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A review of global scenario exercises for food security analysis

Assumptions and results

Michiel van Dijk

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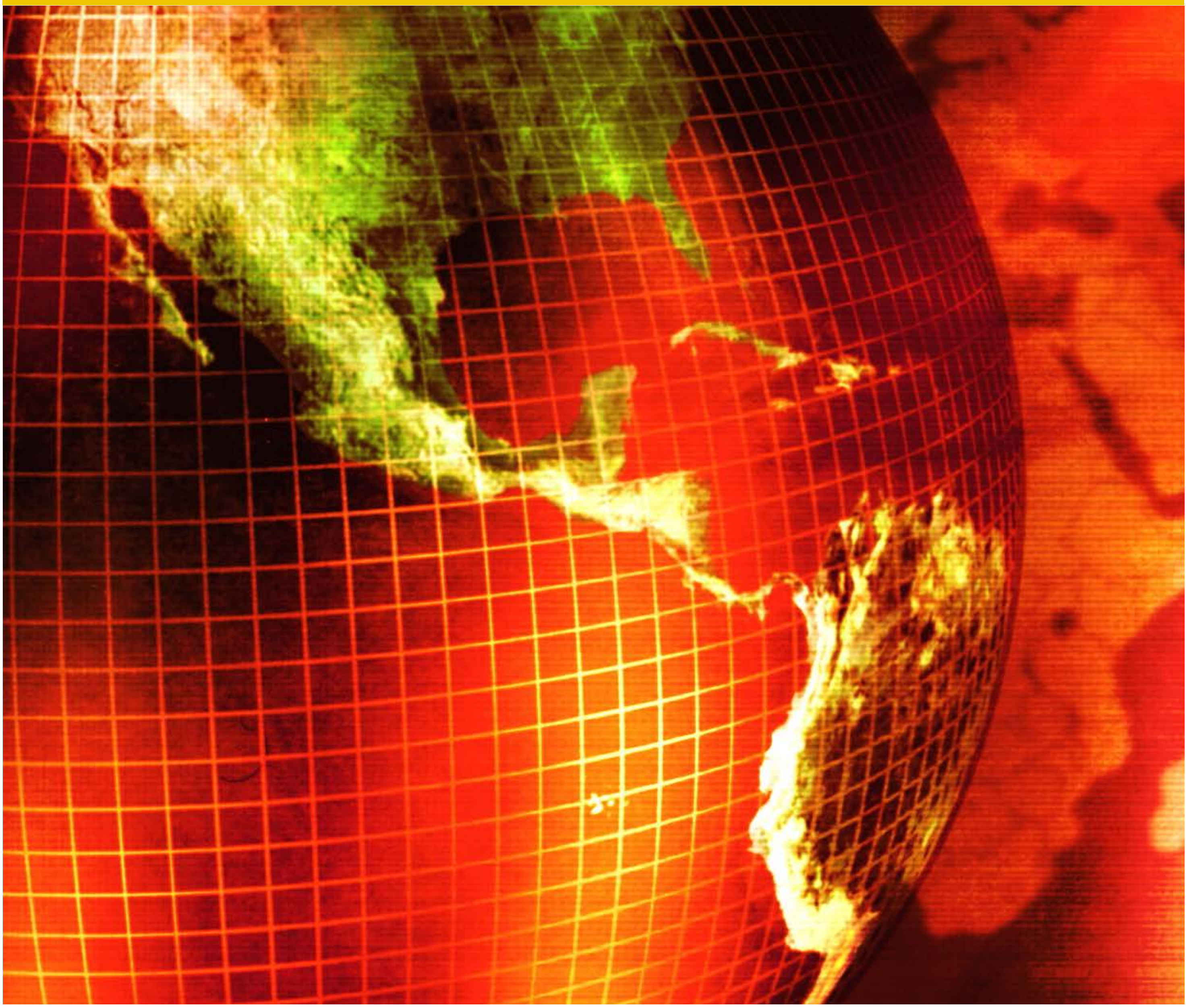

INTERDISCIPLINARY RESEARCH PROJECT
TO EXPLORE THE FUTURE OF GLOBAL
FOOD AND NUTRITION SECURITY

A review of global scenario exercises for food security analysis: Assumptions and results

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Summary

The aim of this study is to review the scenario literature with a particular focus on the implications for global food security. In total nine major global scenario studies, published between 2000 and 2012, are covered. Four out of the nine studies focus explicitly on agriculture and the food system. Four others have a broader or different perspective (e.g. climate change, environment and ecosystems) but nonetheless include elements that are relevant for food security analysis. The ninth study concerns so called Shared Socioeconomic Pathways (SSPs) that are currently being developed as input to the upcoming IPCC Fifth Assessment Report.

