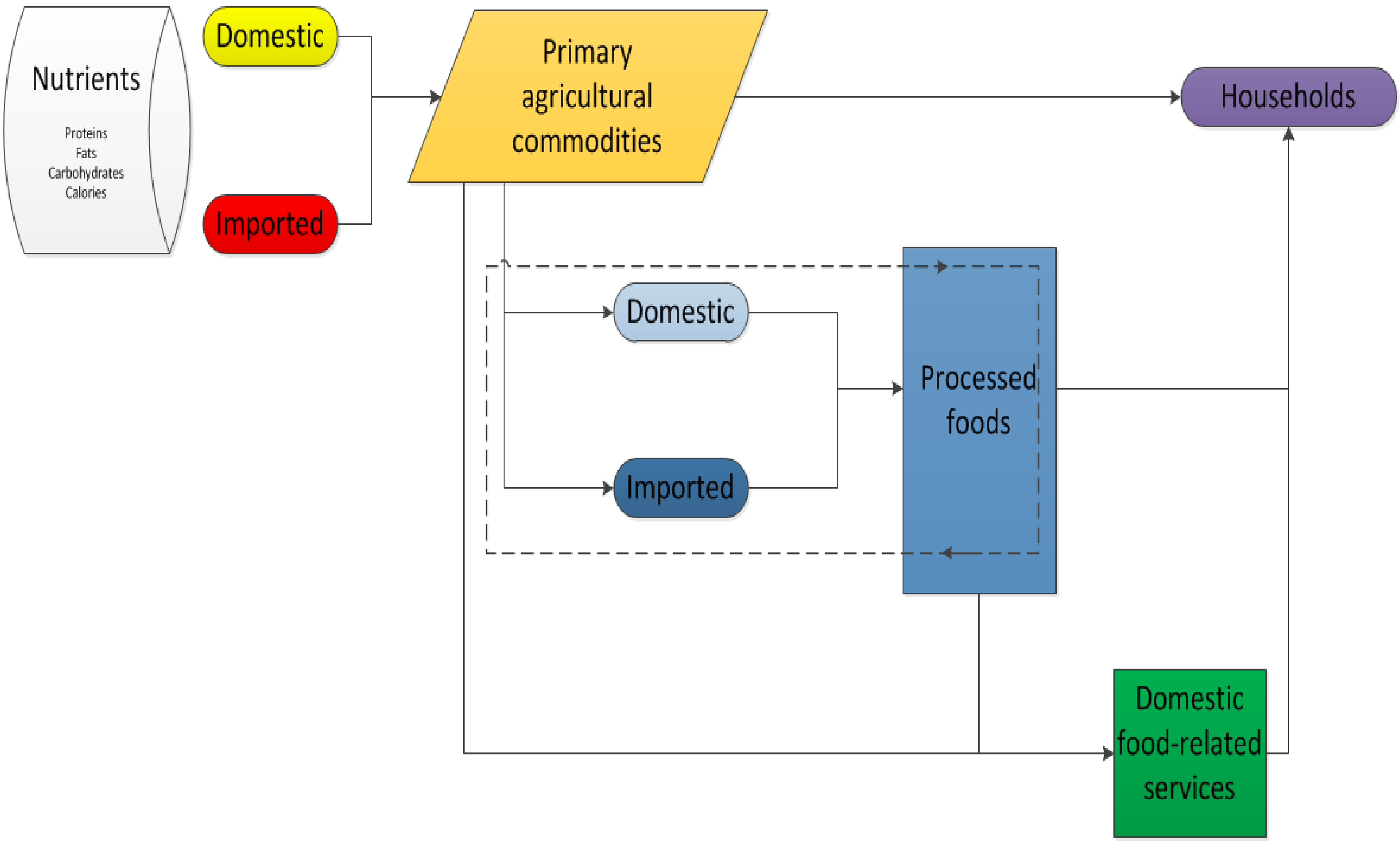

INTERDISCIPLINARY RESEARCH PROJECT
TO EXPLORE THE FUTURE OF GLOBAL
FOOD AND NUTRITION SECURITY

A new methodology for incorporating nutrition indicators in economy-wide scenario analyses

The nutrition module in MAGNET

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Abstract

This paper develops an innovative approach for calculating household nutrition indicators in a Computable General Equilibrium framework, using the flow of primary agri-food commodities through the global economy from farm to fork. It has been incorporated as a nutrition module in MAGNET. The method of tracing nutrients through the food system allows for making agriculture, the food supply chain and the economy as a whole nutrition-sensitive in scenario analyses. The validation of the nutrition outcomes in the base year with global data on nutrient consumption from the FAO reveals important differences which stem from differences in data and assumptions. Various solutions are identified to improve the calculations in the future. In the short run, correction factors are applied in the calculation of indicators in the nutrition module to capture and adjust the methodology for the remaining differences.

Acknowledgments

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1. Introduction

Since the late nineties, efforts have been taking place to incorporate nutrition information associated with the consumption of food by households in computable general equilibrium (CGE) models. This work is motivated by the failure of the demand systems employed in CGE models to capture the issue of diet quality, i.e. the nutritional content of the food consumption basket, as opposed to the quantities of foods consumed. Single country applications include Minot (1998) for Rwanda, CIRDAP (1998) for Bangladesh, Pauw and Thurlow (2010) for Tanzania, and Atkin (2012) for India. Global multi-country applications include Hertel et al. (2007) and Verma and Hertel (2007), using the Global Trade Analysis Project (GTAP) model with a focus on Bangladesh. These studies have, however, narrowly focused on macronutrient (i.e. calorie and sometimes protein) intake, which signals potential deficiencies (or affluence) in quantities consumed, but ignores micronutrient intake.

It is known that insufficient intake of macro or micronutrients could have important negative health effects in the long term, resulting in so-called deficiency diseases (WHO, 2004). Moreover, micronutrients, in combination with limiting fat, salt and sugar intake, have an important role to play in combating diet-related chronic diseases, such as heart and cardiovascular disease, certain types of cancers, diabetes, obesity, osteoporosis and dental disease (WHO, 2004). Opening up the consumption basket in terms of nutrient content - not only macronutrients but ideally also micronutrients - can signal in advance whether the nutrient adequacy of diets will be affected by changes in the wider economy, (monitoring function) and if so, where policy action may be needed. Several authors have identified this as a key area for research in view of rising and increasingly volatile food prices (Wiggins and Levy, 2008) and the need to redirect the diet transition (Haddad, 2003). It is estimated that malnutrition in all its forms is either directly or indirectly responsible for approximately half of all deaths worldwide. This applies to perinatal and infectious diseases as well as chronic diseases (WHO, 2011).

Hence, in order to improve the analysis of dietary change and food and nutrition security at the global, national and household level, it is important that models applied in these fields incorporate more detailed nutritional impacts. This would further pave the way for incorporating health effects associated with changes in diets, food security and nutrition (see, for example, Lock et al., 2010; Rutten and Reed, 2009). Relevant health impacts include changes in mortality and morbidity related to changes in nutrition, which themselves feedback into labour market supply and productivity, wellbeing or utility and health care costs, and are of importance to both developed and developing countries settings. All in all, this allows for the methodological bridging of the traditional agriculture, nutrition and health sciences divide and allows for making agriculture, the broader food supply chain and the economy as a whole, “nutrition-sensitive” (Haddad, 2000; Heady, 2012; Jaenicke and Virchow, 2013; Pinstrup-Andersen, 2013; Ruel and Alderman, 2013).

This paper elaborates on a new methodology by which nutrition impacts may be incorporated in economy-wide analyses. It has been incorporated as a nutrition module in the MAGNET[1] model of the world economy, the GTAP-based model developed at LEI Wageningen UR (Woltjer et al., 2013a,b), but

[1] Modular Applied GeNeral Equilibrium Tool (MAGNET).

lends itself for application in other CGE models. The modular structure of MAGNET allows for inclusion of nutrition indicators in various types of analyses, including biofuel simulations and climate change scenarios. The module calculates the nutrient content associated with the private household consumption of food. It uses FAO data on calories, proteins, fats and (implicitly) carbohydrates as embodied in primary agricultural commodities (including fish) and uses the flow of these commodities through the global economic system - from primary production to consumption of foods and including trade flows - to determine the nutrient content of foods consumed by private households. The module accounts for three channels of private household consumption of nutrients, namely directly via the consumption of (domestic or imported) primary agricultural commodities, indirectly via the consumption of (domestic or imported) processed foods, and indirectly via the consumption of (domestic) food-related services. The module is included as *post sim* calculation, after the household utility maximisation over goods subject to the budget constraint has taken place, and uses fixed nutrient coefficients in relation to quantities produced and consumed. It thus excludes any substitution between different nutrients in response to price changes. This is motivated by the lack of information on the prices of different nutrients and, although more and more information on nutrients is displayed on food packaging, nutrient information is far from perfect and the unit of decision-making on what and how much to consume within households remains food quantities in relation to price and the household's budget. The outcomes of the module are reported using indicators presenting nutrient content by type of nutrient (in terms of calories, proteins, fats and carbohydrates) for each of the channels, by regional source, by sector source and in total.

The approach may be used in future to see how macroeconomic shocks and/or policies impact upon diets, nutrition and health, using healthy diet guidelines such as that of the WHO (WHO, 2003); particularly if extended with micronutrient data. Vice versa, it could be used to analyse how targeted changes in nutrition and diets (motivated by health considerations) impact upon the wider economy. This would extend the work of Srinivasan et al. (2006), Srinivasan (2007) and Shankar et al. (2008), who analyse the impacts of adherence to WHO dietary guidelines on consumption in OECD countries, but do not consider macroeconomic impacts. It would also improve upon the GTAP-based analysis of Thomassin and Mukhopadhyay (2011), who look at the macroeconomic impacts of healthier diets in Canada from the perspective of the required changes in food consumption rather than nutrition. Our method would be able to integrate these approaches. Finally, the approach is applicable to areas outside of the realm of nutrition and health; in principle any attribute related to the production of primary commodities may be included at the source and traced through the global economy, increasing the potential of the approach enormously. An example is to calculate indirect land use effects.

