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# A review of global food security scenario and assessment studies: results, gaps and research priorities

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# A review of global food security scenario and assessment studies: results, gaps and research priorities.

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## Abstract

The food price crisis in 2007/2008 created a sense of urgency to reconsider the challenge of how to feed an increasing population. A number of studies have addressed the demand for and supply of food in the long run using scenario analysis, often combined with model simulations. We compare twelve food security scenario studies that have been published between 2000 and present by analysing the assumptions about key drivers of food security as well as the range in key food security outcomes. We find that most scenarios can be classified using a set of scenario families with comparable assumptions and outcomes. That said, the majority of the scenarios only deal with two of the four dimensions of food security: food availability and food accessibility, largely ignoring food utilisation and stability. We also find that important drivers such as bio-energy, shift in diets and climate change are only partly dealt with while new drivers and determinants such as food waste and alternative sources of food supply are not yet addressed.

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# 1 Introduction

Recent studies suggest the world will need to produce 60 to 100% more food when the global population will reach 9 billion people by 2050. The most widely cited study is FAO (2006), which projects a 70 percent increase in food production between 2005/2007 to 2050. However, this figure has recently be revised downward to 60 percent in an update of the report (Alexandratos and Bruinsma, 2012, p. 7). The latest data is used in this study. The challenge gained momentum when food prices peaked in 2007/2008, putting global food security firmly on the agenda of policymakers. To achieve food security, three goals must be reached (von Braun, 2007): (i) the supply of agriculture produce must match the rapidly increasing and changing demand for food from a larger and more affluent population; (ii) this must be done in ways that are environmentally and socially sustainable; (iii) it should be ensured that the world's poorest people are no longer hungry. This requires radically changing the way food is produced, stored, processed, distributed, and accessed (Godfray et al., 2010), which has far-reaching implications for policymaking.

To guide policymaking in this area, there is a need to understand the main drivers affecting global food supply and demand in the future, as well as gaining better insight into what determines food and nutrition security. The largely unexpected rise in prices in 2007/08 illustrates that there is also a need to take into account uncertainty into long-term projections. Scenario analysis is a useful tool for guiding policy making. It usually explores different futures, allowing making decisions in the context of such different futures that may come to pass. Creating different scenarios also enables one to challenge certain assumptions about the future. The first use of scenario development for strategic planning leads back to the work of Hermann Kahn, who developed scenarios to explore uncertainties related to nuclear warfare and other military planning purposes (Kahn and Wiener, 1967; Kahn, 1961). Simultaneously, the business community, pioneered by Royal Dutch Shell, started to recognise the value of scenarios as a tool to map future uncertainties and inform business strategies (Wack, 1985).

Over the last decade, scenario analysis increasingly has been applied as a tool for dealing with the complexities and uncertainties that are associated with the impact and development of major global and interrelated issues such as climate change, food security and land use. It has been the core methodology in major integrated assessments studies of international institutions like the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Environmental Programme (UNEP). Scenario development is also frequently used in national and regional level assessments. A growing number of studies have used scenario analyses to explore the main drivers affecting global food supply and demand in the future, often combined with model simulations. Several of these studies explicitly focus on agriculture and the food system (Dorin and Paillard, 2009; Fischer et al., 2009; Nelson et al., 2010), while others assess broader issues such as climate change, environment and sustainable ecosystems but with outcomes that are relevant for food security analysis (PBL Netherlands Environmental Assessment Agency, 2012; e.g. UNEP, 2012).

With the challenge of feeding 9 billion people in 2050 high on the policy agenda, we feel that a review of scenario studies is due. The aim of this study is to summarise, compare and evaluate global scenarios with a focus on global food and nutrition security. In reviewing this literature, we address several questions. What are the main assumptions and drivers underlying the scenario studies? Do the studies arrive at comparable outcomes or do they diverge, and why? What are major gaps in the food security scenario studies and how can they be improved?

To answer these questions, we have undertaken a meta-analysis to collect information on existing food security scenario studies that have been published between 2000 and mid-2013. To compare the different studies, we focus on the assumptions about main driving forces and the range of key food security outcomes (e.g. prices of cereals,  calorie availability and undernourishment). We also compare the different studies by using the framework of Van Vuuren et al. (2012), which enables us to classify the scenarios by using a set of scenario families with comparable assumptions and outcomes. Finally, we contrast the existing scenario studies with a conceptual model of food security to identify missing drivers and mechanisms.

The underlying drivers of food and nutrition security are various and cause-effect relations are complex. Most scenario studies necessarily revert to a simplification of these relationships with various assumptions underpinning this simplification of reality. However, we do find that only a few studies deal with emerging issues such as biofuels and changes in diets. More recent research on the importance of drivers such as food waste or alternative sources of food supply (e.g. insects) are not addressed at all.

The structure of this paper is as follows. Section 2 provides a brief background to scenario analysis discussing the definition and characteristics of scenarios as well as different typologies that are proposed in the literature. Section 3 briefly summarises the twelve scenario studies that are reviewed in this report, including background and individual scenarios that are analysed in the studies. Section 4 describes the main drivers and assumptions of each scenario followed by a summary of the food security related outcomes which can be derived from the scenario exercises. In Section 5, a discussion is provided on the extent to which food security is covered by the scenario studies and the possibilities to use existing scenarios studies as a basis in the Food Secure project. Finally, section 6 concludes.

# 2 Conceptual framework

## 2.1 Definitions and characteristics of scenarios

Several definitions for scenarios exist in the literature. In the Millennium Ecosystem Assessment, scenarios are defined as "*plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions on key driving forces and relationships*" (Carpenter et al., 2005). Alcamo and Henrichs (2008) define a scenario as "*a description of how the future may unfold based on 'if-then' propositions an typically consists of a representation of an initial situation and a description of key driving forces and changes that lead to a particular future*" (p.15).

Both definitions capture the key characteristics of most scenarios. Scenarios are a set of stories that describe possible futures as well as the specific developments, events and logic that explain why they come about. To illustrate the uncertainty that is inherent to future development, a set of narratives is drafted to explore various possible pathways, often without assigning a probability to the outcomes. The availability of different but realistic futures makes it possible to think through and compare the potential impact of interventions and decisions (e.g. policies or strategic management decisions) in a structured way.

Scenarios differ from facts, forecasts and predictions , which assume that the 'boundary conditions' of the present will remain the same in the future (Zurek and Henrichs, 2007). Scenarios cover a wider range of futures because they assume that boundary conditions will change over time. Nonetheless, an important feature of scenarios, which makes them different from speculations, is that they reflect plausible representations of the future that logically follow from the interaction of driving forces, the main factors, trends, and processes that determine the development of the system. Scenario analysis may involve qualitative and quantitative approaches or a combination. A common approach in large global integrated assessments is to develop creative storylines, often using participatory methods with stakeholders that are subsequently modelled to analyse the relationship of drivers and quantify the impact of policies.

## 2.2 Scenario families

Several typologies have been proposed in the literature to group scenarios. Common characteristics to distinguish different scenarios include the main issue or question addressed, time period covered, spatial scale, the purpose of the analysis (e.g. policy evaluation), visioning and the process applied to develop the scenario (Berkhout et al., 2002; Börjeson et al., 2006; Reilly and Willenbockel, 2010; van Notten et al., 2003). Several authors have pointed out that scenarios often share common elements, including related storylines, comparable assumptions on the size and direction of driving forces, policies, and more-or-less comparable outcomes (Nakicenovic et al., 2000; Raskin, 2005; also see Rothman, 2008). Recently, Van Vuuren et al. (2012) have proposed a typology of six scenario ‘archetypes’ or scenario ‘families’ derived from the literature on scenarios.[1] Table 1 summarises the key assumptions that define the scenario families

**Table 1: Scenario families**

| Drivers \ Scenario archetype | **Economic optimism** | **Reformed markets** | **Global sustainable development** | **Regional competition** | **Regional sustainable development** | **Business-as-usual** |
|---|---|---|---|---|---|---|
| **Main objective** | **Economic growth** | **Various goals** | **Global sustainability** | **Security** | **Local sustainability** | **Not defined** |
| Economic development | Very rapid | Rapid | Ranging from slow to rapid | Slow | Ranging from mid to rapid | Medium (globalisation) |
| Population growth | Low | Low | Low | High | Medium | Medium |
| Technology development | Rapid | Rapid | Ranging from mid to rapid | Slow | Ranging from slow to rapid | Medium |
| Trade | Globalisation | Globalisation | Globalisation | Trade barriers | Trade barriers | Weak globalisation |
| Policies and institutions | Policies create open markets | Policies reduce market failures | Strong global governance | Strong national governments | Local steering; local actors | Mixed |
| Food security outcomes | Positive | Very positive | Very positive | Very negative | ? | Slightly positive |

Source: Van Vuuren et al. (2012) and authors.

