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The Global Agriculture Perspectives System (GAPS)

Version 1.0

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Abstract

The purpose of this document is to provide a full description of FAO's partial equilibrium modelling system known as GAPS. GAPS has been developed by FAO to study the development of global food markets in the long-term and to assess how socioeconomic fluctuations, climate change and investment pay-offs may affect future global food demand. At its core GAPS is a standard recursive dynamic multi-market and multi-regional partial equilibrium model, complemented by a module enabling to report undernourishment indicators. GAPS is a simple self-contained model which specifies demand and supply for agricultural and food commodities with global coverage and great detail for low and middle income countries. It is shaped around FAOSTAT data on production and commodity balance sheets, which enables a detailed specification of agricultural and food commodities. Furthermore, GAPS allows to assess impacts of changing conditions in food commodity markets on the prevalence of undernourishment. This makes GAPS a suitable tool to simulate future food supply requirements in the context of changing demand and ambition to eradicate hunger and malnutrition.

Keywords: partial equilibrium modelling, agricultural outlook, long-term, food demand, food supply, undernourishment, food security

JEL classification: F01, O13, Q11, Q17, Q18, Q21,

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1 Introduction

1.1 History of long-term projections at FAO

FAO has carried out long-term analyses of the prospects for agriculture and food security since the early 1960s. The main purpose of these analyses is to identify challenges in world food and agricultural sectors and to offer strategic policy perspectives. This information is crucial for FAO's member countries as it offers them an international framework for determining their national policies and plans so as to respond to these emerging challenges. Moreover, this information shapes FAO's priorities for work to be done. The Indicative World Plan for Agricultural Development, published in 1970, was one of the first documents produced in this domain by FAO. Since then, long-term global perspective studies on world agriculture were published about every five to six years, along with more frequent thematic reports. Popular publications have been the series of reports titled "World Agriculture Towards 20XX (Alexandratos, 1988; Alexandratos, 1995; Bruinsma, 2003; FAO, 2006; Alexandratos, 2011; Alexandratos and Bruinsma, 2012), which had 2000 as the first end year. The most recent update, published in 2012, provided an assessment of the prospects till 2050. These studies have relied heavily on the technical expertise available within FAO, which has informed core projections on demand, supply and resource use. Attention was also given to estimates of investment requirements for achieving long-term food security and ending hunger—see for instance Schmidhuber *et al.,* (2011), Schmidhuber and Bruinsma (2011)—land, water and inputs use (Bruinsma, 2011), as well as nutrition (Schmidhuber, 2005; Shetty and Schmidhuber, 2006). The latest study looked at what is needed in order to achieve Zero Hunger by 2030 and provided estimates of additional investments needed to achieve the Sustainability Development Goals 1 and 2 (FAO, IFAD and WFP, 2015a).

A key finding of FAO's most recent long-term projections is that world food production should increase by some 60% from 2005/2007 to 2050, albeit at slower pace than in the last 30-40 years (falling from 2.2% per year during 1961-2007 to 1.1% per year during 2005/2007-2050) following the slowdown in population growth and changes in the composition and level of food consumption associated with growing household incomes. Most of this growth (77%) should take place in low and middle income countries and only 24% in high income ones. Almost 79% of the growth in crop production is anticipated to be the result of higher yields, 11% of increased cropping intensities, whereas the remaining 10% should come from expansion of arable land. The world aggregate growth masks a wide variation across countries and regions. Of particular interest is the extent to which sub-Saharan Africa and South Asia – two of the most food insecure regions worldwide – will progress to higher levels of food consumption and will ensure a sustainable use of their limited natural resources. More than 94% of the growth in crop production in South Asia – a land scarce region - should come from intensification (yield increases), whereas the rate of intensification would be somehow lower in sub-Saharan Africa (80%) and this because farming is based more on rain fed agriculture due to scarce water availability.

The methodology used in the above mentioned studies is described in a number of papers and book chapters (Alexandratos, 1995; Alexandratos *et al.,* 1982; Bruinsma *et al.,* 1983; Bruinsma, 2003; FAO, 2006; and Alexandratos and Bruinsma, 2012). The core work consisted of projecting a set of detailed Supply Utilization Accounts (SUAs) in most countries of the world, whereas a system of accounts ensured consistency between production and consumption at world level, and generated plausible results in countries and markets through technical parameters, partly derived from the Global Agro-Ecological Zones database – GAEZ (IIASA and FAO, 2012). Informed ideas about the future evolution of variables of interest were elicited from experts. In these studies real prices were assumed to remain constant over time and were used solely as weights to aggregate over goods and not to equilibrate markets.

Since 2012, efforts have been underway to complement this methodology in order to accommodate scenario analysis. Consensus emerged that studying alternative scenarios elucidates the sensitivity of the baseline to assumptions and to assess normative propositions. FAO's Global Perspective Studies Team has developed a recursive dynamic multi regional multi commodity partial equilibrium model – Global Agriculture Perspectives System (GAPS) – which simulates national and international agro-food markets and solves for supply, demand and prices that equilibrate markets by equating world supply and demand. Being a simulation model, GAPS has been designed to facilitate scenario analysis. It can be re-run under alternative assumptions at low cost, its details can be scrutinized and discussed, and its results can be reproduced, which alone opens up the possibility of a wider validation of the analyzed scenarios.

This document describes the current version of GAPS, which has been developed so as to create a consistency framework for FAO's long-term projections. GAPS v1.0 has been used to simulate scenarios analyzed in recent work of FAO, IFAD and WFP on what would be needed to achieve zero hunger by 2030 (FAO, IFAD and WFP, 2015a). Furthermore, the model can re-produce the projections of Alexandratos and Bruinsma (2012) when calibrating its dynamic parameters to this baseline. The documentation of version 1.0 helps to provide further *inter alia* accountability on how the projections of Alexandratos and Bruinsma (2012) and of FAO, IFAD and WFP (2015a) were obtained.

GAPS can accommodate exogenous assumptions on elasticities and on shifters of demand and supply curves. The current version of GAPS borrows expectations on the availability of natural resources – land and water needed to support irrigated and rain fed crop production – as well as on the productivity of livestock and on shifts of consumer preferences from Alexandratos and Bruinsma (2012). Furthermore it relies on IMPACT v3.0 (Robinson et al., 2015) regarding the responsiveness of food demand to changes of income and prices and of food production to changes of prices. Ongoing work aims at endogenising these assumptions where possible, including for example the incorporation of endogenous Engel curves of food demand.

1.2 Long-term projections for food and agriculture: what for and how?

To assess the feasibility of achieving sustainable food security, the following three dimensions have to be addressed:

- Food demand: the world population expected to continue to expand until at least 2050, which – together with ongoing urbanization and expected average per capita income growth - will push up global demand for food. These factors are also expected to accelerate dietary shifts from staple foods to more animal protein-rich foods. Continued demand for bioenergy would add to global demand for agricultural production.
- Food supply: in many parts of the world the frontier of available land, water and other natural resources is within near reach, which would require intensified (more efficient) use of those resources in order to meet increases in food demand. In addition to constraints to the availability of natural capital for agriculture, the quality of soils and other resources and

available technologies to enhance productivity will need to be considered so as to assess the long-term prospects for food supply around the world.

- Climate change: Human-induced changes to climate resulting in higher greenhouse gas concentrations are expected to cause temperatures to increase, precipitation patents to change, snow and ice cover to decrease, sea level to rise and weather to variate in a more unpredictable and extreme way. These changes may well limit the availability of natural resources in specific geographic regions, change the way diseases spread and affect the frequency they appear, and affect crop yields and livestock productivity. Although there is little consensus in the literature on the direction of the climate change effects on agricultural production worldwide, it is clear that climate change will indeed affect food supply in a rather uncertain way, whereas reducing greenhouse gas emissions and limiting the temperature increase will require *inter alia* changes in agricultural practises and technologies (FAO, 2016).

Socioeconomic fluctuations, climate change and investment pay-offs have long-term impacts on the global food markets consequently creating the need for long-term analysis of global food markets. Recent stress on food markets, as demonstrated by sharply rising prices, combined with the emergence of biofuels have highlighted some of these key long-term issues and has re-invigorated the interest of policy makers and the general public in global agricultural and food issues.

Demand for biofuels (bio-energy) has increased significantly over the past decade or so and has proven to compete with natural resource use for food production. In order to analyse the use of agricultural products for biofuel, it is necessary to model the linkage between agricultural and energy markets. This is required more in general, since energy prices affect production costs in agriculture. With the increased use of agricultural feedstock in biofuel production agricultural market conditions are influenced both from the supply and demand side, enhancing the impact on prices. In addition, biofuel-related policies and conversion technologies are influencing market conditions worldwide. One complication is that conversion technologies, for instance that of agricultural feedstock in biofuels, should be considered endogenous in a long-term analysis. Relatively high energy prices would likely increase biofuel demand but may also create latent demand for more efficient conversion when combined with higher demand for other than biofuel uses of agricultural feedstock. Lack of historical data, however, makes it difficult to empirically estimate the parameters defining the degree of responsiveness and hence the dynamic evolution of technology over time.

