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We are what we eat: An economic tool for tracing the origins of nutrients with entry points for action

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Abstract

We develop a methodology for incorporating nutrition impacts in economy-wide analyses, providing entry points for where, when and how to act. It accounts for three channels of consumption, directly via primary commodities and indirectly via processed foods and food-related services, and produces indicators showing content by nutrient (currently calories, proteins, fats and carbohydrates), channel, source region and sector. The paper applies the framework in a CGE model (MAGNET) and uses FAO data to project nutritional outcomes resulting from the global food system over time. The analysis confirms that developing regions catch up with developed regions, with the USA at the high-end of nutrient consumption, whilst Southern Africa lags behind. In the USA the processed food channel dominates, whereas in Southern Africa the direct channel dominates. In the USA, and similar regions, fat taxes (thin subsidies) on unhealthy (healthy) processed foods, technologies reducing bad ingredients (e.g. trans fats, salt), improved food labelling, information and marketing campaigns, and/or targeted cash transfers may be worthwhile to investigate. In Southern Africa, and regions alike, technological advances increasing nutrient availability via primary agriculture and/or cash transfers enabling access may be more pertinent. The relative fixedness of sectoral origins shows that consumption habits change slowly and are visible only in the long term. For certain regions, including Southern Africa and USA, nutrient import dependency increases with substantial variations in regional sourcing. This implies that concerted action across the globe is crucial to reach diet, nutrition and health goals, and should include upcoming Asian economies, Africa (excl. Southern Africa) and the Middle East. Heterogeneity of results necessitates future ex-ante quantitative policy analyses on a more detailed and context-specific basis.

Keywords: Food security; diets; nutrition; health; food supply chain; economy-wide scenario analysis

JEL codes: C68, D12, I10, Q17, Q18

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Introduction

"We are what we eat", a phrase originally believed to be coined by the gastronome Anthelme Brillat-Savarin in 1826[1] has generally been interpreted as meaning that the food we eat influences our state of mind and our health. One may take this further by stating that our food choices really tell us a lot about our identity, our attitude towards life and the environment we live in. It goes without saying that food is of utmost importance in life; we need food to function well and live healthily, and spend a lot of time on producing, buying, preparing and eating it. We are what we eat, taken literally, confronts us with one of the greatest societal problems of this day and age which is that we are eating ourselves into ill health and ultimately to death. The evidence is alarming. About 850 million people, mostly living in South Asia and Sub-Saharan Africa, suffer from hunger (FAO 2013a), and over 2 billion suffer from essential micronutrient deficiencies, notably iron, vitamin A, iodine and zinc (WHO 2014), making them vulnerable to infectious diseases and reducing their capacities to live and work. At the same time, nearly 1.5 billion people are obese or overweight due to over-consumption of food and reduced physical activity (Keats and Wiggins 2014), making them prone to chronic diseases, including cardiovascular disease, diabetes and certain types of cancers. Whilst this used to be more of a developed world problem, it is increasingly becoming a problem in developing regions, which are now home to twice as many overweight or obese people as in the developed world and account for 80% of all deaths from chronic diseases, the leading causes of deaths in all regions but Africa (WHO 2013a). Malnutrition in all its forms is estimated to account for approximately 50% of all child deaths worldwide (Black et al. 2013; WHO 2013b) and is accompanied by high human suffering and large global economic losses[2], providing strong moral and economic grounds for action. But where and how to act? The answer to this question is closely intertwined with 'what we eat'.

The food we eat contains a wide diversity of macro and micronutrients in different combinations depending on the product looked at. Before we eat our food, it has been grown or bred and/or processed, may be packed, is stored, and transported to the store or market where we can buy it, after which we purchase the food (depending on our needs, income, prices and preferences), we prepare it (home cooking) or it is prepared for us (restaurants, hotels and catering), all influencing the nutrient composition of the food we eventually eat. Food supply chains, which deliver food from farm to fork, are not confined to national borders, but are increasingly global to benefit from specialisation and lower costs, with food from its raw to final form crossing borders multiple times and directions. Moreover, our world and what we eat is rapidly changing due to various local, national and global drivers of change, which may be grouped into the following broad categories: (1) technological change, economic growth and urbanisation; (2) demographic change stemming from population growth, ageing and the changing role of women; (3) globalisation of trade, foreign direct investments and information flows; (4) changing preferences, influenced by culture, religion, information and advertising; (5) environmental change, including climate change and changes in other environmental factors affecting the availability and quality of natural resources and (6) increasing demands for energy and consequently natural resources for biofuel production. Such processes alter food chains, or more broadly food systems influencing the food security[3] dimensions of availability, access and utilisation (Ingram 2011) over time and dietary and nutrition patterns in the future (Hawkes 2006;

[1] The full phrase is "dis-moi ce que tu manges, je te dirai ce que tu es", which translates as "tell me what you eat and I will tell you what you are" (Brillat-Savarin 1826).
[2] The cost of hunger and undernutrition is estimated in the range of 2-3% of world GDP per year, or 8% of world GDP in the 20th century and 6% in the first half of the 21st century (IFPRI 2014). The cost of overweight and obesity is estimated at around 2-6% or 7% of total health care costs in several developed countries (WHO 2003). Bloom et al. (2011) gather that chronic diseases will cost more than US$ 30 trillion over the coming two decades, representing 48% of global GDP in 2010.
[3] Defined as "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).

Kearney 2010; Keats and Wiggins 2014; Mazzocchi et al. 2012). All in all, 'what we eat' (or will eat) in terms of nutrients, and where they come from at a given point in time, is difficult to ascertain. It is therefore difficult to know where and how to act (and when), both for policy makers and the wider public. Economic models of the Computable General Equilibrium (CGE) type, designed to structure and explain the complex and continuously changing world we live in, could be of assistance in answering these questions.

CGE models comprehensively capture the behaviour of the various actors in the economy and how they interact in markets (Francois and Reinert 1997; Shoven and Whalley 1992). CGE models include food systems and supply chains from farm to fork in various levels of detail and incorporate trade flows at a global, regional or national scale depending on their reach. They are typically used in ex-ante scenario studies to simulate how an economy might react to changes in policy, technology or other external factors ('what if' questions). CGE models, by their nature, are able to come up with a range of plausible futures so as to deal with uncertainty. Aforementioned characteristics favour the employment of CGE models in analyses of food and nutrition security and changing diets. However, they are currently ill-equipped to do so. Since the late nineties, efforts have taken place to incorporate nutrition information associated with the consumption of food by households in CGE models so as 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 all, however, narrowly focused on macronutrient (i.e. calorie and sometimes protein) intake. Moreover, they do not capture where nutrients consumed by households come from, thereby missing out on entry points for action.

This paper elaborates on a new methodology by which nutrition impacts may be incorporated in economy-wide CGE type of analyses.[4] It has been incorporated as a nutrition module in the Modular Applied GeNeral Equilibrium Tool (MAGNET) model, but lends itself for application in other CGE models. The module calculates the nutrient content associated with the private household consumption of foods, taking FAO data on calories, proteins, fats and (implicitly) carbohydrates as embodied in primary agricultural commodities (including fish) as point of departure. It uses the flow of these commodities through the global economic system - from primary production to consumption of foods and taking into account 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: directly via the consumption of primary agricultural commodities, indirectly via the consumption of processed foods, and indirectly via the consumption of food-related services (including for example hotels and restaurants). 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 strengths of our approach viz-a-viz existing ones are threefold. First, it is able to demonstrate the origins of nutrients consumed, over time and in a global, economy-wide context, providing entry points for where (for example which sector, which region, and which component of the food supply chain), when (depending on how diets and nutrition change in response to drivers and policies) and how (for example via taxation, subsidies, information campaigns that influence tastes, investments in

[4] An earlier version of the method can be found in Rutten et al. (2013).

(bio-)fortification or other technological advances) to act if the nutrient adequacy of diets were to change. Several authors have identified this as a key area for research in view of rising and increasingly volatile food prices (Lock et al. 2009; Wiggins and Levy 2008) and the need to redirect the diet transition (Haddad, 2003). It thereby goes one step further than purely monitoring and signalling from the household consumption side. Second, the method is set up in such a way that if micronutrient data, notably iron, zinc, iodine and vitamin A are available, they can easily be added. This would make it suitable for analysing how macroeconomic shocks and/or policies impact upon diets, nutrition and eventually health. Vice versa, it could be used to analyse how targeted changes in nutrition and diets, motivated, for example, by health considerations impact upon the wider economy. This would extend the work of Shankar et al. (2008), Srinivasan et al. (2006) and Srinivasan (2007), 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. It would finally add to Lock et al.'s (2010) study for the UK and Brazil which investigates the impacts of a shift towards healthier diets, considering only the impacts of changes in saturated fat intake, via shifts in the consumption of animal-based products, on population cardiovascular disease risk and the economy. Third, by nature the method can in principle incorporate any attribute related to the production of primary agricultural commodities, which it traces from its source through the global economy to its final destination, including notably land and water use. This extends the applicability of the approach from the area of food security, diets, nutrition and health, to the area of sustainability. Sustainable food and nutrition security[5] has been identified as a priority area of work by the Centre for Integrated Modeling of Sustainable Agriculture and Nutrition Security (CIMSANS 2014) and is also a focus of the Agricultural Model Intercomparison and Improvement Project (AgMIP), a major international effort to improve climate, crop, and economic modelling with a view to improve climate impact projections for the agricultural sector (von Lampe et al. 2014).

In essence, our economic modelling approach makes the concept of 'nutrition-sensitive' agriculture (Chicago Council 2011; FAO 2013b; Fan and Pandya-Lorch 2012; Jaenicke and Virchow 2013; Thompson and Amoroso 2011) operational and allows for the methodological bridging of the traditional divide between agriculture, nutrition and health sciences (Harris et al. 2013). It thereby enables making not only agriculture, but also broader food supply chains (Hawkes and Ruel 2012), food systems (Pinstrup-Andersen 2013), and the economy as a whole nutrition-sensitive. Political will to influence diets is currently lacking due to the fear of alienating farmers, the food industry and consumers who see diets as a matter of personal choice, and this has contributed to the rather limited evidence-base on the effectiveness of policies (Keats and Wiggins, 2014). Ex-ante modelling studies such as these would add to the evidence-base, making the case for public interventions stronger.

The structure of the paper is as follows. First, the paper elaborates on the methodology of the nutrition module, and includes a description of the MAGNET model and data to which it has been applied, the purposely created nutrition data set used in the module, the module equations and resulting indicators, the validation and delimitations of the approach and the reference scenario which has been used to implement the nutrition module over time. The section after discusses nutrition outcomes by region and projected over time, and compares the results, where possible, with existing foresight studies. The

[5] Defined as when "all people at all times have physical, social and economic access to food, which is safe and consumed in sufficient quantity and quality to meet the dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life." (CFS 2012), with sustainability having not only an environmental, but also an economic (business) and social (nutrition, health, cultural diversity, human capital) dimension.

following section places the outcomes in a policy context, identifying entry points for action. By nature of the methodology, these will be limited to quantifiable economic measures. The final section concludes.

Methodology

MAGNET model and data

MAGNET (Modular Applied GeNeral Equilibrium Tool) is a multi-sector, multi-region CGE model that has been widely used to simulate the impacts of agricultural, trade, land and biofuel policies on the global economy (Banse et al. 2008; Francois et al. 2005; Rutten et al. 2013b; Rutten et al. 2014; van Meijl et al. 2006). MAGNET is based on the GTAP model, which accounts for the behaviour of households, firms, and the government in the global economy and how they interact in markets. It includes the food supply chain from farm, as represented by agricultural sectors, via food-processing industries and food-service sectors, to fork, as captured by a 'representative' household, taking into account bilateral trade flows (Hertel 1997).

MAGNET has been extended from the GTAP model so as to make it suitable for in-depth analyses in the area of agriculture, characterised by competing demands from food, feed and biofuels. Most of these changes have been documented in van Meijl et al. (2006), unless noted otherwise. They have been added in separate modules to the GTAP core which can be switched on or off depending on the policy question at hand, making MAGNET particularly flexible for use in applied policy analyses. For the purposes of this study, the land market in MAGNET is modelled with land supply endogenously responding to a land rental rate. An increase in demand for agricultural sectors will lead to land conversion into agricultural land and, if enough land is available, a modest increase in rental rates, whereas if almost all agricultural land is in use (land is scarce) increases in demand will lead to strongly rising rental rates. The allocation of land over sectors takes place according to differing degrees of substitutability. MAGNET includes segmented labour and capital markets, allowing for varying factor remunerations between agricultural and non-agricultural sectors as observed in reality. MAGNET does justice to the inherent variances in the production process of commodities, notably food, feed and fuel (Banse et al. 2008). This results in six distinctly different production structures, including for petrol (substitution between biofuels and fossil fuels), animal products (substitution between pasture land and compound feed), compound feed (substitution among feedstock), chemicals including fertilisers (substitution between land and non-land value added), ethanol (substitution among ethanol feed stock) and crop-producing sectors (substitution between land and fertilisers). MAGNET's consumption structure acknowledges that, whilst household demand for food over time rises as incomes grow, the share of the household budget allocated to food declines and, within food consumption, households substitute away from staple foods to vegetables and fruits, animal products and other processed foods (Verburg et al. 2008). This is achieved by modelling the income elasticities of consumption as a decreasing function of PPP corrected GDP per capita. Originally, the function is commodity- but not region-specific. To improve the reliability of the nutrition module outcomes, the income elasticity function was improved and made regionally dependent to take into account the region-specific relations between calorie consumption and GDP per capita observed in the data. This has been done via a dynamic recalibration procedure of price and income elasticities over time in MAGNET, which shifts the parameters, notably the income elasticities, so as to better project calories per capita per day in the future (see Valin et al. 2014).[6] Finally, key features of the EU Common Agricultural Policy (price and income support to farmers, agricultural market protection measures, agricultural quotas for milk and sugar) and biofuel policy (the biofuel directive) have been included, which influence agricultural markets and, consequently, food supply and prices.

Table 1 MAGNET aggregation: choice of countries/regions, commodities and factors of production

Countries/regions		Commodities		Factors of production	
1	Canada	1	Paddy rice	1	Land
2	USA	2	Wheat	2	Unskilled
3	Mexico	3	Other cereal grains	3	Skilled labour
4	Rest of Central America	4	Oil seeds	4	Capital
5	Brazil	5	Sugar cane, sugar beet	5	Natural
6	Rest of South America	6	Vegetables, fruits, nuts		
7	Northern Africa	7	Other crops		
8	Western Africa	8	Cattle: sheep, goats, horses		
9	Eastern Africa	9	Pigs, poultry, other live animals		
10	Southern Africa	10	Raw milk		
11	EU16	11	Other agriculture		
12	Rest of Western Europe	12	Fishing		
13	EU12	13	Forestry		
14	Rest of Eastern Europe	14	Red meat products: cattle, sheep,		
15	Turkey	15	White meat products: pigs and		
16	Ukraine, Belarus, Moldova	16	Dairy products		
17	Kazakhstan, Kyrgyzstan,	17	Sugar and molasses		
18	Russian Federation, Armenia,	18	Vegetable oils (refined) and fats		
19	Middle East	19	Other food, beverage and tobacco		
20	India, Rest of South Asia	20	Animal feed		
21	South and North Korea	21	Crude vegetable oil		
22	China, Hong Kong, Mongolia and	22	Oil cake		
23	South-east Asia	23	Biodiesel		
24	Indonesia, Papua New Guinea	24	Ethanol		
25	Japan	25	Distiller's dried grains and solubles		
26	Australia, New Zealand	26	Petroleum, coal products		
		27	Chemicals, rubber, plastic products		
		28	Other industry		
		29	Trade services (incl. wholesale,		
		30	Recreation and other services		
		31	Public services (admin, defence,		
		32	Other services		

MAGNET is based on the most recent GTAP database version 8.1 (February 2013; Narayanan et al. 2012), which contains data for 2007. For the purpose of this study, the 134 regions and 57 commodities of the GTAP database have been aggregated into more manageable categories, namely 26 regions and 32 commodities (Table 1, one sector produces one commodity unless stated otherwise). The regional structure divides the world up along broad geographical lines and in terms of regions of varying economic importance. The commodity division distinguishes the twelve primary agricultural sectors (including fishing) available in GTAP at the highest level of detail, including grains (sectors 1-3 in Table 1), crops (4-7), animal produce (8-10) and fishing (12) sectors, forestry, and six processed food categories (14-19) which use inputs from aforementioned primary agricultural sectors. Food-related service sectors, through which a lot of food is consumed indirectly, are also distinguished,

[6] In line with existing projection studies (Alexandratos and Bruinsma 2012; Kruse 2010), a ballpark figure of around 3560 kcal per capita per day was been used as a boundary value for calorie consumption per capita per day. Beyond this level income elasticities for agri-food commodities, products and services have been shifted downward, but in contrast with Valin et al. (2014) only by one shifter for all periods.

notably trade services (29), including wholesale, retail, hotels and restaurants, recreation and other services (30) and public services (31). It further distinguishes sectors through which part of the nutrients available in agricultural commodities are 'lost', including feed (20), crude vegetable oil (21, used to make refined vegetable oil, but also biodiesel), with oil cake (22) as its by-product (used for animal feed), biofuels of biodiesel and ethanol (23, 24), with distiller's dried grains and solubles (25) as by-product of ethanol (used for animal feed). Petroleum and chemicals produce fuels and chemicals (incl. fertilisers) of importance for modelling energy and fertiliser production respectively. Remaining sectors have been aggregated into other agriculture, other industry and other services. The model retains the standard GTAP specification of five factors of production, including skilled and unskilled labour, capital, land, and natural resources.