The paper is organised as follows. Section 2 discusses the FAO data processed for use in the module. Section 3 develops the post-sim calculations for nutrients consumed by households via the three channels of consumption. Section 4 presents nutrition indicators that can be constructed on the basis of the calculations. Section 5 validates the outcomes of the module with nutrition information available from the FAO, analyses the differences and adjusts the methodology for these differences by computing and applying correction factors. Section 6 concludes with areas for further work. The Annex contains the user specifications to activate and use the nutrition module in the MAGNET model.

2. Compiling nutrient data for primary agricultural commodities

This section describes the compilation of the nutrient data associated with primary agricultural production (including fishing) for use in the nutrition module. The construction of the nutrient dataset involved gathering data on nutrients and primary agricultural production from the FAO, combining nutrient data with primary agricultural production data and matching these with the GTAP sectors available in MAGNET.

2.1 Source data

The source data for nutrition information is the FAO nutritive factor data contained in the methodology of the Food Balance Sheets (FAO, 2001). This dataset contains information on calories (kcal per 100 grams), proteins (grams per 100 grams) and fats (grams per 100 grams) by detailed agri-food commodity (446 in total). Two other important sources of data are the FAO primary production data from FAOSTAT and fishery production data (capture and aquaculture) from FishStat. These datasets include production data for primary agricultural commodities (205) and fishing categories (10) by country or region in the world.

2.2 Data manipulations

The challenge is, first, to combine the FAO nutritive factors (by detailed commodity) with the FAO primary production data (by detailed commodity and region) and then to aggregate and match the resulting nutrient data by primary sector with the primary agricultural and fishing sectors in GTAP. There are eleven primary agricultural and fishing sectors in GTAP: paddy rice; wheat; other grains; vegetables and fruits; oil seeds; sugar cane and beet; other crops; cattle; other animal products; raw milk and fishing. Since the level of detail of commodities differs by data source a number of data manipulations have to be carried out. Firstly, the original FAO production data are combined for a period of five years (2005-2009) so as to calculate a five-year average for production volumes in 2007 to cope with missing values and to even out deviating values (e.g. errors, outliers). Secondly, based on the FAO nutritive factors for calories, protein and fat, the nutritive factors for carbohydrates are calculated using the calorific values of protein, fat and carbohydrate.[2,3] Thirdly, the nutritional content associated with the 2007 production volumes is calculated based on the average production volumes for 2007 and the nutritive factors of the primary FAO products. Finally, the production volumes and the nutritional content of FAO primary products (in FAO regions) are aggregated to GTAP primary sectors (11) and GTAP regions (134)[4] using the MetaBase[5] concordance tables. The resulting model source data cover

[2] According to the Atwater general factor system we used the formula: Grams of Carbohydrates = kCalories - (grams of Proteins * 4) - (grams of Fats * 9)) / 4 (FAO, 2003).

[3] Since the FAO (FAO, 2003) considers palm oil as a primary product and applies a nutritive factor of 8.84 kcal per gram of fat for vegetable fats and oils (the Atwater specific factor system) instead of the more general applied factor of 9 kcal per gram of fat (the Atwater general factor system), the calculation of the content of carbohydrates resulted in a negative value for palm oil. We corrected this negative value into a zero.

[4] GTAP v8.1 database (February 2013).

[5] MetaBase is a data management and research tool developed at LEI Wageningen UR which makes data and metadata from a variety of national and international sources available within one system. Concordances between

calories (million kcal), proteins (tonnes), fats (tonnes), carbohydrates (tonnes) and (FAO) quantities (tonnes) by primary commodity and region.[6] The latter, whilst strictly not a nutrient type, is included in the source data to be able to calculate the true quantity of primary commodities contained in foods consumed by households.[7]

3. Calculation of nutrients in primary agricultural commodities consumed directly and indirectly

This section explains the calculations needed to compute the nutrient content associated with the private household consumption of food in the nutrition module.

3.1 Description of method

For the calculation of the nutrient consumption by private households, we use the nutrient data associated with primary agricultural production, compiled following the procedure described in Section 2. However, not all produced primary agricultural commodities are consumed domestically but partly are exported and consumed abroad. Also, primary agricultural commodities do not necessarily end up on households' plate but may be used, for example, as a seed or to produce fuels or chemical goods. The nutrients in these primary agricultural commodities are 'lost' in the sense that they cannot be absorbed by humans anymore. In order to establish the nutrient consumption of private households, we need to account for its share in the supply of primary agricultural commodities. This will be done using quantity shares, assuming a uniform market price of each agricultural commodity for all users.

Private households may consume nutrients via three channels, namely directly via the consumption of primary agricultural commodities (e.g. wheat), indirectly via the consumption of processed foods (e.g. other food), or indirectly via the consumption of food-related services (e.g. trade services containing hotels and restaurants). The first two sources of nutrients can be produced domestically or imported. Since services are mostly non-tradable, we assume that all nutrients used in services production are consumed domestically and by private households, so there are no nutrients in imported or exported services and no nutrients in alternative service uses.

The calculation of the nutrient content of processed foods and food-related services requires tracing how much primary agricultural commodities are used to produce them. This is complicated since often processed foods are used as an input into the production of processed foods. Therefore, an iterative

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the different classifications used by data suppliers facilitate combining and linking of data from these different data sources for use in research, policy and practice.

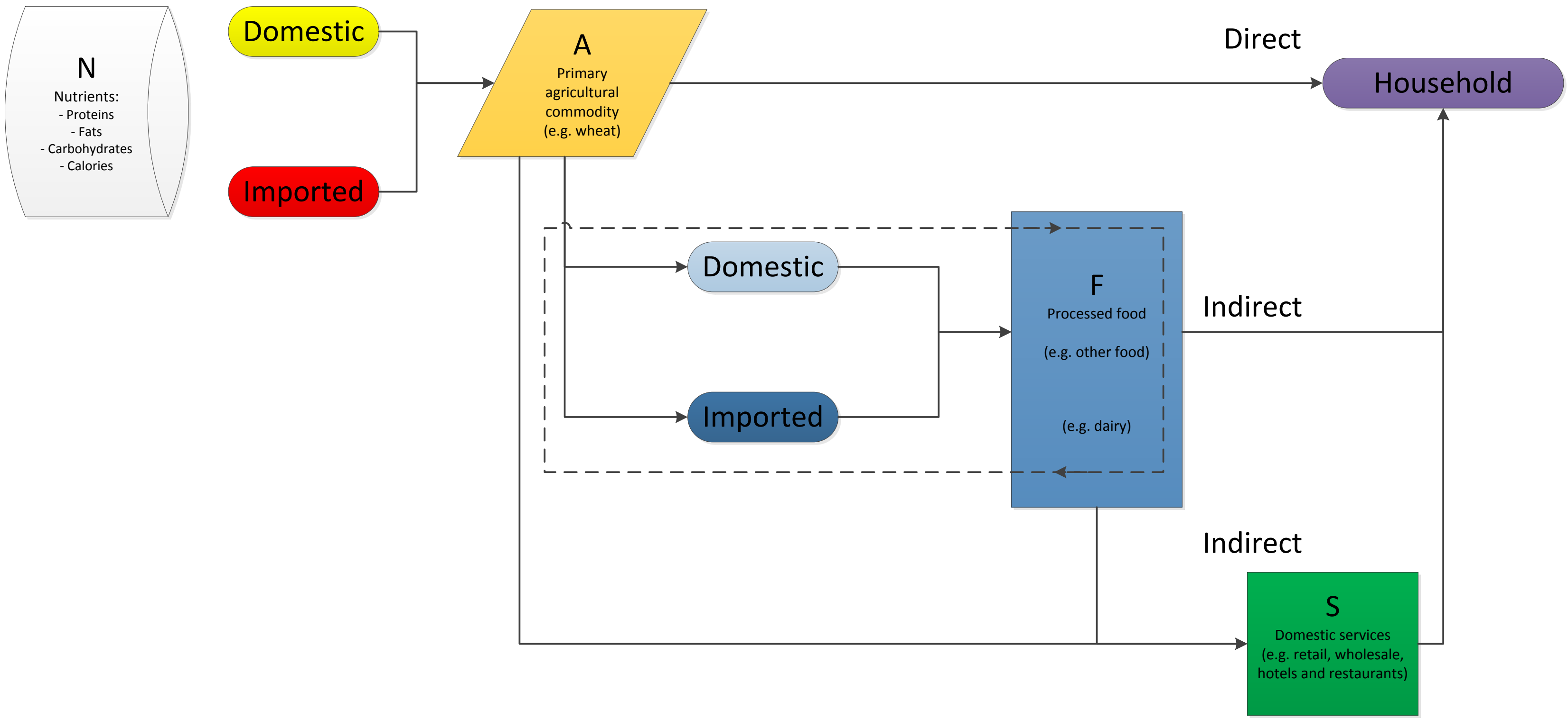
[6] Note that FAO primary production data are not present for Taiwan and so nutrient data for Taiwan in MAGNET are also lacking and may be included in the region of China or Rest of East Asia (xea). This is unclear.