Long-term projections published by FAO have informed analysts and policymakers about the prospects of agricultural development and food security at the global level as well as for specific countries and regions. They have also informed about the possible implications of emerging issues and trends (such as accelerated urbanization). Projections indicate, for instance, which countries and regions are likely to face increased stress on the use of land and other natural resources because of rising food demand, where import requirements may increase to critical levels. The long-term projections focus on structural changes, on productivity growth and on the evolution of demand expected over decades. Given that these variables not only affect policy formulation but can be affected by adopted policies if the latter have lasting impacts, relevant for scenario analysis are policy measures that can shift food demand and supply in the long-run.[1]

[1] The impacts of other policies are better analysed by short- medium-term exercises. For example the reduction of an import tariff bears an impact that may barely be detected after some decades. Announced changes in specific policy measures may affect agricultural markets during a transition time of a couple of years and are studied by FAO in policy focused outlook exercises such as the joint OECD-FAO medium term agricultural outlook (see for example OECD-FAO, 2016).

2 Model specification

The GAPS model, as already mentioned in the previous sections, is designed for supporting FAO's long-term projections on food demand and supply. It is a simulation model in that it simulates the operation of national and international agro-food markets by supply and demand behavior in all markets. It is an equilibrium model as it solves for quantities and prices that equilibrate markets by equating world supply and demand. It is a partial equilibrium model because it deals only with agricultural activities and food commodities and so it covers only part of the entire economic activity. Finally it is a recursive-dynamic because the solution of one period serves as starting point for solving for the next period.

GAPS is solved using the General Algebraic Modelling System (GAMS) software and is structured in a modular way. Specific topics and features are included in separate modules that are linked to the core model whenever needed. Doing so allows to keep the code transparent, the changes traceable and it gives flexibility in using modules that are needed only for addressing specific research questions. Version 1.0 of GAPS includes one module handling the calculation of undernourishment indicators.

This section describes how the current version of the model and the module on undernourishment indicators are specified. Throughout this section the indexes *r*, *i*, t, *αc*, *αl* and *αlp* denote regions, commodities, time period, crop, meat and non-meat producing livestock activities respectively.

2.1 Supply

GAPS implements an activity-commodity framework, borrowed from the National Accountancy framework and so it separates the production activities from commodities produced. This framework was chosen because it can allow to link GAPS with models describing biophysical processes and with General Equilibrium Models that encompass all economic activities, may that be deemed necessary. Currently GAPS identifies 34 crop and 4 livestock activities, the latter separated depending on the breeding purpose of livestock, namely livestock for meat and livestock for milk and eggs (hence 7 livestock activities in total), listed in Table A.1. The sub-sections below deal with each of these groups of activities in turn.[2]

2.1.1 Crop production

Crop production activities, indexed by *αc*, are based on price-sensitive yield and harvested area response functions. Crop production activities are specified by management systems indexed by *fs,* which currently involve irrigated and rain-fed systems. The time varying shifters λ (see for more details Section 2.4) determine the response of production to non-price factors such as technological progress and management practices affecting the productivity of land, whereas the parameters α are the base year calibration factors.

Equation (2.1) determines the yield in tonnes per hectare and is specific to region *r*, crop *αc*, management system *fs* and time period *t*. The model allows for producer prices, *PP*, to differ from consumer prices *PC*. Producer prices are specific to region *r*, crop *αc*[3] and time period *t*. Equation

[2] All supply elasticities (own and cross-price) are currently taken over from the partial equilibrium model IMPACT v3.0 (Robinson et al., 2015).

[3] The index *αcp* is used alternative to the index *αc* to enable accounting for cross-price relationships.

(2.2) is a similar function for total harvested area. Total production is the product of yield and area (equation 2.3). Total crop output (equation 2.4) sums crop production across all farm systems.

$$YLD^{cr}_{r,ac,fs,t} = a^{yld}_{r,ac,fs}\lambda^{yld}_{r,ac,fs,t}\prod_{acp} PP_{r,acp,t}^{\omega^{yld}_{r,ac,acp,fs,t}} \tag{2.1}$$

$$A^{cr}_{r,ac,fs,t} = a^{area}_{r,ac,fs}\lambda^{area}_{r,ac,fs,t}\prod_{acp} PP_{r,acp,t}^{\omega^{area}_{r,ac,acp,fs,t}} \tag{2.2}$$

$$XP^{cr}_{r,ac,fs,t} = YLD^{cr}_{r,ac,fs,t}A^{cr}_{r,ac,fs,t} \tag{2.3}$$

$$XP_{r,ac,t} = \sum_{fs} XP^{cr}_{r,ac,fs,t} \tag{2.4}$$

GAPS is general enough to handle region/activity bundles that have less than full information, for example those without irrigated vs. rain fed splits. For the moment, such bundles have been kept exogenous. This applies mostly in the case of small activities in low and middle income countries.

Fertilizer use in crop production is considered exogenously and projections on future fertilizer use are taken over from Alexandratos and Bruinsma (2012).

2.1.2 Cropping intensity

Following Alexandratos and Bruinsma (2012), GAPS differentiates between arable and harvested cropland per farm system. Cropping intensity (*CI*) is measured as the ratio of harvested area over arable land, as shown in equation (2.5). A cropping intensity level greater than 1 is an indication of multi-cropping, whereas lower than 1 is an indication of set-aside or temporarily fallow land. The dynamics of the cropping intensity index are described in Section 2.7.2.

$$CI_{r,fs,t} = \frac{\sum_{ac} A^{cr}_{r,ac,fs,t}}{Arable\ land_{r,fs,t}} \tag{2.5}$$

2.1.3 Livestock production

The current version of the model considers four types of herd indexed by *al* – cattle, mutton, pig and poultry. All activities produce meat, whereas eggs are produced by poultry and milk by cattle and mutton. Herds are classified into two categories – meat producing (indexed by *al*) and non-meat producing (namely milk and eggs, indexed by *alp*), so that GAPS includes seven livestock activities, namely: cattle, mutton, pig and poultry for meat production, cattle and mutton for milk production (dairy) and poultry for egg production (see Annex 1 for a listing of all activities and commodities).

Supply of meat is the product of herd size, offtake rate (or slaughter rate) and carcass yield (kg of carcass weight per animal slaughtered). Equations (2.6), (2.7) and (2.8) determine respectively herd size (*HERD*), offtake rate (χ^{sr}) and yields (YLD^{lv}) with the factor λ representing time shifting yield growth (see for more details Section 2.4). The product of herd size and the offtake rate are assimilated to the harvested area calculation, with herd size depending on herd and feed prices (*PP* and *PFEED* respectively). In equation (2.6), ω^{herd} is the matrix of own and cross price elasticities and ω^{fd} is the matrix of feed price elasticities and should be negative. The *lv* index denotes the meat-producing livestock sectors. Total meat production, XP_{al} is given by equation (2.9) as the product of yield, offtake rate and herd size.

$$HERD_{r,al,lv,t} = a^{herd}_{r,al,lv,t}\lambda^{herd}_{r,al,lv,t}PP_{r,al,t}^{\omega^{herd}_{r,al,lv,t}}PFEED_{r,al,lv,t}^{\omega^{fd}_{r,al,lv,t}} \tag{2.6}$$

$$\chi^{sr}_{r,al,t} = \alpha^{oftk}_{r,al}\lambda^{oftk}_{r,al,t} \tag{2.7}$$

$$YLD^{lv}_{r,al,t} = \alpha^{yldlv}_{r,al}\lambda^{yldlv}_{r,al,t}PP_{r,al,t}^{\omega^{yldlv}_{r,al,t}} \tag{2.8}$$

$$XP_{r,al,t} = YLD^{lv}_{r,al,t}\chi^{sr}_{r,al,t}HERD_{r,al,lv,t} \tag{2.9}$$

Supply of milk and eggs is represented in an analogous way. The index *lvp* in the *HERD* variable references herd stocks used in producing milk and eggs, whereas the herd size is based on herd (*PP*) and feed (*PFEED*) prices (equation 2.10). The yield equation (2.11) determines the yield for each of these two products produced by each of the *al* sectors. Production is equal to the herd size times the yield and for milk it is summed over all milk-producing livestock activities (namely cattle, sheep and goat). Equation (2.12) represents the livestock non-meat production in a generic fashion where the yield matrix has zero coefficients where needed.

$$HERD_{r,al,lvp,t} = \alpha^{herd}_{r,al,lvp,t}\lambda^{herd}_{r,al,lvp,t}PP_{r,al,t}^{\omega^{herd}_{r,al,lvp,t}}PFEED_{r,al,lvp,t}^{\omega^{fd}_{r,al,lvp,t}} \tag{2.10}$$

$$YLD^{lvp}_{r,al,alp,t} = \alpha^{yldlvp}_{r,al,alp}\lambda^{yldlvp}_{r,al,alp,t}PP_{r,alp,t}^{\omega^{yldlvp}_{r,al,t}} \tag{2.11}$$

$$XP_{r,alp,t} = \sum_{al} YLD^{lvp}_{r,al,alp,t}HERD_{r,al,lvp,t} \tag{2.12}$$

In equations (2.6) to (2.12), the time varying shifters are denoted as λ and the base year calibration parameters as α.

2.1.4 Final agricultural output

Production from the 41 agricultural activities, indexed by *a* is converted to supply of 32 demanded commodities indexed by *i* with the help of a *make* matrix. For most activity/commodity combinations there is a one-to-one mapping. The exceptions are sugar, vegetable oils and cotton. Sugar is expressed in raw sugar equivalent and is produced by sugar beet and sugar cane. The commodity vegetable oil and oilseeds is expressed in vegetable oil equivalent and combines the vegetable oil produced from rapeseed, soybeans, palm kernels, groundnuts, sunflower seed, sesame seed, copra seed, cotton and other oilseeds as well as any remaining part of the oilseeds that is not crushed to make oil (for example oilseeds fed directly to animals or consumed without any further processing as food).[4] Cotton, in the current version of GAPS, is the only sector that produces two commodities, namely cottonseed oil and lint. The commodities are combined linearly – implying a perfect substitution across demanded goods. Similarly, the technology for joint production is a Leontief fixed coefficients technology (which is the case only of cotton). All sectors with a one-to-one mapping have a transformation coefficient of 1. For the other commodities, the transformation coefficient transforms the primary commodity into its sugar, oil or cotton equivalent in the units of demanded goods.