Nutrition source data

The starting point for the calculations in the nutrition module is the nutrient content of primary agricultural commodities produced in every region. The source data are obtained from the FAO, by combining nutritive factor data of the Food Balance Sheets (FAO 2001a) with primary agricultural production data (FAOSTAT) and fishing (capture and aquaculture) data (FishStat), and matching these with the GTAP sectors available in MAGNET.

The FAO nutritive factor data contain 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). The FAO primary agricultural and fishery production data include data for 205 different primary agricultural commodities and 10 fishing categories by country or region in the world. GTAP has 11 primary agricultural and fishing sectors with nutrient content, including paddy rice; wheat; other grains; oil seeds; sugar cane and beet; vegetables, fruits and nuts; other crops; cattle; pigs, poultry and other animals; raw milk and fishing (Table 1).

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 which copes with missing values and evens out deviating values (e.g. errors, outliers). Secondly, the nutritive factors for carbohydrates are calculated using the calorific values of protein, fat and carbohydrates.[7] 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 FAO primary agricultural commodities. Finally, the production volumes and the nutritional content of FAO primary agricultural commodities (in FAO regions) are aggregated to GTAP primary agricultural sectors (11) and GTAP regions (134) using MetaBase[8] concordance tables. The resulting source data for the nutrition module cover calories (million kcal), proteins (tonnes), fats (tonnes), carbohydrates (tonnes) and (FAO) quantities (tonnes) by GTAP primary agricultural commodity and region[9], which can subsequently be further aggregated according to the user's preferences (as in Table 1). Quantities are included in the nutrition source data to be able to calculate the true quantities of primary agricultural commodities contained in foods consumed by households.

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[7] 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). Since the FAO 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.

[8] 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 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.

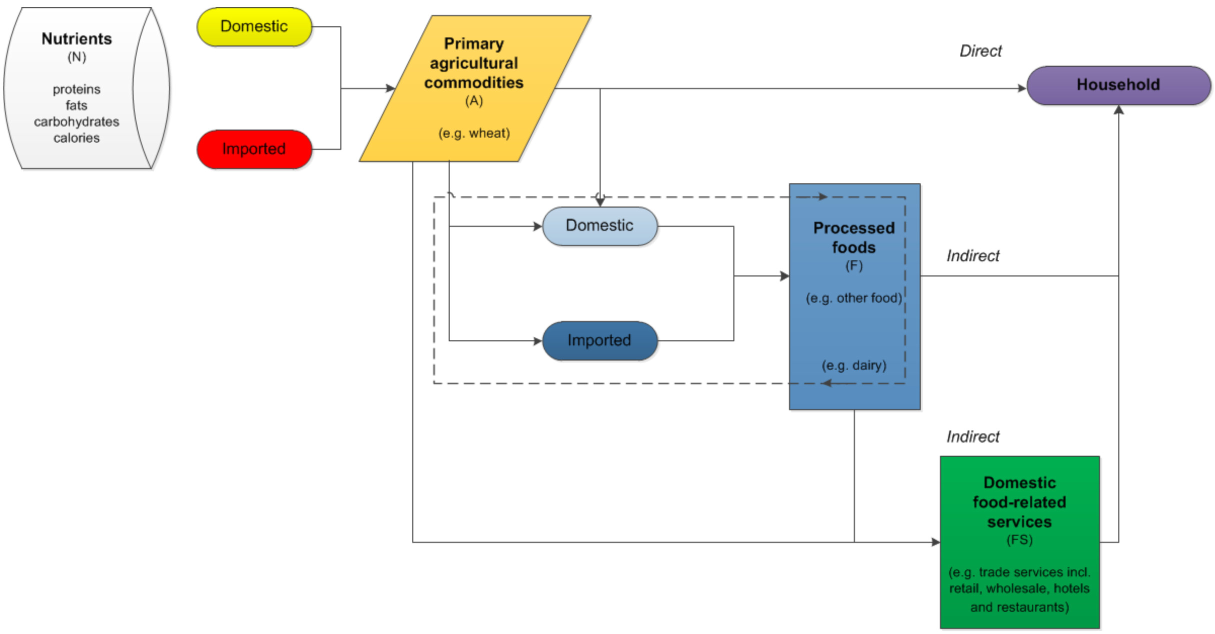
[9] Note that FAO primary production data are not explicitly present for Taiwan and so nutrient data for Taiwan in MAGNET are also lacking. They may be included in the region of China or Rest of East Asia but this is unclear.

Nutrition module

The nutrition module traces the nutrient content in primary agricultural commodities from production to final consumption by households. The method takes into account that not all produced primary agricultural commodities are consumed domestically, but are also partly exported and consumed abroad (or equivalently are not only produced domestically but also come from imports). Also, primary agricultural commodities do not necessarily end up on the household's plate but may be used, for example, as feed 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 have to account for its share in the supply of primary agricultural commodities using quantity shares, assuming a uniform market price of each primary agricultural commodity for all users (as implicit in GTAP).

Private households may consume nutrients via three channels, namely directly via the consumption of primary agricultural commodities (e.g. wheat, as present in MAGNET), indirectly via the consumption of processed foods (e.g. other food, as present in MAGNET), or indirectly via the consumption of food-related services (e.g. trade services, containing hotels and restaurants, as present in MAGNET). The first two sources of nutrients can be produced domestically or imported. Since food-related services mostly are of a local nature, 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.

Fig. 1 Visualisation of the nutrition module with its three channels of household nutrient consumption: directly via primary agricultural commodities and indirectly via processed foods and food-related services



Whereas the calculation of the nutrient content consumed directly via primary agricultural commodities is relatively straightforward, the calculation of the nutrient content of processed foods and food-related services is much more complex as it 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 procedure is needed to calculate the nutrient content of processed foods. The first approximation of the nutrient content 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.

We illustrate the workings of the nutrition module, and specifically the calculation of the nutrient content associated with each channel of household consumption, by means of a fictitious numerical example, shown in Tables 2-4, which has no bearing upon reality. The complete set of module equations has been included in Appendix 1 (MAGNET nutrition module equations).

Table 2 Illustration of direct channel of household nutrient consumption, with information used and calculation of outcomes, for a fictitious country A

Information	Coefficient \ Share	Data
Calories (kcal) in wheat production	NQ_VOM	100000000
Calories (kcal) in wheat imports	NQ_VIM	150000
- from country B: 100000 = 30% of country B's production of wheat		
- from country C: 50000 = 5% of country C's production of wheat		
Share of private household consumption in production of wheat	Q_VDPM/Q_VOM	0.03%
Share of private household consumption in imported wheat	Q_VIPM/Q_VIM	1.5%
Outcomes		
Calories (kcal) in direct consumption by private households of wheat:		
Domestically produced: 0.03% x 100000000	NQD_VDPM	30000
Imported: 1.5% x 150000	NQD_VIPM	2250

Table 2 illustrates how to calculate the household consumption of nutrients via the direct consumption of primary agricultural commodities, using the example of calories (kcal) contained in wheat for a hypothetical country A. Country A is an important producer of wheat and produces mostly for the export market. Country A produces 100 million calories in wheat and consumes 150000 calories via wheat imports, which are wheat exports from other countries - country B and C, each exporting respectively 30% and 5% of their wheat production to country A. Knowing that the share of household consumption in the production and imports of wheat is 0.03% and 1.5% respectively, household consumption of calories via the direct consumption of domestically produced and imported wheat is 0.03% x 100 million = 30000 calories and 1.5% x 150000 = 2250 calories respectively.

Building on the example of Table 2, Table 3 demonstrates how to calculate the household consumption of nutrients indirectly via the consumption of processed foods, using the example of calories (kcal) contained in wheat used to make other food (e.g. bread and pizza) and dairy products (e.g. milk and cheese) for our hypothetical country A. For simplicity it abstracts from the channel of trade, i.e. imported wheat, dairy and other food, which are simply a fraction of other countries' production of these goods destined for exports to country A, with dairy and other food imports adhering to the same iteration procedure as explained below for domestically produced dairy and other food. Moreover, processed foods other than dairy and other food are assumed absent.

Table 3 Illustration of indirect channel of household nutrient consumption via processed foods, with information used and calculation of outcomes, for a fictitious country A

Information[a]	Coefficient \ Share	Data
Round 1		
Total calories (kcal) in wheat used to produce other food (e.g. bread, pizza)	NQIF_VFM	7000000
- from wheat used to produce other food: 7% x 100000000		
Total calories (kcal) in wheat used to produce dairy (e.g. milk, cheese)	NQIF_VFM	500000
- from wheat used to produce dairy: 0.5% x 100000000		
Round 2		
Total calories (kcal) in wheat used to produce other food	NQIF_VFM	7012500
- from wheat used to produce other food: 7% x 100000000		
- from wheat used to produce dairy used to produce other food: 2.5% x 500000		
Total calories (kcal) in wheat used to produce dairy	NQIF_VFM	521000
- from wheat used to produce dairy: 0.5% x 100000000		
- from wheat used to produce other food used to produce dairy: 0.3% x 7000000		
Final round (Round 5)[b]		
Total calories (kcal) in wheat used to produce other food	NQIF_VFM	7013026
Total calories (kcal) in wheat used to produce dairy	NQIF_VFM	521039
Share of private household consumption in production of other food	Q_VDPM/Q_VOM	55%
Share of private household consumption in production of dairy	Q_VDPM/Q_VOM	60%
Outcomes		
Calories (kcal) in indirect consumption by private households of wheat via other food: 55% x 7013026	NQIF_VDPM	3857164
Calories (kcal) in indirect consumption by private households of wheat via dairy: 60% x 521039	NQIF_VDPM	312623

[a] For ease of exposition trade (imports) is abstracted from, so imports of wheat, other food and dairy used to produce other food and dairy are not included in the calculations. Moreover other processed foods are abstracted from. [b] At Round 5, the iteration has converged to a stable solution

Given that in country A 7% of wheat production is used to produce other food, and 0.5% of wheat production is used to produce dairy, the calories in wheat used to produce other food and dairy can be calculated as 7% x 100 million = 7 million and 0.5% x 100 million = 0.5 million calories respectively. This is the first approximation of calories in wheat used in other food and dairy respectively (Round 1 in Table 3). However, dairy is also used to produce other food and vice versa other food is also used to produce dairy. This is taken into account in the second iteration (Round 2 in Table 3). Specifically, knowing that 2.5% of dairy, using wheat, is used to produce other food and 0.3% of other food, using wheat, is used to produce dairy, calories in wheat used to produce other food and dairy can be calculated as 7% x 100 million (as in Round 1) + 2.5% x 0.5 million (from Round 1, dairy) = 7012500 calories and 0.5% x 100 million (as in Round 1) + 0.3% x 7 million (from Round 1, other food) = 521000 calories respectively. Continuing the iterations, whereby the result from Round 2 enters into the calculations of Round 3, and so on, the total amount of calories in wheat used to produce other food and dairy is found to converge to 7013026 and 521039 calories respectively (Round 5 in Table 3). Knowing that the share of household consumption in the production of other food and dairy is 55% and 60% respectively, household consumption of calories in wheat via the indirect consumption of other food and dairy can be calculated as 55% x 7013026 = 3857164 calories and 60% x 521039 = 312623 calories respectively.

Table 4 Illustration of indirect channel of household nutrient consumption via domestic food-related services, with information used and calculation of outcomes, for a fictitious country A

Information[a] and outcomes	Coefficient \ Share	Data
Total calories (kcal) in wheat used to produce food-related services (e.g. hotels and restaurants) - from wheat used to produce food-related services: 0.08% x 100000000 - from wheat used in other food used to produce food-related services: 8% x 7013026 - from wheat used in dairy used to produce food-related services: 13% x 521039	NQIS_VFM	708777

[a] Using information and outcomes of Table 2 and 3

Continuing from the examples of Tables 2 and 3, the calculation of the household consumption of nutrients indirectly via the consumption of food-related services is now relatively straightforward. Table 4 shows how to perform the calculations using the example of calories (kcal) in wheat and calories in wheat in other food (e.g. bread and pizza) and dairy (e.g. milk and cheese) used to make food-related services (e.g. trade services, containing hotels and restaurants) for country A. Given that 0.08% of wheat, 8% of other food and 13% of dairy is used to produce food-related services, the total amount of calories in wheat used to produce food-related services can be calculated as 0.08% x 100 million + 8% x 7013026 + 13% x 521039 = 708777 calories. This is also the total amount consumed via food-related services by households in country A.

Nutrition indicators

After having calculated the household consumption of nutrients via the 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 for all primary agricultural commodities (so not only wheat), all nutrient (so not only calories), and all regions (not only one country), various nutrition indicators can be constructed. These include:

- nutrition indicators by channel – signifying the relative importance of the various channels of household consumption of nutrients
- total and per capita nutrient indicators – which can be compared with prevailing dietary guidelines to reveal the nutrient adequacy of diets
- nutrition indicators by regional source – demonstrating the import and regional import dependency when it comes to household consumption of nutrients and
- nutrition indicators by primary agricultural sector source – indicating dependency on primary agricultural sectors when it comes to household consumption of nutrients.

The equations for these indicators have been included in the Appendix 1 (MAGNET nutrition module equations). The use of these indicators will be illustrated with an application of the nutrition module in MAGNET to a reference scenario for the future as explained below.

Validation and delimitations

The outcomes of the nutrition module in terms of household nutrient consumption need to be validated against available data, whilst the limitations of the data used themselves and the model also need to be recognised.

In order to check whether the outcomes of the nutrition module in MAGNET in the base year 2007 make sense we compare the outcomes with worldwide data on nutrition from the FAO based on food available for human consumption in 2007 (FAO Food Supply data from FAOSTAT).[10] The FAO data contain the total quantity of food 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 weaknesses of the FAO data have been reviewed in detail elsewhere (Kearny 2010; Hawkesworth et al. 2010), and mainly point to the following two issues:

1. The FAO data are a measure of food availability not actual consumption. This generally leads to an overstatement of food consumption and nutrition, especially in developed countries where food waste by households and in retail is a large problem.[11] It may lead to an understatement of food consumption and nutrition in developing countries, where official data on home production of agri-food commodities are missing;
2. The FAO relies on member states for the underlying data, with gaps, especially in developing countries, being filled by own modelling and imputed data. The quality of these FAO data and

[10] We specifically use FAO Food Supply data on nutrients by region and by commodity, based on an average for the years 2005 to 2009 to even out deviating values (including errors and outliers).

[11] Whilst the availability of data on food waste has improved, especially with the publication of a separate report on global food loss and waste by the FAO (FAO 2011), these data also suffer from serious drawbacks as definitions and methods of data collection differ by country (Rutten 2013).

computations is withering, given also that food systems are becoming increasingly complex (Hawkesworth et al. 2010).

Regarding the latter point, our method is actually designed to improve the understanding of complex processes from agri-food production, to food processing, to food consumption and nutrition, but it can only be as good as the source data used. The FAO is the sole provider of consistent world-wide food and nutrition data and so, despite its shortcomings, is our best data source.

Bearing these shortcomings in mind, how do the nutrition module outcomes compare to the FAO data on food and nutrients available for human consumption? We find that the nutrition module outcomes exceed the FAO data by 17 to 57 per cent. The difference is most pronounced for proteins (57%) and quantities of primary produce (29%) and least pronounced for calories (22%), carbohydrates and fats (17%). Deviations thus differ by nutrient and are not identical to those related to the quantities of primary produce. These results conceal differences at the primary sector and regional level and it should be noted that the nutrition module does not always produce higher outcomes compared with the FAO (Rutten et al. 2013a). Regarding primary agricultural sectors, notable outliers (all in terms of overestimation) are sugar cane and beet, oil seeds and, to a lesser extent, other cereal grains. The FAO, by exception, expresses sugar, oils and fats and beverages not in their primary equivalents, implying that the nutrition module to FAO comparison for these commodities is false and that ideally FAO data used for validation of the nutrition module outcomes should all be expressed in their primary equivalents. Regarding regions, FAO Food Supply data for consumption are missing for Hong Kong, Singapore, Taiwan, Oman, Bahrain, Qatar and Rest of World. This also explains part of the overestimation of the nutrition module viz-a-viz FAO Food Supply data. Regional outliers in terms of overestimation of the nutrition module viz-a-viz FAO nutrition data include: Oceania, 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).