[7] The model source data are included in FAOnutrition.har in the subdirectory 0_Database\2_OtherData\FAO\update_Aug2012\HAR_files and will be automatically included in the Database Creation step in MAGNET if the file '2_faostat_2008_2009.har' is included in 'Choose files for extra data' option. The header "NVOL" is the header containing the nutrient source data, which is defined over the original number of GTAP regions (134), GTAP sectors (57) – NB the non-primary sectors containing zeros – and nutrient types (4 plus quantities of production from FAO).

procedure is needed to calculate the nutrient content of processed foods. The first approximation of the nutrient contents of processed foods takes into account only the nutrient content of primary agricultural commodities used to produce processed foods. The second approximation takes into account the result of the first approximation of the nutrient content of processed foods used to produce the processed foods. In the third approximation, we use the second approximation results and so on. We check empirically how many approximations are necessary to get a reasonably low approximation error. For the indirect consumption of nutrients via food-related services, it is assumed that they use primary agricultural commodities (containing nutrients), or processed foods using primary agricultural commodities or processed foods, and so on (following the same iterative process). We abstract from the possibility that processed foods use food-related services or that food-related services use other food-related services. The approach is summarised in Figure 1.

it is important to note that **the nutrition module will only lead to sensible and accurate outcomes if the chosen aggregation separates primary agricultural commodities from processed food commodities and food-related services.** This is due to the fact that nutrients are assumed to enter via primary agricultural commodities at the most detailed level specified in GTAP, and end up being consumed by households via direct consumption, processed food and food-related services. The aggregation should therefore distinguish at least one primary agricultural sector (containing the eleven GTAP primary sectors with nutrients), one processed food sector (containing the processed food sectors in GTAP), and one food-related service sector (including service sectors in GTAP and notably trade-related services).

Figure 1 Visualisation of the approach towards nutrient consumption by private households in the nutrition module



3.2 Naming of new sets and coefficients

Nutrition indicators are included in the nutrition module as coefficients that carry the current quantity of nutrients, which can be updated after each period using the outcomes of the model. The logic for the naming of the nutrition-related coefficients uses the following prefixes:

- N stands for Nutrient
- Q for Quantity (or volume)
- D for Direct consumption
- IF for Indirect consumption via processed Foods
- IS for Indirect consumption via food-related Services.

Since nutrients are calculated for primary agricultural commodities, processed foods and food-related services, we introduce the following sets[8]:

- A for primary Agricultural commodities (in MAGNET: PRIM_AGRI)
- F for processed Foods ((in MAGNET: PROC_FOOD)
- FS for Food-related Services (in MAGNET: FOOD_SERV)[9]
- N for Nutrient type (calories, proteins, fats, carbohydrates; in MAGNET: NUTRIENTS)

A, F and FS are traded commodities (part of TRAD_COMM), with the latter two being a subset of production sectors (PROD_SECT).

3.3 Initialisation of quantity data

We first define and initialise the quantities (volumes) in the base data, using the prevailing 2007 dollar values and assuming that prices equal one (Harberger convention) (Table 1).

Table 1 Initialisation

Equation	Description
Q_VOM(i,s) = VOM(i,s)	Quantity of output of commodity i in region s
Q_VIM(i,s)= VIM(i,s)	Quantity of imports of commodity i in region s
Q_VDPM(i,s) = VDPM(i,s)	Quantity of private (household) consumption of domestic good i in region s
Q_VIPM(i,s) = VIPM(i,s)	Quantity of private (household) consumption of imported good i in region s

[8] Note that a set for agricultural sectors exists in MAGNET. As it is used for the mobile endowments and CAP modules of MAGNET, it defines agricultural sectors in a different way and therefore cannot be used here. Specifically, for nutrition purposes the set for primary agricultural commodities contains primary agricultural commodities that are food-related (excluding plant-based fibres and wool), including also non-land using sectors and the primary sector of fishing which in the aforementioned modules is usually considered a non-agricultural sector. A set for food commodities also exists in MAGNET, which is used in the consumption module. As it includes processed food sectors but also all primary agricultural sectors, it can also not be used here.

[9] In MAGNET we have added a set NON_FOOD to account for all other commodities, i.e. commodities not containing nutrients or containing nutrients but not for human consumption. This set is not currently used.

Q_VDFM(i,k,s) = VDFM(i,k,s)	Quantity of intermediate (firm) demand for domestic good i demanded by k in region s
Q_VIFM(i,k,s) = VIFM(i,k,s)	Quantity of intermediate (firm) demand for imported good i demanded by k in region s
Q_VXMD(i,r,s) = VXMD(i,r,s)	Quantity of exports/imports of good i from region r to region s

The quantities thus represent quantities in constant 2007 dollars. We then update these quantities with the changes in the quantities resulting from the model:

Q_VOM(i,s) = qo(i,s);

Q_VIM(i,s)= qim(i,s);

Q_VDPM(i,s) = qpd(i,s);

Q_VIPM(i,s)= qpm(i,s);

Q_VDFM(i,j,s)= qfd(i,j,s);

Q_VIFM(i,j,s) = qfm(i,j,s);

Q_VXMD(i,r,s) = qxs(i,r,s);

3.4 Reading in nutrient data for primary agricultural commodities

Using the foregoing nomenclature, the coefficient indicating the quantity of nutrient n produced by primary agricultural commodity i in region s is given by:

NQ_VOM(n,i,s), where $i \in A$, $n \in N$.

NQ_VOM(n,i,s) is read in from the base data (see section 2 for a description of how these data have been compiled).

Nutrient consumption in a region will not only stem from primary agricultural commodities produced domestically, but also from imports. The quantity of nutrients n contained in imports of primary agricultural commodity i (e.g. wheat) in region s is given by:

NQ_VIM(n,i,s) = sum{r,REG, NQ_VOM(n,i,r)* Q_VXMD(i,r,s)/ Q_VOM(i,r)} $n \in N$, $i \in A$

These coefficients are written to the base data and view files with headers “NVOM” and “NVIM” respectively.

Note that, as with the quantities above, the quantity of nutrients, NQ_VOM(n,i,s), should also be updated with the change in the accompanying output over time, qo(i,s):

NQ_VOM(n,i,s) = qo(i,s);

3.5 Nutrients in direct consumption by private households via primary agricultural commodities

The first and easiest step is to calculate nutrients contained in the direct consumption of primary agricultural commodities by households, both from domestic sources and imports.

Private household consumption of nutrients n via domestically produced primary agricultural commodity i (e.g. wheat) in region s can be calculated as:

NQD_VDPM(n,i,s) = NQ_VOM(n,i,s)* Q_VDPM(i,s)/Q_VOM(i,s) $\quad n \in N, i \in A$

Similarly, private household consumption of nutrients n via imported primary agricultural commodity i (e.g. wheat) in region s is given by:

NQD_VIPM(n,i,s) = NQ_VIM (n,i,s) * Q_VIPM(i,s)/Q_VIM(i,s) $\quad n \in N, i \in A$

These coefficients are written to the view files with headers "NADP" and "NAIP" respectively.

3.6 Nutrients in indirect consumption by private households via processed foods

Households also consume nutrients contained in primary agricultural commodities indirectly, i.e. via the consumption of processed foods, both produced domestically and from imports. Processed foods are produced using inputs from domestic and imported primary agricultural commodities as well as from other domestic and imported processed foods, which themselves are produced by domestic and imported primary agricultural inputs and processed foods, and so on. The calculation of nutrients contained in domestically produced and imported processed foods thus involves an iterative procedure, which can be implemented in the model as follows.

The nutrients n contained in primary agricultural commodity i used to produce processed food j in region s (e.g. nutrients in wheat used to produce other food in a region) is initially set to zero:

NQIF_VFM(n,i,j,s) = 0 $\quad n \in N, i \in A, j \in F$

The total imports of nutrients n in primary agricultural commodity i via processed food j by region s (e.g. nutrients in wheat imported indirectly via other food in a region) can be calculated as:

NQIF_VIM(n,i,j,s) = sum{r,REG, NQIF_VFM(n,i,j,r) * Q_VXMD(j,r,s)/ Q_VOM(j,r)} $\quad n \in N, i \in A, j \in F$

Whereby the ratio is the share of the processed food product j (e.g. other food) exported from region r to region s in total production of j in r.

NQIF_VFM can then be calculated as follows:

NQIF_VFM(n,i,j,s) = NQ_VOM(n,i,s)* Q_VDFM(i,j,s)/Q_VOM(i,s)

nutrients in **domestic** primary agricultural commodity i (e.g**. wheat**) used to produce processed food j (e.g. other food) in region s

+ NQIF_VIM(n,i,s) * Q_VIFM(i,j,s)/Q_VIM(i,s)

nutrients in **imported** primary agricultural commodity i (e.g. **wheat**) used to produce processed food j (e.g. other food) in region s

+ sum{(j1,F, NQIF_VFM(n,i,j1,s)*Q_VDFM(j1,j,s)/Q_VOM(j1,s)}

nutrients in primary agricultural commodity i (e.g. wheat) used in **domestic** processed food J1 (e.g**. dairy**) used to produce processed food j (e.g. other food) in region s

+ sum{(j1,F, NQIF_VIM(n,i,j1,s)*Q_VIFM(j1,j,s)/Q_VIM(j1,s)}   n ϵ N, i ϵ A, j ϵ F

nutrients in primary agricultural commodity i (e.g. wheat) used in **imported** processed food J1 (e.g**. dairy**) used to produce processed food j (e.g. other food) in region s

It is crucial that the last two formulae, for NQIF_VIM and NQIF_VFM, are repeated several times to calculate the grey shaded coefficients correctly.[10]

It is now possible to compute the nutrients n contained in indirect consumption by households of primary agricultural commodity i used to produce domestic processed food j in region s (e.g. indirect nutrient consumption of wheat used to produce other food in a region):

NQIF_VDPM(n,i,j,s) = NQIF_VFM(n,i,j,s)*Q_VDPM(j,s)/Q_VOM(j,s)   n ϵ N, i ϵ A, j ϵ F

where the ratio is the share of domestic product j (e.g. other food) consumed by private households in the total production of j in region s.