The first part of the study provides a brief background to scenario analysis discussing the definition and characteristics of scenarios as well as different typologies and archetypes that are proposed in the literature. Following sections briefly summarise the nine scenarios studies that are reviewed in this report, including background, individual scenarios, drivers, assumptions and food security related outcomes that can be derived from the scenario exercises.

This study finds that all of the scenarios only deal with two of the four dimensions of food security: food availability and food accessibility, while food utilisation and stability are hardly covered. This is mainly caused by the nature of the models that are used to quantify the scenarios. In general, the models are developed to simulate bio-physical and market dynamics but have only very limited capacity to analyse food demand and food security at the household and individual level. It is also found that none of the scenarios addresses the on-going transition from a fossil-based to a bio-based economy. Climate change is dealt with in two of the studies and is expected to affect negative effects on food security.

It is also shown that the scenarios studies could be classified using a set of archetype scenarios with comparable assumptions and outcomes. Macro-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.

Finally, the question was discussed whether it is useful to develop new global scenarios for the analysis of food security issues. It is argued that the SSPs, which will be completed by the end of 2012, might be a good starting point for such studies.

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Introduction

1.1 Background[1]

In 2012, the Food Secure project, a five year initiative funded by the EU FP7 Framework Programme, started. The aim of the project is to improve *"the resilience of the food system by providing means to mitigate risks and uncertainties in the world food system caused by economic and climatic shocks while providing for sustainable growth"*. As part of Work Package 5, a set of scenario narratives will be developed in cooperation with stakeholders. The scenario narratives will provide guidance to modelling and policy guidance in the other work packages of Food Secure. This background paper has been written to guide and inform the near future planning for Work Package 5, in particular the design of the scenario building process.

1.2 Objective

This study aims to provide a review of the scenario literature with particular focus on the implications for global food security. It presents concise information on the background of the studies, individual scenario narratives, assumptions and food security outcomes. This information will help answer the question whether completely new scenarios need to be developed within Food Secure, or whether the scenario building process can build on existing scenarios (in modified form).

Note that most of the scenario studies reviewed here are large and 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. It outside the scope of this study to provide a review of all findings at multiple scales. Instead, the focus lies predominantly on presenting and analysing the assumptions and outcomes related to food security. Due to the large number of scenario studies and individual scenarios, only brief summaries of storylines and assumptions are presented, focussing 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 (see Annex 2 for sources).

1.3 Approach

Information has been collected by means of a literature survey. Main sources of information are the original scenario reports and previous scenario reviews. References are provided at the end of this report and in the Annex.

1.4 Structure of the report

After the introduction, 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 nine scenarios 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.

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[1] This paper was co-funded by Oxfam Novib. A slightly different version of the document with the title "A review of global scenarios for food security analysis" will be released as Oxfam Research paper in the fall of 2012.

2 Scenario analysis

2.1 Definitions and characteristics

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 1961; Kahn & Wiener 1967). Simultaneously, the business community, pioneered by Royal Dutch Shell, also 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), which are discussed below. Scenario development is also frequently used in national and regional level assessments.[2]

Several definitions for scenarios are given 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), while 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).