Apart from the previously discussed differences in coverage and/or composition of regions and sectors, remaining differences are likely to be explained by differences in MAGNET and FAO methodologies. These include the absence of stock changes and food losses in MAGNET, which FAO does account for but only after harvesting and before final consumption.[12] These remaining differences are captured by applying correction factors to the nutrition indicators calculated for each of the channels of consumption.[13] The correction factors are calculated by dividing household nutrient consumption by nutrient type, primary agricultural sector and region (NQSECT, see Appendix 1) by the FAO data on nutrients available for human consumption by nutrient type, primary agricultural sector and region, used in the validation.

The combination of the characteristics of the data and the CGE nature of the model used to apply the nutrition module delimits the use of the approach to the analysis of medium to long term trends in food

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[12] MAGNET does not make explicit food waste by households and in retail, but FAO also does not, so this cannot explain the differences in outcomes. The same is true for the change in nutrient content and composition when mixing and processing agri-food products. MAGNET outcomes may further be improved by accounting for quality differences (i.e. differences in nutrient content) between domestically produced and trade agri-food commodities, but no data are available as yet to do so. The same is true for the implicit assumption that the prices of primary agricultural commodities are the same across all uses (e.g. for wheat used in processed foods, wheat directly consumed by households, or exported wheat), an assumption stemming from the fact that the GTAP data are in values and prices are assumed one in the base year as in most CGE models.

[13] 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 (Appendix 1).

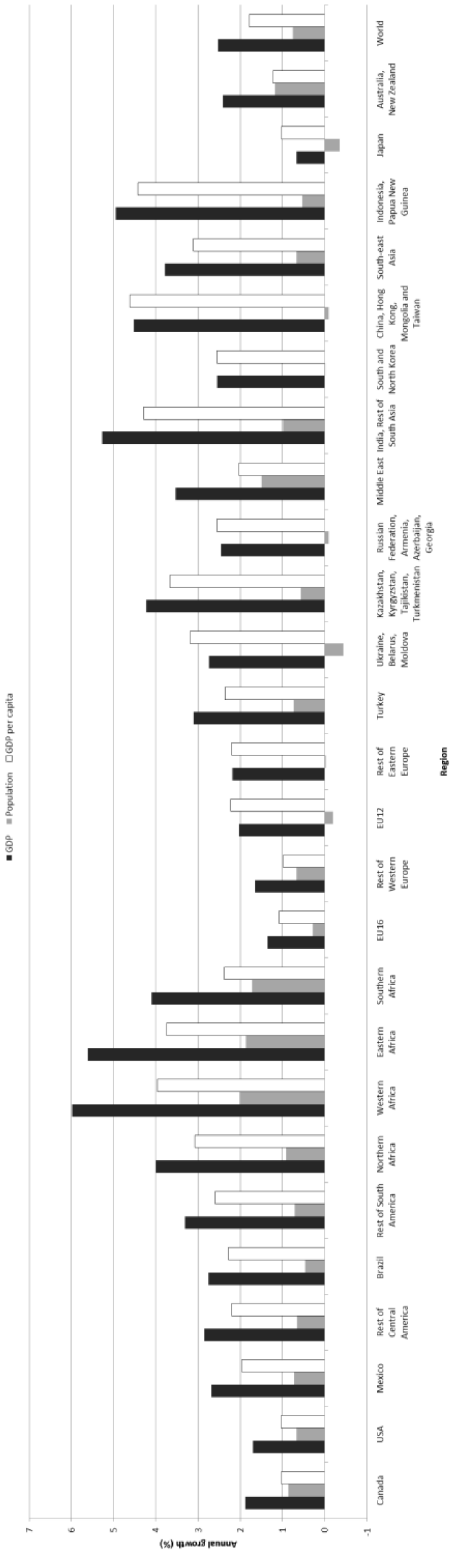
available for human consumption in relation to nutritional requirements across all countries and regions in the world. This is also a key strength of the approach. It does not provide detail at the sub-regional, household or individual level which requires different sets of data and modelling tools, with their own strengths and weaknesses (Kearney 2010; Hawkesworth et al. 2010).

Projecting into the future: SSP2 Middle of the Road Scenario

The reference scenario used to demonstrate the outcomes of the nutrition module in the future and to identify entry points for action is the Shared Socio-economic Pathway "Middle of the Road" (SSP2) scenario. This scenario is one of five potential scenarios for the future for use in climate change analyses (O'Neill et al. 2012), that are increasingly used as a basis for foresight in the area of sustainable food and nutrition security (Valin et al. 2014; van Dijk and Meijerink 2014). Of the SSP scenarios, the Middle of the Road scenario is the reference, also called baseline or business as usual, scenario, in which past trends are largely observed to continue in the future. It is characterised by "...some progress towards achieving development goals, reductions in resource and energy intensity at historic rates, and slowly decreasing fossil fuel dependency." (O'Neill et al. 2012). The scenario has been quantified by the OECD and IIASA and, for the purpose of this paper, is implemented in MAGNET from 2007-2010 and then onwards from 2010 to 2020, 2020 to 2030 and up to 2050, the time horizon commonly used, also in other scenario studies.[14] The exogenous yield changes were derived from FAO projections by Bruinsma (2003) and corrected to take into account differences between macroeconomic growth in the SSP2 scenario compared with FAO projections, and also adjusted for endogenous, economically driven, intensification. The reference scenario assumes no policy changes in the simulation periods, but only apply existing policies and those agreed upon for the future, such as milk quota abolition in the EU and mandatory biofuel targets in 2020 worldwide.

[14] Results of the Agricultural Model Intercomparison and Improvement Project (AgMIP), focusing on possible futures for agricultural markets and global food security in the presence of climate change, demonstrate that in the long term (time horizon up to 2050) projections differ across models despite the harmonisation of key assumptions implicit in models and scenarios (von Lampe et al. 2014). The value of basic model parameters, such as income and price elasticities, and data and analysis on economic behaviour and biophysical drivers, seem of crucial importance. Hence, the further into the future the higher the margin of uncertainty will be. Whilst we will not repeat this model comparison exercise, we will report key factors that explain our results.

Fig. 2 Annual population and GDP growth by region in the SSP2 Middle of the Road scenario in MAGNET, 2007-2050



The growth trajectory of the SSP2 scenario is one in which worldwide GDP and population are shown to grow on average by 2.5% and 0.8% per year over the period 2007-2050 (Figure 2). This results in a world population of 9.14 billion in 2050, from 6.62 billion people in 2007, and more than doubling of global GDP per capita over this period (112.6% increase). Fast growing economies include the extended regions of China, Indonesia and India with annual per capita GDP growth rates exceeding 4%, whereas Oceania, EU16, North America and Japan fall behind, with annual per capita GDP growth rates of well below 2%.

Results

In this section we report the outcomes of the nutrition module for the SSP2 Middle of the Road Scenario. We start with food consumption trends that follow from the underlying growth trajectory, and continue by decomposing these trends further in terms of their content of, respectively, calories, proteins and fats, and, for each of these, the channels through which these are consumed and associated sectoral/regional origins.[15] The projected consumption patterns will be compared with healthy diet guidelines where possible. Overall trends in food consumption and calorie consumption will be contrasted with outcomes of other studies, notably that of Alexandratos and Bruinsma (2012). All other indicators have not been reported elsewhere and so will be discussed as they are, highlighting interesting patterns and new insights that emerge. Supplementary tables and figures that could not be placed in the main text have been provided for in Appendix 2 (Additional nutrition projections).

Food consumption trends

Food consumption rises everywhere for all food products. With population growth in the SSP2 Middle of the Road scenario similar to that projected by the FAO, but GDP growth projections being higher, the changes in food consumption exceed those projected by the FAO. Specifically, FAO expects overall food demand to grow by 54% from 2007 up to 2050 measured in terms of calories (Alexandratos and Bruinsma 2012), whereas we find food demand to grow by 62% in this period, compared to 74% on average found by other models (Valin et al. 2014). The food consumption trends from our modelling exercise are accompanied by roughly constant global consumer market prices for food (weighted average of primary, processed and service-related agri-food sectors), differences in income growth projections thus explaining most of the change in global food demand.

The overall trends in food consumption, however, conceal differences across sectors and regions (Table 5). Our results confirm the major patterns that are predicted for the future by other scenario studies. Notably, in line with Alexandratos and Bruinsma (2012), we find that growth in per capita food available for human consumption in developed regions over time is levelling off viz-a-viz that in developing regions (growth over the period 2007-2050 of 9% and 21% respectively, compared to a world average of 16%) as per capita consumption levels are increasingly saturated. The dietary transition towards more meat, sugar, oils and fats in these regions is mostly completed (as visualised by small increases in consumption of sugar, vegetable oils, milk and to a lesser extent meat), as well as in the fast growing developing regions of China and Brazil (not shown separately). In most other developing regions, the dietary transition is still ongoing, though at a slow pace due to low per capita income growth and slowly changing habits and cultures (notably in India no red meat consumption and in Muslim cultures no pork). Consequently, per capita consumption of grains as the main staple in

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[15] Carbohydrates are not reported on as, being the most important component of energy supply, trends in carbohydrates will follow that of total energy, and indirectly follow from analyses of calorie, protein and fat projections.

developing regions continues to grow (notably maize at a rate of 34% over the period 2007-2050 compared to 10% for paddy rice and wheat, for which consumption is levelling off from 2020 onwards and even declining towards 2050).

Whereas the absolute numbers reported in Table 5 will generally differ from that of other scenario studies (Valin et al. 2014; Alexandratos and Bruinsma 2012) due to differences in methodologies used, our projected growth trends differ markedly in two respects. Firstly, in contrast with expectations on dietary transition, per capita sugar consumption in developing regions (and as a result also for the world in total) is displaying a negative rather than positive growth trend (of -13%). This is entirely due to the expected increase in demand for biofuels. The rising importance of biofuels increases demand for sugar crops and prices, leading to lower levels of human consumption in developing regions where populations are more sensitive to price changes.[16] Secondly, while paddy rice consumption is expected to rise in developed regions, the 44% projected growth seems higher than average, and can be explained from the increased importance of other (processed) food consumption (which in our model includes processed rice).

[16] From 2020 onwards, biofuel shares remain fairly constant across regions, so our projections seem reasonable.

Table 5 Global and regional food (available for human) consumption projections by sector in primary equivalents, 2007-2050

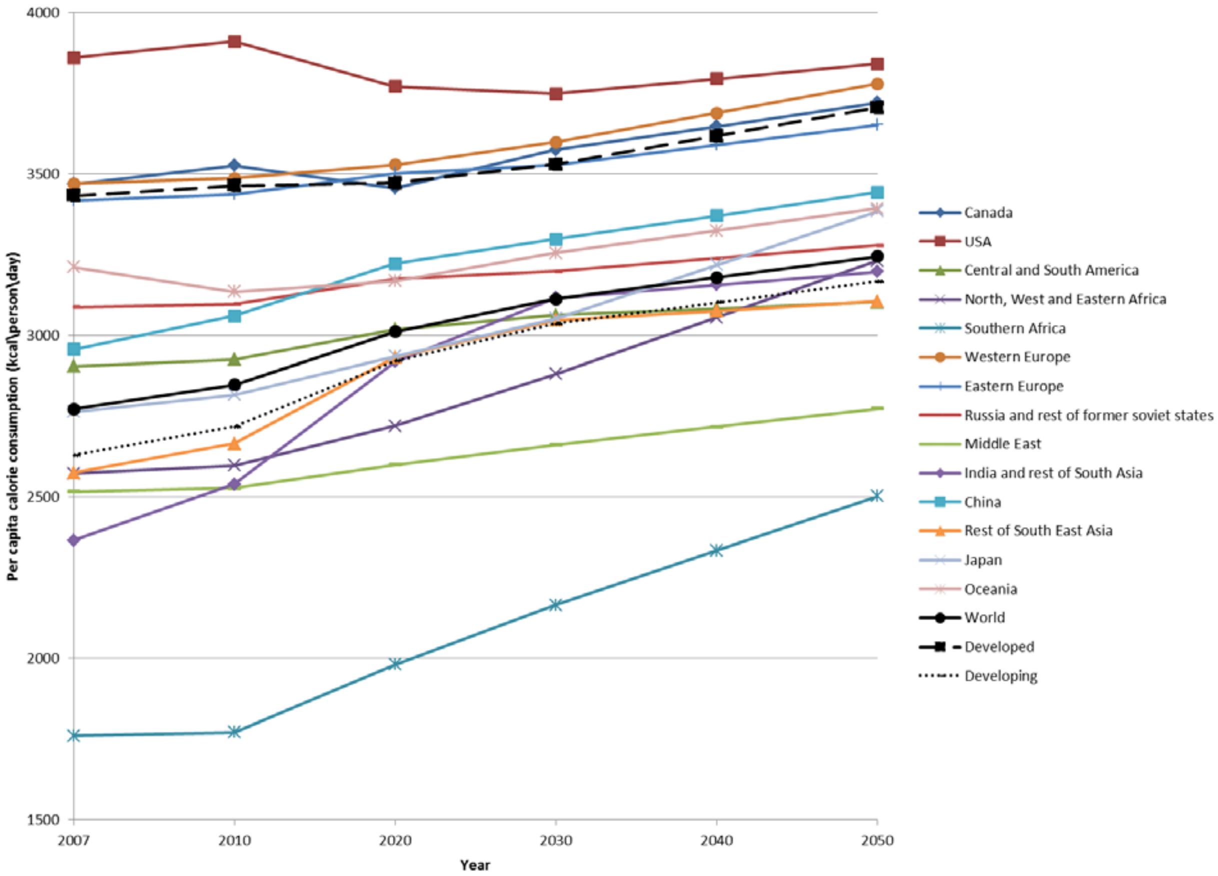
Region	World						Developed[a]						Developing[b]					
Indicator	Per capita consumption (kg\person\year)					Growth (%)	Per capita consumption (kg\person\year)					Growth (%)	Per capita consumption (kg\person\year)					Growth (%)
Year \ Period	2007	2010	2020	2030	2050		2007	2010	2020	2030	2050		2007	2010	2020	2030	2050	
Paddy rice	79	82	89	91	90	14%	17	18	19	21	25	44%[e]	92	96	103	104	101	10%
Wheat	65	67	69	69	68	5%	96	96	94	93	94	-2%	59	61	64	65	64	9%
Other (incl. maize)	59	60	63	66	73	23%	96	97	96	96	97	1%	51	53	57	61	69	34%
Grains	203	209	221	227	231	14%	209	210	209	210	216	4%	202	209	224	229	234	16%
Veg. oils	18	18	19	20	21	17%	25	25	25	24	25	0%	16	17	18	19	20	24%
Sugar	28	28	28	27	25	-11%[d]	46	48	47	47	47	2%	24	24	24	23	21	-13%[d]
Veg., fruits, nuts	267	273	288	302	328	23%	309	313	320	328	351	14%	257	264	282	297	324	26%
Other crops	4	4	4	5	7	87%[c]	8	9	10	12	16	104%[c]	3	3	3	4	5	92%[c]
Crops	316	323	340	354	380	20%	388	394	401	411	439	13%	300	308	328	344	370	23%
Red meat	14	14	14	14	15	8%	28	28	28	29	31	9%	10	11	11	11	12	15%
White meat	39	40	42	43	43	9%	79	80	82	86	92	15%	30	31	34	35	34	13%
Meat	53	54	56	57	57	9%	107	109	111	115	122	14%	41	42	45	46	46	13%
Milk	86	87	87	89	92	7%	220	221	220	221	229	4%	57	58	62	64	68	20%
Fish	19	20	23	25	28	44%	27	27	28	30	32	20%	18	19	22	25	27	53%
Total	677	693	727	752	789	16%	951	962	970	987	1039	9%	618	637	680	708	746	21%

Source: MAGNET projections [a] Canada, USA, Western and Eastern Europe, Russia, Japan, Oceania [b] World, excluding Developed [c] Crops other than vegetable oils, sugar, vegetables, fruits and nuts display relatively high growth percentages due to small initial levels of per capita consumption [d] Negative growth due to increased demand for biofuels leading to increased demand for sugar crops and prices [e] Relatively high growth due to rising importance of processed food consumption (incl. processed rice)

Calorie consumption trends

It is generally more instructive to look at consumption patterns in terms of a common unit of measurement, notably calories for which comparator projection data exist (Figure 3).