The Economic optimism (also referred to as Conventional markets) scenarios place a strong focus on market dynamics, assuming there is free trade at the global level. Economic optimism is usually associated with rapid technology development and high economic growth. The Reformed market scenarios have a similar logic and philosophy as the first scenario family but include some additional policy assumptions aimed at correcting market failures with respect to social development, poverty alleviation or the environment. The Global sustainable development scenarios are characterised by environmental protection and reduced inequality, achieved through global cooperation, lifestyle change and more efficient technologies. The Regional competition (sometimes referred to as Regional markets) scenarios assume that regions will focus more on their own, immediate interests and regional identity, which is often assumed to result in rising tensions among regions and/or cultures. The Regional sustainable development scenarios focus on finding regional solutions for current environmental and social problems, usually combining drastic lifestyle changes with decentralization of governance. Finally, the Business-as-usual scenarios assume past trends will continue in the future

[1] Cumming et al. (2005) provide an alternative but comparable set of archetype scenarios.

and no new major policies are introduced. Van Vuuren et al. (2012) acknowledge that Business-As-Usual scenarios are different than the other five scenarios because they do not involve assumptions about future uncertainties and the storyline is generally less developed.

### 2.3 Linking scenario families to food security

Although the scenario families only list the drivers that characterise different futures, they also provide an interesting starting point to identify potential food security outcomes that are associated with the scenario families. In this regards, it is useful to start with the accepted definition of food security: *"Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life"* (FAO, 1998). This definition consists of four key dimensions: availability (i.e. sufficient quantities of food), access (i.e. adequate resources to obtain food), utilization (i.e. nutritious and safe diets, and clean water) and stability (i.e. the temporal dimension of the other three dimensions). In this paper, food security outcomes broadly refer to the sum of the four food security dimensions.

The last row in Table 1summarizes the expected outcomes for each of the scenario families. In particular, we expect that global food security will strongly improve in worlds that resemble the Global sustainable development and Reformed markets scenario. Globalisation and rapid yield growth increase food availability, while at the same time, food accessibility is enhanced because of the reduction in inequality and poverty that is characteristic for both scenarios. A shift towards more healthy lifestyles, reduction in pesticides and improved quality of water contribute positively food utilization and nutrition security. In the Economic optimism scenario family, food security outcomes are positive mainly because of free trade policies and rapid technical change. However, due to remaining income inequality and environmental problems, improvements in food accessibility and nutrition are limited. The Regional competition scenario family results in the most negative food security outcomes as a consequence of protectionist trade policies, limited technological advancement and rapid population growth that hamper food availability and slow income growth and increasing inequality that reduces food accessibility. Food security outcomes for the Regional sustainable development scenario family are not clear at forehand. Changes in lifestyle (e.g. less consumption of meat) are expected to contribute positively to food availability and utilisation. Conversely, the foreseen reduction in international trade will contribute negatively to food availability. Furthermore, trends in economic development and technological change, which tend to positively affect food security outcomes, are mixed. Finally, food security in the Business-as-usual scenarios (or Baseline Scenarios) is expected to improve slightly in line with historical trends.

## 3 Selection of studies

This section briefly summarises a number of scenario studies that include an assessment of global food security under different futures. Most scenario studies we review comprise of complex integrated assessments that often provide qualitative and quantitative information on a wide range of socio-economic and environmental issues at the global and regional level. We do not provide a review of findings at multiple scales, as this is outside the scope of this study. Instead, the focus lies predominantly on presenting and analysing the assumptions and outcomes related to food security at the global level. Detailed information on the narratives, driving forces and models as well as results at lower geographical scales, if available, can be found in the original scenario studies.

To select the scenario studies, we build on existing surveys of environmental and food system scenario studies by Zurek (2006), Rothman (2008), Reilly and Willenbockel (2010) and Wood et al. (2010), complemented by a literature search.[2] The following criteria are used to select the scenario studies:

- *Content.* Studies mostly contain information on the implications for future food security under one or more scenarios, referring to at least one of the four key dimensions of food security: availability, access, utilization and stability (FAO, 1998).[3]
- *Quantification.* Scenarios studies include a quantification (i.e. by using models) of key food security variables.
- *Time horizon*. Studies explore the medium to long, covering the period up to 2030/2050, which seems to be the standard horizon for many scenario studies.[4]
- *Year of publication.* This review focus on the most recent studies and therefore a choice was made to include only studies that have been published from the year 2000 and onwards. Some organisations publish updated scenario studies every three to five year (e.g. the *Global Environmental Outlook* produced by the United Nations Environmental Programme (UNEP)). In such cases, only the most recent study is included.

[2] We have consulted the following databases: Google Scholar, CAB Direct and Scopus. In addition, as the majority of scenario studies are published as non-refereed reports, we also have looked for the latest documents on websites of international organisations and leading research institutes that have experience with scenario analysis.

[3] This review does not cover the analysis of the new Share Socio-economic Pathways (SSPS) (Kriegler et al., 2012; O’Neill et al., 2012) that were partially analysed in the ongoing Agricultural Model Intercomparison and Improvement Project (AgMIP.) (Nelson and Shively, 2013). At the time of writing of this paper, the data was not available. Moreover, as the principal aim of the AgMIP project is to compare model results, the SSPs are modelled in a somewhat stylised way, which might not be directly comparable with the scenarios that are reviewed here.

[4] For this reason, the review does not comprise the regular short to medium run food and agriculture assessments, such as the *FAO/OECD Agricultural Outlook,* FAO’s *State of Food and Agriculture* and the *State of the World* by the Worldwatch Institute. See McCalla and Revoredo (2001) for a detailed analysis and comparison of such studies.

- *Global coverage.* The scenario studies provide information on global food security under different future pathways. Scenario studies that target a specific region or country are excluded.[5]
- *Originality:* In some cases the scenario storylines or model quantification is re-used in follow-up studies. Only when the underlying assumptions, model approach or quantitative results differ substantially from the original study, follow-up work is included. For example, the *Future of Food and Farming: Challenges and choices for global sustainability* report by the Foresight Programme of the UK government summarises results from Nelson et al. (2010) and is therefore not reviewed.

Table 2 summarizes the twelve scenario studies that are reviewed in this report, which, in total, encompass 43 individual scenarios. Five of the studies were undertaken by international organisations, such as the often cited FAO report *The World Agriculture Towards 2030/2050*, but also studies by IFPRI and UNEP, one by an international NGO (Oxfam), three by national research institutes (PBL, ABARES and CIRAD-INRA) and two were broad collaborations that involved a number of researchers from diverse backgrounds (MA, IAASTD). Only one study (SRES) was published as a peer-reviewed article in a scientific journal although its researchers are affiliated with a number of international institutions and contributed to the IPCC Fourth Assessment Report (Easterling et al., 2007). In practice, most scenarios studies are performed by a small group of researchers and institutions that have the necessary expertise and capacity to develop and operate the integrated socio-economic and bio-physical models that are needed for the quantification of scenario assessments.[6] It is striking that half of the studies do not focus on food and nutrition security but instead target complex issues such as climate change, ecosystems, biofuels and environment, and produce food security related outcomes as intermediate results or 'by-products'. Of the remaining studies, the most analyse future agricultural production and prices without putting food security central. Only two studies (OFID and IMPACT 2050) focus explicitly on food security, albeit in combination with biofuels and climate change.