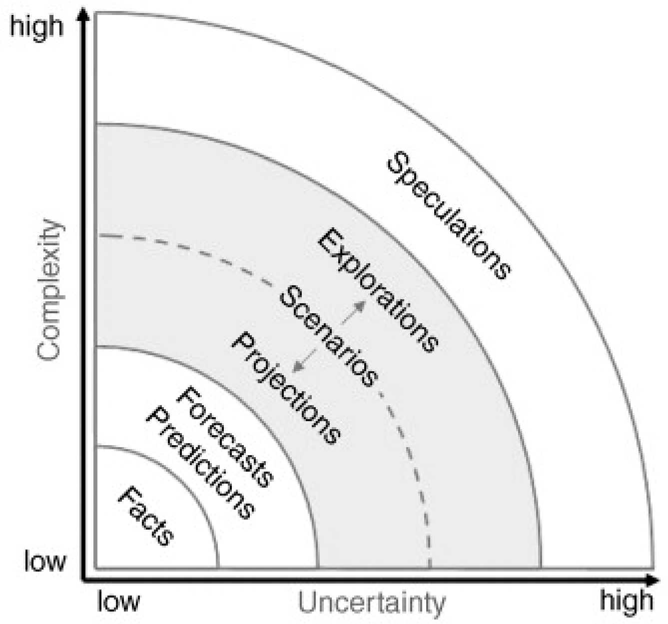
Both definitions capture the key characteristics of most scenarios. Scenarios are a basically set of stories that describe potential futures as well as the specific developments and events that explain why they come about. To illustrate the uncertainty of future development, several stories are developed 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 possible impact of interventions and decisions (e.g. policies or strategic management decisions) in a structured way.

Scenarios differ from facts, forecasts and predictions (Figure 1) which assume that the 'boundary conditions' of the present will remain the same in the future. 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

[2] Integrated assessment is a type of assessment that integrate and combines knowledge from two or more domains into a single framework. It is commonly used in the environmental sciences and environmental policy analysis because environmental problems are caused by and have impact on a variety of domains, including socio-economic, institutional, environmental and demographic.

stakeholders that are subsequently modelled to analyse the relationship of drivers and quantify the impact of policies.

Figure 1: Complexity and uncertainty associated with forward looking assessments.

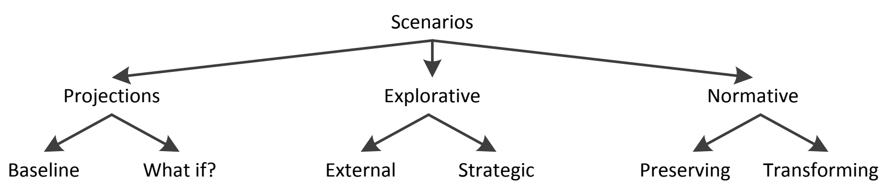


Source: Zurek and Henrichs (2007)

2.2 Typology of scenarios

Several typologies have been proposed in the literature to group scenarios. Common characteristics that have been used to distinguish scenarios include, the process applied to develop the scenario, the main issue or question addressed, time period covered and spatial scale (e.g. van Notten et al. 2003). Also more recently a typology based on content (e.g. storyline and scenario logic) has been proposed (see below). In most cases the type of scenario chosen to assess complexity and uncertainty of a system will depend on the purpose of the exercise. In this regard, Borjeson et al. (2006) (but also see Berkhout et al. 2002; Westhoek et al. 2006; and Reilly & Willenbockel 2010) provide a useful typology that is based on the principal question that users may want to pose about the future. These are; What will happen?, What can happen? and How can a specific target be reached?, and correspond with probable, possible and preferable future states. This translates into a typology of three major classes of scenarios: projections, exploratory scenarios and normative scenarios that each can be divided into two groups (Figure 2).

Figure 2: Scenario typology



Note: The typology is based on Borjeson *et al.* (2006) but slightly modified according to Reilly and Willenbockel (2010), which is more in line with the terminology used in major environmental and food system scenarios.

Projections include baseline scenarios that describe the future state of a system with no policy changes. They are also referred to 'business as usual' 'reference' and 'best guess' scenarios. Baseline scenarios are mostly used as a reference point to examine how a system changes when a number of 'what-if' assumptions are made. Projections involve a certain degree of probability or likelihood in their construction as the analysis is centred on one single scenario – the baseline – which is assumed to describe the future. Usually, they do not assume changes in the structure and boundary conditions of the system and therefore might fail to capture major transformative change, novelty or surprises. Projections are best used for planning to analyse foreseeable changes and evaluate policy shocks in the medium term (10-20 years). Often the emphasis lies on quantification of results while the storyline is of less importance.