Fig. 3 Worldwide calorie(s available for human) consumption, kcal per capita per day, 2007-2050



Source: MAGNET projections. Notes: for ease of readability the regions in the model have been grouped to broader geographic conglomerates, with the projection for 2040 linearly interpolated from the projections for 2030 and 2050.

In most regions per capita calories available for human consumption features a slump over the period 2007-10 – reminiscent of the financial crisis –, with calorie consumption generally catching up from 2020 onwards, worldwide calories available for human consumption reaching an average of 3250 kcal in 2050. At the very high end are, notably, USA but also Western and Eastern Europe and Canada, with developed regions reaching a level of daily per capita calorie consumption of around 3700 kcal on average, whereas at the low end is Southern Africa, reaching a level of around 2500 kcal, with developing regions reaching a level of daily per capita calorie consumption of around 3150 on average. The latter region nonetheless records the highest growth in calorie consumption of 42% over the period 2007-2050, compared with 17% for the world on average, and, respectively, 20% and 8% for developing regions and developed regions on average. Another region that is doing remarkably well in this respect is India and Rest of South Asia, recording a growth of 35% in daily per capita calorie consumption over the same period.

These projections are in line with the FAO projections of Alexandratos and Bruinsma (2012), our calorie consumption figures on average being within a bound-with of +/-200 kcal per capita per day of the figures reported in this study. Specifically, we project the share of the world population living in regions with over 3000 kcal per capita per day to change from 25% in 2007 (28% in Alexandratos and Bruinsma 2012) to 86% in 2050 (57% in Alexandratos and Bruinsma 2012, the difference being explained by India and rest of South Asia slightly going over the 3000 mark in our modelling exercise). Similarly, we project the share of the world population living in regions with less than 2500 kcal per capita per day to change from 35% in 2007 (the same in Alexandratos and Bruinsma 2012) to 3% in 2050 (5% in Alexandratos and Bruinsma 2012), comprising the Southern African population.[17]

Combining these trends with the previously shown GDP growth trends (Figure 2) reveals that whilst per capita GDP is an important explanatory variable of nutrition (here calories available for human consumption), it is not the only one. First, looking at the starting values in 2007, whilst the extended region of China has a per capita GDP that lies below of Rest of Southeast Asia (not shown), it has almost 400 kcal per capita per day more available for consumption (Figure 3). Secondly, whilst the extended region of China records the highest per capita GDP growth of all regions, this does not translate into the highest per capita calorie availability growth (for which Southern Africa performs best). In sum, a higher (growth in) per capita GDP does not translate one to one in a higher (growth in) calorie availability per capita, a finding also supported by other literature (e.g. Bocoum et al. 2014).

Bearing this in mind, what do the calorie figures convey in terms of nutrition (and health) messages? Taking an average dietary energy requirement of 2000 kcal per capita per day[18], the trends in calories available for human consumption illustrate that, some convergence between developing and developed regions is taking place over time with developing regions catching up with developed regions and all regions reaching levels of over and above 2000 kcal per capita per day. However, the problem of excess calories for consumption and related obesity problems seems to remain much worse in developed regions compared with developing regions. The patterns moreover are likely to conceal within region or country differences with pockets of undernutrition existing in many developing, but likely also developed, regions that on average seem to be doing well.[19]

Zooming in on the regions that are on, respectively, the high and low end of daily calorie consumption, the USA and Southern Africa, the channels of consumption, and the sectoral and regional origins of the calories consumed may convey more information on the nature of the problem and so potential solutions (Table 6).

[17] Other patterns that are roughly in line with Alexandratos and Bruinsma (2012) are that we find that the share of calories available for human consumption attributable to grains is relatively constant around 48% globally (49% in Alexandratos and Bruinsma 2012), and in developing regions 53% in 2007 and 51% in 2050 (47% in 2050 in Alexandratos and Bruinsma 2012). In other words, grains continue to be the main source of total calorie consumption in developing regions. In developed regions, the share of calorie consumption attributable to grains hovers around a much lower share of 32% and can mostly be explained from indirect consumption of grains via processed foods and meats. In developed regions, most calories directly or indirectly stem from the consumption of meats, eggs, milk and vegetable oils sources, accounting for a constant share of around 40% (compared to 35% in Alexandratos and Bruinsma 2012). In developing regions this share is projected to be relatively constant at 24% (increasing from 22% in 2007 to 28% in 2050 in Alexandratos and Bruinsma 2012).

[18] Energy requirements differ by person, notably by gender, age and activity level (see, for example, FAO 2001b).

[19] Put differently, the double burden of over and undernutrition is likely to co-exist at the same time and place within regions or countries (the model, currently only showing patterns for the average household, does not allow these patterns to be shown).

Table 6 The channels of consumption (directly via primary agricultural commodities, indirectly via processed foods, indirectly via food-related services), primary sector and source region origins of calorie(s available for human) consumption, USA and Southern Africa, 2007-2050, % shares

Region	USA						Southern Africa				
Year	2007	2010	2020	2030	2050		2007	2010	2020	2030	2050
Channel of consumption (% shares)											
Direct via primary agricultural commodities	12	12	12	13	15		58	58	56	55	52
Indirect via processed foods	63	63	62	62	61		38	38	40	42	44
Indirect via food-related services	26	26	25	25	25		4	4	4	4	4
Primary sector dependency (% shares)											
Paddy rice	2	2	3	3	4		5	6	6	7	9
Wheat	16	16	16	15	15		11	11	11	11	10
Other grains	8	8	8	8	7		35	35	35	34	32
Veg. oils	19	19	18	18	17		11	11	11	11	10
Sugar	17	17	16	16	15		7	7	7	7	6
Veg., fruits, nuts	10	10	10	11	12		20	20	21	21	21
Other crops	1	1	1	2	4		0	0	0	0	0
Red meat	3	3	3	3	3		3	3	3	3	3
White meat	12	12	12	13	12		4	4	4	4	5
Milk	11	11	11	11	11		2	2	2	2	2
Fish	1	1	1	1	1		1	1	1	1	1
Import dependency (% shares)	10	10	12	14	19		11	11	12	13	17
2010 Top 10 regional import dependency (% shares)											
South-east Asia	16	17	18	19	20	South-east Asia	18	19	24	30	35
Canada	15	14	11	8	6	Rest of South America	15	15	15	14	11
Rest of South America	9	10	10	9	9	Brazil	11	11	10	8	5
Brazil	9	9	8	7	5	India, Rest of South Asia	8	8	6	6	12
Mexico	9	9	8	7	6	USA	6	5	3	2	1
China, Hong Kong, Mongolia and Taiwan	8	9	13	17	17	EU16	5	4	4	3	2
EU16	7	7	5	4	2	Canada	4	3	3	2	1
Indonesia, Papua New	5	5	6	7	8	China, Hong Kong,	2	3	5	7	8

Guinea						Mongolia and Taiwan					
Rest of Central America	5	5	4	3	2	Eastern Africa	1	1	1	2	2
India, Rest of South Asia	5	5	3	2	4	Middle East	1	1	1	2	2
Other	10	11	13	15	22	Other	3	3	4	5	8

Source: MAGNET projections

Table 6 demonstrates that in the USA most of calories that are available for human consumption are procured indirectly via processed foods (over 60%), whereas in Southern Africa most is procured directly, although this share is on the decline (from 58% in 2007 to 52% in 2050) stemming from a rise in the importance of the processed food channel (share on the rise from 38% in 2007 to 44% in 2050). Most calories available for human consumption in the USA can be traced back to the primary sectors of vegetable oils, sugar and wheat (shares of 15% or more)[20], whereas in Southern Africa calories originate mostly from other grains (over 30%), followed by vegetables, fruits and nuts (around 20%). Whilst the channels of consumption change, sectoral origins remain remarkably fixed, suggesting consumer preferences for food commodities and/or products do not change much over time and are, to a large extent, culturally determined. Considering the regional origins of calories, for both the USA and Southern Africa most calories come from domestic production (over 80%), but its reliance on imports does increase over time (from around 10% in 2007 to around 18% in 2050). Regional sourcing of these imports changes dramatically over time, with South-east Asia remaining USA's most important supplier of imported calories in 2050 (share of 20%, from 16% in 2007), followed by China (share of 17% from 8% in 2007), at a cost of Canada (share of 6% in 2050 from 15% in 2007) and other Central and South American regions. In Southern Africa, Central and South American regions, USA, Canada and EU16 also lose terrain to the benefit of South-East Asia (calorie import share increases from 18% in 2007 to 35% in 2050), India and Rest of South Asia (share increases from 8% in 2007 to 12% in 2050), China (share increases from 2% in 2007 to 8% in 2050) and a little from the Middle East and the rest of Africa.

Are these patterns generalizable to other regions in the world? Table 2A in Appendix 2 (Additional nutrition projections) demonstrates that in developed regions most calories available for human consumption are consumed indirectly via processed foods, over 50% on average, whereas in developing regions this is less so the case (notably in Africa), although on average still close to 50% is consumed via processed food commodities in developing regions, primarily reflecting consumption patterns in Asian and Central and South American economies. All in all the direct consumption channel still increases in importance relative to the indirect consumption channel, mostly due to dietary patterns in developing regions (direct consumption channel share increases from 39% in 2007 to 45% in 2050). This is in contrast with the pattern observed in Southern Africa. In many developing and emerging economies more and more calories are obtained via food-related services (food-service channel share increases from 12% to 15% on average). Table 2B in Appendix 2 (Additional nutrition projections) reveals that across the globe, changes in primary sector origins of calories available for human consumption from 2007 to 2050 remain within the +/-5% bound (pp difference) with calorie shares accounted for by wheat, other grains and sugar commodities generally declining, and also

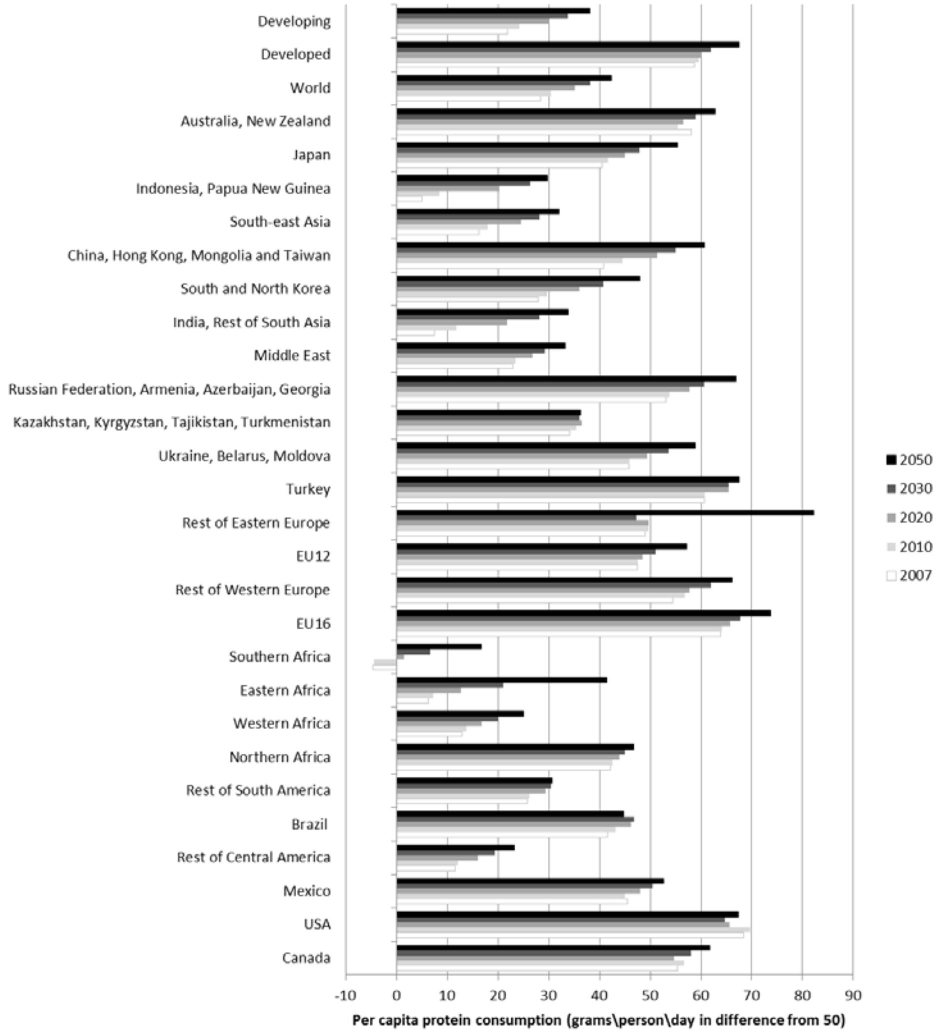
[20] Note that around 12% of calories come from white meat and only 3% from red meat, which is due to the fact that these animals are fed from cereal grains which thus adds to the share attributable to grains and lowers the shares for meat.

calorie shares for rice in Asian regions, to the benefit of, notably, white meat, vegetables and fruits, and other crops. The conclusion that dietary patterns across different types of commodities/products change only slowly over time continues to hold. Regarding regional origins of calories, Table 2C in Appendix 2 (Additional nutrition projections) shows that whilst some regions, the Americas, Europe, India and Rest of South Asia, Southern Africa, Japan and Oceania, increasingly rely on imports to supply calories to their populations, other regions are not and increasingly rely on domestic sources, notably North, West and Eastern Africa and the Middle East. The model projections into the future count on these regions increasing their agricultural production and export potential, also visible from positive changes in the use of these regions as a source of calorie imports by other regions (Table 2C, row entries for aforementioned regions). Continuing to look across the rows of Table 2C, the extended region of China, South-east Asia and Indonesia and Papua New Guinea are also shown to become more important suppliers of imported calories around the world. Looking across the columns of Table 2C, regional sourcing of calorie imports by other regions in the world are shown to change drastically over time, with Canada, Central and South America relying more on calorie imports from Western Africa, China and South-east Asia at the cost of imports from within the region and the EU16. Sourcing patterns for North, West and Eastern Africa calorie imports are similar to that of Southern Africa, though the calorie import share of North, West and Eastern Africa accounted for by Southern Africa falls and India and South-east Asia become less important source regions for calorie imports by Western Africa. For the other regions, Asia (notably China and South-east Asia, but not India) and Africa (excl. Southern Africa) become more important calorie source regions, at the cost of existing trading blocs (the Americas, Europe).

Protein consumption trends

It is interesting to have a look whether the trends observed in calories available for human consumption over time also hold for other nutrients, firstly proteins (Figure 4).

Fig. 4 Worldwide protein(s available for human) consumption, grams per capita per day, difference from 50 grams per capita per day, 2007-2050



Source: MAGNET projections. Note: 10-15 percent of our daily calories should come from proteins (FAO WHO 2003), about 56 grams for men and 46 for women, leading us to use an average daily recommended intake level of 50 grams per person (Keats and Wiggins 2014).

As with energy supply, protein supply available for human consumption increases over time generally increases, with the exception of the USA where proteins available in 2007 already exceeded the 50 grams per capita per day norm by more than a factor two. Globally, over the period 2007-2050 proteins available for human consumption increase by 18%, 8% in developed and 23% in developing regions. The latter regions start off from a much lower level of, on average, 72 grams of proteins per capita per day compared with 109 grams in developed regions and so some catching up is taking place. This projected rise in consumption of proteins is reflecting the ongoing dietary transition, mostly in developing regions, towards more meats, dairy, eggs and fish over time. The Southern African region is the only region starting off at a level of below 50 grams of proteins per capita per day, specifically 47 grams in 2007, but is able to go over the 50 grams mark around 2020. As with calories, the projected trends conceal differences at the country and within country level, where pockets of underconsumption of proteins may well co-exist with overconsumption elsewhere.

We again zoom in on the USA and Southern Africa regions that are respectively on the high and low end of daily protein consumption. Table 7 displays the channels of consumption, and the sectoral and regional origins of the calories consumed of these regions.