To conduct the comparative analysis that is presented below, we have constructed a database that contains information on driving forces and food security related outcomes by scenario. The data was collected by means of an extensive review of relevant scenario reports and, if available, associated electronic databases on the internet. In some cases the data is an approximation of the original figures since data tables were not available and information had to be 'read' from figures and graphs. Where needed values are converted in the same units (e.g. tonnes per ha in case of yields) and linear or

[5] For this reason, we do not include the findings of Global Environmental Change and Food Systems (GECAFS) programme, which developed food security scenarios for the Caribbean (CAR), the Indo-Gangetic Plain (IGP) and Southern Africa.

[6] In particular, PBL's IMAGE model, IFPRI's IMPACT model and IIASA's World food system model have been used in two or more of the reviewed scenario studies.

geometric projections and interpolation is used to construct time series for the total horizon of the scenario under study.[7] It was not possible to obtain full information on all 43 scenarios in the database due to limited or incomplete information in the original reports.

**Table 2: Characteristics of Scenario Studies**

| Study* | Year of publication | Main focus | Organisation** | Number of scenarios*** | Horizon | Food security indicators | Reference |
|---|---|---|---|---|---|---|---|
| SRES | 2004 | Climate change | Individual researchers | 4 | 1990-2080 | Food prices | (Parry et al., 2004) |
| MA | 2005 | Ecosystems and services | Multiple institutions | 4 | 1997-2050 | Food prices, Cal. availability, child malnutrition | (Carpenter et al., 2005) |
| CAWMA | 2007 | Water | IWMI | 7 | 2000-2050 | Cal. availability | (IWMI, 2007) |
| Agrimonde | 2009 | Food supply | CIRAD-INRA | 2 | 2003-2050 | Cal. availability | (Dorin and Paillard, 2009) |
| OFID | 2009 | Biofuels and food security | IIASA | 5 | 1990-2030 | Food prices, undernourishment | (Fischer et al., 2009) |
| IAASTD | 2009 | Agricultural R&D | Multiple institutions | 5 | 2000-2050 | Food prices, Cal. availability, child malnutrition | (McIntyre et al., 2009) |
| IMPACT 2050 | 2010 | Food security and climate change | IFPRI | 3 | 2010-2050 | Food prices, Cal. availability, child malnutrition | (Nelson et al., 2010) |
| Oxfam | 2011 | Food supply and prices | Oxfam | 3 | 2004-2030 | Food prices | (Willenbockel, 2011) |
| GEO-5 | 2012 | Environment | UNEP | 2 | 2005-2050 | Food prices, Cal. availability, child malnutrition | (UNEP, 2012) |
| RIO+20 | 2012 | Environment | PBL | 3 | 2010-2050 | undernourishment | (PBL Netherlands Environmental Assessment Agency, 2012) |
| WAT 2050 | 2012 | Food and agriculture | FAO | 1 | 2005/07-2050 | Cal. availability, undernourishment | (Alexandratos and Bruinsma, 2012) |
| ABARES | 2013 | Food supply and prices | ABARES | 4 | 2007-2050 | Food prices | (Linehan, Verity et al., 2013) |

Notes: *SRES: Special Report on Emissions Scenarios; MA: Millennium Ecosystem Assessment; CAWMA: Comprehensive Assessment of Water Management in Agriculture; OFID: OPEC Fund for International Development; IAASTD: International Assessment of Agricultural Science and Technology Development; GEO: Global Environmental Outlook; WAT: World Agriculture Towards; ABARES: Australian Bureau of Agricultural and Resource Economics and Sciences; **IWMI: International Water Management Institute; CIRAD: Centre de coopération Internationale en Recherche Agronomique pour le Développement; INRA: Institute National de la Recherche Agronomique; IIASA: International Institute for Applied Systems; IFPRI: International Food Policy Research Institute; UNEP: United Nations Environment Programme; PBL: Netherlands Environmental Assessment Agency; FAO: Food and Agriculture Organisation. ***The number of scenarios that are analysed in the various diagrams is lower because it is not possible to retrieve data for all variables.

## 4 Analysis

In this section, we analyse and discuss the assumptions on three key scenario drivers, followed by a review of food security indicators that are presented in the studies. It is not easy to derive simple conclusions on future food security from the various scenario studies because of the diversity in

[7] In almost all studies, GDP projections and yields are expressed in growth rates while absolute values are presented for population and the food security related outcomes. In order to compare the scenarios and construct the plots, the following procedure is used. First, for each variable the data is converted into the comparable units. Second, for each variable-scenario combination, the starting value of the projection is taken from historical information. Finally, for each variable-scenario combination the data series for the full horizon of the study is constructed by means of extrapolation or interpolation. In case of GDP and yields, the projection is a simple growth function using annual compound rates of growth. For all other variables, linear interpolation is used to obtain values between the starting year and available observations.

underlying assumptions, storylines, combination of models and indicators. To structure the discussion we apply the scenario typology developed by Van Vuuren et al. (2012) discussed above. Building on their work, we allocate all scenarios to one of the six scenario families (see Annex). It is not possible to map all scenarios. In particular the scenario studies that apply projections using “what if?” questions (e.g. IAASTD, OFID and ABARES), apply policy experiments to Business-as-usual scenarios while keeping the major driving forces constant. They, therefore, tend to fall ‘in between’ scenario families. Nonetheless, a sufficient number of scenarios can be classified in order to identify the broad mechanisms that determine global food security under different futures. Also note that due to missing data, it is possible that not all six scenario families are presented for some of the variables.

To compare the various scenarios we adopt a type of diagram that is also used frequently in the climate change scenario literature (Nakicenovic et al., 2000; van Vuuren et al., 2011). The plot shows projections for individual scenarios as well as an area that marks the total range of possible values, which can be regarded as a measure of uncertainty. To place the information into perspective, we also show the historical trend and projections for FAO’s frequently cited WAT 2050 study.

### 4.1 Food security drivers

To quantify and simulate different scenarios, biophysical, economic or integrated models are used (See Reilly and Willenbockel, 2010 for an overview). A key input in these models are assumptions on a limited number of exogenous driving forces that form the heart of a scenario exercise. In the scenario literature, three key driving forces are central: population growth (also including urbanisation), economic development and technological change (i.e. agricultural productivity in terms of yields, frequently also incorporating irrigation).[8] Other important factors that often characterise a scenario are assumptions on policies (e.g. trade and environmental policies) and institutions (see Table 1). These are difficult to compare directly but are to a certain extent captured by the scenario family classification. In addition, several studies also include assumptions on number of other drivers that are particularly important from a food security perspective such as biofuels, climate change and diets. These are discussed in Section 5.

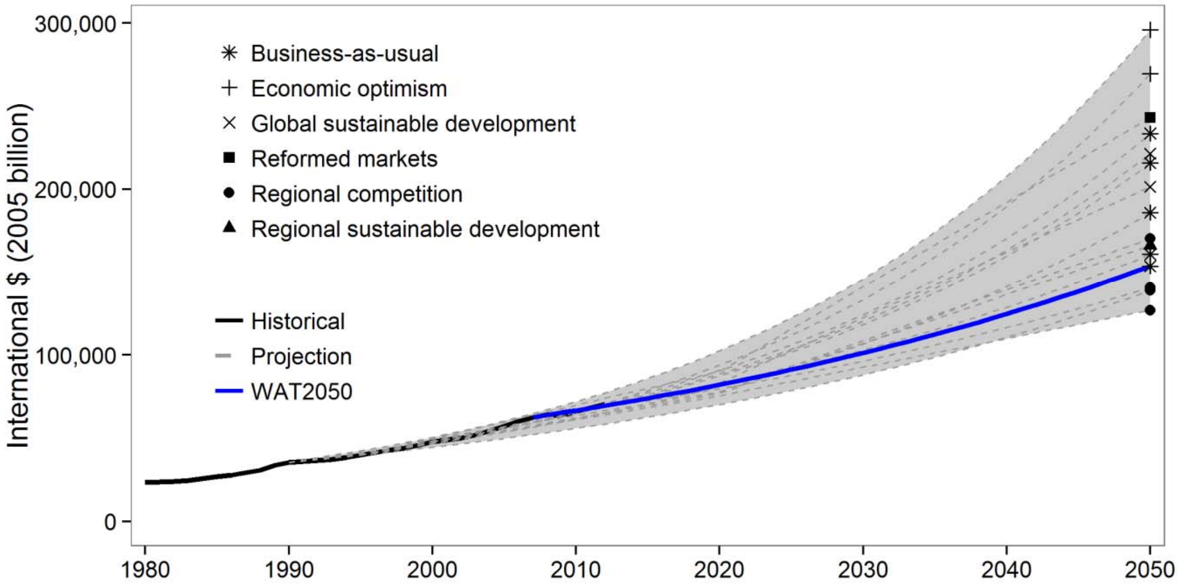
Figure 1,

Figure 2 and Figure 3 depict the assumptions on the three key drivers for the various scenarios. Assumptions about global population vary between 7.9 and 12.4 billion people in 2050. For the Business-as-usual scenarios, projections are usually set between 8.2-9.5 billion people but seem to

[8] The majority of studies provide information on future yields, which are a key determinant of agricultural production. Computable General Equilibrium (CGE) models, which are often used in scenario assessments, also model technical change by means of total factor productivity, which captures technological advance of all factors of production. As this measure is not available in for all studies and difficult to compare across it is not presented here.