Equation (2.13) converts output from activities into commodity supply. The coefficients of the make matrix are contained in a^{mk} that is largely diagonal with unit values on the diagonal – with the exception of the columns for sugar, oilseeds and cotton. The equation also allows for a uniform

[4] The current version of GAPS does not consider oilmeals, oilcrops are assumed to produce only edible oils and not oilmeals. Work currently undertaken to update the base year data will enable to mode both edible oils and oilmeals.

shifter, χ^{dx}, which in this version of GAPS is used only to allow accounting discrepancies in the base data. The index α refers to all crop and livestock activities which have been indexed as αc, αl and αlp in equations 2.1 to 2.12.

$$XS_{r,i,t} = \chi^{dx}_{r,i,t} \sum_a a^{mk}_{r,a,i,t} XP_{r,a,t} \tag{2.13}$$

2.2 Domestic demand

Domestic demand is driven by prices, population and income and is decomposed into the following six elements:

1) food demand (human consumption)
2) biofuels
3) other (industrial use)
4) seeds
5) animal feed
6) waste
7) change in inventory

Statistical discrepancies in the base year data are kept unchanged throughout the simulations. Population and income – approximated by GDP – enter the model as exogenous variables and can vary depending on the specific scenarios studied. The equations are calibrated on the basis of population expectations and GDP projections. In the calibration process population expectations are used in levels whereas GDP is used as an index relative to the base year.

Equation (2.14) defines the GDP per capita index, *YPC*, where the time index t_0 represents the base year. Equation (2.15) defines the GDP index, *Y*.

$$YPC_{r,t} = \left(\frac{GDP_{r,t}}{Pop_{r,t}}\right) \Big/ \left(\frac{GDP_{r,t_0}}{Pop_{r,t_0}}\right) \tag{2.14}$$

$$Y_{r,t} = \frac{GDP_{r,t}}{GDP_{r,t_0}} \tag{2.15}$$

The demand equations – apart from seed, waste and stock changes – are price and income sensitive iso-elastic Cobb-Douglas functions.[5]

Equation (2.16) represents food demand in region *r* for period *t*, for commodity *i* where the index *i* is used to represent commodities used for human consumption. The term on the right-hand side is the product of total population and per capita demand. The latter is a function of per capita income, with an income elasticity of η^c and domestic consumer prices, *PC*, where ε^c represents the matrix of own- and cross-price elasticities. The factor λ^c is a time-varying food demand shifter (see also Section 2.4). The parameter α^c is the base year calibration factor.

$$CD_{r,i,t} = Pop_{r,t}\alpha^c_{r,i}\lambda^c_{r,i,t} YPC_{r,t}^{\eta^c_{r,i,t}} \prod_j PC_{r,j,t}^{\varepsilon^c_{r,i,j,t}} \tag{2.16}$$

Equation (2.17) determines the demand for biofuels with a similar structure as of food consumption, though this is an aggregate of national demand that depends on GDP alone and is not adjusted by population size. Similarly, other (or industrial) demand relies on total income (equation

[5] Currently, all elasticities (income, own and cross-price elasticities) are taken over from the partial equilibrium model IMPACT v3.0 (Robinson et al., 2015).

2.18). Both equations allow for time-varying shifters, represented by the respective λ factors and for calibrating to the base year by the respective α parameters. Income elasticities for biofuel and other demand are denoted by η^{bf} and η^{od} respectively whereas own and cross price elasticities by ε^{bf} and ε^{od} respectively.

$$BF_{r,i,t} = \alpha_{r,i}^{bf} \lambda_{r,i,t}^{bf} Y_{r,t}^{\eta_{r,i,t}^{bf}} \prod_j PC_{r,j,t}^{\varepsilon_{r,i,,j,t}^{bf}} \tag{2.17}$$

$$OD_{r,i,t} = \alpha_{r,i}^{od} \lambda_{r,i,t}^{od} Y_{r,t}^{\eta_{r,i,t}^{od}} \prod_j PC_{r,j,t}^{\varepsilon_{r,i,,j,t}^{od}} \tag{2.18}$$

Demand for seeds (*SEED*) is a fraction of own supply (equation 2.19). The parameter α^{sd} is the base year calibration factor whereas the factor λ^{sd} is a time varying shifter.

$$SEED_{r,i,t} = \alpha_{r,i}^{sd} \lambda_{r,i,t}^{sd} XS_{r,i,t} \tag{2.19}$$

Feed demand depends on the size of the underlying herds of the different livestock activities. For each herd type, *al*, and for the two broad livestock categories, (meat and non-meat producing) indexed by *lvt*, a total feed demand is generated as a price sensitive function of the herd size. Equation (2.20) describes demand for the aggregate feed bundle, *XFD*, where *HERD* represents the herd size, *PFEED* is the aggregate price of feed and ε^{pfd} the price elasticity. The parameter χ^{xfd} is the base year calibration factor and λ^{xfd} is a non-price shifter in the demand for feed (per head) and can vary over time. In GAPS v1.0 total feed refers only to the primary equivalent of the commodities listed in Table A.2 used as compound feed and not to grazing.

$$XFD_{r,al,lvt,t} = \chi_{r,al,lvt}^{xfd} \lambda_{r,al,lvt,t}^{xfd} HERD_{r,al,lvt,t} \left(PFEED_{r,al,lvt,t}\right)^{\varepsilon_{r,al,lvt,t}^{pfd}} \tag{2.20}$$

The aggregate feed bundle is allocated across feed components using a constant elasticity of substitution (CES) technology function (equation 2.21). The parameter σ^f represents the substitution elasticity across feed components as a function of changes in relative feed prices.[6] The model allows for feed specific changes in efficiency over time by means of the λ^{fd} factor.[7] The aggregate price of feed is determined using the CES dual price expression (equation 2.22).[8] Equation (2.23) aggregates total feed demand for feed commodity *i* across all herd types and categories. The α parameters in equations (2.21) and (222) are the base year calibration factors.

$$FEED_{r,i,al,lvt,t} = \alpha_{r,i,al,lvt}^{fd} \frac{XFD_{r,al,lvt,t}}{\lambda_{r,i,al,lvt,t}^{fd}} \left(\frac{\lambda_{r,i,al,lvt,t}^{fd} PFEED_{r,al,lvt,t}}{PC_{r,i,t}}\right)^{\sigma_{r,al,lvt,t}^{f}} \tag{2.21}$$

$$PFEED_{r,al,lvt,t} = \left[\sum_i \alpha_{r,i,al,lvt}^{fd} \left(\frac{PC_{r,i,t}}{\lambda_{r,i,al,lvt,t}^{fd}}\right)^{\left(1-\sigma_{r,al,lvt,t}^{f}\right)}\right]^{1/\left(1-\sigma_{r,al,lvt,t}^{f}\right)} \tag{2.22}$$

$$TFEED_{r,i,t} = \sum_{al} \sum_{lvt} FEED_{r,i,al,lvt,t} \tag{2.23}$$

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[6] The CES share parameters are calibrated to the 2015 feed components as they can be different from the 2005/07 levels. Feed is exogenous in 2005/07.

[7] The database of the model (Alexandratos and Bruinsma, 2012) does not break feed components across the various livestock sectors. A matrix has been created which is consistent with aggregate feed demand and allocates feed to the various livestock sectors based on their relative herd size.

[8] Currently, both the price elasticity ε^{pfd} and the substitution elasticity across feed components σ^f are calibrated to IMPACT's v3.0 behavioural parameters, where aggregate feed demand is represented by a Cobb-Douglas function.

Waste is a fixed share of total domestic absorption (excluding stock changes, *STB*, and statistical discrepancies of the base year data, *DISC*).[9] Total absorption, *XA*, is the sum across all demand sources including waste, stock changes and discrepancies, whereas the last two components are exogenous (equations 2.24 and 2.25, respectively).[10]

$$WASTE_{r,i,t} = \alpha^{w}_{r,t,t}\left(CD_{r,i,t} + BF_{r,i,t} + OD_{r,i,t} + SEED_{r,i,t} + TFEED_{r,i,t}\right) \quad (2.24)$$

$$XA_{r,i,t} = CD_{r,i,t} + BF_{r,i,t} + OD_{r,i,t} + SEED_{r,i,t} + TFEED_{r,i,t} + WASTE_{r,i,t} + STB_{r,i,t} + DISC_{r,i,t} \quad (2.25)$$

2.3 Trade, prices and market equilibrium

GAPS is a net trade model, where the commodities are assumed to be homogenous across countries/regions. Net trade for each region is the difference between supply and demand (equation 2.26). If supply is greater than domestic absorption then the particular region is a net exporter. The magnitude of net-trade positions, however, is constrained by the global commodity equilibrium condition discussed in the section below. The model includes import and export variables only for reporting convenience.

$$NT_{r,i,t} = XS_{r,i,t} - XA_{r,i,t} \quad (2.26)$$

GAPS solves for a set of domestic and world market prices that clear domestic and international commodity markets. The model assumes a closed world economy so that at the end of every simulation period global demand equals supply. The world market price of a commodity (*PW*) adjusts every time an exogenous shock is introduced in the model, so that markets are cleared and each adjustment is passed to domestic prices via the price transmission mechanism. Changes in domestic prices in turn, stimulate changes in domestic supply and demand and subsequently in international trade. The solution is achieved after one or more iterations until world supply and demand balance. This mechanism is ensured by equation (2.27), which technically speaking is a constraint on the combined optimization problems of consumers and producers, thus yielding PW as its dual value.