Table 7 The channels of consumption (directly via primary agricultural commodities, indirectly via processed foods, indirectly via food-related services), primary sector and source region origins of protein(s available for human) consumption, USA and Southern Africa, 2007-2050, % shares

Region	USA						Southern Africa				
Year	2007	2010	2020	2030	2050		2007	2010	2020	2030	2050
Channel of consumption (% shares)											
Direct via primary agricultural commodities	14	14	14	15	16		53	53	52	51	50
Indirect via processed foods	62	62	62	61	60		42	42	44	45	45
Indirect via food-related services	24	24	24	24	23		5	5	4	4	5
Primary sector dependency (% shares)											
Paddy rice	1	1	2	2	2		4	4	4	5	7
Wheat	17	17	17	16	16		13	13	12	12	12
Other grains	3	3	3	3	3		33	33	33	32	29
Veg. oils	3	3	3	2	2		4	4	3	3	3
Sugar	0	0	0	0	0		2	2	2	2	2
Veg., fruits, nuts	9	9	10	10	10		18	18	18	18	18
Other crops	1	2	2	2	3		1	1	1	1	1
Red meat	13	13	13	12	12		8	8	9	9	10
White meat	27	27	27	27	27		10	10	10	11	11
Milk	19	19	19	19	19		5	5	4	4	5
Fish	5	5	5	5	5		3	3	4	4	4
Import dependency (% shares)	9	9	11	13	17		11	11	11	12	15
2010 Top 10 regional import dependency (% shares)											
Canada	20	19	15	11	8	Rest of South America	16	16	16	16	14
South-east Asia	13	13	14	15	15	South-east Asia	14	14	18	23	27
Rest of South America	10	10	11	11	12	Brazil	9	9	8	7	4
Mexico	10	10	9	8	6	India, Rest of South Asia	8	8	6	6	11
China, Hong Kong, Mongolia and Taiwan	7	8	14	20	20	USA	7	6	4	3	1
Brazil	7	7	7	5	4	EU16	6	6	5	4	3
EU16	8	7	5	4	2	Canada	5	4	3	3	2
Australia, New Zealand	6	6	7	6	6	China, Hong Kong, Mongolia and Taiwan	3	3	7	11	11
India, Rest of South Asia	5	5	3	2	4	Middle East	1	1	2	2	3
Rest of Central America	5	5	4	3	2	Eastern Africa	1	1	1	2	3

Other	9	10	12	14	21	Other	4	4	5	6	9

Source: MAGNET projections

It shows that in the USA proteins are mostly (for around 60%) are procured indirectly via processed foods, whereas in Southern Africa mostly is procured directly (around 50%) but this share is on the decline to the benefit of the indirect processed food channel. This is unsurprising since most protein-rich foods (e.g. meats, milk), require some form of processing before they can be eaten. Comparison with Table 6 for calories in the USA and Southern Africa, reveals that the percentage shares by channel are almost identical for calories and proteins, which is to be expected for all macronutrients since they provide the energy (calorie) content of foods. The same cannot be said for the sectoral origins of proteins versus calories. In the USA proteins mostly come from red and white meat products, milk and wheat (% shares of around 13%, 27%, 19% and 17% respectively), whereas in Southern Africa most proteins originate from vegetables, fruits and nuts (18%) and other grains (around 30%), although the latter are slightly falling to the benefit of livestock products. Nonetheless, for both regions sectoral origins, as before, remain remarkably fixed. As with calories, most proteins in the USA and Southern Africa regions are supplied using domestic production, although the importance of imported proteins increases over time, from 9% to 17% in the USA and from 11% to 15% in Southern Africa, with considerable variation in regional sources of imported proteins. Whilst the absolute numbers and ordering of regional sources differ somewhat from that of Table 6, for imported calories, the top 10 regional import sources and changes over time are roughly the same. Notably visible are the increasing importance of China and South-east Asia for imports of proteins by the USA, at the cost of other countries in the region. In Southern Africa, Central and South American regions, USA, Canada and EU16 also lose terrain to the benefit of South-East Asia, India and Rest of South Asia, China and the Middle East and the rest of Africa.

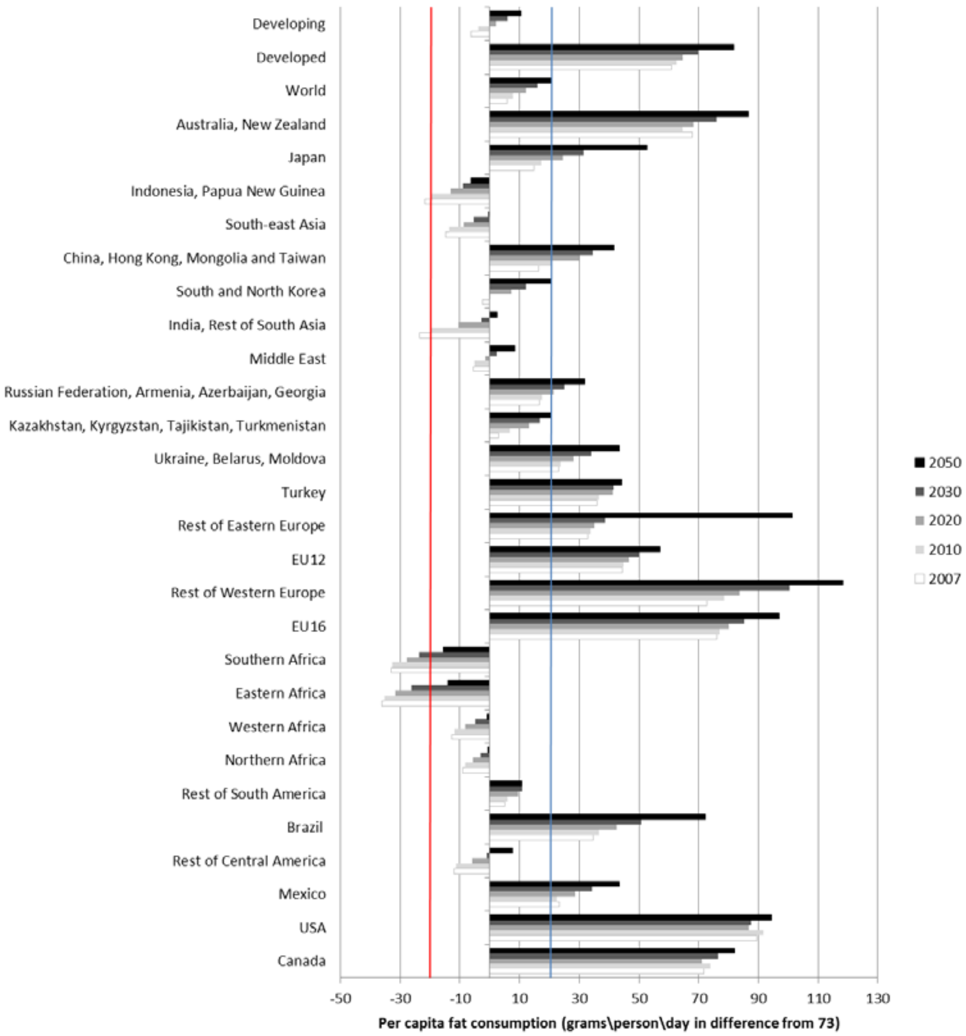
The protein consumption channels and sourcing patterns for other regions in the world are shown in Tables 2D (channels of consumption), 2E (primary sector sourcing) and 2F (regional sourcing) in Appendix 2 (Additional nutrition projections). As with calories, they reveal that, across the globe, changes in primary sector origins of proteins available for human consumption from 2007 to 2050 with a few exceptions also remain within the +/-5% bound (pp difference) with protein shares accounted for by wheat and other grains generally slowly decline, and also protein shares for rice in Asian regions, to the benefit of, notably, white meat, fish, vegetables and fruits, and other crops (Table 2E). Changes in the regional origins of proteins (Table 2F) and the channels of consumption (Table 2D), whilst numbers differ, are similar to those described for calories and therefore not repeated.

Fat consumption trends

For fats, the projected trends of availability for human consumption in the future are as follows (Figure 5).

World fat consumption is projected to increase by 19% over the period 2007-2050, with developing regions' fat consumption growing faster than and so catching up with developed regions (25% compared with 15% respectively). In contrast with the analyses for calories and proteins availability, not only Southern Africa but other regions as well start off at too low levels of fat. These regions include Indonesia and Papua New Guinea, India and Rest of South Asia, Eastern Africa, which are below the 53 grams of fats per capita per day line, and South-east Asia, Middle East, Western and Northern Africa and Rest of Central America which are below the 73 grams per capita per day line. On the other side most other regions have way over the 93 grams of fat per capita per day. The fast growing fat consumption, notably in developing regions, is reflecting the ongoing diet transition towards more fatty products, which in these countries may well coexist with insufficient access to essential fats for other parts of the population (concealed in the regional figures). For ease of comparison with the analyses of energy and protein availability for human consumption we first zoom in on Southern Africa and USA, after which we broaden the analysis to other regions in the world.

Fig. 5 Worldwide fat(s available for human) consumption, grams per capita per day, difference from 73 grams per capita per day, 2007-2050



Source: MAGNET projections. Note: in line with Keats and Wiggins (2014) we use the USDA guideline of an average of 53 to 93 grams of fat per capita per day, translating into a midrange of 73 grams of fat per capita per day. The red line and blue line indicate the 53 grams and 93 grams mark respectively.

Regarding the sourcing of fats consumed in the USA and Southern Africa, patterns are largely congruent with those observed for calories and proteins, but perhaps a little more extreme (Table 8). Specifically, around 2/3rd of fats in the USA is procured indirectly via processed foods, whereas close to the same percentage in Southern Africa is being procured directly via primary agricultural commodities, with the latter being on the decline (from 61% in 2007 to 56% in 2050) to the benefit of processed foods. The share of fats consumed via food-related services, around 25% in the USA and 3% in Southern Africa, as before, remain largely constant. Most prominent sectoral origins of fats (subsequent rows in Table 8) both in the USA and Southern Africa are vegetable sources (close to 50%), with livestock products accounting for most of the remainder in the USA, whereas other grains and livestock products account for the remainder in Southern Africa. There seems to be some movement in the sourcing of fats, notably over time in Southern Africa the dependency of fats from vegetable sources declining by 4% to the benefit of meats in Southern Africa. Again, this reflects the ongoing (and alarming) dietary transition towards a more meat-based diet. Other primary sector shares, as before, remain remarkably constant.

Table 8 The channels of consumption (directly via primary agricultural commodities, indirectly via processed foods, indirectly via food-related services), primary sector and source region origins of fat(s available for human) consumption, USA and Southern Africa, 2007-2050, % shares

Region	USA						Southern Africa				
Year	2007	2010	2020	2030	2050		2007	2010	2020	2030	2050
Channel of consumption (% shares)											
Direct via primary agricultural commodities	8	8	9	10	12		61	61	59	58	56
Indirect via processed foods	67	67	67	66	65		36	36	38	39	41
Indirect via food-related services	25	25	24	24	23		3	3	3	3	3
Primary sector dependency (% shares)											
Paddy rice	0	0	0	0	0		0	0	0	0	1
Wheat	2	2	2	2	2		2	2	2	2	2
Other grains	0	0	0	0	0		13	13	13	13	12
Veg. oils	49	49	48	47	45		52	52	51	50	48
Sugar	0	0	0	0	0		0	0	0	0	0
Veg., fruits, nuts	3	3	3	3	3		3	3	3	3	3
Other crops	1	1	2	4	7		1	1	1	1	1
Red meat	4	4	4	4	4		8	8	9	9	10
White meat	23	23	23	23	22		14	14	14	15	16
Milk	17	17	17	16	16		6	6	6	6	6
Fish	1	1	1	1	1		1	1	1	1	1
Import dependency (% shares)	6	7	9	12	17		8	8	9	11	15
2010 Top 10 regional import dependency (% shares)											
Indonesia, Papua New Guinea	17	17	17	17	18	South-east Asia	16	17	22	26	31
Canada	16	14	10	6	4	Rest of South America	15	15	14	12	10
South-east Asia	14	14	14	14	13	EU16	15	12	8	6	4
China, Hong Kong, Mongolia and Taiwan	11	12	19	25	24	Brazil	10	11	9	6	3
EU16	11	10	7	4	3	China, Hong Kong, Mongolia and Taiwan	4	5	13	20	18
Western Africa	5	6	11	15	23	USA	5	4	3	2	1
Rest of South America	6	6	6	5	5	Eastern Africa	3	3	3	3	5
Mexico	6	5	4	3	2	India, Rest of South Asia	3	3	2	1	3
Australia, New Zealand	4	4	4	3	3	Canada	2	2	1	1	0
Brazil	3	4	3	2	1	Australia, New Zealand	1	1	1	2	2
Other	9	8	6	5	5	Other	4	4	6	9	15

Source: MAGNET projections

Whilst in both regions most fats are sourced domestically, they more and more rely on imports for the supply of fats for human consumption, the share of fat imports over the period 2007 to 2050 increasing from 6% to 17% in the USA and from 8% to 15% in Southern Africa, with varying and considerably changing regional origins of fat imports over time. Whilst in the USA fat imports in 2007 mostly came from Indonesia and Papua New Guinea (17%), Canada (16%), South-east Asia (14%), China (11%) and the EU16 (11%) in 2050 most important fat suppliers are China (24%), Western Africa (23%), Indonesia and Papua New Guinea (18%) and South-east Asia (13%), with notably Canada and the EU16 losing out. In Southern Africa, South-east Asia, Rest of South America, EU16 and Brazil provided for most of the imported fats in 2007 (fat import shares of 16%, 15%, 15% and 10% respectively), whereas in 2050 most important fat suppliers to the Southern African market are South-east Asia, China and Rest of South America (fat import shares of 31%, 18% and 10% respectively), the Americas and the EU16 significantly losing out. The emerging importance of developing and emerging regions in fat supply to the USA and Southern Africa at the cost of American and EU countries is also observed in the analyses for calories and proteins, though the specific regions of importance and the changes therein differ somewhat.

The fat consumption channel and sourcing patterns for other regions in the world are shown in Tables 2G (channels of consumption), 2H (primary sector sourcing) and 2I (regional sourcing) in Appendix 2 (Additional nutrition projections). As with calories and proteins, they reveal that across the globe, changes in primary sector origins of fats available for human consumption from 2007 to 2050 with a few exceptions remain within the +/-6% bound (pp difference), with vegetal sources rising in importance in developed regions at the cost of animal sources, whereas in developing regions patterns in this respect are mixed. So whilst diets are changing this is a slow-going process. Changes in the regional origins of fats are more extreme and, although numbers differ, similar to those described for calories and proteins. Notably the rising importance of Western Africa, China and South-east Asia at the cost of the EU and the Americas is very visible from the figures. Finally, as for calories and proteins, the indirect channel of the consumption of fats via processed foods remains the dominant channel of food consumption in developed regions whereas in developing regions the direct channel remains important, although in emerging economies the indirect channel is almost as important and food-related service consumption of fats is on the rise.

Discussion

An important question is what our results imply for policy. We have reviewed the available policy options as identified in the literature (Appendix 3). The literature distinguishes between policies with an explicit dietary or nutrition aim versus policies that have a different goal, but nonetheless may influence dietary, food security and nutrition outcomes (Keats and Wiggins 2014). We focus on the former, but – recognising the dependency of diets and nutrition on factors within the broader economy – also briefly discuss how the latter affect diets and nutrition. We further concentrate on quantifiable measures, now or in the near future, i.e. measures that can or can potentially be taken on board in CGE or other macro types of analysis.

In constructing our overview, we made use of existing review articles and provide the main insights regarding the use, successes and failures of such policies. As noted by Keats and Wiggins (2014) and Capacci et al. (2012), evidence on use and effectiveness of policies is scarce, with evaluations – if carried out at all – being of poor quality, reflecting the low priority that is given to dietary policies. Ex-ante policy analysis, for which this study provides a starting point, could add to the scant evidence-base, providing outcomes of baseline reference and what-if scenarios of potential futures.

Table 3A (Appendix 3) provides an overview of the identified policy options targeting diets and nutrition. The overview makes clear that there are trade-offs within and across types of policies, whether directly or indirectly influencing diets and nutrition, which more often than not have to do with the varying and sometimes conflicting nature of diet and nutrition goals (e.g. focusing on under- and/or over nutrition and/or poor quality diets) within and across countries. Future ex-ante simulation analyses of impacts only can and should evaluate these on a context-specific basis. This also comes out of our results, which due to their aggregated nature conceal potential differences within regions and countries, and across socio-economic groups, but at the same time does reveal diverging trends across countries and regions over time. Also whilst trends in the projections over time are roughly similar across the macro nutrients looked at (see below), differences do exist, due to the fact that the nutrient content of the various agri-food commodities differ and so the availability of nutrients is affected differently by changes in the global economy. This would be even more so if the method would be extended to micronutrients. This heterogeneity also needs to be taken into account in impact analyses of various policy options targeting diet and nutrition goals. Some trade-offs are likely to be unavoidable.