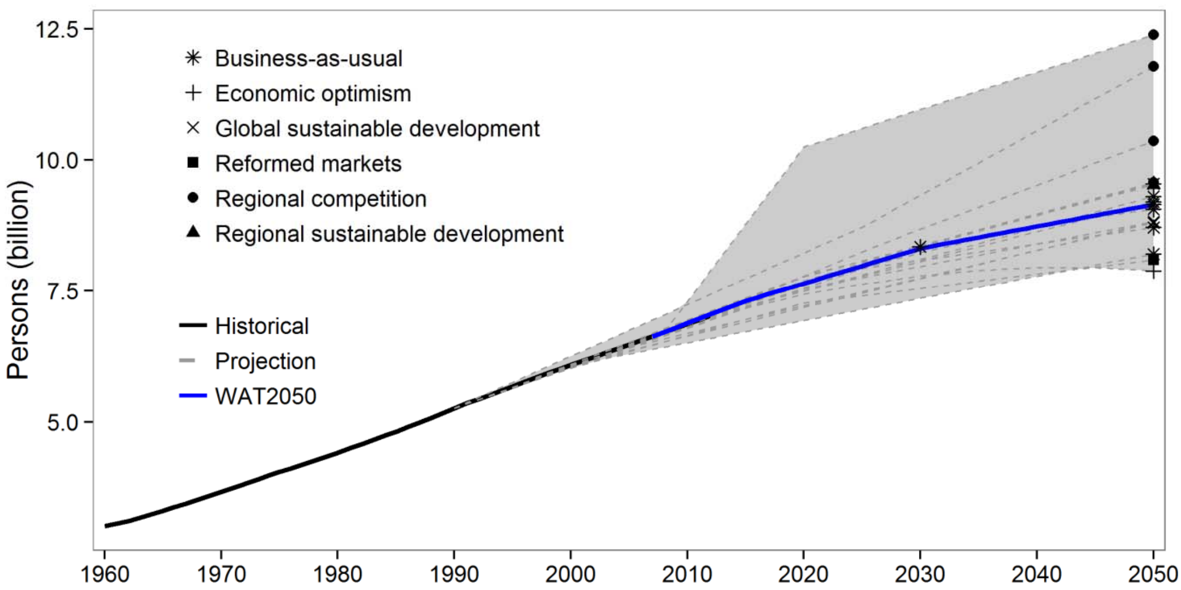
have been scaled up in the most recent assessments. Global future GDP growth ranges from 1.9 to 3.6 per cent per year and baseline projections are around 2.8-3.2 per cent annually.

**Figure 1: Global GDP (PPP) - historical trend and future projections**




Source: Historical GDP (PPP) series from World Bank (2013a); Future projections from Table 2.
Notes: Number of scenarios: 16; Some of the scenarios use the Business-as-usual scenario assumptions for GDP for other scenarios as well. To avoid overplotting, only the Business-as-usual scenario is indicated; Scenarios without a scenario family marker are not allocated (see Annex).

**Figure 2: Global Population - historical trend and future projections**



Source: Historical population series from World Bank (2013a); Future projections from Table 2.
Notes: Number of scenarios: 19; Some of the scenarios use the Business-as-usual scenario assumptions for population for other scenarios as well. To avoid overplotting, only the Business-as-usual scenario is marked; Scenarios without a scenario family marker are not allocated (see Annex).

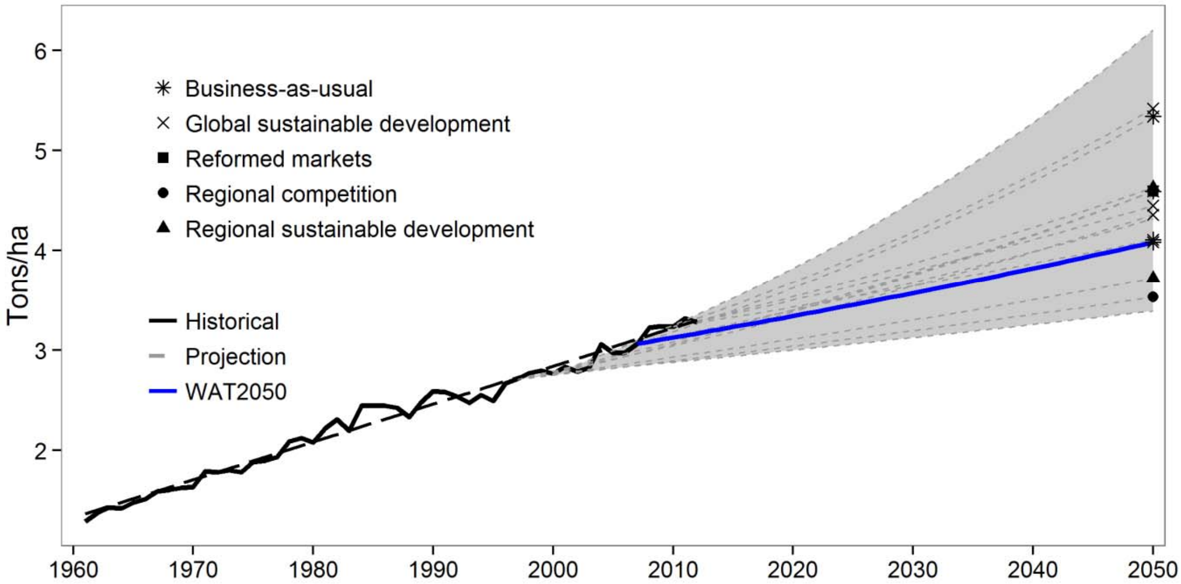
Information on yields is more difficult to compare across scenarios for a number of reasons. First, although the majority of studies only report yield growth for rainfed and irrigated areas combined, a few studies provide separate projections for the two types of farming systems. Second, some studies model yield growth of individual crops (mostly, maize, rice and wheat) whereas others estimate yield growth for cereals as a group. Finally, in most cases it is not clear from the studies if the presented figures for yield growth should be interpreted as linear or geometric growth rates. This is important as a number of studies have pointed out that yield trends are best projected by using a linear model (Fischer and Edmeades, 2010; Hafner, 2003). Using geometric rates will therefore result in too optimistic yield projections (WRI, 2013). However, as this issue is not explicitly addressed in any of the scenario studies, we assume that (standard) geometric growth rates are applied. To make the comparison possible, Figure 3 depicts trends in rainfed and total yields, which are often in the same range, for cereals only.[9]

Total (rainfed and irrigated) cereal yield growth varies from 1.6 to 0.41 percent per year (1.16 and 0.56 percent for rainfed yield). Business-as-usual projections for yield growth are between 0.6 (rainfed) and 1.3 (total) percent per year. It is interesting that almost all scenarios project that cereal yield growth will be considerably lower than the historical trend of 1.8 percent for the period 1961-2012. Most studies assume that the past trends of decreasing (geometric) yield growth will continue in the future because of a combination of factors: (1) the opportunities to increase yield and exploit existing yield gaps are more and more exhausted (WRI, 2013); (2) there remain considerable socio-economic constraints to increase yields in majority of developing countries (Alexandratos and Bruinsma, 2012); (3) the expansion into marginal (low yielding) land (e.g. Sub Saharan Africa) (Paus, 2013) and (4) the lower investment in agricultural R&D (Alston et al., 2009; McIntyre et al., 2009).[10] In this regard, it seems that yield projections of at least the early scenario studies (MA with base year 1997 and IAASTD with base year 2000) have been too pessimistic as historical data on yields for the period 1997-2010 indicate that this decrease has not (yet) materialised.