In theory, the variable *GBAL* should be zero, but the model allows carrying over observable global discrepancies.

$$\sum_r NT_{r,i,t} = GBAL_{r,t} \quad (2.27)$$

Given the long-range perspective of the model, changes of domestic prices relative to the base year– both demand and supply – are equated to the changes of global prices relative to the base year assuming perfect transmission between global and domestic markets, no trade or policy wedges and no transport costs. Equations (2.28) and (2.29) reflect these conditions. For the producer prices – given the assumption of perfect substitution across commodities – the law of one price must hold for all production activities *a* used to form supply of commodity *i*. For joint

[9] FAOSTAT defines waste as a fixed percentage of availability, namely production plus imports plus stock withdrawals. Assuming though that global net trade is zero, this formulation becomes equivalent to equation 2.24. The latter has been preferred in order to avoid a circular mathematic expression.

[10] Total absorption is denoted in FAOSTAT's supply and use accounts as total domestic utilization.

production, where a fixed coefficient technology holds, the prices are the weighted average of the relevant world prices.[11] The factor χ^{pp} is used to normalise the prices in the base simulation.

$$PC_{r,i,t} = PW_{i,t} \tag{2.28}$$

$$PP_{r.a.t} = \chi^{pp}_{r,a,t} \sum_i a^{mk}_{r,a,i,t} PW_{i,t} \tag{2.29}$$

Equations (2.28) and (2.29) can be extended to accommodate simulations of scenarios that assume country and commodity specific price differentials among world, border and domestic market prices.

2.4 Dynamics

The dynamics involve updating the equation shift parameters. These are intended to be movements in the shifters that cannot be explained by changes in the underlying exogenous and endogenous variables such as population, GDP and prices. They are typically calibrated in the baseline scenario and line up with priors about future conditioned or other assumptions that can be explicit or implicit. Alternative, or "what if" scenarios typically assume that these shift parameters are fixed.[12]

2.4.1 Demand shifters

There are demand shifters for food demand, biofuels and other (industrial) demand. Each has the same basic form. The shifters are updated using a growth formula that depends on a sector-specific and a uniform growth factor. Equation (2.30) provides the update equation for the food demand shifters, where the γ coefficients are the relevant growth factors. In a baseline, these may be endogenous in order to achieve some other target, such as a specific target for food demand, either by sector or in aggregate. The equations allow for non-unitary gap sizes for years, i.e. the model is not necessarily solved annually, and *n* represents the gap between solution years. Equations (2.31) to (2.33) represent similar expressions for exogenous trends in respectively biofuels, other (industrial) and seed demand.

$$\lambda^{c}_{r,i,t} = \lambda^{c}_{r,i,t-1}\left(1 + \gamma^{c,1}_{r,i,t} + \gamma^{c,2}_{r,t}\right)^{n} \tag{2.30}$$

$$\lambda^{bf}_{r,i,t} = \lambda^{bf}_{r,i,t-1}\left(1 + \gamma^{bf,1}_{r,i,t} + \gamma^{bf,2}_{r,t}\right)^{n} \tag{2.31}$$

$$\lambda^{od}_{r,i,t} = \lambda^{od}_{r,i,t-1}\left(1 + \gamma^{od,1}_{r,i,t} + \gamma^{od,2}_{r,t}\right)^{n} \tag{2.32}$$

$$\lambda^{sd}_{r,i,t} = \lambda^{sd}_{r,i,t-1}\left(1 + \gamma^{sd,1}_{r,i,t} + \gamma^{sd,2}_{r,t}\right)^{n} \tag{2.33}$$

Feed demand shifters have two components. The first changes feed efficiency at the aggregate level and is represented by the growth factor γ^{xfd}. Equation (2.34) determines the growth in overall feed efficiency. The second component allows for changes in the feed composition (equation 2.35). The shifters are specific to both feed type, indexed by *i*, as well as potentially to the purpose of herd, i.e. meat, milk or eggs. There is a uniform shifter that allows for targeting the growth in feed demand for a specific feed component.

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[11] This should be revised in next versions of the model in case technical coefficients change over time and individually.

[12] In the current version of the model all shift parameters have been calibrated to Alexandratos and Bruinsma (2012). Ongoing efforts aim at endogenizing their growth across time.

$$\lambda^{xfd}_{r,al,lvt,t} = \lambda^{xfd}_{r,al,lvt,t-1}\left(1+\gamma^{xfd}_{r,al,lvt,t}\right)^{n} \quad (2.34)$$

$$\lambda^{fd}_{r,al,lvt,t} = \lambda^{fd}_{r,al,lvt,t-1}\left(1+\gamma^{fd,1}_{r,i,al,lvt,t}+\gamma^{fd,2}_{r,i,t}\right)^{n} \quad (2.35)$$

2.4.2 Production shifters

The crop supply equations have two shifters, one for each of yields and area, represented by equations (2.36) and (2.37) respectively. One of the growth factors is both sector and farm system specific (indexed by *fs*) and the other is only sector specific. Note that production activities are indexed by *a*, and the index *ac* is a sub-index for crops.

$$\lambda^{yld}_{r,ac,fs,t} = \lambda^{yld}_{r,ac,fs,t-1}\left(1+\gamma^{yld,1}_{r,ac,fs,t}+\gamma^{yld,2}_{r,ac,t}\right)^{n} \quad (2.36)$$

$$\lambda^{area}_{r,ac,fs,t} = \lambda^{area}_{r,ac,fs,t-1}\left(1+\gamma^{area,1}_{r,ac,fs,t}+\gamma^{area,2}_{r,ac,t}\right)^{n} \quad (2.37)$$

Cropping intensity is defined at the aggregate level for crops, though differentiated by farm system. Cropping intensity has a single growth factor for each farm system as expressed in equation (2.38).

$$CI_{r,fs,t} = CI_{r,fs,t-1}\left(1+\gamma^{ci}_{r,fs,t}\right)^{n} \quad (2.38)$$

The final set of equations deal with herd and yield growth in the livestock sectors – one set for the meat producing sectors and one set for the non-meat sectors (milk and eggs) and a growth equation for the offtake rate in the meat sectors. Equation (2.39) determines the growth factor for herds in both meat and other livestock products sectors. Equation (2.40) expresses the growth factor for yields in the meat producing sectors. Equation (2.41) represents the growth factor for the offtake rate in the meat producing sectors. Finally, equation (2.42) gives the growth factor for yields for milk and eggs, differentiated by herd when it comes to milk.

$$\lambda^{herd}_{r,al,lvt,t} = \lambda^{herd}_{r,al,lvt,t-1}\left(1+\gamma^{herd}_{r,al,lvt,t}\right)^{n} \quad (2.39)$$

$$\lambda^{yldlv}_{r,al,t} = \lambda^{yldlv}_{r,al,t-1}\left(1+\gamma^{yldlv}_{r,al,t}\right)^{n} \quad (2.40)$$

$$\lambda^{oftk}_{r,al,t} = \lambda^{oftk}_{r,al,t-1}\left(1+\gamma^{oftk}_{r,al,t}\right)^{n} \quad (2.41)$$

$$\lambda^{yldlvp}_{r,al,alp,t} = \lambda^{yldlvp}_{r,al,alp,t-1}\left(1+\gamma^{yldlvp}_{r,al,alp,t}\right)^{n} \quad (2.42)$$

2.5 Undernourishment module

The undernourishment module of GAPS v1.0 enables the calculation of undernourishment in the future and hence complements FAO's work on the State of Food Insecurity. The module is used typically as a post-processing one, namely it uses information from the core GAPS. It can however be used to enable the simulation of scenarios that require achieving a specific level of undernourishment (for example achieving zero hunger, as it was done in FAO, IFAD and WFP, 2015a).