The main results of the scenario run with the nutrition module can be summarised by the following patterns. Firstly, whilst developing regions are catching up with developed regions and slowly undergo the dietary transition, Southern Africa is a region that is still lagging behind. At the high end of nutrient consumption are developed regions, North America, and notably the US, Europe and Oceania. Secondly, looking more closely at the outliers, in the USA the processed food channel of nutrients is relatively important whereas in Southern Africa the direct consumption of primary agricultural commodities is important (though declining somewhat over time). From a modelling perspective, this suggests that in the USA, fat taxes (thin subsidies) on unhealthy (healthy) processed foods, technological advances that reduces the content of bad ingredients in processed foods (e.g. trans fats, salt), improved food labelling and information and marketing campaigns, and perhaps (conditional) cash transfers to target groups may be worthwhile to investigate. In Southern Africa, it seems worthwhile to consider technological advances in nutrients, agronomic practices and other technological advances that directly improve the availability of nutrients via primary agricultural commodities, and cash transfers that enable access to these commodities in ex-ante quantitative policy assessments. Depending on which channel dominates, similar measures or policies could be looked into in other regions. Thirdly, the relative fixedness of sectoral origins (i.e. stickiness to specific agri-food products), however, suggest that it may be difficult to change consumption patterns due to habits, beliefs and culture and results are likely to be visible only in the long term. Fourthly, for some (but not all) countries, including Southern Africa and the USA, nutrient import dependency over time increases with substantial variations in regions of origin, which implies that diets and nutrition are increasingly determined by food supplied from global food supply chains, making concerted action across the globe crucial to reach diet, nutrition and health goals. Generally, over time Asian economies, but also Africa (excl. Southern Africa) and the Middle East, gain ground as important suppliers of agri-food commodities and nutrients at a cost of Europe and the Americas so these are important players to take into consideration.

Conclusions

This study has developed a novel methodology by which nutrition impacts may be incorporated in economy-wide analyses of diets and nutrition. It is able to demonstrate the regional and sectoral origins of nutrients consumed, and the channels through which they are consumed (directly via primary agricultural commodities or indirectly via processed foods or food-related services), over time and in a global, economy-wide context, providing entry points for where, when and how to act if the nutrient adequacy of diets were to change. Further work should – next to addressing data and methodological issues identified in the paper – concentrate on 1) adding micro nutrients, 2) incorporating health impacts 3) inclusion of other non-nutrient attributes, notably land and water use, to extend applicability of the approach to the area of sustainability, 4) carrying out ex ante policy analysis, and 5) generally scaling down results (i.e. decomposing impacts across different types of countries and regions, households, different types of sectors, and so on). This can be achieved either within a general equilibrium model or by combination with other types of models, including partial equilibrium models that capture in more detail agri-food sectors, biophysical models that capture the wider ecosystem, household models that capture household heterogeneity and nutrition and population health models that capture individual level nutrition and health effects. Such interdisciplinary approaches, as recently adopted in CIMSANS and AgMIP projects, do justice to the complex, multidimensional, multiscale and dynamic nature of food systems. Applying such approaches in ex-ante policy analyses would add to the scant evidence-base and would strengthen the case for public interventions so as to improve worldwide diets, nutrition and health.

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Appendix 1: MAGNET nutrition module equations

This appendix contains the MAGNET nutrition module equations in GEMPACK (Harrison et al. 2014), the computer language in which MAGNET and GTAP are written. Whilst basic knowledge of the GTAP model (Hertel 1997) comes in handy, the module equations and descriptions have been written up in a complete and self-explanatory manner.

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 percentage change outcomes of the model. The logic for the naming of the nutrition-related coefficients follows GTAP conventions and uses the following prefixes to standard GTAP coefficient names:

- 'N' 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 (including fishing) commodities, processed foods and food-related services, we introduce the following sets:

- 'A' for primary agricultural commodities
- 'F' for processed foods
- 'FS' for food-related services
- 'N' for nutrient type (calories, proteins, fats, carbohydrates, and quantities)

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

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 as in GTAP (Harberger convention):

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
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 (following the GEMPACK language, changes are in small caps and the updating is achieved by using an equality statement):

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);

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 the Methodology section 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)} $n \in N, i \in A$

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);

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) $n \in N, i \in A$

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) $n \in N, i \in A$

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 n ϵ N, i ϵ A, j ϵ 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)} n ϵ N, i ϵ A, j ϵ 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

+ 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 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.[1]

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

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

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.

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 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.

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.

Nutrition indicators

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.

Nutrition indicators 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

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

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

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

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

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. Note that a 'per day' indicator can be obtained by division through 365.

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 of nutrients for household consumption, i.e. how vulnerable it is to changes in the world market.

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

NQRIMP(n,r,s) =

sum{i, [Q_VIPM(i,s) / Q_VIM(i,s)] * [NQ_VOM(n,i,r) * Q_VXMD(i,r,s) / Q_VOM(i,r)]}

Quantity of nutrients n consumed by households in region s via direct imports of primary agricultural commodities from r

+ sum{i, sum{j, [Q_VIPM(j,s) / Q_VIM(j,s)] *

[NQIF_VFM(n,i,j,r)*Q_VXMD(j,r,s)/Q_VOM(j,r)] }}

Quantity of nutrients n consumed by households in region s via indirect imports of primary agricultural commodities via processed foods from r

n ϵ N, i ϵ A, j ϵ F

The share of nutrients n consumed by households in region s from imported source region r in total imported nutrient consumption:

NQRIMPSHR(n,r,s) = NQRIMP(n,r,s) / NQIMP(n,s) n ϵ N

This indicator demonstrates the dependency of one region on imports of nutrients for household consumption from another region.

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

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

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

Finally, this indicator reveals the dependency of households in a region on nutrients from a particular primary agricultural sector.

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Appendix 2: Additional nutrition projections

This Appendix contains tables with additional nutrition projections produced using the MAGNET nutrition module.

Table 2A Worldwide calorie consumption channels, 2007 and 2050, % shares

Channel	Direct – primary agricultural commodities		Indirect - processed foods		Indirect - food related services	
Region \ Year	2007	2050	2007	2050	2007	2050
Canada	13	19	68	63	19	18
USA	12	15	63	61	26	25
Mexico	35	37	65	62	1	1
Rest of Central America	34	33	55	53	11	15
Brazil	16	18	70	65	15	17
Rest of South America	25	27	60	50	15	22
Northern Africa	57	59	31	26	11	15
Western Africa	84	91	14	7	2	2
Eastern Africa	80	81	15	14	5	5
Southern Africa	58	52	38	44	4	4
EU16	23	22	56	55	21	22
Rest of Western Europe	25	25	60	59	15	17
EU12	48	50	39	36	12	15
Rest of Eastern Europe	63	53	32	41	5	5
Turkey	45	51	51	43	4	6
Ukraine, Belarus, Moldova	60	65	34	25	6	10
Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan	72	68	23	18	6	14
Russian Federation, Armenia, Azerbaijan, Georgia	45	46	42	35	13	18
Middle East	49	49	43	39	9	12
India, Rest of South Asia	37	38	56	52	6	10
South and North Korea	20	20	52	43	28	36
China, Hong Kong, Mongolia and Taiwan	31	34	49	35	21	31
South-east Asia	21	22	63	51	17	27
Indonesia, Papua New Guinea	24	26	66	55	10	18
Japan	8	8	70	70	22	22
Australia, New Zealand	16	17	57	58	27	25
World	36	42	51	43	14	16
Developed	23	24	56	55	21	22
Developing	39	45	49	40	12	15

Source: MAGNET projections

Table 2B Primary sector origins of worldwide calorie(s available for human) consumption, 2007 and 2050, % shares

Year	**2007**											**2050**										
Region \ Sector	Paddy rice	Wheat	Other grains	Veg. oils	Sugar	Veg., fruits, nuts	Other crops	Red meat	White meat	Milk	Fish	Paddy rice	Wheat	Other grains	Veg. oils	Sugar	Veg., fruits, nuts	Other crops	Red meat	White meat	Milk	Fish
Canada	3	19	7	18	14	13	1	3	13	9	1	5	16	6	16	9	19	4	3	12	8	1
USA	2	16	8	19	17	10	1	3	12	11	1	4	15	7	17	15	12	4	3	12	11	1
Mexico	2	8	35	9	15	10	0	3	11	6	1	2	8	33	11	13	10	1	3	13	5	1
Rest of Central America	13	11	19	11	15	15	1	2	7	5	1	17	9	17	12	12	17	1	2	8	5	1
Brazil	11	12	10	16	13	15	0	5	10	7	0	11	12	10	21	10	15	0	5	10	7	1
Rest of South America	10	17	12	11	14	15	1	6	8	7	1	10	16	12	11	11	17	1	6	9	6	1
Northern Africa	6	40	14	8	9	13	1	2	2	4	1	7	34	15	8	7	16	2	2	2	5	1
Western Africa	12	6	30	15	4	29	1	1	1	1	1	10	3	32	15	2	34	1	1	1	1	1
Eastern Africa	6	10	35	7	6	26	0	3	1	6	0	6	10	34	7	5	28	1	3	1	5	0
Southern Africa	5	11	35	11	7	20	0	3	4	2	1	9	10	32	10	6	21	0	3	5	2	1
EU16	2	21	7	16	11	13	1	3	13	12	2	3	20	6	14	8	13	5	3	13	12	2
Rest of Western Europe	1	20	5	12	15	11	2	3	15	14	2	3	18	5	13	10	12	4	3	18	13	2
EU12	1	26	12	11	11	12	1	1	14	11	1	2	25	11	11	9	12	3	1	14	10	1
Rest of Eastern Europe	1	26	13	10	9	15	1	3	9	11	0	5	20	8	11	9	14	4	4	14	12	0
Turkey	2	41	5	16	8	15	0	1	2	7	0	3	39	5	15	6	17	1	2	4	9	1
Ukraine, Belarus, Moldova	1	26	12	11	14	14	1	3	8	9	1	1	25	11	10	12	15	3	2	9	10	1
Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan	2	46	5	9	6	11	1	6	3	11	0	3	42	4	13	6	10	1	7	4	9	0
Russian Federation, Armenia, Azerbaijan, Georgia	1	33	9	9	12	13	1	4	7	10	1	2	31	9	8	9	13	1	3	9	11	2
Middle East	8	37	4	11	10	15	1	3	4	6	0	9	37	4	11	7	16	1	4	5	5	1
India, Rest of South Asia	32	21	7	10	9	11	1	1	1	7	0	31	20	6	11	5	14	1	1	2	8	1
South and North Korea	30	11	11	13	8	13	0	2	8	2	3	27	12	10	14	7	14	0	1	8	1	4
China, Hong Kong, Mongolia and Taiwan	27	20	5	9	2	15	0	2	17	2	2	24	20	5	9	1	15	0	2	20	1	2
South-east Asia	48	5	5	8	8	11	1	1	10	1	2	44	6	5	8	7	13	2	1	11	1	3
Indonesia, Papua New Guinea	48	6	9	13	6	11	1	1	3	1	2	44	7	9	12	4	13	1	1	5	0	4

Japan	22	14	8	18	10	8	1	1	9	5	6	24	12	6	19	7	9	4	1	8	5	6
Australia, New Zealand	3	18	5	16	14	12	1	7	11	12	1	4	16	4	16	12	13	2	7	14	11	1

Source: MAGNET projections

Table 2C Regional origins of worldwide calorie(s available for human) consumption, 2007 and 2050 import shares (%) and change in sourcing (share 2050 – 2007, %)

Importing region	Canada	USA	Mexico	RestCeAmer	Brazil	RestSoAmer	NoAfrica	WeAfrica	EaAfrica	SoAfrica	EU16	RWeEurope	EU12	REaEurope	Turkey	UkrainePlus	AsiaStan	RussiaPlus	MiddleEast	IndiaPlus	Korea	ChinaPlus	SaEaAsia	IndonesiaPlus	Japan	Oceania
Import share 2007	26	10	8	18	11	7	26	10	5	11	24	39	12	13	4	7	12	12	36	2	17	4	11	5	17	10
Import share 2050	34	19	8	22	17	5	10	4	3	17	31	44	18	61	5	8	11	10	30	5	15	3	9	3	26	15
Change in source region (% share 2050 - % share 2007)																										
Canada	0	-9	0	-2	0	-4	-3	1	-10	-2	-1	-1	0	0	-2	0	0	0	-2	-12	-1	0	-1	0	-1	-2
USA	-28	0	-33	-23	-6	-10	-13	-8	-12	-5	-2	-1	-1	0	-10	-3	0	-3	-8	-2	-10	-6	-4	-3	-6	-6
Mexico	0	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rest of Central America	-1	-3	0	0	0	-1	0	0	0	0	-1	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0
Brazil	-3	-4	0	0	0	-5	-1	-7	-2	-6	-3	-5	5	0	-1	-2	-1	-12	-6	-3	-3	0	-2	-1	-2	-1
Rest of South America	2	-1	16	4	-18	0	8	5	0	-4	3	2	2	3	-3	0	0	2	0	0	0	0	0	0	-1	0
Northern Africa	1	0	0	0	0	0	0	6	2	1	2	4	1	2	2	0	1	1	1	0	0	0	0	0	0	0
Western Africa	13	12	2	4	5	3	7	0	4	3	13	14	12	9	9	16	4	6	6	49	6	3	9	2	5	6
Eastern Africa	0	0	0	0	0	0	0	0	0	1	5	1	1	2	0	0	1	0	2	2	0	0	0	0	0	0
Southern Africa	0	0	0	0	0	0	0	-1	-3	0	-2	0	-1	0	0	0	0	0	0	-1	0	-1	0	0	0	-1
EU16	-3	-5	-1	-2	-20	-1	-5	3	-4	-3	0	-32	-16	-9	-7	-10	-2	-7	-4	-1	-1	-3	-2	-2	-2	-8
Rest of Western Europe	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0
EU12	0	0	0	0	0	0	1	0	0	0	-1	-1	0	-6	-3	-3	-5	-1	0	0	0	0	0	0	0	0
Rest of Eastern Europe	0	0	0	0	0	0	0	0	0	0	0	-1	-2	0	0	0	0	0	0	0	0	0	0	0	0	0
Turkey	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0
Ukraine, Belarus, Moldova	0	0	0	0	0	0	1	0	-2	0	0	0	0	0	-4	0	-5	-4	2	0	0	0	0	0	0	0
Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan	0	0	0	0	0	0	-3	0	0	0	0	-1	-1	0	-1	-2	0	-10	-2	-1	0	0	0	0	0	0
Russian Federation, Armenia, Azerbaijan, Georgia	0	0	0	0	0	0	0	1	-3	0	0	1	1	-2	0	-2	3	0	4	-1	0	-1	0	0	0	0
Middle East	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0	-1	0	0	0	0	0	0
India, Rest of South Asia	0	-1	0	0	0	0	0	-4	7	3	0	0	0	0	0	-1	-1	-1	-3	0	-2	0	-5	-3	-1	-2
South and North	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Korea																										
China, Hong Kong, Mongolia and Taiwan	9	9	6	8	2	3	2	0	2	5	9	15	6	14	5	7	7	21	4	1	13	0	8	9	6	22
South-east Asia	9	3	6	14	38	3	4	-3	8	17	4	3	6	3	14	9	2	5	5	-4	0	5	0	2	0	2
Indonesia, Papua New Guinea	2	3	1	1	1	1	0	0	1	1	3	1	1	2	3	0	0	1	1	0	1	2	4	0	4	2
Japan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0
Australia, New Zealand	0	-1	2	0	0	-1	0	0	-1	0	0	0	0	0	0	0	0	0	-1	-1	-2	-2	-2	-7	0	0

Source: MAGNET projections

Table 2D Worldwide protein consumption channels, 2007 and 2050, % shares

Channel	Direct – primary agricultural commodities		Indirect - processed foods		Indirect - food related services	
Region \ Year	2007	2050	2007	2050	2007	2050
Canada	16	20	63	59	21	20
USA	14	16	62	60	24	23
Mexico	38	43	62	56	1	1
Rest of Central America	35	36	54	51	11	14
Brazil	18	22	68	60	14	17
Rest of South America	26	30	60	50	14	20
Northern Africa	61	63	28	23	11	14
Western Africa	81	88	17	9	2	3
Eastern Africa	82	84	13	12	4	4
Southern Africa	53	50	42	45	5	5
EU16	22	22	61	61	17	17
Rest of Western Europe	19	19	65	64	16	17
EU12	49	50	42	38	10	11
Rest of Eastern Europe	61	52	34	44	5	4
Turkey	53	61	42	33	4	6
Ukraine, Belarus, Moldova	62	68	32	22	6	9
Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan	81	82	17	12	2	6
Russian Federation, Armenia, Azerbaijan, Georgia	47	48	38	32	14	20
Middle East	51	52	40	36	9	12
India, Rest of South Asia	48	51	45	39	7	11
South and North Korea	25	25	44	36	31	39
China, Hong Kong, Mongolia and Taiwan	36	40	43	30	21	30
South-east Asia	29	30	54	43	17	27
Indonesia, Papua New Guinea	30	41	58	42	11	18
Japan	13	14	62	61	25	25
Australia, New Zealand	12	14	57	58	31	28
World	39	46	47	38	14	16
Developed	24	25	56	56	19	20
Developing	44	51	43	34	12	15