[9] We also created a similar graph but assuming linear growth rates. The relative ranking of the different scenarios does not change but there are considerable absolute differences. Applying geometric growth rates results in yields that are approximately 1-1.5 ton/ha higher than linear growth rates. See WRI (2013, p. 55) for a similar comparison.

[10] Cereal yield growth declined from 3.2 percent per year in 1960 to 1.5 percent in 2000 (Fischer et al., 2011; Alston et al., 2009).

**Figure 3: Global Yield - historical trends and future projections**




Source: : Historical yield series from FAO (2013a); Future projections from Table 2.
Notes: Number of scenarios: 14; Historical yield is an area weighted average; Scenarios without a scenario family marker are not allocated (see Annex).

As is to be expected the projections for GDP, population and yields are in line with traits of the six scenario families in Table 1. The Economic optimism scenario, and to a lesser extent the Reformed market and Global sustainable development scenarios, shows the highest GDP growth, the lowest population development and highest yield growth (not available for the Economic optimism scenarios), while the Regional competition scenarios show the reverse pattern. The projections for the three drivers of the Regional sustainable development and Business-as-usual scenarios are more mixed but generally show a 'middle of the road' pattern.

### 4.2 Food security outcomes

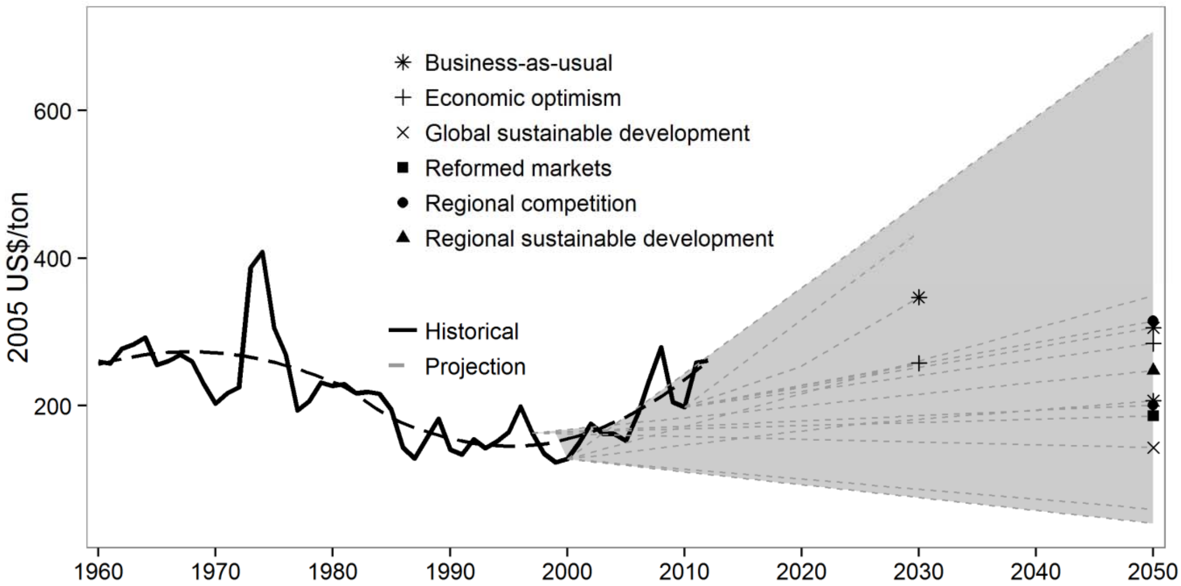
Four indicators of food security are presented in the various documents. Eight studies provide outcomes in terms of food prices (in absolute numbers or growth), seven studies provide outcomes for calorie availability (in kilocalorie per person per day), four studies provide outcomes for child malnutrition (in absolute numbers or percentage) and three studies provide information on future prevalence of undernourishment (in absolute numbers or percentage) (Table 2).

Figure 4a-c show a very mixed pattern of future food price development ranging from an enormous increase to a substantial reduction in maize, rice and wheat prices. Overall, it seems that prices are decreasing or remain stable for the Global sustainable development and Reformed market scenarios and increase the most for the Regional competition scenarios, followed by the Economic optimism scenario family. The latter finding is however surprising as this archetype scenario is expected to result in positive results with respect to food prices and other food security outcomes. The figure suggest that this finding is related to a change in perception about future food price trends after the 2007/2008 food price crisis. The Business-as-usual scenarios of studies that were conducted before 2007/08 project a relative small increase in food prices (around 206, 275 and 140 US$/ton for wheat, rice and maize, respectively) while Business-as-usual studies that were organised thereafter project a much higher price increase (around 305, 670 and 330 US$/ton). The latter figures are higher than those for the Economic optimism scenarios, which have only been modelled in post 2007/08 studies.

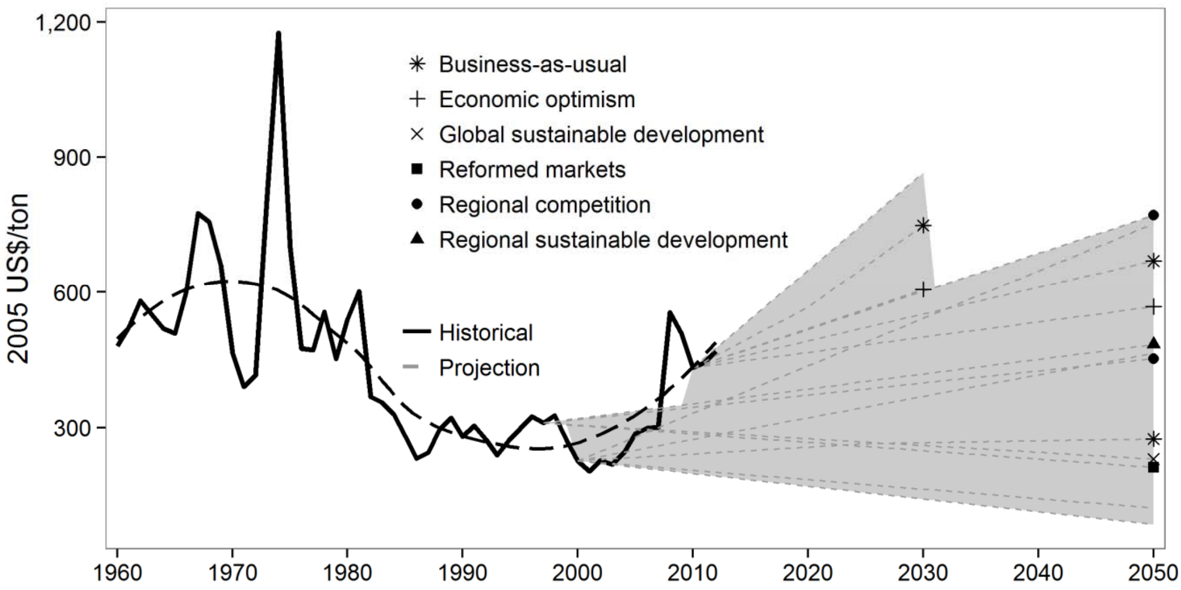
The figures also suggest that the trend of increasing food prices, which already started several years before but peaked around 2007/8, was not anticipated by any of the scenarios that were undertaken before the food price crisis. Only one study (IAASTD) includes two scenarios that project a steep increase in food prices from 2000 onwards. In these scenarios, the rise in prices is predominantly caused by only one factor, very low investment in agricultural R&D that leads to lower annual growth rates of cereal yield.