Food demand is converted into per capita terms before calculating the energy embedded in consumed food (*CD*). The parameter χ^{w} in equation (2.43) adjusts for potential weight losses when the mass of the produced commodities is converted in the mass equivalent of the commodity consumed.[13]

$$CPC_{r,i,t} = \chi^{w}_{r,fm,i}\frac{CD_{i,i,t}}{Pop_{r,t}} \tag{2.43}$$

One aspect of food security is the amount of average daily dietary energy supply, DES, calculated by converting the total annual consumption by commodity into daily per capita caloric availability. The conversion is provided by equation (2.44), where the parameter ϕ converts annual per capita consumption into an average daily caloric intake. For commodities where supply and demand is not modelled in GAPS, there is no modelling of actual physical intake and only the calories per capita are measured, which we allow to vary with per capita income.14 This is the case of other meat and meat products, fish, spices, nuts and any other commodities (see list of commodities in Table A.2). The total daily energy supply, DES, is the sum of calories from all sources as captured in equation (2.45). The index it in equations (2.44) and (2.45) denotes all food commodities, both those for which supply and demand is modelled and those for which only the calorie per capita consumption is measured.

$$\begin{cases} CAL_{r,it,t} = \varphi_{r,it,t} CPC_{r,it,t} & \text{if} \quad it \in i \\ CAL_{r,it,t} = \alpha^{c}_{r,it}\lambda^{c}_{r,it,t} YPC_{r,t}^{\eta^{c}_{r,it,t}} & \text{if} \quad it \notin i \end{cases} \tag{2.44}$$

$$DES_{r,t} = \sum_{it} CAL_{r,it,t} \tag{2.45}$$

The percent of undernourished can be calculated based on three parameters: the *DES*, the threshold for a minimum diet also known as the Minimum Daily Energy Requirement (*MDER*) and an estimate of the standard deviation of the underlying distribution of caloric intake by the national population (or equivalently the coefficient of variation). Equation (2.46) converts the estimate of the coefficient of variation of the log-normal distribution *CV* to the standard deviation of the log-normal distribution.[15] Equation (2.47) measures the percent of the population estimated to be under the *MDER* threshold, where the function *SNCDF* is the cumulative distribution function for the standard normal distribution. The number of undernourished is simply the product of P^0 with the size of the population, (equation 2.48).

$$\sigma^{u}_{r,t} = \sqrt{\log\left(CV^{2}_{r,t} + 1\right)} \tag{2.46}$$

$$P^{0}_{r,t} = SNCDF\left(\frac{\log\left(\frac{MDER_{r,t}}{DES_{r,t}}\right)}{\sigma^{u}_{r,t}} + 0.5\sigma^{u}_{r,t}\right) \tag{2.47}$$

$$Under_{r,t} = P^{0}_{r,t} Pop_{r,t} \tag{2.48}$$

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[13] This holds for paddy rice of which the consumed volume is converted into milled rice equivalent for calculating further its energy content.

[14] As mentioned in Sections 2.1 and 2.2, GAPS v1.0 models the demand of 32 commodities which are supplied by 41 agricultural activities.

[15] In 2012 FAO revised its methodology to measure undernourishment and instead of the log-normal distribution uses the skew-normal distribution (http://www.fao.org/economic/ess/ess-fs/fs-methods/fs-methods1/en/). Own experiments showed that using the skew-normal distribution gives differences in the prevalence of undernourishment but by 2050 these are small (below 2%), which is well within any uncertainty range over a 40-year projection time horizon. To keep the calculations as simple as possible, we use the log-normal distribution in GAPS. To note, the latest refinement of the methodology suggests that the selection of the functional form for the distribution depends on the asymmetry of the data evaluated and there are indeed cases where the log-normal distribution should be applied (Wanner et al., 2014).

Further indicators are the average calorie gap index for the percent of population that is undernourished, which measures the average distance to the *MDER* threshold by the undernourished population, P^1, given by equation (2.49). Equation (2.50) captures the severity of undernourishment which gives higher weight to those that are the furthest from the *MDER* threshold, P^2.[16]

$$P^1_{r,t} = P^0_{r,t} - \frac{DES_{r,t}}{MDER_{r,t}} \, SNCDF\left(\frac{\log\left(\frac{MDER_{r,t}}{DES_{r,t}}\right)}{\sigma^u_{r,t}} - 0.5\sigma^u_{r,t}\right) \qquad (2.49)$$

$$P^2_{r,t} = MDER_{r,t} P^1_{r,t} \qquad (2.50)$$

2.6 Data

GAPS is intended to be flexible in terms of its dimensions and so is arranged around three levels of aggregation. The first level concerns entering data and processing data, the second on the disaggregation selected to run a simulation scenario and the third on the disaggregation selected to present the results.

Routines for processing data are developed depending on the data to use for a specific simulation. These include processing data on the UN population estimations and projections, data regarding the so-called Shared Socioeconomic Pathways (see Section 3.1) and FAO's data on the State of Food Insecurity (see for example FAO, IFAD and WFP, 2015b).

GAPS v1.0 includes routines for producing post-simulation statistics, tables and charts as for example those reported in Alexandratos and Bruinsma (2012). The model's results are often presented aggregated both when it comes to regions and to commodities, referring for example to geographic regions, commodity families etc.

Applications of the model so far use as core database the one used in Alexandratos and Bruinsma (2012), which is reconciled using information from FAOSTAT (commodity and food balance sheets, production and land use statistics) It is complemented with information from the GAEZ database and FAO's Aquastat, with the average of 2005/2007 being the base year. The database is comprised of 41 agricultural activities and 32 commodities for 110 countries or regions for which projections are made individually, i.e. 97 low and middle income countries and one group of "Other Developing" (comprising the small low and middle income countries with FBS data in 2005/07 but not projected individually), 8 high income and 4 groups of high income countries (EU-27, other Western Europe, other Eastern Europe and central Asia).[17] The 105 countries and the 5 regions comprise 182 countries out of the 230 countries and territories considered in the 2010 revision of

[16] These measures were introduced by Foster et al., (1984) and are encapsulated in the generic expression: $P_a(z) = \int_0^z \left(\frac{z-x}{x}\right)^{\alpha} f(x)dx$, where z is a threshold, such as poverty line or MDER and f is the probability distribution of food consumption, such as a log-normal.

[17] The designation "high income" or "developed" and "low and middle income" or "developing" countries is intended for statistical convenience and does not necessarily express a judgment about the stage of development reached by a particular country. It has been kept to preserve the link between historical experience and possible future outcomes. The countries grouped as high income (developed) and low and middle income (developing) are listed in the Appendix of Alexandratos and Bruinsma (2012).

the UN population projections (UN, 2011).[18] The remaining countries are grouped into a residual region identified with the label *NES* and are mostly small island nations. They only appear in tables with total world population and are otherwise not modelled endogenously. Annex 1 lists the activities, commodities and countries of GAPS database.

[18] The 2012 revision of World Population Prospects has 233 countries/territories includes the split of Sudan into Sudan and South Sudan and of Netherlands Antilles into three components. These are aggregated to the 230 level of aggregation where needed.

3 Illustrative scenario analysis

To illustrate the potential applicability of GAPS for studying how alternative scenarios may affect food demand and supply in the long-run, this section assesses the impact of using an alternative socio-economic path compared with that used to derive the long-term scenario of Alexandratos and Bruinsma (2012) (referred to hereafter as the AT2050 report). For illustrative purposes, we use the so-called SSP2 scenario (explained in Section 3.1), which has been developed by the integrated assessment modelling community for assessing long-term climate change scenarios.

3.1 Scenario set up

The SSP2 scenario is one of the five so-called Shared Socioeconomic Pathways (SSPs) (Kriegler *et al.,* 2012; Moss *et al.,* 2010; O'Neill *et al.,* 2014; van Vuuren *et al.,* 2012). The SSP scenarios have been developed by modeling teams from the Integrated Assessment Modeling Consortium (IAMC)—an international network focused on the bio-physical and economic aspects of climate change—and are meant to replace the so-called Special Report on Emission Scenarios (SRES).[19] The SSP scenarios are thought to be "reference" pathways and make no explicit assumptions on climate change impacts nor do they consider climate change mitigation policies. The SSP2 scenario is known as "middle of the road" or "business as usual" scenario as it assumes that historical trends and patterns will continue in the future, whereas there will be only some progress towards achieving development goals in the long-term (O'Neill *et al.,* 2012).

The SSP storylines have been converted into projections by several of the modeling teams within the IAMC. All research groups harmonized on a single set of population projections developed by the International Institute for Applied Systems Analysis (IIASA). Three research groups were engaged in quantifying GDP projections up to 2100. Each used a different methodology, although all harmonized to the IIASA population projections (SSP database, 2012). Two groups (IIASA and OECD) produced GDP projections per country, whereas the Potsdam Institute for Climate Impact Research (PIK) produced GDP projections for 26 regions which cover the entire world. The Global Perspective Studies Team harmonized the IIASA and OECD GDP projections to a common base year (2007), gap filled all missing countries (for the 230 countries that are listed in the index *c0*) and used cubic-splining techniques to annualise GDP over the period 2007-2100. In this report we use the OECD GDP projections.

In SSP2, global population is assumed to reach 10 billion persons towards 2100 (9.1 by 2050) with fertility and mortality rates being balanced. The IIASA SSP2 projections are to a large extent calibrated to the UN's 2010 population revision.[20] Differences involve projected population growth in specific regions. In detail, population is expected to grow faster in Sub-Saharan Africa and in South Asia under SSP2 than in AT2050, and to decline in East Asia (in China in particular) (Figure 1).