Explorative scenarios are designed to give room to 'out of the box' thinking and typically involve the development of a set of rich narratives that describe possible polar worldviews. To facilitate easy communication and discussion of multiple futures, scenario practitioners tend to work with a set of four scenarios that are formulated along two, relatively independent, high impact and highly uncertain dimensions of the system. The four scenarios can then be compared using a quadrant in which the dimensions form the axes (e.g. Figure 3 and Figure 4). Scenarios often cover multiple decades and sometimes centuries, and allow for changes in the structure of the system and boundary conditions. The emphasis lies on qualification of scenarios, although many recent studies combine storylines with modelling to quantify outcomes. The external type focus on driving forces that are exogenous to the system and beyond the control of the actors for whom the scenarios are being developed. The picture of different futures is particularly useful to guide strategic business decisions or inform policies in situations of rapid and irregular change when the future is difficult to predict. Strategic explorative scenarios focus on the range of possible consequences of policies and strategic decisions while taking into account external drivers. They make it possible to analyse and compare the impact of decisions in the context of different futures.

Normative scenarios are designed to support vision building. They involve the creation of stories that meet specific outcomes or targets, for example the description of a future that is desired or should be avoided by all means. Backcasting is used to identify the pathways and decisions points to reach the specific vision of the future. The time horizon is usually beyond 25 years. Preserving scenarios outline pathways on how a certain normative target can be efficiently met without major changes in the system. This can be done using some type of optimising model or qualitative planning. Transforming scenarios assume that the target will not be reached if on-going development continues and structural change or trend break in the system is needed.

2.3 Archetypical scenarios

Several authors that reviewed the scenario literature have pointed out that scenarios often share common elements, including related storylines, comparable assumptions on the size and direction of driving forces and policies, and more-or-less comparable outcomes (Nakicenovic et al. 2000; Raskin 2005; also see Rothman 2008). Van Vuuren et al. (2012) propose a typology of six archetype scenarios, which can be derived from the literature.[3] Table 2 summarises the key assumptions that defined the archetype scenarios.

- Economic optimism/conventional markets scenarios are scenarios that have a strong focus on market dynamics, free trade at the global level and economic optimism, usually associated with rapid technology development and high economic growth.
- Reformed market scenarios are scenarios that have a similar logic and philosophy as the first archetype scenarios but include some additional policy assumptions aimed at correcting market failures with respect to social development, poverty alleviation or the environment.
- Global sustainable development scenarios are scenarios characterised by environmental protection and reducing inequality, based on solutions found through global cooperation, lifestyle change and more efficient technologies.
- Regional competition/regional markets scenarios are scenarios that assume that regions will focus more on their more immediate interests and regional identity, often assumed to result in rising tensions among regions and/or cultures.
- Regional sustainable development scenarios are scenarios that focus on finding regional solutions for current environmental and social problems, usually combining drastic lifestyle changes with decentralization of governance.
- Business-as-usual scenarios are scenarios that assume past trends will continue in the future 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 it does not involve assumptions about future uncertainties and the storyline is often less developed.

Table 1: Scenario archetypes

	Economic optimism	Reformed markets	Global sustainable development	Regional competition	Regional sustainable development	Business-as-usual
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
Main objectives	Economic growth	Various goals	Global sustainability	Security	Local sustainability	Not defined
Environmental protection	Reactive	Reactive and proactive	Proactive	Reactive	Proactive	Reactive and proactive
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

Source: Van Vuuren et al. (2012).

3 Global scenario studies with a (partial) focus on food security

This section briefly summarises a number of scenario studies that include an assessment of global food security under different futures. The selected studies comprise large global integrated assessments that

[3] Van Vuuren et al. (2012) use the term 'scenarios families' instead of archetype scenarios to denote a group of scenarios that share common underlying assumptions and result in comparable outcomes. Here the term 'archetypical' is preferred to avoid confusion with the SRES scenarios (see below) that also use the concept of scenarios families but with a different meaning. Cumming et al. (2005) provide an alternative but comparable set of archetypical scenarios.

focus on the environment or climate change but also provide some information on food production and consumption, and studies that are specifically set up to assess the development of future agriculture and food system. It builds 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 with information from a literature search. The following criteria were 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).
- *Quantification.* Scenarios studies should include quantification (using models) of key food security variables.
- *Time horizon.* Only studies that look at the medium to long run are covered. Hence, the overview does not comprise the regular short to medium run food and agriculture assessments by international institutions such as the *FAO/OECD Agricultural Outlook*, FAO's *State of Food and Agriculture* and the *State of the World* by the Worldwatch Institute.[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 in 2000 or later. 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.
- *Global coverage.* The scenario studies must provide information on global food security under different future pathways. Scenario studies that target a specific region or country are excluded. For this reason, it was decided not to include the findings of Global Environmental Change and Food Systems (GECAFS) programme which has developed food security scenarios for the Caribbean (CAR), the Indo-Gangetic Plain (IGP) and Southern Africa.[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 also discussed. 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 nine scenario studies that are reviewed in this report.[6] Four out of the nine studies focus explicitly on agriculture and the food system. The ninth study concerns the new socioeconomic scenarios – the so called Shared Socioeconomic Pathways (SSPs) – that are currently being developed as input to the upcoming IPCC Fifth Assessment Report (AR5), which will be released at the end of 2014. These scenarios have not been published yet but are included because of