**Figure 4a-c: Cereal food prices - historical trend and future projections**

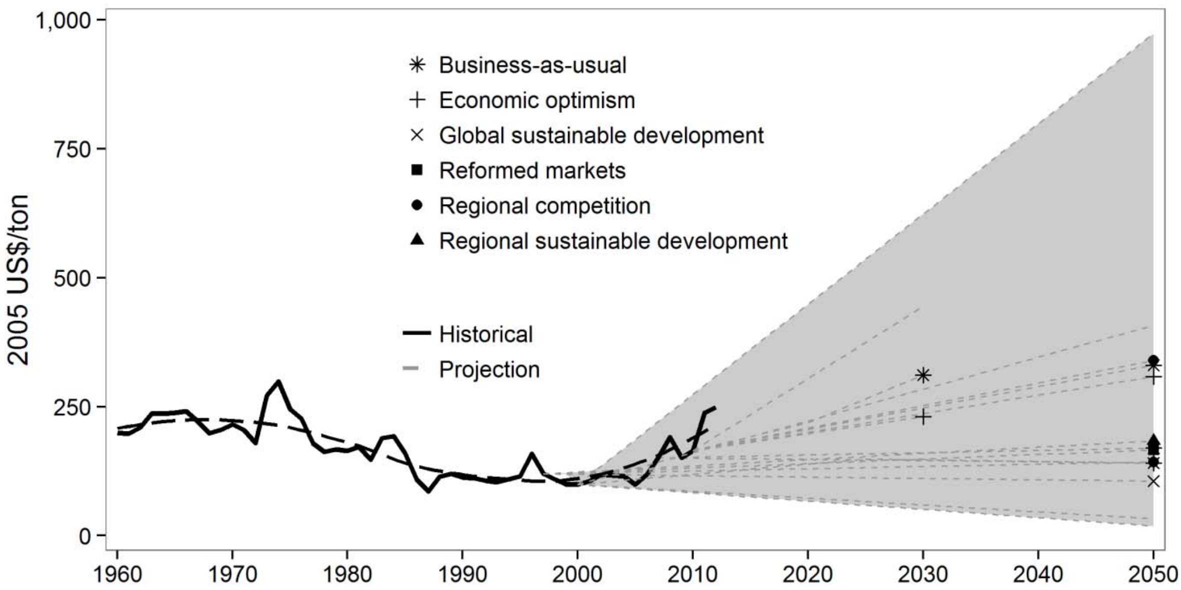
**(a) Wheat**



**(b) Rice**




**(c) Maize**

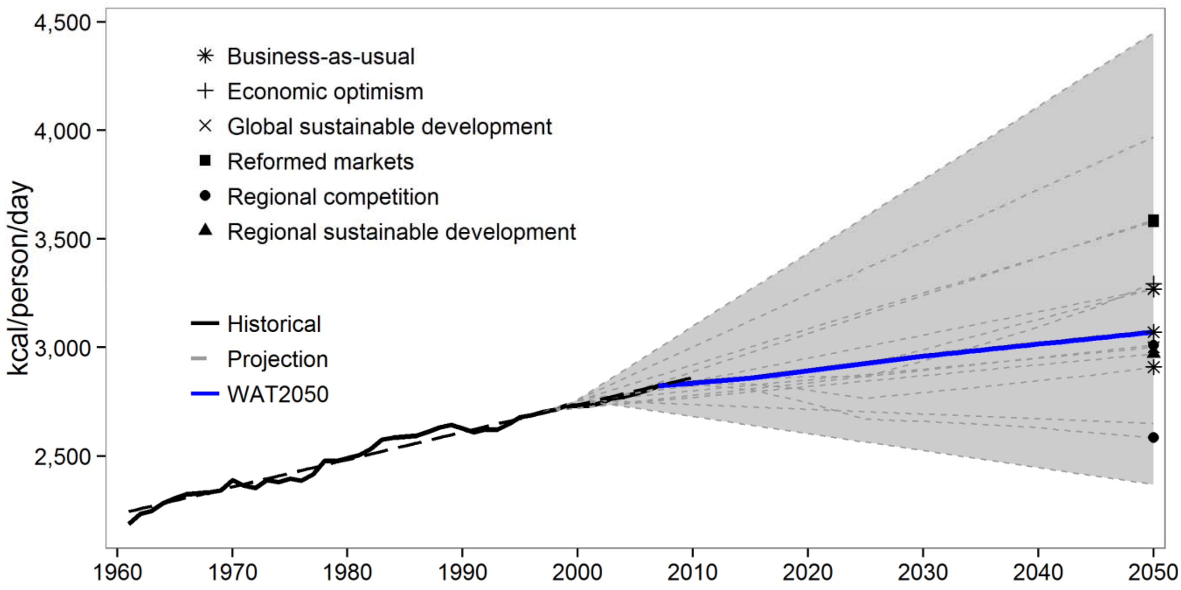



Notes: Number of scenarios: (a) 15 (b) 15, (c) 17 ; Scenarios without a scenario family marker are not allocated (see Annex) ; The WAT 2050 study does not present projections for cereal prices.
Source: Historical trend from World Bank (2013b); Future projections from Table 2.

Similar to food prices, the projections for future calorie availability show widely increasing and decreasing patterns, ranging from 2370 to 4450 kcal per person per day (2909 and 3268 for the

Business-as- usual scenarios, Figure 5). The estimations for each of the scenario families are in line with expectations. Calorie availability is highest in the Reformed markets and Global sustainable development scenarios, followed by Economic optimism, and lowest in the Regional competition scenarios, while the Regional sustainable development and Business-as-usual scenarios are in the middle.

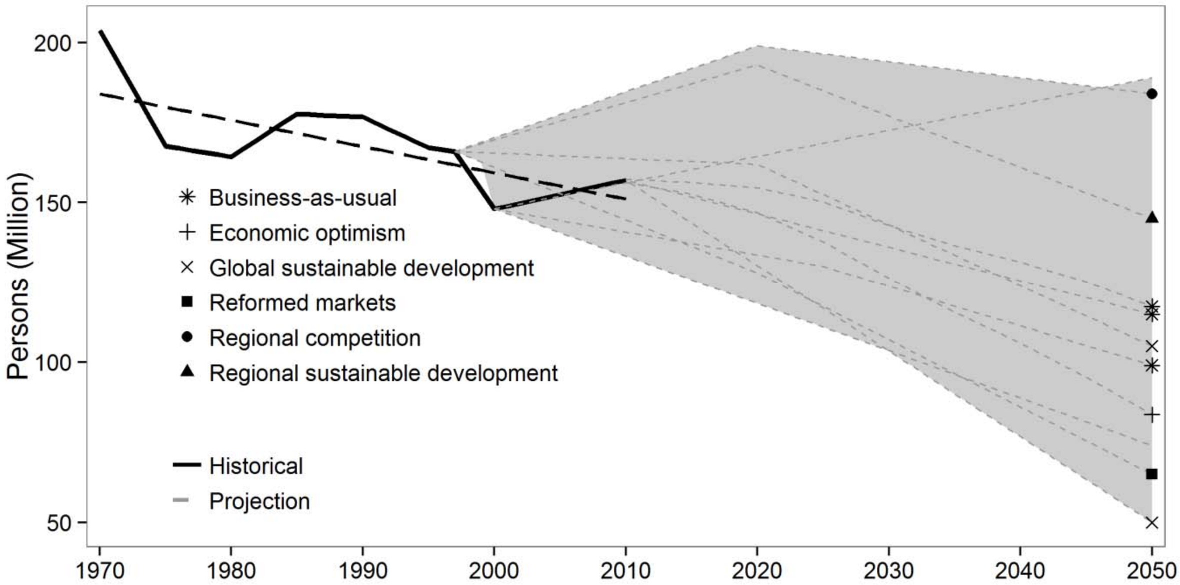
**Figure 5: Calorie availability - historical trend and future projections**




Notes: Number of scenarios 15; Scenarios without a scenario family marker are not allocated (see Annex).
Source: Historical calorie availability series from FAO (2013a); Future projections from Table 2.