Source: MAGNET projections

Table 2E Primary sector origins of worldwide protein(s available for human) consumption, 2007 and 2050, % shares

Year	**2007**											**2050**										
Region \ Sector	Paddy rice	Wheat	Other grains	Veg. oils	Sugar	Veg., fruits, nuts	Other crops	Red meat	White meat	Milk	Fish	Paddy rice	Wheat	Other grains	Veg. oils	Sugar	Veg., fruits, nuts	Other crops	Red meat	White meat	Milk	Fish
Canada	2	20	4	4	1	13	2	12	23	14	6	3	17	3	3	1	17	4	12	23	12	6
USA	1	17	3	3	0	9	1	13	27	19	5	2	16	3	2	0	10	3	12	27	19	5
Mexico	1	7	30	1	3	12	1	11	19	11	4	2	7	28	1	2	12	1	12	21	9	5
Rest of Central America	10	12	18	2	0	19	2	7	16	11	4	13	10	15	2	0	20	2	7	18	10	4
Brazil	8	11	6	3	6	16	2	17	17	12	2	8	11	6	3	5	17	2	16	18	12	3
Rest of South America	7	17	9	1	0	12	2	17	18	13	5	7	15	9	1	0	13	2	17	19	11	7
Northern Africa	4	42	13	1	0	14	1	6	6	7	4	5	35	14	1	0	18	1	6	7	8	6
Western Africa	10	7	32	7	0	24	1	5	5	3	6	8	4	35	7	0	28	1	3	4	2	7
Eastern Africa	4	11	33	2	0	25	1	8	3	10	2	5	11	32	2	0	28	1	8	2	10	2
Southern Africa	4	13	33	4	2	18	1	8	10	5	3	7	12	29	3	2	18	1	10	11	5	4
EU16	1	21	3	1	6	10	2	9	22	19	7	2	20	3	1	3	9	3	9	24	18	8
Rest of Western Europe	1	20	3	1	9	8	2	10	17	22	8	2	18	2	1	5	8	3	9	23	21	7
EU12	1	28	7	1	0	10	1	5	25	19	4	1	26	7	1	0	10	2	5	27	17	5
Rest of Eastern Europe	0	26	8	1	4	15	2	9	13	19	2	3	19	5	1	3	12	2	12	22	20	2
Turkey	1	44	4	2	6	17	1	4	7	12	2	1	39	3	1	4	17	1	5	10	14	3
Ukraine, Belarus, Moldova	1	26	7	1	8	13	1	7	16	15	5	1	24	7	1	7	13	1	6	18	16	6
Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan	2	45	3	0	1	9	1	14	6	18	1	2	43	3	0	1	9	1	15	8	16	1
Russian Federation, Armenia, Azerbaijan, Georgia	1	31	4	1	6	10	1	10	15	16	6	1	28	4	1	5	10	1	8	17	17	10
Middle East	5	39	4	1	3	15	1	7	13	9	2	6	37	4	1	2	15	2	9	15	8	3
India, Rest of South Asia	25	25	8	3	0	17	2	3	2	13	3	22	22	6	3	0	19	2	2	4	12	8
South and North Korea	18	11	7	7	0	17	1	5	16	2	15	16	12	6	7	0	17	1	4	17	2	19
China, Hong Kong, Mongolia and Taiwan	16	21	2	5	0	17	0	5	22	3	8	14	20	2	5	0	16	0	5	25	2	10
South-east Asia	36	6	3	4	0	11	2	4	17	3	15	33	6	3	4	0	13	2	4	18	2	16
Indonesia, Papua New Guinea	40	7	10	7	0	8	1	3	7	2	14	32	7	8	5	0	8	1	3	11	1	25

Japan	12	11	1	10	0	7	2	5	19	8	24	13	10	1	9	0	8	2	6	18	8	24
Australia, New Zealand	2	19	2	1	4	9	1	21	19	16	6	2	16	2	1	4	9	2	20	22	15	6

Source: MAGNET projections

Table 2F Regional origins of worldwide protein(s available for human) consumption, 2007 and 2050 import shares (%) and change in sourcing (share 2050 – 2007, %)

Importing region	Canada	USA	Mexico	RestCeAmer	Brazil	RestSoAmer	NoAfrica	WeAfrica	EaAfrica	SoAfrica	EU16	RWeEurope	EU12	REaEurope	Turkey	UkrainePlus	AsiaStan	RussiaPlus	MiddleEast	IndiaPlus	Korea	ChinaPlus	SaEaAsia	IndonesiaPlus	Japan	Oceania
Import share 2007	19	9	8	18	3	6	24	10	5	11	24	26	12	12	3	6	7	11	30	2	13	4	11	6	14	8
Import share 2050	26	17	8	21	4	4	9	4	2	15	32	33	17	63	4	6	7	10	24	5	11	2	9	3	22	13
Change in source region (% share 2050 - % share 2007)																										
Canada	0	-13	0	-3	-1	-7	-3	1	-13	-3	-1	-1	0	-1	-3	0	0	-1	-1	-23	-1	-1	-1	0	-1	-4
USA	-33	0	-39	-24	-6	-11	-14	-12	-14	-6	-2	-1	-1	-1	-9	-5	-1	-6	-9	-3	-11	-8	-6	-8	-8	-8
Mexico	0	-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rest of Central America	-1	-3	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brazil	-1	-3	0	0	0	-5	0	-2	0	-4	-2	-2	0	0	-1	-5	-2	-10	-5	0	-2	-1	0	0	-1	-1
Rest of South America	5	2	23	7	-8	0	9	6	0	-2	8	4	6	5	0	0	0	4	2	0	0	0	0	1	0	1
Northern Africa	1	1	0	0	0	0	0	7	2	1	2	7	2	2	2	1	1	1	1	1	0	0	0	0	0	1
Western Africa	12	10	2	4	6	2	6	0	3	3	11	7	16	10	7	9	5	5	3	39	3	3	6	2	3	5
Eastern Africa	0	0	0	0	0	0	0	0	0	2	2	1	0	1	1	0	2	1	3	5	0	0	0	0	0	0
Southern Africa	0	0	0	0	0	0	0	-1	-1	0	-1	-1	0	0	0	0	0	0	0	-1	0	-1	0	0	0	-1
EU16	-4	-5	-2	-2	-10	-1	-4	2	-5	-3	0	-36	-20	-10	-8	-5	-2	-9	-4	-1	-2	-3	-2	-3	-3	-10
Rest of Western Europe	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	-3	0	0	0	1	0	0	0	0	-1	-1
EU12	0	0	0	0	0	0	1	0	0	0	-2	-1	0	-8	-1	-2	-2	-1	0	0	0	0	0	0	0	0
Rest of Eastern Europe	0	0	0	0	0	0	0	0	0	0	-1	-2	-1	0	-1	0	0	0	0	0	0	0	0	0	0	0
Turkey	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0
Ukraine, Belarus, Moldova	0	0	0	0	0	0	1	0	-2	0	0	0	-1	-1	-2	0	-6	-5	2	0	0	0	0	0	0	0
Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan	0	0	0	0	0	0	-3	0	0	0	0	-2	-1	0	-1	-2	0	-10	-2	-1	0	0	0	0	0	0
Russian Federation, Armenia, Azerbaijan, Georgia	0	0	0	0	0	0	0	1	-4	0	0	1	0	-3	0	0	1	0	5	-1	0	0	0	0	0	0
Middle East	1	1	0	0	0	0	0	0	2	2	1	1	1	1	0	0	0	0	0	-1	0	0	0	0	0	0
India, Rest of South Asia	0	-1	0	0	0	0	0	-4	11	3	0	0	0	0	0	0	-1	-1	-3	0	-1	0	-5	-2	-1	-2
South and North	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	-1	0

Korea																										
China, Hong Kong, Mongolia and Taiwan	11	13	5	11	6	4	2	0	3	8	12	22	9	18	9	13	13	28	6	4	15	0	11	12	10	31
South-east Asia	7	3	4	8	13	2	2	-4	6	13	4	3	4	2	6	4	1	2	3	-1	2	6	0	9	0	0
Indonesia, Papua New Guinea	1	2	1	1	0	0	0	0	1	1	1	1	1	1	2	0	0	1	0	1	1	2	3	0	2	1
Japan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0	0	0	0
Australia, New Zealand	0	0	4	1	0	-1	1	-1	-1	1	0	0	0	1	0	0	0	0	-2	-3	-4	-3	-2	-12	2	0

Source: MAGNET projections

Table 2G Worldwide fat consumption channels, 2007 and 2050, % shares

Channel	Direct – primary agricultural commodities		Indirect - processed foods		Indirect - food related services	
Region \ Year	2007	2050	2007	2050	2007	2050
Canada	7	9	73	71	20	19
USA	8	12	67	65	25	23
Mexico	25	27	74	72	1	1
Rest of Central America	29	28	58	57	12	15
Brazil	22	21	71	72	7	7
Rest of South America	16	19	71	63	13	17
Northern Africa	46	49	42	36	12	16
Western Africa	82	87	16	10	2	3
Eastern Africa	84	86	14	11	2	2
Southern Africa	61	56	36	41	3	3
EU16	7	8	71	69	23	23
Rest of Western Europe	22	21	67	66	11	14
EU12	30	35	57	50	13	15
Rest of Eastern Europe	61	47	35	49	4	4
Turkey	46	52	50	43	4	5
Ukraine, Belarus, Moldova	54	60	41	31	6	9
Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan	52	47	39	34	8	19
Russian Federation, Armenia, Azerbaijan, Georgia	48	51	43	38	9	12
Middle East	50	49	44	42	6	9
India, Rest of South Asia	62	55	35	41	2	4
South and North Korea	43	43	33	28	23	29
China, Hong Kong, Mongolia and Taiwan	35	41	45	31	20	28
South-east Asia	42	41	44	35	14	24
Indonesia, Papua New Guinea	48	50	43	35	8	15
Japan	8	8	68	69	24	23
Australia, New Zealand	16	16	57	59	26	25
World	36	42	50	43	14	14
Developed	14	15	65	63	21	21
Developing	46	51	44	37	11	12

Source: MAGNET projections

Table 2H Primary sector origins of worldwide fat(s available for human) consumption, 2007 and 2050, % shares

Year	**2007**											**2050**										
Region \ Sector	Paddy rice	Wheat	Other grains	Veg. oils	Sugar	Veg., fruits, nuts	Other crops	Red meat	White meat	Milk	Fish	Paddy rice	Wheat	Other grains	Veg. oils	Sugar	Veg., fruits, nuts	Other crops	Red meat	White meat	Milk	Fish
Canada	0	2	0	47	0	3	1	4	26	16	1	0	1	0	47	0	4	3	4	25	14	1
USA	0	2	0	49	0	3	1	4	23	17	1	0	2	0	45	0	3	7	4	22	16	1
Mexico	0	1	12	33	0	4	1	4	32	11	1	0	1	10	40	0	3	1	4	32	8	1
Rest of Central America	1	2	8	47	0	4	1	4	21	12	1	1	1	6	50	0	4	1	4	22	9	1
Brazil	1	1	1	49	0	2	0	10	24	11	0	0	1	1	60	0	2	0	7	20	9	0
Rest of South America	1	2	2	41	0	3	1	13	22	14	1	1	2	2	42	0	3	1	13	23	12	2
Northern Africa	1	9	8	45	0	5	1	7	8	15	1	1	7	7	45	0	6	4	6	8	15	2
Western Africa	1	1	12	66	0	6	1	4	5	3	2	1	1	13	68	0	7	1	2	4	3	2
Eastern Africa	1	2	14	39	0	6	1	11	6	19	1	1	2	14	39	0	7	1	10	6	19	1
Southern Africa	0	2	13	52	0	3	1	8	14	6	1	1	2	12	48	0	3	1	10	16	6	1
EU16	0	2	0	40	0	3	1	4	26	21	2	0	2	0	38	0	3	8	4	25	19	2
Rest of Western Europe	0	2	0	32	0	4	2	4	31	23	2	0	2	0	33	0	4	6	3	33	18	1
EU12	0	3	1	35	0	2	2	2	33	21	1	0	3	1	32	0	2	6	2	33	19	1
Rest of Eastern Europe	0	4	1	35	0	5	3	6	25	21	1	0	2	0	31	0	3	7	7	31	17	0
Turkey	0	5	0	60	0	8	1	3	5	15	1	0	5	0	54	0	9	1	4	7	18	1
Ukraine, Belarus, Moldova	0	4	1	40	1	3	1	6	22	20	1	0	3	1	35	1	3	8	5	23	20	2
Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan	0	8	0	37	0	3	2	18	9	22	0	0	6	0	44	0	2	3	16	11	16	0
Russian Federation, Armenia, Azerbaijan, Georgia	0	4	1	36	0	2	2	9	20	23	2	0	3	1	31	0	2	4	7	23	24	3
Middle East	1	8	2	47	0	8	1	8	11	14	1	1	7	1	46	0	8	3	9	12	12	1
India, Rest of South Asia	3	5	4	53	0	4	1	2	3	24	1	3	4	3	53	0	4	2	1	6	22	2
South and North Korea	3	2	2	52	0	5	0	4	24	5	4	2	2	2	54	0	4	1	3	24	4	4
China, Hong Kong, Mongolia and Taiwan	3	4	0	29	0	4	0	4	51	3	1	3	3	0	27	0	3	0	4	55	2	2
South-east Asia	6	1	1	37	0	4	1	2	41	3	4	6	1	1	35	0	5	3	2	41	2	4
Indonesia, Papua New Guinea	7	1	4	65	0	3	1	2	11	1	3	7	1	4	57	0	4	1	2	18	1	6

Japan	2	2	0	54	0	2	2	2	20	8	8	1	1	0	55	0	2	8	2	17	7	6
Australia, New Zealand	0	2	0	40	0	3	1	11	22	20	1	0	1	0	39	0	3	2	9	26	18	1

Source: MAGNET projections

Table 2I Regional origins of worldwide fat(s available for human) consumption, 2007 and 2050 import shares (%) and change in sourcing (share 2050 – 2007, %)

Importing region	Canada	USA	Mexico	RestCeAmer	Brazil	RestSoAmer	NoAfrica	WeAfrica	EaAfrica	SoAfrica	EU16	RWeEurope	EU12	REaEurope	Turkey	UkrainePlus	AsiaStan	RussiaPlus	MiddleEast	IndiaPlus	Korea	ChinaPlus	SaEaAsia	IndonesiaPlus	Japan	Oceania
Import share 2007	22	6	8	20	35	8	15	4	3	8	18	36	11	13	5	10	14	12	32	2	35	4	14	3	16	10
Import share 2050	29	17	8	27	47	6	9	1	3	15	27	48	19	62	8	14	13	15	28	5	32	2	12	2	24	17
Change in source region (% share 2050 - % share 2007)																										
Canada	0	-11	-1	-2	0	-1	-3	0	-4	-1	0	0	-1	0	-1	0	0	-1	-4	-6	-2	0	-1	0	-4	-5
USA	-41	0	-45	-26	-5	-5	-17	-6	-9	-4	-1	-1	-1	-1	-9	-4	-1	-7	-7	-2	-15	-10	-6	-10	-11	-10
Mexico	0	-3	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1
Rest of Central America	0	-2	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brazil	0	-2	0	-1	0	-5	-2	-4	-1	-7	-2	-11	0	-1	-1	-4	-1	-10	-8	0	-6	-1	-1	0	-1	-1
Rest of South America	3	-1	28	-1	-17	0	1	2	-2	-5	4	1	3	3	-5	-1	0	1	-3	-1	0	2	-1	1	-1	0
Northern Africa	1	0	0	0	0	0	0	3	1	1	3	3	1	2	1	0	0	0	1	0	0	0	0	0	0	1
Western Africa	14	19	3	5	4	4	18	0	15	7	16	26	19	13	13	26	3	12	15	27	10	4	9	3	10	5
Eastern Africa	0	0	0	0	0	0	2	0	0	2	0	0	0	1	0	0	1	0	3	1	1	1	0	0	0	0
Southern Africa	0	0	0	0	0	0	0	-2	-5	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1
EU16	-5	-8	-3	-4	-25	-4	-8	-13	-8	-10	0	-39	-22	-21	-11	-22	-2	-19	-7	-4	-1	-3	-3	-6	-3	-15
Rest of Western Europe	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0
EU12	0	0	0	0	0	0	-1	0	0	0	-3	-2	0	-12	-6	-4	0	-2	0	0	0	0	0	0	0	0
Rest of Eastern Europe	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	0
Turkey	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	-1	0	0	-1	0	0	0	0	0	0	0
Ukraine, Belarus, Moldova	0	0	0	1	0	0	0	0	-1	0	0	0	-2	-1	-7	0	-4	-7	0	2	0	0	0	0	0	0
Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan	0	0	0	0	0	0	-1	0	0	0	0	0	-1	0	0	0	0	-1	-1	0	0	0	0	0	0	0
Russian Federation, Armenia, Azerbaijan, Georgia	0	0	0	0	0	0	-2	0	-1	0	0	0	0	0	0	-4	-3	0	0	-1	0	0	0	0	0	0
Middle East	1	0	0	0	0	0	0	0	-1	3	1	1	1	1	0	0	0	0	0	-3	0	0	0	0	0	0
India, Rest of South Asia	0	-1	0	0	0	0	-1	-2	0	0	0	0	-1	0	-2	-1	-1	-2	-4	0	-3	0	-10	-3	0	-3
South and North	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Korea																										
China, Hong Kong, Mongolia and Taiwan	14	13	11	13	1	4	3	1	4	14	16	23	10	26	6	8	11	31	5	1	17	0	12	25	6	36
South-east Asia	11	-1	2	21	43	7	9	-5	17	15	5	0	7	2	23	14	3	5	12	9	0	3	0	7	1	0
Indonesia, Papua New Guinea	4	1	1	1	1	1	1	1	1	1	3	2	1	2	2	0	0	2	2	2	0	3	6	0	4	1
Japan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0
Australia, New Zealand	0	-1	3	0	0	-1	0	-2	-4	1	0	0	0	0	0	0	0	0	-2	-2	-1	-3	-1	-19	0	0

Source: MAGNET projections

Appendix 3: Review of quantifiable policy options that directly or indirectly affect diets and nutrition

This Appendix contains a review of quantifiable policy options that could be used in ex-ante policy analyses using the MAGNET nutrition module.