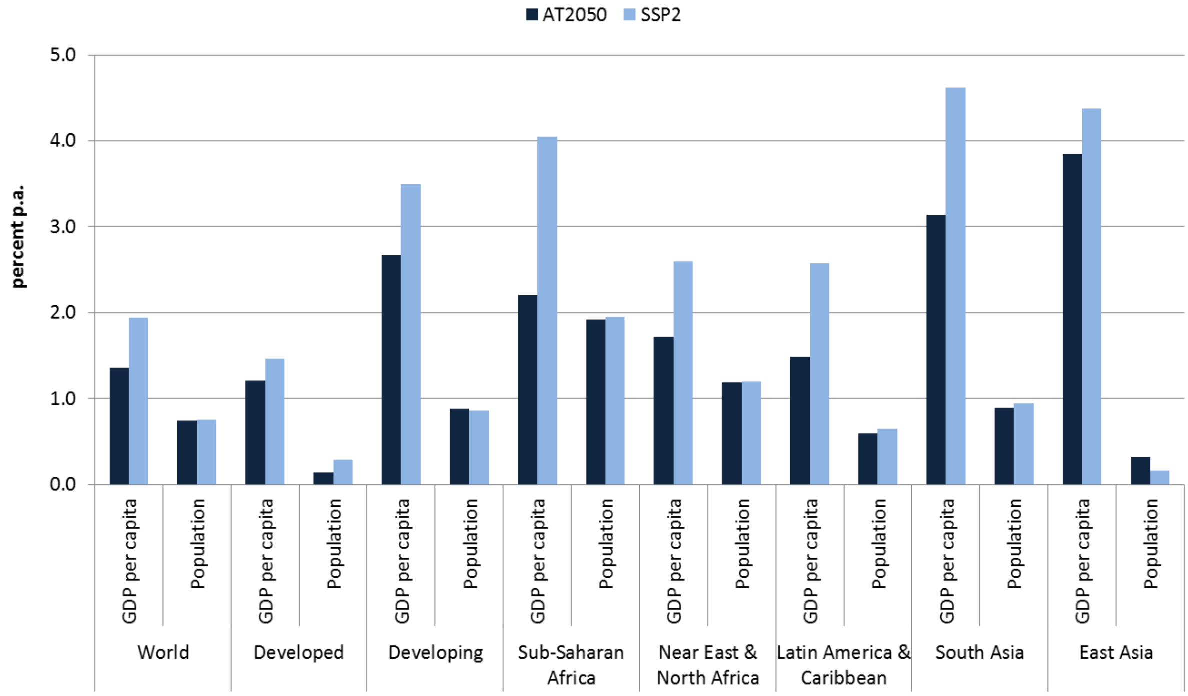
Economic growth in SSP2 is assumed to remain uneven, with low and middle income countries converging only slowly to the income level of high income ones. Compared to the AT2050, however, GDP per capita in SSP2 is projected to grow by 0.4 percentage points faster over 2005/07-2050 (Figure 1). The growth rates are projected to be higher in all regions under SSP2 and are the

[19] The work of the various modelling groups within the IAMC feed in directly into the reports of the Intergovernmental Panel on Climate Change (IPCC), for example the 5th Assessment Report.
[20] The AT2050 report relied on the 2008 revision of the UN's periodic population projections (UN, 2009).

highest for Sub-Saharan Africa and South Asia, where GDP per capita is projected to grow almost by two times and 1.5 times faster over 2005/07-2050 respectively. These, when compounded over decades, make profound differences to the projected income levels.

Higher economic growth is expected to increase food demand and so drive food consumption per capita upwards. Higher population growth should result in increased food consumption but the changes in per capita consumption will depend on whether the increase of total food consumption is higher than the population growth or not. Population decline should lead to lower food consumption and in turn to lower agricultural production.

Figure 1 GDP and population growth rates per region across SSP2 and AT2050 over 2005/07-2050



Source: SSP database (2012); own calculations

3.2 Illustrative results

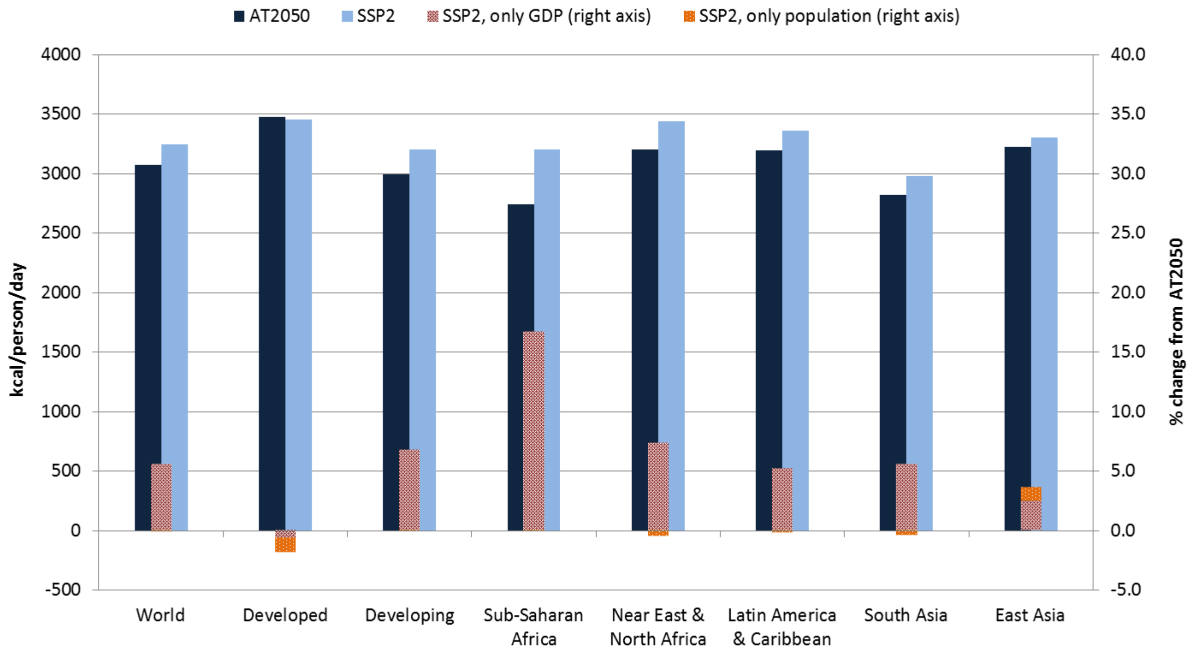
The results shown in the rest of this section compare the AT2050 projections with a ceteris paribus scenario that incorporates SSP2 population and GDP growth. Technological growth and natural resource availability between 2005/07 and 2050 are taken from the AT2050 report. This implies that the results shown do not depict how the situation may develop to 2050 – to do this technological growth and natural resources availability should have been aligned with the assumptions on economic growth in particular – but rather illustrate potential uses of the GAPS model.

Figure 2 shows the projected calorie per capita by 2050 under the SSP2 and the AT2050 projections (left axis), whereas the change between the SSP2 and the AT2050 scenarios is decomposed into GDP and population components (left axis).

Global calorie intake per capita by 2050 would increase on average by 6% with the increase being attributed mainly to the higher GDP growth rate of SSP2. Most of the increase would be realised in

Sub-Saharan Africa (from 2742 kcal/person/day to 3200 kcal/person/day), where GDP per capita is assumed to grow most compared to AT2050. In high income countries (denoted as developed in Figure 2) population growth under SSP2 would not drive food demand high enough and so food calories would need to be distributed to more people resulting in a decrease of calorie per capita, albeit rather marginal (by about 1.2%). The reverse would occur in East Asia where population under SSP2 is assumed to grow slower than in AT2050 and so the consumed calories would need to be distributed to less people, driving calorie per capita upwards by 1.2%. Income growth in East Asia would contribute to an additional 2.4% increase of calories per capita (compared to AT2050).

Figure 2 Calorie per capita in 2050 under AT2050 and SSP2 and decomposition of the SSP2 effects

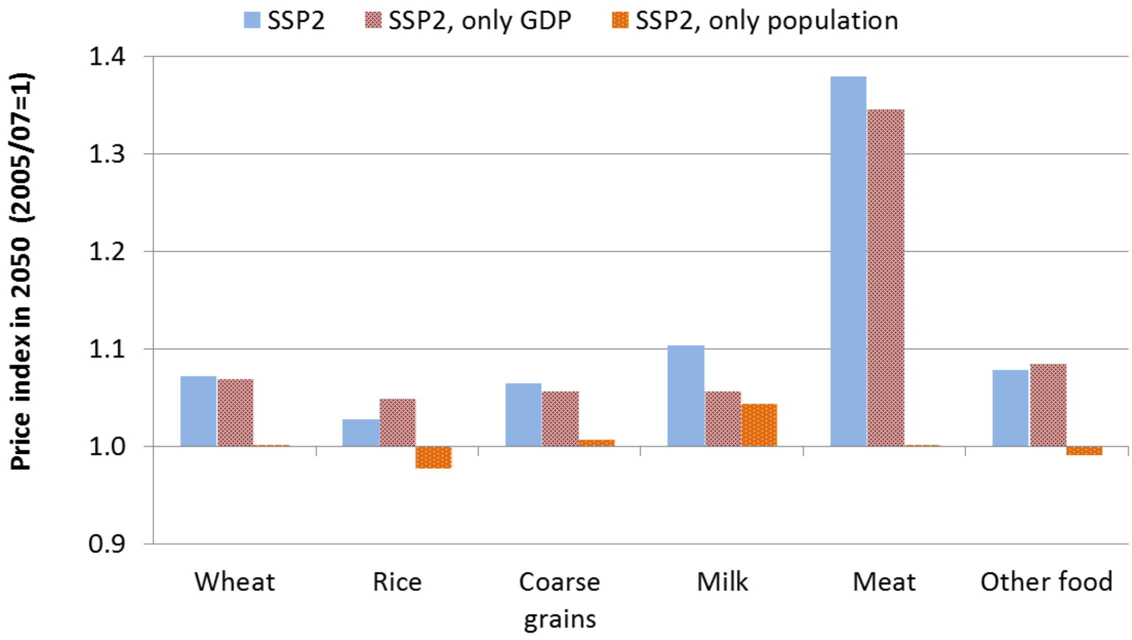


Source: own simulations with GAPS

If we assume that the minimum dietary energy requirements and the index of inequality in 2050 are as in the AT2050 report, the increase of calorie per capita in low and middle income countries and especially in Sub-Saharan Africa would translate to fewer undernourished people and so the percent of undernourished population in these countries would fall from 4.1% to 2.3%.