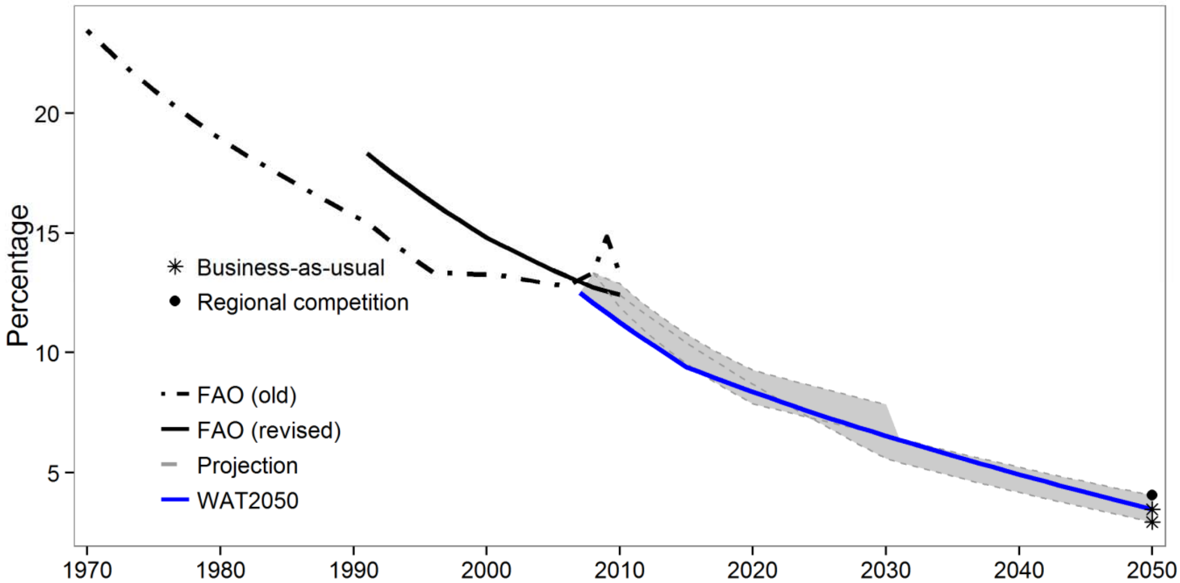
The scenario outcomes for child malnutrition are also diverse, ranging from 50 to 189 million children in 2050 (99 and 117 for the Business-as-usual scenarios) and outcomes are in line with the expectations for the various scenario families. However, in contrasts to the plots for food prices and calorie availability, the majority of scenarios foresee a downward trend in child malnutrition in the coming decades. Only three scenarios, predict a different pattern. Both the Regional competition and the Regional sustainable development scenario project an increase in undernourished children up to 2020, followed by a decline. The other scenario (IAASTD Low AKIS Low) is characterised by very limited yield growth, resulting limited calorie availability, high food prices and, consequently, increasing child malnutrition. It is also important to note that the figure compares absolute figures of child malnutrition. To compare the scenarios it would be better to present data on the share of children that suffer from malnutrition to take into account differences in assumptions on population growth between. Information on the total number of children per scenario to make this calculation is, however, not available.

**Figure 6: Child malnutrition - historical trend and future projections**




Notes: Number of scenarios 11; Scenarios without a scenario family marker are not allocated (see Annex) ; The WAT 2050 study does not present projections for cereal prices.
Source: Historical trend from Smith and Haddad (2000), Carpenter *et al.* (2005) and Nelson *et al*. (2010); Future projections from Table 2.

**Figure 7: Prevalence of undernourishment - historical trend and future projections**




Notes: Number of scenarios 4; Figures apply to developing countries; Scenarios without a scenario family marker are not allocated (see Annex).
Source: FAO (old) from FAO(2010), FAO (revised) from FAO (2013b); Future projections from Table 2

Finally, Figure 7 presents historical trends and future projections for the global prevalence of undernourishment up to 2050. Two historical series from the FAO are plotted: the old estimations up to 2010 and the revised series. The main difference is that the revised series take into account food losses at the retail level, which significantly changes the estimations for undernourishment (FAO, 2012).[11] As only three studies present data on the prevalence of undernourishment it is difficult to make inferences on the relationship between scenario family and undernourishment outcomes. Nonetheless, the two Business-as-usual scenarios and the two other scenarios expect that the historical trend of falling prevalence of undernourishment will continue from around 12 (FAO old) - 13 (FAO revised) percent in 2010 to approximately 3 percent in 2050.

### 4.3 Scenarios that lead to a food secure world

We find that broadly speaking, scenarios that belong to the same family provide similar outcomes. The Business-as-usual scenarios foresee an improvement, albeit slight, in global food security outcomes up to 2050. Food prices are expected rise because of increasing demand, lower yield growth and expanding international food trade. As food becomes less affordable, food consumption (calorie availability) only increases marginally. Nonetheless, the share of children that suffer from malnutrition declines with 75 percent because of income effects and improved support services.

In the Economic optimism and Reformed markets scenarios, global food security indicators improve substantially mainly because of the combination of an increase in agricultural productivity, economic growth and emphasis on free trade. Also, in the Global sustainable development scenario, food availability and accessibility improve substantially. In fact, the underlying assumptions that are responsible for this result are very similar to the Economic Optimism scenario: increasing international trade in food commodities, economic growth and above all a high rate of technological change triggered by large investments in agricultural R&D and support services. These also ensure that food price increases in the future are limited. The main difference with the other scenarios is that these processes are guided by strong global governance and therefore lead to a more equitable and sustainable world. Finally, in the Regional competition scenario and, to a lesser extent, in the Regional sustainable development scenario, perspectives for global food security are negative. Food availability is hampered by trade protection and limited investment in agricultural productivity leading to lower economic growth and reduced food accessibility as a resultant.

[11] As, the revision of undernourishment figures was only undertaken after publication of the scenario studies, where needed the old series have been used as starting values for the projections.

# 5 Discussion

## 5.1 Incorporating food security in global scenario exercises

The discussion about what constitutes food security has intensified over the last years. When food security issues were first highlighted in the seventies, the focus was on whether a nation could provide enough food to meet the aggregate requirements of its people, and food security was expressed in terms of tonnes of grain or food kilocalories (Boucher, 1999). Several recent discussions, such as the Food Security and Nutrition Forum organised by FAO (FAO, 2009), have highlighted the multi-faceted nature of food and nutrition security. Food security and nutrition security are two closely related but different concepts. Nutrition security requires that household members have access not only to food, but also to other requirements for a healthy life, such as health care, a hygienic environment and knowledge of personal hygiene. Food security is a necessary but insufficient condition for ensuring nutrition security (IFAD, 2013). It seems as if most scenario studies have not yet incorporated the results of these discussion. The scenario studies reviewed in this paper use four indicators of food security: food prices, calorie availability, child malnutrition and prevalence of undernourishment, which cover two of the four dimensions of food and nutrition security: food availability and food accessibility, while food utilisation and stability are hardly covered. One could argue that child malnutrition partly takes into account food utilisation as it is not only caused by a low intake of calories, but also caused by deficiencies in nutrition of a child or mother (Martorell, 1999).

A number of reasons explain why scenario analysis have paid little attention to indicators of the food utilisation and stability dimensions. Firstly, most scenario analyses pay little attention to the consumption side of food security because of the type of models used. These are generally suited to provide an elaborate treatment of the bio-physical production side of the food system (i.e. yield and land use) and market transactions (i.e. demand and supply), but are not well equipped to deal with the consumption side (household income and composition of the diet) and short to medium term effects (i.e. shocks and cyclical effects). This probably also explains the popularity of the IMPACT model – used in half of the scenario studies – which is one of the few global models able to compute child malnutrition figures and food price change for a large number of crops and livestock types. A similar observation was made by Wood et al. (2010, p. 59), who meticulously map the causal linkages between environmental change and food security emphasised in three major global environmental assessments: MA, IPCC Fourth Assessment and GEO-4:*"Data, knowledge and expertise gaps are even more apparent with regard to processes influencing the non-supply-related food security outcomes. […]. This likely reflects a less than adequate prior understanding or articulation of the potential pathways of impact between environmental change and access and utilisation outcomes. […]. Many of these factors are driven to a much greater extent by local socio-economic and intrahousehold conditions and customs"*.