[4] See McCalla and Revoredo (2001) for a detailed analysis and comparison of such studies.

[5] As part of the MA also a large number of regional assessments were organised, including regional scenarios: http://www.maweb.org/en/Multiscale.aspx [Accessed 6 July, 2012]. See Zurek and Henrichs (2007) for an in-depth discussion on linking scenarios across geographical scales.

[6] Two additional scenario studies were identified over the course of the research: The *World Water Development Report (WWDR),* which is published every three years by the United Nations Educational, Scientific and Cultural Organization (UNESCO), and, very recently, *Roads from Rio+20 Pathways to achieve global sustainability goals by 2050* by the Netherlands Environmental Assessment Agency. Due to time constraints it has not been possible to include these studies. An attempt will be made to include them in a follow-up to this paper. Also note that the IPCC in collaboration with the scientific community are currently developing new socio-economic scenarios to assess climate change impact. Storylines will be available end of 2012-beginning 2013 (Moss et al. 2010).

their potential future importance as key reference scenarios for the scientific community, also including the analysis of global food security. Details on the models used and sources are provided Annex 1 and Annex 2, respectively.

Table 2: Characteristics of Scenario Studies

Study	Year*	Main focus	Scenario type	Process	Scenarios/Projections	Regions	Horizon
SRES	2000	Greenhouse gas emissions	Exploratory – external	Multi-stakeholder	A1, A2, B1, B2 plus variations.	11	1990-2080
MA	2005	Ecosystems and services	Exploratory – strategic	Multi-stakeholder	Global orchestration, Techno garden, Adapting mosaic, Order from strength	6	1997-2050
CAWMA	2007	Water and agriculture	Projection – what if? & Normative preserving	Multi-stakeholder	Baseline, five what if? scenarios and one normative scenario.	7	2000-2050
IAASTD	2006	Agricultural R&D	Projection – what if?	Multi-stakeholder	Baseline, four what if? Scenarios.	5	2000-2050
WAT 2050	2006/2009	Food and agriculture	Projection – baseline	Internal	Baseline	5-7	2005/07-2050
Agrimonde	2009	Food and agriculture	Projection – baseline, Normative – transforming		Agrimonde GO and Agrimonde 1	6	2003-2050
IMPACT 2050	2010	Food security and climate change	Hybrid of Projection – what if? And Explorative – strategic	Internal	Pessimistic, baseline, optimistic		2010-2050
GEO-5	2012	Environment	Normative – transforming	Multi-stakeholder	Conventional worlds, Sustainable worlds	1	2005-2050
SSPs	2013	Climate change	Explorative - external	Scientific community	Te be decided	?	40 to 100 years

* Refers to the year when final reports are or will be published.

3.1 IPCC Special Report on Emissions Scenarios (SRES)

In 2000, the Intergovernmental Panel on Climate Change (IPCC) published the Special Report on Emissions Scenarios (SRES). The report describes four scenario 'families', made up of groups of individual scenarios that were created to investigate future patterns of greenhouse gas emissions. The SRES scenarios consist of a narrative storyline and a quantification of emissions that serve as an input to economic and climate models to make projections on future climate change. The scenarios were used in the IPCC Third Assessment Report (AR3), published in 2001, and in the IPCC Fourth Assessment Report (AR4), published in 2007.