The AT2050 report assumes that real prices should stay constant over time. The ceteris paribus scenario illustrated in this paper, however, results in increased consumption and so translates in pressure on agricultural markets, which is in turn reflected in higher world market prices (Figure 3). This pressure is more pronounced for non-staple food markets (namely meat and milk products) because the richer consumers get, the more meat and less staple food they consume. Rice prices are expected to increase less compared to wheat and coarse grains because SSP2 foresees a slower population increase in East Asia. As a result global rice consumption would be lower compared to the AT2050 (note that per capita consumption would be higher as explained above). This is why the SSP2 population projections under ceteris paribus would lead to a decrease in rice world market prices by around 2%.

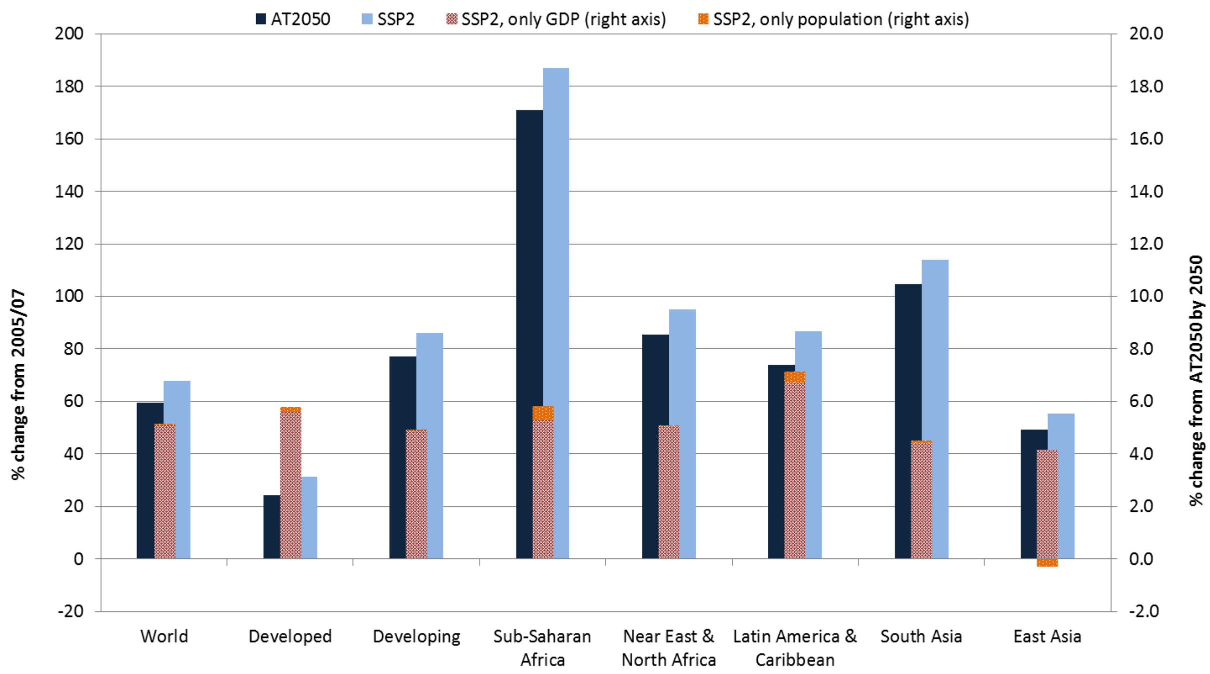
Figure 3 World market price changes per major food commodities by 2050



Source: own simulations with GAPS

Higher world market prices should stimulate production, which under SSP2 would grow by some 68% over 2005/07-2050 and so be slightly higher compared to the 60% projected growth of AT2050 (Figure 4 – left axis). Agricultural production of low and middle income countries would grow by 86% and of high income ones by 32% over the same period. This should be seen against the 77% and 24% increase of total agricultural production projected in AT2050 for low and middle income and high income countries respectively between 2005/07 and 2050.

Figure 4 Production growth over 2005/07-2050 and decomposition of the SSP2 effects



Source: own simulations with GAPS

To note, although changes of domestic prices in GAPS v1.0 are equated to the relative changes of world market prices relative to their respective base year values, the responsiveness of production (yield and area harvested for crops, herd size and yield for livestock) to price changes differs per country and activity and depends on the supply elasticities. This is why for a given simulation year the change of production is not the same across countries and commodities. The changes of supply over time (for example between 2005/07 and 2050) also depend on technological progress and the availability of natural resources, which have been taken from AT2050 and are country/region and activity specific.

When comparing the projections for 2050, agricultural production worldwide would be by 5.1% higher under SSP2 compared to the AT2050 (Figure 4 – right axis). The change would be more marked in Latin American countries (difference between SSP2 and AT2050 of 7.1%) followed by Sub-Saharan Africa and by high income countries (difference between SSP2 and AT2050 of nearly 6% for each of the regions). Most of the increase would be because of higher GDP growth. Population growth would contribute only marginally to the growth of production: in Sub-Saharan Africa by 0.5%, in Latin America by 0.4% and in high income countries by 0.2%. In East Asia the slower population growth under SSP2 would lead to a decline in agricultural production by 0.3% compared to the levels projected in the AT2050 report.

To note, compared to the base year of GAPS (2005/07), by 2050 Sub-Saharan Africa would achieve the highest production growth under both the AT2050 and the SSP2 scenarios. This is because in absolute terms production is relatively low and so the percent change is high. In absolute terms production in Sub-Saharan Africa will remain at lower levels than in other regions and by 2050 will account for 9% of the global agricultural production (was around 5% in 2005/07).

The increase of production in low and middle income countries as a group under SSP2 would not be sufficient to satisfy their higher demand. Their net imports in 2050 would be 31% higher than in AT2050 (valued at 2004/06 international prices, from ICP$44 billion to ICP$58 billion) and would be counterbalanced by the excess supply of high income countries. Under SSP2 low and middle income countries would almost triple their import demand for meat compared to the AT2050 and would turn from net exporters of beef into net importers. Regarding other major commodity groups like cereals and oilseeds/vegetable oil, import demand in low and middle income countries in 2050 under SSP2 would be 13% and 11% higher than in AT2050, respectively.

4 Concluding remarks

This paper describes the development of a new analytical tool that enables the Global Perspective Studies team to undertake a broad set of simulations. These relate to some of the inherent uncertainties about long-term projections and in particular to the underlying drivers affecting food demand and supply – demographics, economic growth, technological progress and climate change. Especially climate change increases the level of uncertainty as it affects the availability of natural resources and the productivity levels that can be achieved and so is a rising concern of policy makers and civil society more broadly. Beyond uncertainties regarding the main drivers, further uncertainties are regarding supply and demand behaviour – for the present day economy, and on how behaviour changes over time – as well as policies that can affect the structure of food production.

The new analytical framework provides a globally consistent set of relations that can be used to test alternative specifications, drivers and parameter estimates. It is designed to be used to dialogue with experts—in-house and across the globe—to provide a powerful combination of state-of-the-art modelling with expert knowledge.

Future improvements in the second version of the model will include an enhanced livestock module that will incorporate multiple production systems and an improved representation of energy embedded in feed as well as a better specification and parameterization of consumer demand.

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Annex

Table A.1 List of activities

Code[1]	Long name	Commodity produced[2]
wht	Wheat	wht
ric	Rice	ric
maz	Maize	maz
brl	Barley	brl
mil	Millet	mil
sor	Sorghum	sor
xce	Other cereals	xce
pot	Potatoes	pot
swp	Sweet potatoes	swp
csv	Cassava	csv
xcr	Other roots	xcr
pnt	Plantains	pnt
sgb	Sugar beet	sug
sgc	Sugar cane	sug
pls	Pulses	pls
veg	Vegetables	veg
ban	Banana	ban
cit	Citrus	cit
xfr	Fruits	xfr
xol	Oilcrops, n.e.s.	osd
rol	Rapeseed	osd
pol	Palm oil	osd
soy	Soy beans	osd
grd	Ground nuts	osd
snf	Sunflowers	osd
ses	Sesame	osd
coc	Coconuts	osd
cac	Cocoa	osd
cof	Coffee	cac
tea	Tea	cof
tob	Tobacco	tob
cot	Seed cotton	osd, cot
xfb	Fibres	xfb
rub	Rubber	rub
bef	Cattle for meat production	bef
mut	Mutton for meat production	mut
pig	Pig	pig
plt	Poultry for meat production	plt
bef(mlk)	Cattle for milk production	mlk
mut(mlk)	Mutton for milk production	mlk
plt(egg)	Poultry for egg production	egg

Notes: [1] summarized in equations (2.1) to (2.13), (2.20) to (2.22) and (2.34) to (2.42) by indexes αc (crop activities), αl and αlp (livestock activities meat and non-meat producing) and α (all activities); [2] summarized in equations (2.13), (2.16) to (2.33) and (2.43) by index i.