Policy measures with a dietary or nutrition aim

Whilst there are various ways of categorising measures targeting food consumption or nutrition (Capacci et al. 2012; Keats and Wiggins 2014), we opt to follow the main actors in the food supply chain (primary agriculture, processing food industry, food-related services, and consumers) as these form the building blocks of our nutrient-tracing methodology (Table 3A). We further distinguish between measures targeting the food security dimensions of respectively food availability (quantity and quality) versus food access and utilisation, the former operating more on the supply side (upper left side of Table 3A), the latter operating more on the demand side (bottom right side of Table 3A).

Policies with a dietary or nutrition aim by nature mostly target the demand side, i.e. consumers, as they ultimately make the decisions as to what and how much of different types of food (and so nutrients) to consume. Consumers generally may change their behaviour in response to price incentives (via taxes and subsidies), income incentives (cash transfers), or provision of information by which they can make better dietary choices.

Price incentives could take the form of ‘fat taxes’ on unhealthy foods (such as fast foods, soft drinks and sweets) or ‘thin subsidies’ on healthy foods (such as fruits and vegetables). Whilst mostly discussed in the context of developed countries, little is known on the impacts of fat taxes due to very recent implementation in a few countries, including in Finland, Denmark and France (Mazzocchi et al. 2012; Capacci et al. 2012). These impacts depend on the size of the tax and on price elasticities. Evidence from the US, which experimented with ‘twinkie taxes’ on soft drinks and sweets in the 1960s, reveals that impacts on diets have been negligible, whilst generating a substantial amount of tax revenues (Capacci et al. 2012). In developing countries, impacts would be larger due to more price elastic demand. Cecchini et al.’s (2010) model-based analysis of health effects and cost-effectiveness of a selection of interventions in low and medium income countries demonstrates that fiscal measures – in the form of fat taxes and fruit and vegetable subsidies – are (health) cost saving and generate relatively high health effects in the medium to long term. According to Capacci et al. (2012), care should be taken with the regressive nature of fat taxes, which should be balanced with the likely progressive health effects of such taxes (the poor are likely to change their diets more in response to fiscal instruments). Subsidy measures are relatively rare, but evidence suggests that subsidies may be more (cost) effective than taxes, although subsidies may also lead to an increase in intakes of unhealthy nutrients, stemming from the income effect. Fat taxes sometimes have also sometimes been reported to lead to increased intake of unhealthy ingredients, which is due to the cross price effects (e.g. a tax on fat leading to a rise in salt intake). Due to their unpopularity with the wider public and the food industry it proves difficult to introduce or keep food taxes (Keats and Wiggins 2014). Rather, politicians have mostly relied on public information campaigns to influence consumer behaviour.

Information to consumers can be channelled via improved food labelling, and information and marketing campaigns targeting healthier eating behaviour. The challenge for modelling lies in translating these into likely changes in consumption behaviour (e.g. via shifts in taste), which may be difficult to effectuate due to strong cultural habits and beliefs. In developing countries messages focus relatively more on the care and nutrition of infants (Keats and Wiggins 2014). Campaigns could also target a reduction of food waste which not necessarily focuses on the nutritional quality of diets but rather on the quantity of food available for human consumption (although this may affect nutritional content). Restrictions on the marketing of unhealthy foods aim to discourage unhealthy diets. This is complicated due to the increasingly globalised natured of food marketing, and influenced by the rising importance of transnational food corporations, the globalisation of marketing itself and of internet and communication technology (Hawkes 2006). In Europe, advertising controls have mostly been restricted to protect the young (Capacci et al. 2012). Public information campaigns are much more common, with campaigns stressing the importance of diversification (balanced diets) with a focus on specific foods, notably discouraging excessive consumption of foods with fat, salt and sugar and stimulating vegetable and fruit consumption and foods rich in fibre. Nutrition labelling is also widely applied in the EU since it is regulated by EU law. Effectiveness studies on food labelling, information and marketing campaigns, and restrictions on the latter are not only flawed in their design, but they also reveal limited impacts in terms of actual changes in consumer behaviour (Capacci et al. 2012). Nonetheless, effects for some, such as regulation of advertising to young people, are likely to only become visible in the long run. According to Cecchini et al. (2012), food labelling has the second largest health effects of measures targeting consumer behaviour in low and medium income countries and also has favourable health cost saving implications, followed by mass media campaigns and food advertising regulation. However, as asserted by the literature at large, a combination of measures would be most effective in terms of health gains and cost-effectiveness, taking into account health cost savings in the long run.

Whereas aforementioned policies mostly focus on middle and high income settings, cash or in-kind transfers primarily take place in low income settings (Mazzocchi et al. 2012), where undernutrition is the prime concern. Transfers may take place from governments to governments, governments to households, or from households to households, within countries or between countries, may or may not be conditional, and may be in cash or in kind (food aid). The goal of food aid often is food provision to tackle acute or chronic undernutrition. It has been criticised for being used as a means to promote donor exports and as a means to dispose of surplus production, which negatively affects the development of local markets. In the last twenty years, the use of food aid as a policy instrument has declined dramatically due to trade reforms and domestic support policy reforms. Emergency food aid nonetheless has increased slightly, but is said to be unreliable and not reaching the poor. As a consequence of these developments, it seems that food aid has not been effective in terms of having a long run nutritional impact. This moreover has led to a preference for cash transfers, which have shown to be more cost effective though across regions timely disbursement is a concern. Domestic food aid programmes remain important in developed and developing country settings (e.g. food stamps in the US, food vouchers in the UK, food for education programmes in Mexico and Brazil, and food for work programs in India, Ethiopia and Bangladesh). Such programmes generally focus on overall food security and calorie intake, rather than intake of specific nutrients and seem to have been successful in doing so.

Policies on the supply side (notably in primary agriculture) are traditionally considered to be indirectly influencing diets and nutrition. In line with the literature on the importance of making agriculture and food systems nutrition-sensitive, we depart from this habit since food availability is an explicit dimension of food security and directly influencing diets and nutrition via quantities of food (and nutrients) available for consumption. We distinguish between technological improvements via which this is achieved, either focusing on changing nutrient content explicitly (relevant for primary agriculture and processed food industries) or other technologies, or via increases in natural resources that could be used to grow more food (relevant for primary agriculture only). Technological improvements often, at the same time, focus on reducing food losses and food waste, which has therefore been mentioned explicitly. Governments could push technological advances or increased resources towards food production via explicit funding, price incentives (taxes and subsidies) or rules and regulations, but we chose entry points into the modelling (exogenous technology parameters and factor input variables) for the main supply side segments of the food supply chain (primary agriculture, processed food industry and food-related services) as means of categorisation so as to avoid the difficulty of having to estimate these links.

Traditionally the focus in agriculture was on increasing productivity and specifically that of land (yields). The evidence suggests that yield increases, mostly realised during the Green Revolution, have gone at a cost of the nutritional quality of crops. Not only have legume crops and pulses, traditional local cultivars, been displaced by nutritionally inferior cereals and tubers, modern cereal varieties also contain lower levels of essential minerals as a result of the dilution effect associated with larger yields (Christinck and Weltzien 2013; Zhao and Shewry 2011). That is, whilst harvested minerals per area may have gone up, nutrient content per unit of product decreased. And modern cereal crops often only produce higher yields in situations where conditions are favourable, not in marginal conditions in which food and nutrition insecurity and vulnerability to climate shocks prevails. A move back to neglected crops that do well under these marginal conditions along with selection of crops on the basis of micronutrient content could be a solution (Jaenicke and Virchow 2013; Christinck and

Weltzien 2013). In situations where diversification into more nutritional crops is not be possible, e.g. for those on low income, biofortification may be another way forward. Biofortification is the fortification of crops, either genetically, via breeding, or agronomically, via soil or foliar (Zhao and Shewry 2011). It has the advantage of not having to rely on further processing and transport which is often infeasible in very poor and/or rural areas with households having little financial means to buy foods other than staple crops (Christinck and Weltzien 2013; Zhao and Shewry 2011). Biofortification mostly focuses on enhancement of crops with respect to nutrients that a large population is deficient in, notably vitamin A (e.g. in maize, cassava and sweet potato), zinc and iron (e.g. cereals and beans), but also iodine and selenium. If crop breeding is achieved via genetic modification, then consumer acceptance becomes a very important element of success (e.g. acceptance of change of colour that comes with vitamin A biofortification of orange fleshed sweet potato introduced in Mozambique or golden rice introduced in South and South East Asia), next to adoption by farmers. According to an ex ante assessment of HarvestPlus, a pioneer in the biofortification of crops, biofortification can be a highly cost-effective means to tackle micronutrient malnutrition (Meenakshi et al. 2010). Consumer acceptance and food safety issues are also crucial for the ultimate success of developments of novel foods, such as insect-based foods high in proteins. The challenge for modelling is to capture the change in resource use stemming from the technological improvement and to capture the impact on outputs, whether focusing on nutrient content or productivity/yields in general. Moreover, only if the methodology developed in this paper is adapted to trace nutrient content back to soils, is the modelling of agronomic fortification via enhancements of the soil feasible. Increased resources, such as land and water, to enable higher agricultural production levels, is also propagated as a solution (Lock et al. 2009; FAO 2013b) but could prove difficult due to increased competition for scarce natural resources from other uses such as feed, biofuels, forestry, biodiversity and residential areas. Increasing resources can only be modelled if these resources are properly accounted for in the model (sometimes problematic for water, traditionally a non-priced resource).

The stage of food processing also offers an opportunity to enhance foods with nutrients, called food supplementation or fortification. Examples are adding iodine to salt, vitamin A or folic acid to bread, iron to breakfast cereals, and vitamin A to vegetable oils. Food supplementation forms a good alternative to diversification but only works if the food supply chain is well functioning well, i.e. if foods are able to reach the market and the end consumer (Jaenicke and Virchow 2013; Zhao and Shewry 2011). The opposite of food supplementation or fortification is to reduce the content of nutrients that are harming population health, such as salt and trans fatty acids, mostly of concern in middle and high income countries. As with the dilution effect associated with yield increases in agriculture, in food processing food losses can reduce food and nutrients available for consumption. Similarly food processing, whilst sometimes needed in order to make food safe (e.g. pasteurised milk), palatable (grains) and available all year round (canned, dried or froze fruit and vegetables), can have negative health consequences through excess energy, sugar, salt and fat. These contradicting processes, with the negative impacts more often than not dominating in the debate, lead to negative and opposing attitudes by local and organic food movements (Keding et al. 2013).

Relatively little attention is given in the literature to food-service sectors, whereas evidence suggests that gains are to be realised from technological advances in food storage and preparation, and from reducing food waste specifically (WRAP 2011; Rutten et al. 2013).

Table 3A Policy measures with a dietary or nutrition aim: categorised by food chain element, food security dimension and category of measures

Food security dimension:	**Food availability**			**Food access and utilisation**		
Food chain element:	**R &D investment in nutrient technology**	**R & D investment in other technologies**	**Natural resources**	**Taxes and subsidies**	**Information**	**In-kind or cash transfers**
Primary agriculture	Genetic (via crop breeding) or agronomic (via soil or foliar) biofortification	Increase yields (productivity of land) or productivity of a combination of production factors and intermediate inputs (pesticides, fertiliser, seed) via plant breeding or other improved agronomic practices Technologies to reduce food losses Technologies that create novel foods	Free up land for the production of food; Increase availability of high quality water	x	x	x
Processed food industry	Supplementation Reduction of bad ingredients	Technological advances in food processing Technologies to reduce food losses	x	x	x	x
Food-related services (distribution)	x	Technological advances in food storage and preparation Technologies to reduce food waste	x	x	x	x
Consumers: households and individuals	x	x	x	Fat taxes (unhealthy foods) Thin subsidies (healthy foods)	Food labelling Information and marketing campaigns targeting healthier and diversified eating behaviour and reducing food waste Restricting marketing of unhealthy foods	(Conditional) cash transfers and food aid (within or between countries)

Complementary policies indirectly affecting diets and nutrition

Policy measures that do not target diets and nutrition but nonetheless affect it, have been extensively reviewed by Mazzocchi et al. (2012). The brief overview presented here is primarily based on this source of information. The most important policies indirectly affecting diets and nutrition can be categorised into domestic support policies aimed at protecting farmers, trade policies stimulating trade / protecting domestic markets, biofuel policies encouraging biofuel production and climate change policies fostering adaptation to or mitigation of climate change.[2] The majority of these policies directly relate to the major drivers of change of food systems change, food security, diets and nutrition identified in the introduction. If put in a similar structure as in Table 3A, they would appear on the food supply side (top three rows), with domestic support and trade policies affecting mostly primary agriculture and processed foods through (input and output) taxes and subsidies (and for trade measures also via non-tariff measures); biofuel policies affecting food availability in primary agriculture primarily by diverting natural resources away from food production; and climate change and policies to address these also affecting food availability in primary agriculture primarily via yields (e.g. drought-tolerant crop varieties) and natural resources or more generally factors of production (e.g. irrigation, reforestation, relocation of crop areas and people, i.e. migration). Since measures in the latter categories have been discussed already, policy measures to mitigate or adapt to climate change are not explicitly discussed further.

Regarding biofuel policies, biofuel production expansion directly reduces the availability of some food crops, notably maize and sugar cane and so increasing their prices and thereby encouraging substitution towards rice and wheat consumption, whose prices then also increase. This is likely to have impacted upon diets of the poor, that are dominated by grains, but according to Mazzocchi et al. (2012) concrete evidence for this is lacking. Any quantitative modelling study should distinguish between impacts on net food producers, who are depending on food prices as source of income and (for whom biofuel production could be an important source of income too) and net food consumers, whose expenses are influenced by the height of food prices.

On agricultural policies, Mazzocchi et al. (2012) find that agricultural support policies in the OECD according to some studies have led to a deterioration of diets because of subsidised production of dairy (leading to excessive consumption of fats), but according to other, more convincing evidence has led to dietary improvements since support policies have increased domestic prices, acting as a food tax, and relatively more so for energy-dense commodities (sugar, beef and milk) than for vegetables and fruits. Undoing this would therefore worsen diets, though it is found that the effects will have been small due to the weak price transmission between agricultural policies and consumer food prices. Elsewhere, in non-OECD countries, support levels have been much less and evidence on dietary impacts is very limited, though price transmission effects may be stronger due to lower levels of processing and value addition along the food supply chain. According to Mazzocchi et al. (2012), the weak evidence-base suggests that socio-demographic and agricultural productivity changes are relatively more important levers.

Trade policies, like domestic support policies, have also been liberalised since the Uruguay Round in 1994 leading to reductions in tariffs and export subsidies and agreements on non-tariff barriers. With the Doha round, so far, failing no further progress has been made. Mazzocchi et al. (2012) conclude that, since price impacts for agri-food commodities are found to be limited in economic simulation models, the expansion of non-agricultural trade and accompanying worldwide economic growth has had much more impact on diets by increasing the availability and consumption of processed foods (notably oils and meats) than traditional trade policy reform.

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FOODSECURE
FOR POLICIES THAT MATTER

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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