Similarly, the nutrients n contained in the indirect consumption by households of primary agricultural commodity i used to produce imported processed food j in region s (e.g. indirect nutrient consumption of wheat from imported processed food) can be specified as:

NQIF_VIPM(n,i,j,s) = NQIF_VIM(n,i,j,s) * Q_VIPM(j,s)/Q_VIM(j,s)   n ϵ N, i ϵ A, j ϵ F

where the ratio is the share of imported product j (e.g. other food) consumed by private household in total imports of j in region s.

These last two coefficients are written to the view files with headers “NFDP” and “NFIP” respectively.

3.7 Nutrients in indirect consumption by private households via domestic food-related services

Finally, households consume nutrients contained in primary agricultural commodities indirectly via the use of food-related services (most notably trade services containing retail, wholesale, hotels and

[10] We find that the iterative process converges. The module incorporates ten iterations in total. At the tenth iteration, total nutrient consumption by households (see Section 4.2) displays a negligible difference with the previous iteration of less than 0.1% for all nutrients and all countries in the world.

restaurants). We assume for simplicity that all nutrients embodied indirectly in food-related services are consumed domestically and by private households as most of these services will be set up to serve the local consumers (private households) and not exported abroad. As with processed foods, food-related services are produced using primary agricultural commodities and processed foods from the domestic market and from abroad, with processed foods themselves being produced by primary agricultural commodities and processed foods, and so on, and therefore use the results of the iterative procedure for processed foods (Section 3.6).

Specifically, nutrients n contained in primary agricultural commodity i used to produce food-related services j in region s (e.g. nutrients in wheat used in trade services in a region) can be formulated as:

NQIS_VFM(n,i,j,s) = NQ_VOM(n,i,s)* Q_VDFM(i,j,s)/Q_VOM(i,s)

nutrients in **domestic** primary agricultural commodity i (e.g**. wheat**) used to produce food-related services j (e.g. trade services) in region s

+ NQ_VIM(n,i,s) * Q_VIFM(i,j,s)/Q_VIM(i,s)

nutrients in **imported** primary agricultural commodity i (e.g. **wheat**) used to produce food-related services j (e.g. trade services) in region s

+ sum{(j1,F, NQIF_VFM(n,i,j1,s)*Q_VDFM(j1,j,s)/Q_VOM(j1,s)}

nutrients in primary agricultural commodity i (e.g. wheat) used in **domestic** food j1 (e.g**. dairy**) used to produce food-related services j (e.g. trade services) in region s

+ sum{(j2,F, NQIF_VIM(n,i,j2,s)*Q_VIFM(j2,j,s)/Q_VIM(j2,s)} n ϵ N, i ϵ A, j ϵ FS

nutrients in primary agricultural commodity i (e.g. wheat) used in **imported** food j2 (e.g**. dairy**) used to produce food-related services j (e.g. trade services) in region s

These are all consumed by households.

This coefficient is written to the view files with header “NSDP”.

4. Module outcomes: reporting of nutrient content of food commodities and products consumed by private households

We can now construct a set of nutrition indicators using the computed values of nutrient consumption by households via direct consumption of primary agricultural commodities (domestic and imported), indirect consumption via processed foods (domestic and imported) and indirect consumption via domestic food-related services.

4.1 Nutrition indicator by channel

Quantity of nutrients n in direct household consumption of primary agricultural commodity i (e.g. wheat) in region s:

NQD_VPM(n,i,s) = NQD_VDPM(n,i,s) + NQD_VIPM(n,i,s) n ϵ N, i ϵ A

Quantity of nutrients n consumed directly by households in region s:

NQD(n,s) = sum(i ϵ A, NQD_VPM(n,i,s)) n ϵ N

This indicator is written to view files with header "NQD".

Quantity of nutrients n consumed indirectly by households via processed food j (e.g. other food) in region s:

NQIF_VPM (n,j,s) = sum(i ϵ A, NQIF_VDPM(n,i,j,s) + NQIF_VIPM (n,i,j,s)) n ϵ N, j ϵ F

Quantity of nutrients n consumed indirectly via processed foods by households in region s:

NQIF(n,s) = sum(j ϵ F, NQIF_VPM(n,j,s)) n ϵ N

This indicator is written to the view files with header "NQIF".

Quantity of nutrients n consumed indirectly by households via food-related service j (e.g. trade services) in region s:

NQIS_VPM(n,j,s) = sum(i ϵ A, NQIS_VFM(n,i,j,s)) n ϵ N, j ϵ FS

Quantity of nutrients n consumed indirectly via food-related services by households in region s:

NQIS(n,s) = sum(j ϵ FS, NQIS_VPM(n,j,s)) n ϵ N

This indicator is written to view files with header "NQIS".

A comparison of these indicators show the degree to which households procure nutrients through each channel.

4.2 Total and per capita nutrition indicators

Total quantity of nutrients n consumed by households in region s:

NQT(n,s) = NQD(n,s) + NQIF(n,s)+NQIS(n,s) n ϵ N

This indicator is written to the view files with header "NQT".

Per capita quantity of nutrients n consumed by households in region s:

NQPC(n,s) = NQT(n,s) / POP(s) n ϵ N

This indicator can be used to analyse how diets have changed (more or less healthy) by comparison with prevailing healthy diet guidelines, e.g. from the WHO. This indicator is written to the view files with header "NQPC". Note that a 'per day' indicator can be obtained by division through 365.

4.3 Nutrition indicator by regional source

Quantity of nutrients n consumed by households in region s from domestic sources:

NQDOM(n,s) = sum(i ϵ A, NQD_VDPM(n,i,s)) + sum(i ϵ A, (sum(j ϵ F, NQIF_VDPM(n,i,j,s))))

+ sum(j ϵ FS, NQIS_VPM(n,j,s)) n ϵ N

Quantity of nutrients n consumed by households in region s from imported sources:

NQIMP(n,s) = sum(i ϵ A, NQD_VIPM(n,i,s)) + sum(i ϵ A, (sum(j ϵ F, NQIF_VIPM(n,i,j,s)))) n ϵ N

Dependency of region s' consumption of nutrient n on imports (share in total):

NQIMPSHR(n,s) = NQIMP(n,s) / NQT(n,s) n ϵ N

The latter indicator signifies how dependent a region is on imports for nutrients, i.e. how vulnerable it is to changes in the world market.

It is written to the view files with header "NISH".

4.4 Nutrition indicator by sector source

Quantity of nutrients n consumed by households in region s from primary source i:

NQSECT(n,i,s) = NQD_VPM(n,i,s) + sum(j ϵ F, (NQIF_VDPM(n,i,j,s) + NQIF_VIPM(n,i,j,s)))

+ sum(j ϵ FS, (NQIS_VFM(n,i,j,s)) n ϵ N, i ϵ A

This coefficient is written to the view files with header "NQSC".

Per capita quantity of nutrients n consumed by households in region s from primary source i:

NQSECTPC(n,i,s) = NQSECT(n,i,s) / POP(s) n ϵ N, i ϵ A

This coefficient is written to the view files with header "NSPC".

Dependency of region s' consumption of nutrient n on primary agricultural sector i (share in total):

NQSECTSHR(n,i,s) = NQSECT(n,i,s) / NQT(n,s) n ϵ N, i ϵ A

This coefficient is written to the view files with header "NSSH".

5. Validation of module outcomes

In this section we validate the outcomes of the nutrition module in MAGNET in the base year (2007) using global data on nutrition from the FAO based on food available for human consumption in 2007. We analyse differences that occur by nutrient, nutrient and primary commodity, and nutrient and region, account for potential reasons for these differences and identify potential solutions. We subsequently apply correction factors to the nutrition indicators calculated for each of the channels of consumption in the nutrition module which captures and adjusts the methodology for these various differences. The performance of the module over time will be addressed in future work, as it may require changes in the consumption function.

5.1 Data source for validation: FAO Food Supply data

We use FAO data on nutrients by region and by commodity from the Food Supply data for “2007” (based on an average of the data for the years 2005 to 2009 to even out deviating values (e.g. errors, outliers) to validate the model outcomes. These data show the total quantity of food stuff produced in a region added to the total quantity imported and adjusted for stock changes. This quantity is then distributed over different uses, including exports, livestock feed, seed use, and losses due to storage and transport; resulting in the quantity of food available for human consumption in primary product equivalents.

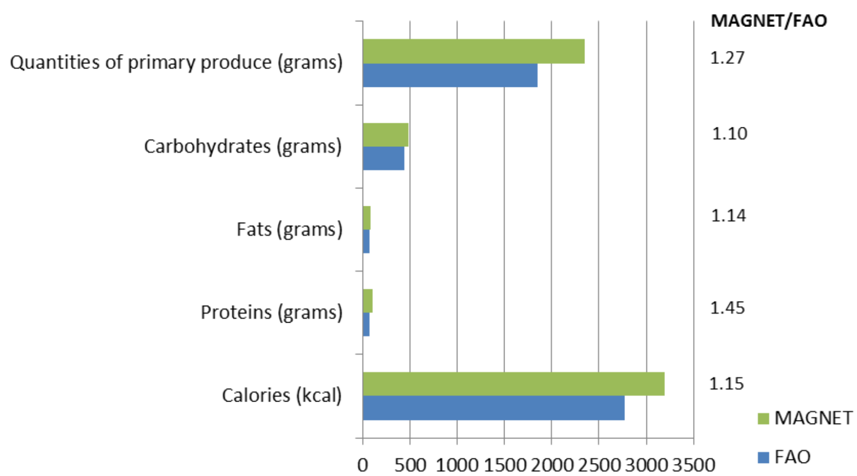
The FAO data and methodology used to derive these data have various characteristics which need to be borne in mind in the validation, including (1) FAO depends on member states for the underlying data and so its quality is not guaranteed, (2) focusing on energy requirements rather than micronutrients due to the lack of micro nutrient data at the global level and (3) food available for consumption differs from the amount actually consumed. Its main strength and benefit for our research is its world-wide coverage of nutrient data.