Table A.2 List of demanded commodities

Code[1]	Long name	Mapping to FAOSTAT commodities in Food Balance Sheets / Supply and Use accounts: FAOSTAT code	Long name
Commodities for which supply and demand is projected			
WHT	Wheat	2511	Wheat and products
RIC	Rice	2805	Rice (Milled Equivalent)
MAZ	Maize	2514	Maize and products
BRL	Barley	2513	Barley and products
MIL	Millet	2517	Millet and products
SOR	Sorghum	2518	Sorghum and products
XCE	Other cereals	2520	Cereals, Other
		2516	Oats
		2515	Rye and products
POT	Potatoes	2531	Potatoes and products
SWP	Sweet potatoes	2533	Sweet potatoes
CSV	Cassava	2532	Cassava and products
XCR	Other roots and tubers	2535	Yams
		2534	Roots, Other
PNT	Plantain	2616	Plantains
SUG	Sugar	2541	Sugar non centrifugal
		2542	Sugar (Raw Equivalent)
		2536	Sugar cane[2]
		2537	Sugar beet[2]
PLS	Pulses	2546	Beans
		2547	Peas
		2549	Pulses, Other and products
VEG	Vegetables	2601	Tomatoes and products
		2602	Onions
		2605	Vegetables, Other
BAN	Bananas	2615	Bananas
CIT	Citrus	2611	Oranges, Mandarins
		2612	Lemons, Limes and products
		2613	Grapefruit and products
		2614	Citrus, Other
XFR	Other fruit	2617	Apples and products
		2618	Pineapples and products
		2619	Dates
		2620	Grapes and products (excl wine)
		2625	Fruits, Other
OSD	Vegetable oils and oilseeds	2572	Groundnut Oil
		2574	Rape and Mustard Oil
		2577	Palm Oil
		2576	Palmkernel Oil
		2571	Soyabean Oil
		2579	Sesameseed Oil
		2575	Cottonseed Oil

		Mapping to FAOSTAT commodities in Food Balance Sheets / Supply and Use accounts	
Code[1]	Long name	FAOSTAT code	Long name
		2573	Sunflowerseed Oil
		2578	Coconut Oil
		2580	Olive Oil
		2555	Soyabeans[3]
		2556	Groundnuts (Shelled Eq)[3]
		2557	Sunflower seed[3]
		2558	Rape and Mustardseed[3]
		2559	Cottonseed[3]
		2560	Coconuts – incl. Copra[3]
		2561	Sesame seed[3]
		2562	Palm kernels[3]
		2570	Oilcrops, Other[3]
		2563	Olives (including preserved)[3]
CAC	Cocoa	2633	Cocoa Beans and products
COF	Coffee	2630	Coffee and products
TEA	Tea	2635	Tea (including mate)
TOB	Tobacco	2671	Tobacco
COT	Cotton (lint)	2661	Cotton lint
XFB	Other fibers	2662	Jute
		2663	Jute-Like Fibres
		2664	Soft-Fibres, Other
		2665	Sisal
		2666	Abaca
		2667	Hard Fibres, Other
RUB	Rubber	2672	Rubber
BEF	Beef	2731	Bovine Meat
MUT	Mutton	2732	Mutton & Goat Meat
PIG	Pig meat	2733	Pigmeat
PLT	Poultry	2734	Poultry Meat
MLK	Milk	2848	Milk - Excluding Butter
		2740	Butter, Ghee
		2743	Cream
EGG	Eggs	2744	Eggs
Commodities for which only calorie demand is projected			
RMO	other edible oils	2586	Oilcrops Oil, Other
		2581	Ricebran Oil
OMT	Meats nes not in SUA	2735	Meat, Other
		2736	Offals, Edible
OTH	Not elsewhere specified	2543	Sweeteners, Other
		2544	Molasses
		2551	Nuts and products
		2582	Maize Germ Oil
		2640	Pepper
		2641	Pimento

Code[1]	Long name	Mapping to FAOSTAT commodities in Food Balance Sheets / Supply and Use accounts	
		FAOSTAT code	Long name
		2642	Cloves
		2645	Spices, Other
		2655	Wine
		2656	Beer
		2657	Beverages, Fermented
		2658	Beverages, Alcoholic
		2680	Infant food
		2737	Fats, Animals, Raw
		2745	Honey
		2748	Hides and skins
		2749	Meat Meal
		2761	Freshwater Fish
		2762	Demersal Fish
		2763	Pelagic Fish
		2764	Marine Fish, Other
		2765	Crustaceans
		2766	Cephalopods
		2767	Molluscs, Other
		2768	Meat, Aquatic Mammals
		2769	Aquatic Animals, Others
		2775	Aquatic Plants
		2781	Fish, Body Oil
		2782	Fish, Liver Oil
		2855	Fish Meal
		2899	Miscellaneous

Notes: 1 summarized in equations (2.13), (2.16) to (2.33) and (2.43) by index i; 2 expressed in raw sugar equivalent;3 expressed in oil equivalent.

Table A.3 Regional aggregation

Region		Mapping with countries in UN 2010 population revision
Code	**Long name**	
AFG	Afghanistan	AFG
AGO	Angola	AGO
ARG	Argentina	ARG
AUS	Australia	AUS
BDI	Burundi	BDI
BEN	Benin	BEN
BFA	Burkina Faso	BFA
BGD	Bangladesh	BGD
BOL	Bolivia (Plurinational State of)	BOL
BRA	Brazil	BRA
BWA	Botswana	BWA
CAF	Central African Republic	CAF
CAN	Canada	CAN
CHL	Chile	CHL
CHN	China	CHN
CIV	Côte d'Ivoire	CIV
CMR	Cameroon	CMR
COD	Democratic Republic of the Congo	COD
COG	Congo	COG
COL	Colombia	COL
CRI	Costa Rica	CRI
CUB	Cuba	CUB
DOM	Dominican Republic	DOM
DZA	Algeria	DZA
ECU	Ecuador	ECU
EGY	Egypt	EGY
ERI	Eritrea	ERI
ETH	Ethiopia	ETH
GAB	Gabon	GAB
GHA	Ghana	GHA
GIN	Guinea	GIN
GMB	Gambia	GMB
GTM	Guatemala	GTM

Region		Mapping with countries in UN 2010 population revision
Code	**Long name**	
GUY	Guyana	GUY
HKG	Hong Kong, China Special Administrative Region	HKG
HND	Honduras	HND
HTI	Haiti	HTI
IDN	Indonesia	IDN
IND	India	IND
IRN	Iran (Islamic Republic of)	IRN
IRQ	Iraq	IRQ
ISR	Israel	ISR
JAM	Jamaica	JAM
JOR	Jordan	JOR
JPN	Japan	JPN
KEN	Kenya	KEN
KHM	Cambodia	KHM
KOR	Korea, Republic of	KOR
LAO	Lao People's Democratic Republic	LAO
LBN	Lebanon	LBN
LBR	Liberia	LBR
LBY	Libya	LBY
LKA	Sri Lanka	LKA
LSO	Lesotho	LSO
MAR	Morocco	MAR
MDG	Madagascar	MDG
MEX	Mexico	MEX
MLI	Mali	MLI
MMR	Myanmar	MMR
MNG	Mongolia	MNG
MOZ	Mozambique	MOZ
MRT	Mauritania	MRT
MUS	Mauritius	MUS
MWI	Malawi	MWI
MYS	Malaysia	MYS
NAM	Namibia	NAM

Region		Mapping with countries in UN 2010 population revision
Code	Long name	
NER	Niger	NER
NGA	Nigeria	NGA
NIC	Nicaragua	NIC
NPL	Nepal	NPL
NZL	New Zealand	NZL
PAK	Pakistan	PAK
PAN	Panama	PAN
PER	Peru	PER
PHL	Philippines	PHL
PRK	Korea, Democratic People's Republic of	PRK
PRY	Paraguay	PRY
RUS	Russian Federation	RUS
RWA	Rwanda	RWA
SAU	Saudi Arabia	SAU
SDN	Sudan	SDN
SEN	Senegal	SEN
SLE	Sierra Leone	SLE
SLV	El Salvador	SLV
SOM	Somalia	SOM
SUR	Suriname	SUR
SWZ	Swaziland	SWZ
SYR	Syrian Arab Republic	SYR
TCD	Chad	TCD
TGO	Togo	TGO
THA	Thailand	THA
TTO	Trinidad and Tobago	TTO
TUN	Tunisia	TUN
TUR	Turkey	TUR
TWN	Taiwan	TWN
TZA	United Republic of Tanzania	TZA
UGA	Uganda	UGA
URY	Uruguay	URY
USA	United States of America	USA
VEN	Venezuela (Bolivarian Republic of)	VEN

Region		Mapping with countries in UN 2010 population revision
Code	**Long name**	
VNM	Viet Nam	VNM
YEM	Yemen	YEM
ZAF	South Africa	ZAF
ZMB	Zambia	ZMB
ZWE	Zimbabwe	ZWE
E27	European Union 27	AUT, BEL, BGR, CYP, CZE, DEU, DNK, ESP, EST, FIN, FRA, GBR, GRC, HUN, IRL, ITA, LTU, LUX, LVA, MLT, NLD, POL, PRT, ROU, SVK, SVN, SWE
OWE	Rest of Western Europe	CHE, ISL, NOR
OEE	Rest of Eastern Europe	ALB, BIH, BLR, HRV, MDA, MKD MNE, SRB
CAS	Central Asian Republics	ARM, AZE, GEO, KAZ, KGZ, TJK, TKM, UKR, UZB
ODV	Other low and middle income countries	ANT, ARE, ATG, BHS, BLZ, BMU, BRB, BRN, COM, CPV, DJI, DMA, FJI, GNB, GRD, KIR, KNA, KWT, LCA, MAC, MDV, NCL, PNG, PYF, SLB, STP, SYC, VCT, VUT, WSM

Notes: For more information on the countries considered in the United Nations 2010 revision of population projections please refer to UN (2011). Countries not listed in the table but considered in UN (2011) are not modelled in GAPS. These are mostly small islands (some 48 countries) and are considered only when reporting world population figures.

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