The four 'explorative' scenarios are structured around two axes that exhibit opposite tendencies: one axis varying between economic and environmental values, the other between globalisation and regionalisation. The storylines are summarized as follows (Nakicenovic et al. 2000):

- The A1 scenario describing a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies.
- The A2 scenario describing a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.
- The B1 scenario describing a convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information

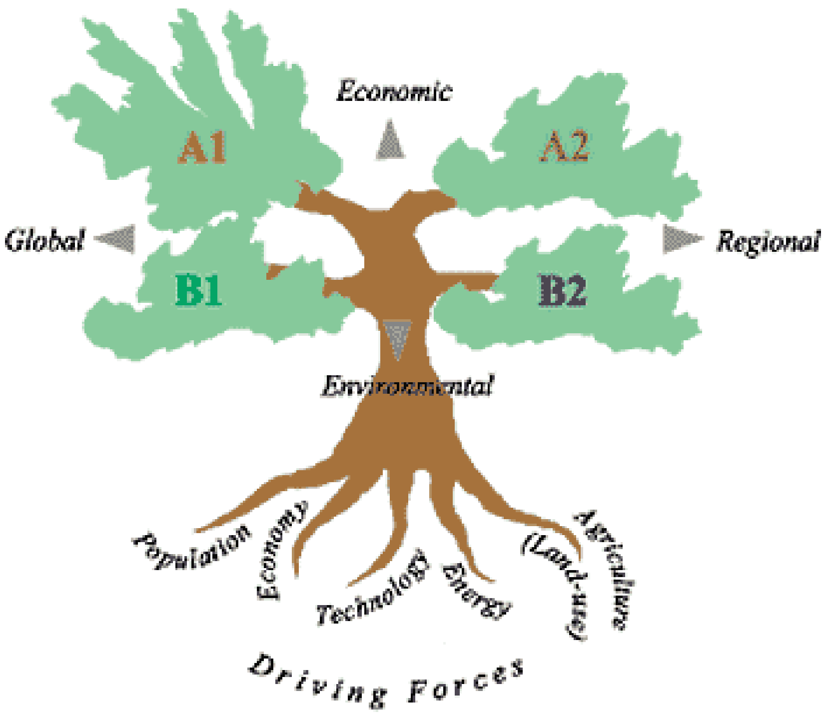
economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.

- The B2 scenario describing a world in which the emphasis is on local solutions to economic, social, and environmental sustainability

The scenario families describe the development and impact of key driving forces such as population and economic, growth, technical change and energy use along the two axes (Figure 3). Individual scenarios share the same characteristics but differ in details. For example the IPCC's Third and Fourth Assessment Report include three A1 scenarios that are distinguished by their technological emphasis: fossil-intensive (A1FI), non-fossil energy sources (A1T) or a balance across all sources (A1B).

The SRES scenarios themselves contain only limited information on the impact of climate change on food security. This issue was specifically analysed by Parry et al. (2004), which findings are summarised in this report. They apply a crop model to examine the bio-physical effect of climate change on crop yields. Next, the implications for cereal production, prices and risk of hunger are investigated by means of a computable general equilibrium model for four scenarios: A1F1, A2, B1 and B2.

Figure 3: SRES scenario structure



Source: http://sedac.ciesin.columbia.edu/ddc/sres/ [Accessed 8 July, 2012]

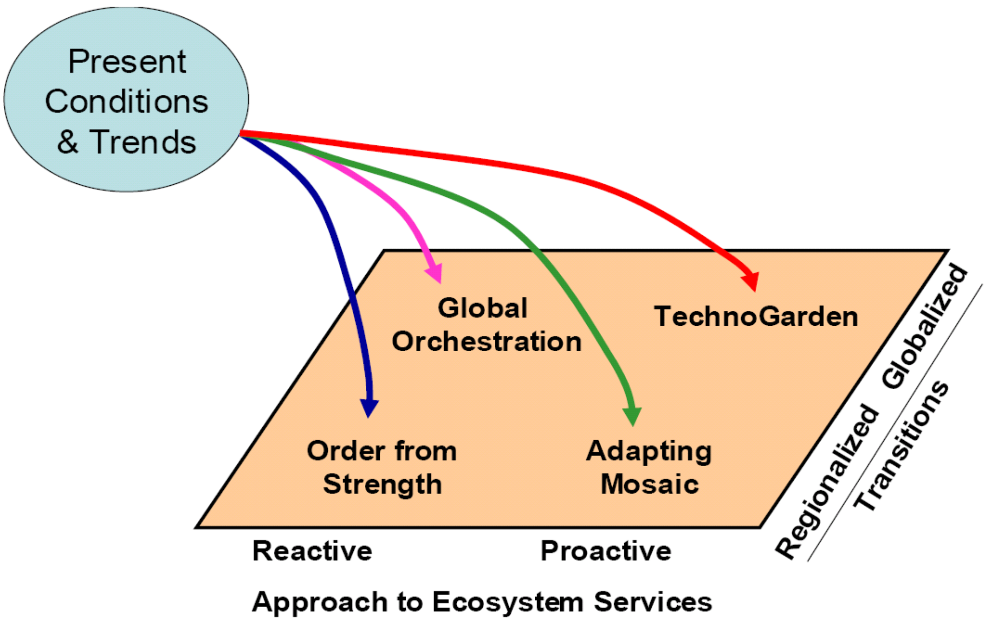
3.2 Millennium Ecosystem Assessment (MA)