5.2 A comparison of MAGNET nutrition module outcomes with FAO data in the base year

5.2.1 Validation at the global level

Looking at the worldwide nutrition outcomes produced by MAGNET’s nutrition module and those from the FAO in 2007 (Figure 2), we observe that MAGNET outcomes are a factor 1.1 to 1.45 times those of FAO, such that MAGNET outcomes exceed those of FAO by 10 to 45 per cent. The difference is most pronounced for proteins (45%) and quantities of primary produce (27%). Deviations differ by nutrient and are not identical to those related to the quantities of primary produce.

Figure 2 Global annual household consumption (per capita, per day)



5.2.2 Validation at the primary commodity level

Comparing nutrition outcomes produced by MAGNET's nutrition module traced back to their primary equivalent (coefficient NQSECT) for all regions in the world with FAO data (Figure 3-7), reveals that MAGNET sometimes overstates but also sometimes understates viz-a-viz FAO outcomes. Specifically, MAGNET understates the nutrient content of fishing, other animal products and other crops (and also cattle and wheat if fats are excluded). However, MAGNET overstates the nutrient content of oil seeds, other grains and vegetables and fruits.

Figure 3 Global annual household consumption of calories (million kcal)

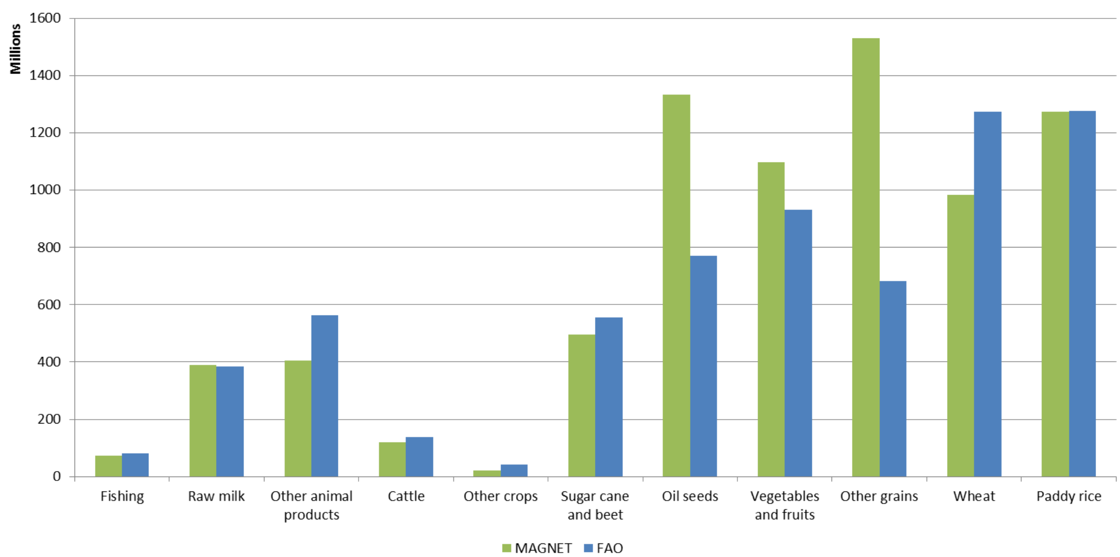


Figure 4 Global annual household consumption of proteins (tonnes)

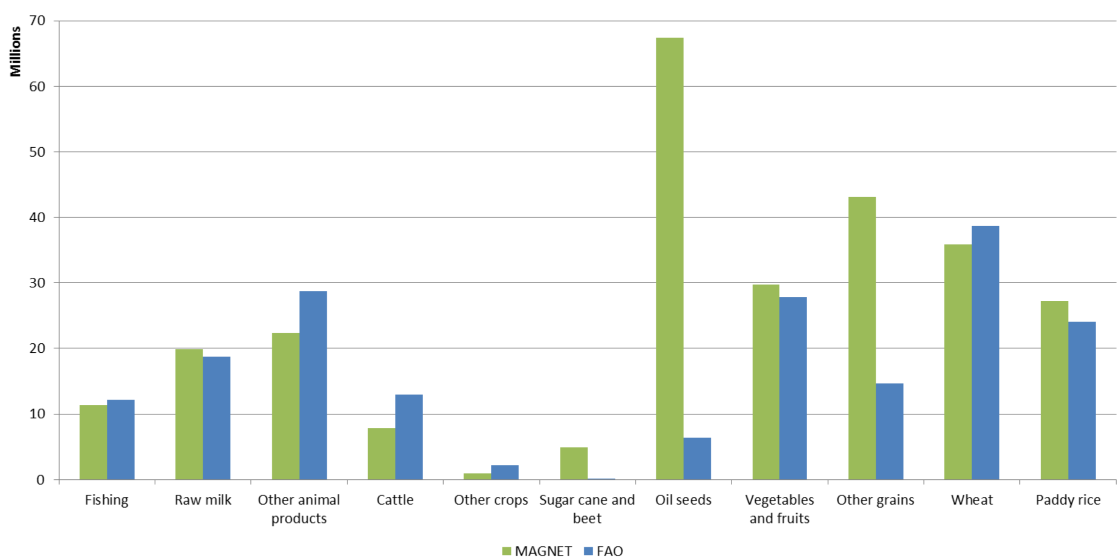


Figure 5 Global annual household consumption of fats (tonnes)

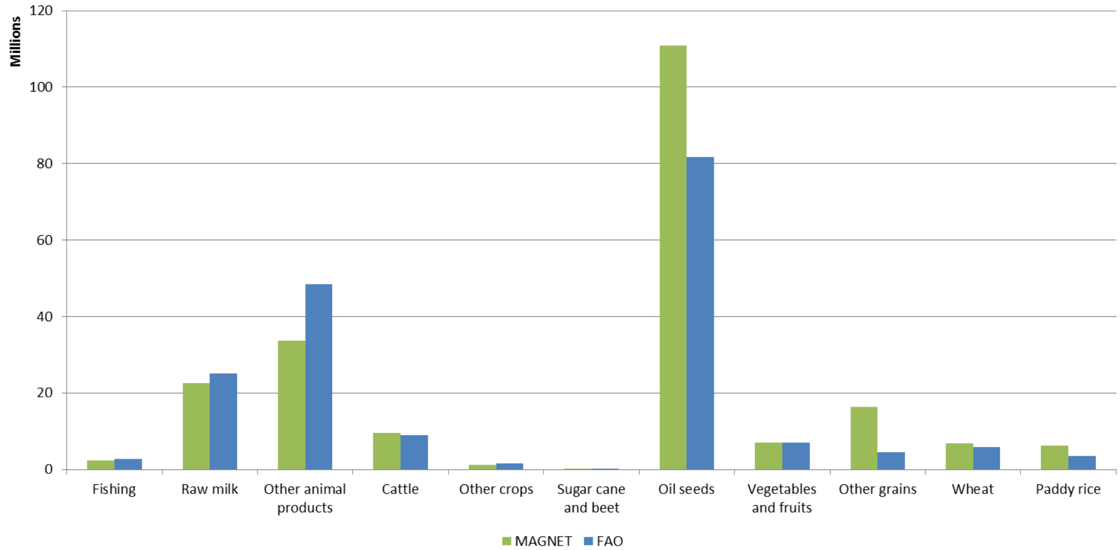
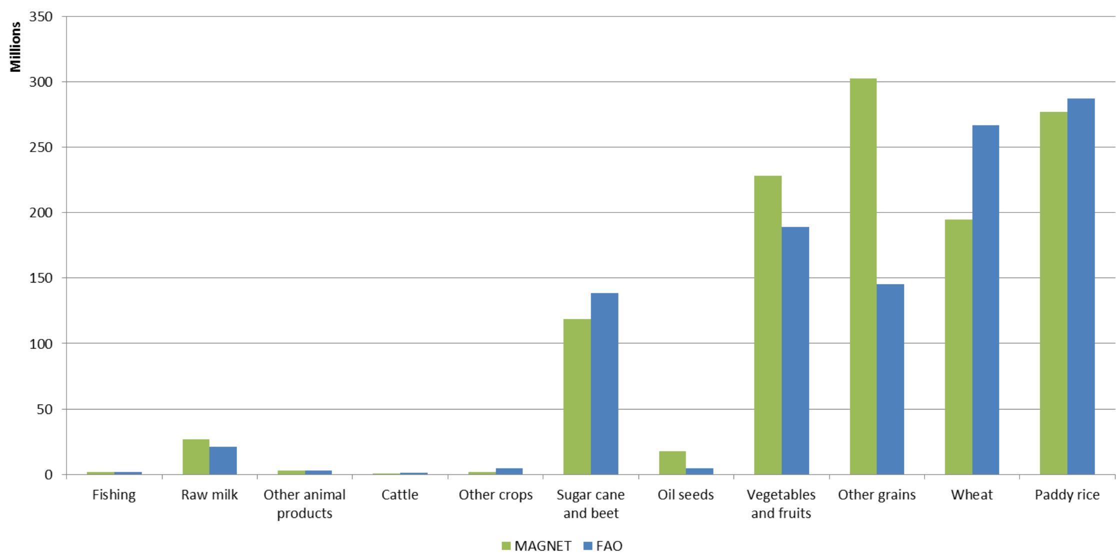