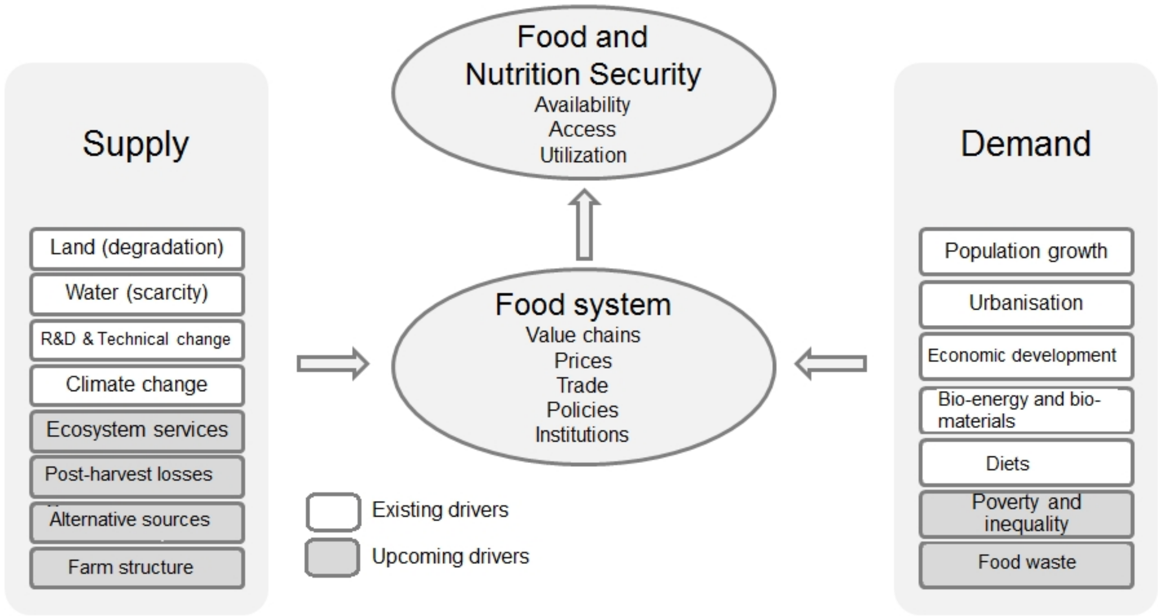
Secondly, to measure food consumption, micro-level data is required that describe household and individual income, expenditures, diet diversity and food intake, which are not easily available for many countries and regions. For this reason, the scenario studies are not able to present outcomes on poverty related issues for which this type of data is needed. Most scenario studies use calorie availability as a proxy for consumption instead. However, this may not be an accurate measure as it refers to the average amount of food available for human consumption – usually based on aggregate data commonly estimated by the FAO Food Balance Sheets – and as such is a poor estimate of actual food consumption. The averages may conceal the fact that food consumption at the household level may widely differ because it depends on household income, distribution of food between household members, as well as waste and losses of food in the household.

Thirdly the studies we examined have a long term focus and are usually not equipped to examine the impact of short-term shocks (e.g. wars and famines) or cyclical effects (e.g. recurrent weather patterns like El Nino) which are of a short to medium term nature.

### 5.2 New drivers of food security outcomes

Figure 8 presents a stylized representation of the drivers of food and nutrition, similar to approach that is used in most integrated assessment models. The drivers highlighted in white are taken into account by most scenario studies. Three of them: population growth, economic development and technical change have already been discussed above. Three other drivers that are also expected to have a substantial impact on global food are climate change, the increasing use of bio-energy and bio-materials, and the shift in diets and consumer preferences. Although the majority of scenario studies highlight these issues, their treatment is mostly superficial and only limited details are presented. Two studies (SRES and IMPACT 2050) provide a very elaborate analysis of the impact of climate change on food security outcomes. Overall, climate change has a negative impact on food security indicators, although when $CO_2$ fertilisation is taken into account the effect is ambiguous. One study (OFID) presents a very detailed assessment of the impact of biofuels on food security outcomes. It finds that even with a relatively swift deployment of second-generation technologies, the number of undernourished people will increase with 10 percent in comparison to a scenario in which biofuel demand does not increase. Finally, several studies have pointed out that the demand for meat and dairy products will increase in the future, predominantly as a consequence of changing diets in developing countries, while at the same time the consumption of cereals, pulses, roots and tubers is expected to level off (Knudsen et al., 2006; Regmi and Meade, 2013). Only a few studies, in particular WAT 2050, MA and RIO+20 specifically account for this change in global diets in (some of) their projections.

**Figure 8: Global drivers of food and nutrition security**




Apart from these 'conventional' drivers of food security, recently, a number of other driving forces have been identified in the literature. These are yet to be fully incorporated into scenario studies, partly because they represent new developments (e.g. alternative sources of food supply such as insects and algae) or because they represent rethinking the food security and nutrition security concept (e.g. the role of poverty and inequality). The drivers marked in light grey highlight these new drivers on both the supply and demand side. On the supply side, they are (the trade-off between) ecosystem services (Power, 2010), post-harvest losses (Parfitt et al., 2010), alternative sources of food supply (van Huis, 2013) and farm structure (Wiggins, 2009). On the demand side, new drivers are food waste, and poverty and inequality. Poverty and inequality, off course, have been a longstanding concern and its relationship with food security is well known (Sen, 1982). However, it is a new driver in the sense that only recently efforts are made to include it into food security assessments. A new initiative that aims to incorporate a large number of the food security drivers into modelling and scenario framework is FOODSECURE (www.foodsecure.eu), an interdisciplinary project that aims to explore the future of food and nutrition security.

## 6 Conclusions

This study reviews twelve important scenario studies that in one way or the other incorporate the implications for food security of different futures.

We show that scenarios studies may be classified using a set of scenario families with comparable assumptions and outcomes. global-level food security outcomes are most positive in scenarios which emphasise the importance of international trade and above all the investment in technological change (i.e. yield improvement). Scenarios that combine these assumptions with strong global governance are expected to result in a world with less inequality and more attention for the environment. The differences within the same archetype of (quantified) scenario outcomes are predominantly a result of differences in data sources and model structure (see also von Lampe et al., 2013).

We find, though, that the studies mainly deal with two of the four dimensions of food security: food availability and food accessibility, while food utilisation and stability are hardly covered. The reason for this is the nature of the models used, which are well developed to simulate bio-physical and market dynamics but have limited capacity to analyse the household and individual part of food demand and food security.

In addition to this limitation of the models used, we identify several new developments that are key to food security, but which have not yet been (fully) incorporated into the models used in scenario analyses. Climate change, bio-fuels and materials, and diets, which are considered to be important drivers of global food security, are only partly assessed in most studies. Other aspects, such as the trade-off between ecosystem services, post-harvest losses, alternative sources of food, farm structure as supply side drivers and poverty and inequality, and food waste as demand side drivers have hardly been incorporated, although several efforts are underway. These new developments open up new pathways for research.

Finally, we draw attention to the fact that there is a need for improved specification of scenario assumptions and related modelling, in particular in the area of yield projections. These have a significant impact on the food security outcomes. It needs to be clarified whether yields growth is linear or geometric, which will require additional research in this area.

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## Annex: Classification of scenarios according to scenario families

| | Economic Optimism | Reformed Markets | Global Sustainable Development | Regional Competition | Regional Sustainable development | Business-as-usual | Not classified |
|---|---|---|---|---|---|---|---|
| SRES | A1 | | *B1* | A2 | | *B2* | |
| MA | | *Global orchestration* | Techno garden | Order from strength | *Adopting mosaic* | | |
| CAWMA | | | *Optimistic rainfed, Expanding irrigated areas, improving irrigation performance, Comprehensive* | | | | Pessimistic rainfed, |
| Agrimonde | | *Agrimonde GO* | Agrimonde 1 | | | | |
| OFID | | | | *REF-01* | | | WEA-V1/V2, TAR-V1/V2 |
| IAASTD | | | | | | Reference scenario | High AKST High; High AKST , Low AKST Low; Low AKST |
| IMPACT 2050 | Optimistic | | | *Pessimistic* | | Baseline | |
| Oxfam | Optimistic | | | | | Baseline | Climate change |
| GEO-5 | | | Sustainable worlds | | | Conventional worlds | |
| RIO+20 | | | Global technology, *Consumption change* | | Decentralised solutions | Trend | |
| WAT 2050 | | | | | | Baseline | |
| ABARES | *Trade liberalisation* | | | | | Reference scenario | Rainfall deficiency, Biofuels changes |

Source: Van Vuuren et al. (2012). Classification of additional scenarios by authors based on storylines.
Note: Italics are used to indicate that scenarios are not completely consistent with the group in which they are classified

## 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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