The Millennium Ecosystem Assessment aims to "*assess the consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being*" (Carpenter et al. 2005, p. xiii). The initiative was launched by United Nations Secretary-General Kofi Annan in June 2001 and findings were published in 2005. Similar to the SRES scenarios, four global scenarios were developed using along two principal axes. One describes contrasting global governance structures for international cooperation and trade (regionalised versus globalised), the other opposing attitudes towards ecosystem management (pro-active versus reactive). In comparison to the SRES scenarios, the MA scenarios are much more framed around policy choices and are therefore categorised as exploratory and strategic. The four scenarios are summarised as follows (Carpenter et al. 2005) (also see Figure 4).

- The Global orchestration scenario describing a globally connected society that focuses on global trade and economic liberalization and takes a reactive approach to ecosystem problems but that also takes strong steps to reduce poverty and inequality and to invest in public goods such as infrastructure and education.
- The Order from strength scenario describing a regionalized and fragmented world, concerned with security and protection, emphasizing primarily regional markets, paying little attention to public goods, and taking a reactive approach to ecosystem problems.
- The Adapting mosaic scenario describing a world in which regional watershed-scale ecosystems are the focus of political and economic activity. Local institutions are strengthened and local ecosystem management strategies are common; societies develop a strongly proactive approach to the management of ecosystems.
- The Techno garden scenario desribing a globally connected world relying strongly on environmentally sound technology, using highly managed, often engineered, ecosystems to deliver ecosystem services, and taking a proactive approach to the management of ecosystems in an effort to avoid problems.

A large number of models were ‘soft linked’ to quantify the MA scenarios at various levels (from landscape to national and global) and aspects (socio-economic and biophysical), including integrated assessment, partial equilibrium, hydrology and biophysical modelling tools (see Annex 1).

Figure 4: MA scenarios



3.3 Comprehensive Assessment of Water Management in Agriculture (CAWMA)

The Comprehensive Assessment of Water Management in Agriculture (CAWMA) was a five-year (2001-2006) research program involving more than 700 policy makers and researchers from universities, international institutions, NGOs and ministries, with the objective to identify existing knowledge and stimulate discussion on ways to manage water resources so that they continue meeting the needs of humans and ecosystems. The overarching question the CAWMA aims to answer is: How can water in agriculture be developed and managed to help end poverty and hunger, ensure environmentally sustainable practices, and find the right balance between food and environmental security?

The research program also includes a scenario exercise to assess future food supply and demand and how it depends on available water resources for the period 2000-2050 (de Fraiture et al. 2007; de Fraiture & Wichelns 2010). The procedure involves the establishment of a baseline projection of future food supply and demand based on present conditions and expected development, and a comparison with five alternative projections that reflect changes in exogenous drivers and policies (e.g. what if? questions) and an optimistic normative scenario in which strategies from the other five scenarios are combined to arrive at a preferred future to meet the target of feeding 9 billion people in 2050:

1. Optimistic rainfed: Investment in rural rainfed areas and smallholders lead to improved water management practices, including water harvesting and supplemental irrigation.
2. Pessimistic rainfed: Upgrading of rainfed areas is not successful.
3. Expanded irrigated areas: Food self-sufficiency and better access to agricultural water through expansion of irrigated areas, particularly in Asia and Sub-Saharan Africa.
4. Improving irrigation performance: Improving performance of existing irrigated areas.
5. Trade: Trade from water abundant countries to water-scarce countries.
6. Optimistic: plausible scenario combining policies from the five other scenarios with variations across regions.