Figure 6 Global annual household consumption of carbohydrates (tonnes)

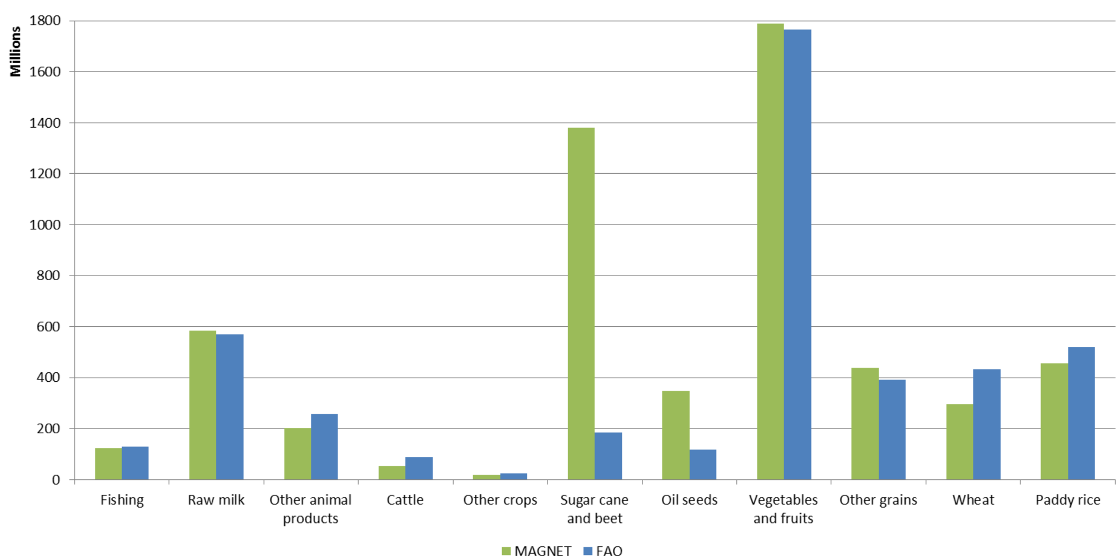


A further investigation of the factors of MAGNET to FAO outcomes (Figure 8) shows that nutrient content that can be traced back to especially sugar cane and beet, oilseeds and, to a lesser extent, other grains in MAGNET seems out of line. However, also confirmed by the factor 7 and 3 MAGNET/FAO ratios for respectively sugar cane and beet and oil seeds in terms of quantities, the FAO by exception expresses sugar, oils and fats and beverages not in their primary equivalents, but in their final form.[11] Given that sugar is mostly made from sugar cane and beet, MAGNET outcomes on calories (Figure 3) and

[11] See http://faostat.fao.org/site/616/default.aspx#ancor [accessed November, 2013]. Also mentioned here is that FAO does not express by-products into their primary equivalent, which may also explain some of the differences in outcomes in as far these by-products contain nutrients.

carbohydrates (Figure 6), the most important nutrients of this commodity, are very much in line with that of FAO. This is less so the case for oil seeds. Oil seeds are a highly processed commodity, with main destination as human food for oil and as animal food for meal and it may very well be that MAGNET and FAO make different assumptions when it comes to these processes. The substantially higher nutrient content of other grains in MAGNET compared to FAO (Figures 3 – 6) may be explained by the fact that it includes nutrients from beverages. These differences imply that the MAGNET to FAO comparison for these commodities cannot be made and that ideally FAO data used for validation of MAGNET outcomes should all be expressed in their primary equivalents, which would reduce the differences between MAGNET and FAO for the previously mentioned commodity groups.

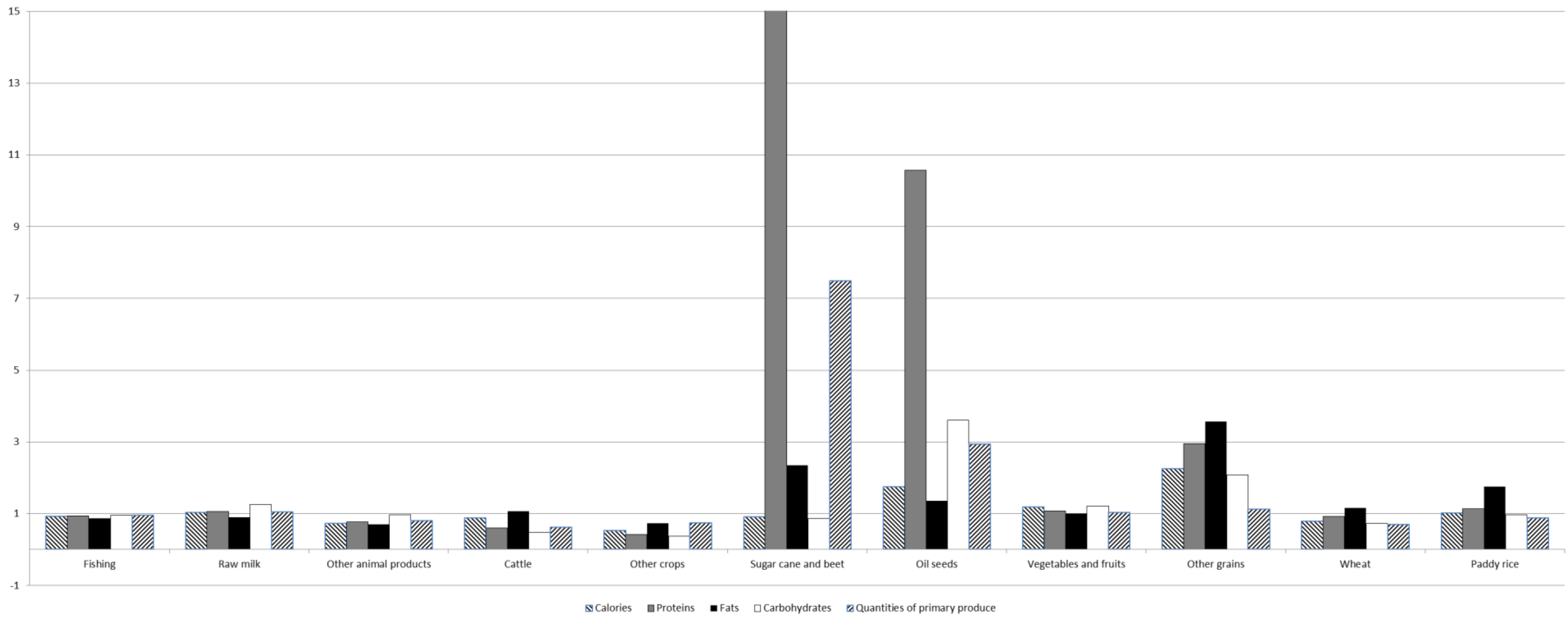
Figure 7 Global annual household consumption of quantities of primary produce (tonnes)



5.2.3 Validation at the regional level

Comparing nutrition outcomes produced by MAGNET's nutrition module by region (coefficient NQT) with FAO data, gives rise to the following patterns. First and foremost, FAO Food Supply data for consumption are missing for Hong Kong, Singapore, Taiwan, Oman, Bahrain, Qatar and Rest of World. This may explain part of the overestimation of MAGNET viz-a-viz FAO Food Supply data when it comes to the world total for consumption (Section 5.2.1) and by primary commodity (Section 5.2.2). As with primary commodities, MAGNET outcomes do not always exceed those of FAO: MAGNET underestimates consumption outcomes compared to FAO for 9% to 28% of regions, depending on the nutrient looked at (Table 2, first column). Regions for which MAGNET produces too low outcomes across all nutrient indicators include Mongolia, South Korea, China, Kenya, Albania, Rest of East Asia, Rest of South African Customs Union, and Rest of Former Soviet Union (Figure 9). MAGNET outcomes exceed those of FAO by up to a 100% for the majority of regions (57% to 76% of regions; Table 2, second column). For the remaining 12% to 33% of regions MAGNET exceeds FAO consumption outcomes by more than 100% (Table 2, third column).

Figure 8 Household consumption and nutrition outcomes by primary commodity: ratio MAGNET/FAO



Note: the MAGNET/FAO ratio for proteins that can be traced back to sugar cane and beet is extremely high at a value of around 42 (outside Figure 8)

Figure 9 Part I Household consumption and nutrition outcomes by region: ratio MAGNET/FAO

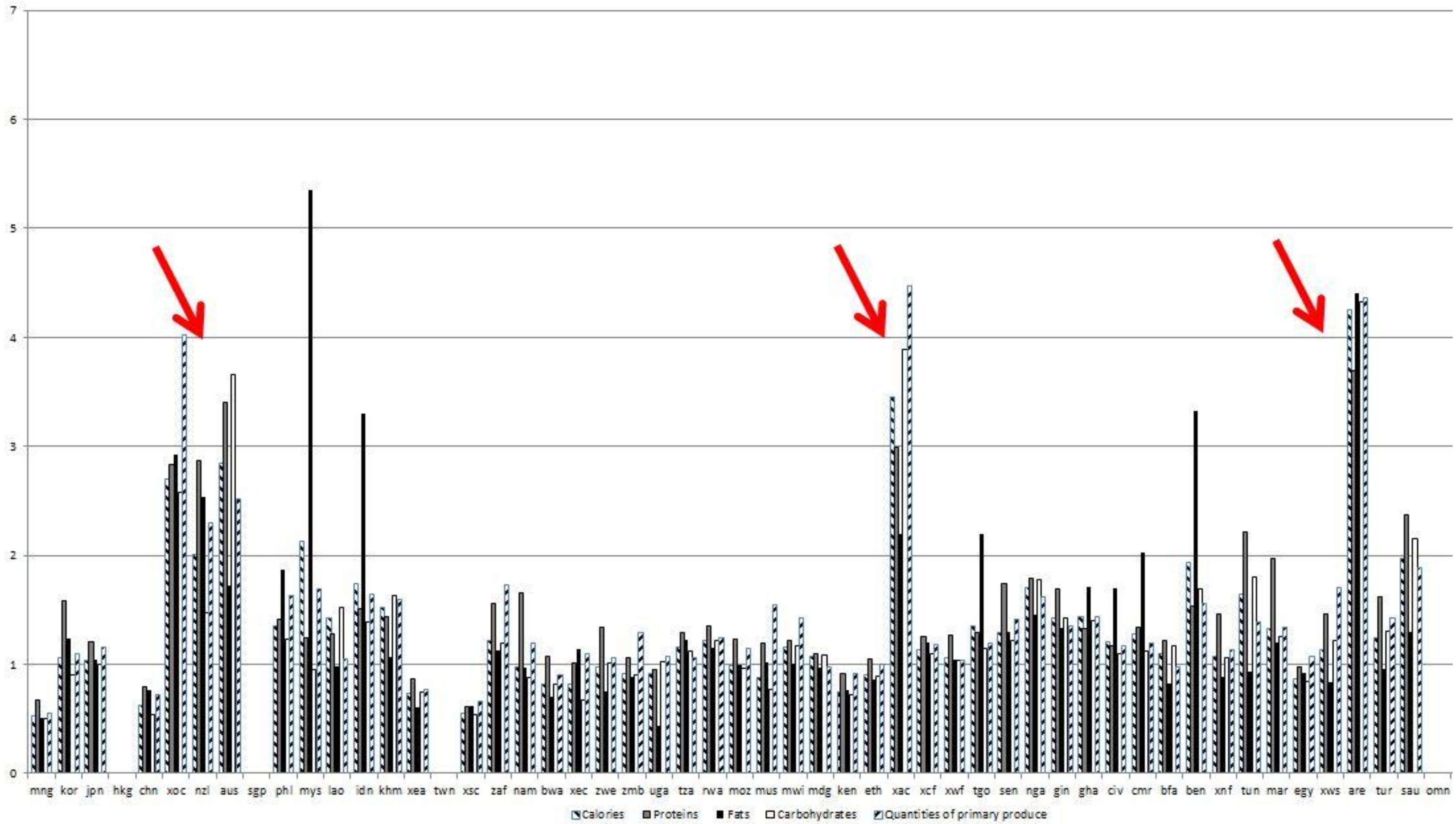


Figure 9 Part II Household consumption and nutrition outcomes by region: ratio MAGNET/FAO

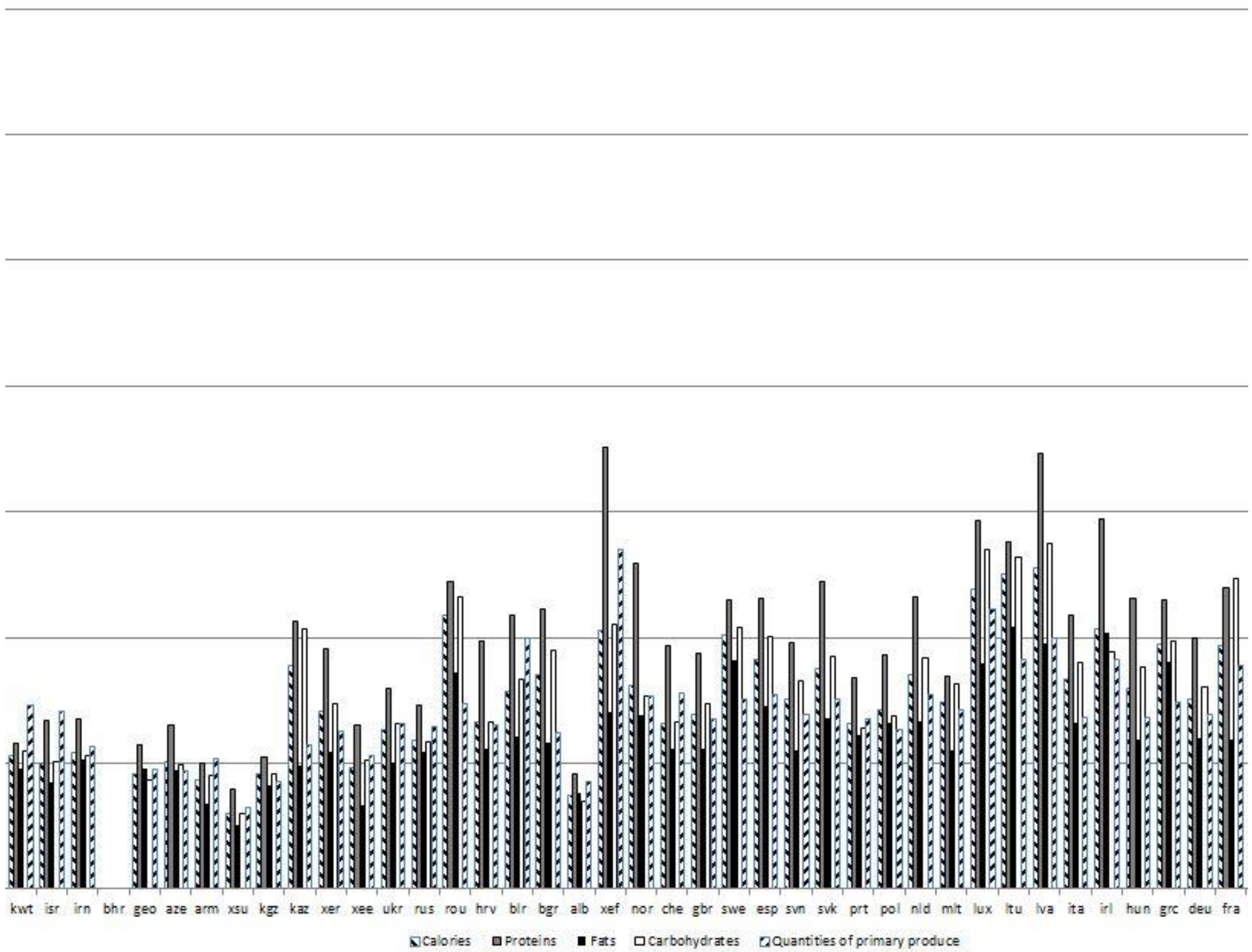
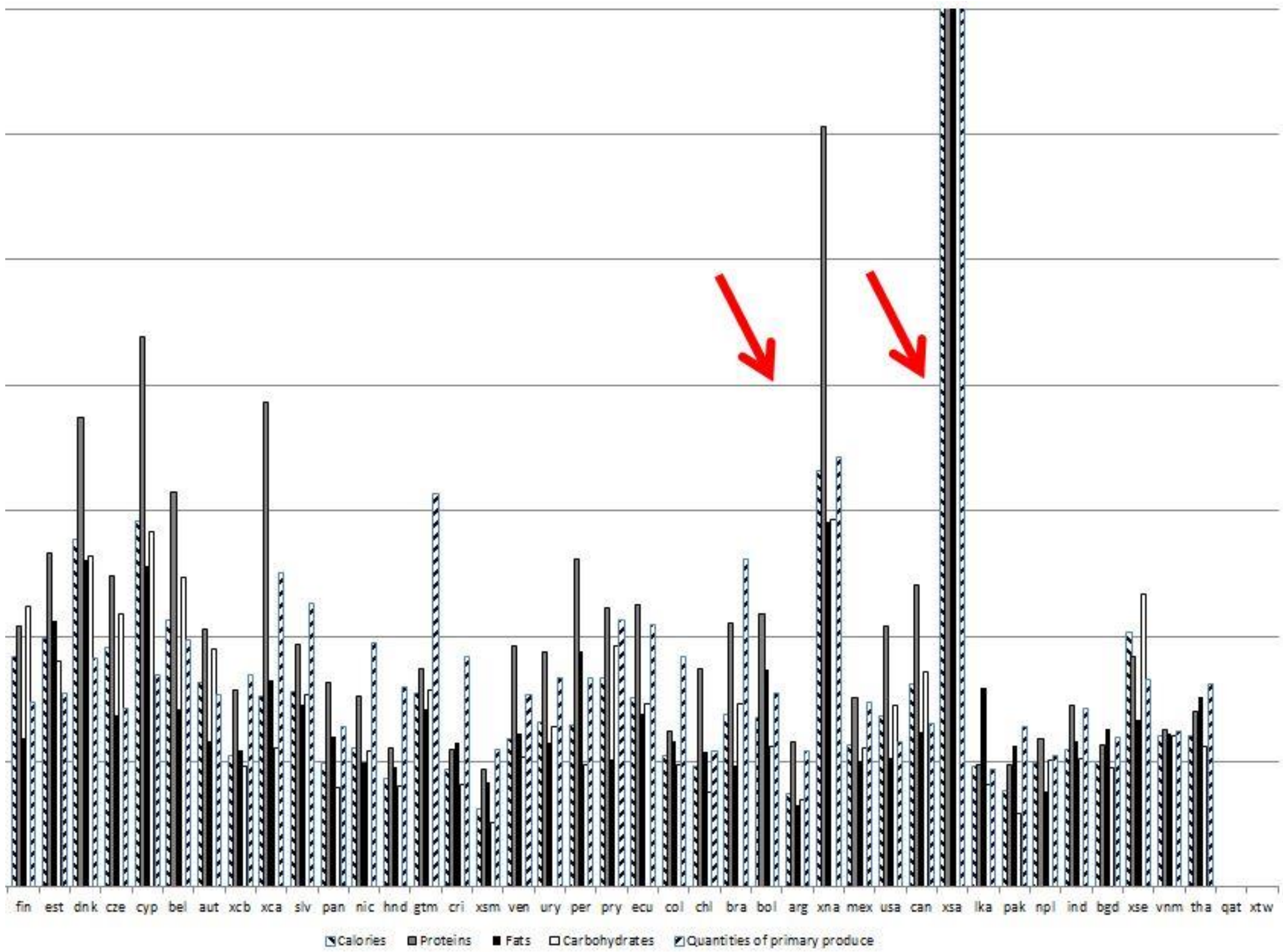


Figure 9 Part III Household consumption and nutrition outcomes by region: ratio MAGNET/FAO



Note: Rest of South Asia (xsa) is the most extreme outlier, with MAGNET consumption outcomes approximately 43 to 84 times that of FAO (outside Figure 9). FAO Food Supply data for consumption are missing for Hong Kong, Singapore, Taiwan, Oman, Bahrain, Qatar and Rest of World. MAGNET/FAO factors for these regions cannot be calculated.

Notable outliers in terms of overestimation of MAGNET viz-a-viz FAO nutrition data include (red arrows in Figure 9): Oceania (Australia, New Zealand and Rest), South Central Africa (Angola, Congo), United Arab Emirates, Rest of North America and Rest of South Asia (Afghanistan, Bhutan, Maldives). For the regional (rest of) groups this may be caused by a lack of data on the FAO side as some small islands are missing (likely registered under their mainland). For some countries there are outliers regarding fats (black columns in Figure 9) and proteins (grey columns in Figure 9) specifically. MAGNET produces outcomes in a bandwidth of 10% around FAO outcomes in 11% to 22% of the regions of the model (Table 2, fifth column). All in all, MAGNET produces nutrition outcomes that are relatively high compared to FAO outcomes by region.

Table 2 Frequency of countries with deviations in outcomes between MAGNET and FAO

Nutrient \ MAGNET deviation from FAO (%)	(- 100, 0]	(0, 100]	> 100	Total	-/+ 10% band width
Calories	24%	61%	15%	100%	21%
Proteins	9%	57%	33%	100%	11%
Fats	28%	59%	13%	100%	22%
Carbohydrates	26%	57%	17%	100%	20%
Quantities of primary produce	12%	76%	12%	100%	17%

5.3 An inventory of causes of differences between FAO and MAGNET

There are many reasons why the nutrition outcomes of the MAGNET model differ from the FAO Food Supply data on nutrients. Some of these relate back to the characteristics of the FAO Food Supply data mentioned before, but some also relate to MAGNET and GTAP's underlying CGE methodology. First, MAGNET and FAO differ in terms of their sector and region coverage and composition. We already observed that FAO does not have consumption data for several MAGNET regions. Also some small islands are missing, which may or may not be included in other regions. Moreover, certain sectors in the FAO Food Supply data are defined differently and expressed in terms of their final equivalent, not primary equivalent, explaining the differences with MAGNET outcomes when it comes to sugar cane and beet, oil seeds and other grains. This should be corrected for. Second, the FAO food balances are likely to differ from the flow of commodities in MAGNET (and GTAP). MAGNET (and GTAP) does not account for stock changes and for food losses, whereas the FAO does. Also, food available for human consumption (from FAO) is not the same as the indicator of actual food consumption (as is calculated in GTAP and MAGNET). Third, another difference may occur due the inherent assumption in our approach that prices of a primary commodity are the same for all uses (e.g. wheat used in processed foods, or wheat directly consumed domestically, or wheat exported abroad). We do not have true prices in MAGNET nor quantity data; our calculations are based on using 'quantity shares' derived from GTAP value data and assuming prices are one in the base year ('Harberger convention' commonly adopted in most CGE models). Fourth, our point of departure is that nutrients enter at the level of production and that exports take on the same nutrient value per unit. This may not be the case, as the primary commodities that stay in a region may be of different quality than what is exported (for example 'true wheat' is exported, but 'wheat including a straw by-product' stays inside the region). Whereas MAGNET (as GTAP) by means of the Armington assumption accounts for differences in product quality/intra-industry trade, we do not have source of information for taking into account nutrient quality differences in domestic versus trade primary commodities, as the FAO perhaps has done. This problem is magnified by the aggregative nature of MAGNET, which MAGNET shares with most other CGE models, which implies that the different sectors that are distinguished in an economy produce a wide variety of commodities, the composition of which may differ very much by region looked at (and from what is exported). Finally, in the process from a primary agri-food commodity to a processed food product, nutrients get lost and the nutrient composition changes, not necessary linearly with what is used from primary agricultural commodities.

Table 3 summarises the causes of potential differences that may occur, the direction of effect and gives potential solutions that could be tackled in the longer term.

Table 3 Summary of potential differences of MAGNET nutrition module outcomes with FAO data

Causes	Direction of effect	Potential solution
1. MAGNET and FAO Food Supply data differ in coverage and/or composition of regions and sectors	?	Make data consistent as much as possible
2. MAGNET has a different flow of agri-food commodities through the economy, including that MAGNET: - does not account for stock changes and food losses - incorporates 'true consumption', not what is available for consumption)	? ?, + -	Incorporate FAO Food Balance Sheet data in MAGNET
3. MAGNET assumes that prices of agri-food commodities are the same across uses	?	Include true quantities (from FAO) and prices
4. MAGNET assumes the same nutrient content for production and exports of agri-food commodities	?	Use FAO Food Balance Sheet and/or IFPRI data for nutrients related to trade flows
5. In the process from a primary agri-food commodity to a processed food product, nutrients get lost and the nutrient composition changes, not necessary linearly	+	Check with food processing/nutrition science

Notes: a + (-) indicates that MAGNET is likely to over- (under-) estimate nutrition values

5.4 Calculating correction factors

A short run solution, which we have adopted to bring MAGNET nutrition module outcomes in line with FAO Food Supply data on nutrients is to apply correction factors to the nutrition indicators calculated for each of the channels of consumption in the MAGNET nutrition module[12] which captures and adjusts the methodology for these various differences. The application of the correction factors boils down to dividing the nutrition indicators by the MAGNET/FAO factors by nutrient, primary commodity and region (shown in the previous sections, but at a more aggregated level). In this way all information relating to the flow of nutrients from farm to fork within the context of the global economy, which is well-captured

[12] Specifically a correction factor has been applied to NQD_VDPM and NQD_VIPM for the direct consumption via primary commodities; NQIF_VDPM, NQIF_VIPM for the indirect consumption via processed foods; NQIS_VFM for the indirect consumption via food-related services.

by the MAGNET model, is safeguarded, whilst allowing for producing outcomes that reflect the global nutrition outcomes of the FAO, currently the most reliable source of worldwide data on food security and nutrition.

6. Conclusions

This paper summarises an approach for including nutrition indicators associated with private (household) consumption in a CGE model, using the flow of primary agri-food commodities through the global economy from farm to fork. The validation of an application of this approach in MAGNET with FAO data on nutrients available for human consumption has shown important differences in outcomes between MAGNET and FAO. Various solutions are identified to improve the nutrition calculations in the future. As a short run solution, correction factors are applied to adjust for any remaining differences. Further work is needed in various areas, including in order of importance: (1) a more detailed investigation of the differences between MAGNET and FAO nutrition consumption outcomes and tackling these where necessary and possible (2) validation of module outcomes over time (with a likely reprogramming of the consumption function), (3) the incorporation of micronutrient data (vitamins and minerals), (4) the application of the approach illustrating macroeconomic impacts on diets and nutrition from changes in exogenous drivers or policy changes, (5) vice versa optimisation or targeting of diets in a more healthy direction and implications for the global economy, agricultural production, trade and land use, (6) incorporation of health impacts (labour productivity, labour time, utility, health cost savings) and (7) broader population dynamics.

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ANNEX

User specifications to activate and use the nutrition module in MAGNET

The user specifications for this module are relatively straightforward (Table A1 and A2). As mentioned in the main text, the nutrition module will only lead to sensible and accurate outcomes if the chosen aggregation separates primary agricultural commodities from processed food commodities and food-related services. The aggregation should thus distinguish at least one primary agricultural sector (containing the eleven GTAP primary sectors with nutrients), one processed food sector (containing the processed food sectors in GTAP), and one food-related service sector (including service sectors in GTAP and notably trade-related services).

Table A1 DSS settings to activate the module

DSS tab	DSS question	Actions	Comments
Database	Files for extra data	-	2_FAOSTAT_2000_2009.har includes the nutrition data so that they are taken on board in the Database creation step
Model	Includes for Magnet	Select nutrition\nutrition	Adds the model code
Scenario (Gemse)	Model parameters file	Check the **FCAT** header to see where each sector/commodity is placed.	If you change the parameters by hand, it is best to give it a new name in order to prevent that DSS overwrites the file when re-running the model tab of DSS

Table A2 Adjustments to headers in ModelSettings.prm file

Header	Required setting	Comments
FCAT	Categorizes the sectors/commodities in your model as primary agriculture, processed food or food-related services	Done automatically on the basis of GTAP sectors, but check whether if you aggregate sectors the placing of commodities is still correct. The placing of sectors/commodities within FCAT influences the calculation of nutrients

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

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