All scenarios are simulated by means of partial equilibrium model (WATERSIM) that consists of two integrated modules: a food production and demand module based on a partial equilibrium model, and a water supply and demand module based on a water balance and accounting framework. Food demand is a function of population growth taken from the UN, income projections taken from the MA Techno Garden scenario and food demand elasticities derived from the IMPACT model.

3.4 International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD)

The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) is an international effort initiated by the World Bank and FAO "*to assess the impacts of past, present and future agricultural knowledge, science and technology on the: reduction of hunger and poverty; improvement of rural livelihoods and human health; and equitable, socially, environmentally and economically sustainable development*" (McIntyre et al. 2009, p. vi). The assessment was undertaken between 2005 and 2007 and involved more than 400 experts, whose work was overseen by a multi-stakeholder Bureau. The exercise also included a scenario analysis up to 2050 using a baseline projection approach that is combined with a number of What if? questions.

The reference scenario describes a business-as-usual future in which the world develops in the same manner as it does today. It is assumed that no new major policies are introduced that might put the world on a different development trajectory. Key driving forces are population growth which follows the UN medium projection and GDP growth which is based on the MA Techno Garden scenario. Investment in agricultural research and development is assumed to decline slowly over time leading to limited improvements in yields in line with Alexandratos (2006). The reference scenario is used to examine the impact of additional investment in agricultural knowledge, science and technology. In total four policy experiments are implemented that can be divided into two groups. One group assumes that investment in agriculture results in either higher (High agricultural knowledge, science and technology (AKST)) or lower (Low AKST) growth in crop yield and livestock numbers. The second group describes similar scenarios but with even more (High AKST High) or less investment in agricultural combined with more (High AKST High) or less (Low AKST Low) expenditures on irrigation infrastructure, access to drinking water, and secondary education for females. All scenarios are quantified using a set of models, with a central role for the IMPACT model.

3.5 FAO World Agriculture Towards 2050 (WAT)

The FAO regularly publishes *World Agriculture Towards (WAT)* reports, which assess the prospects worldwide for food and agriculture, including fishery and forestry. It presents a baseline projection for major food and agricultural indicators, including (irrigated and rainfed) land use, yield and production, consumption and trade. Commodity and country specific projections are constructed by combining Engel demand functions and exogenous information on population and GDP growth from the most recent publication of UN *World Population Prospects* and World Bank *Global Economic Prospects*, respectively. The initial baseline results are subsequently reviewed by experts to arrive at a set of feasible indicators. In addition, for cereal, livestock and oilseeds sectors a partial equilibrium model (FAO World Food Model) is used (Bruinsma 2003).

The latest assessment (Alexandratos 2006), which presents projections to 2015, 2030 and 2050, has recently been revisited (Alexandratos 2011; also see Bruinsma 2009) to incorporate the impact of the 2007/8 global food price crisis on global food production, additional demand for agricultural products and for land needed for biofuel production, and updated projections for population and GDP growth. Unless otherwise noted, results from the revised study are presented here.

3.6 Agrimonde

Agrimonde is a foresight exercise undertaken by the French research institutes INRA and CIRAD between 2006 and 2008. The aim was to "*produce scenarios of global and regional evolution in agricultural production, consumption and trade, as well as in scientific and technical knowledge on agriculture, with a view to drawing conclusions on the possible roles for research, public policies and international regulations*" (Dorin & Paillard 2009, p. 2). Two scenarios for the period to 2050 are constructed. First a reference trend-based scenario, Agrimonde GO, that reconstructs the 'Global Orchestration' scenario of the MA from a food and agricultural perspective. Second, a normative scenario, Agrimonde 1, based on work by Michel Griffon, assumes that by 2050 the world has developed a sustainable agricultural system characterised by ecosystem preservation and ecological intensification. The latter refers to a set of agricultural technologies that economise on inputs and are less harmful to the environment as compared to current technologies, which focus on more intensive use of pesticides, chemical fertilizers and equipment. The scenario methodology consists of two parts. The quantification of the scenarios with Agribiom, a model to simulate the world's production, trade and uses of physical food biomasses for six main regions, and a qualitative analysis and refinement of the scenarios by a panel of experts.

3.7 International Food Policy Research Institute (IMPACT 2050)

The International Food Policy Research Institute regularly prepares scenario studies using IMPACT, a partial equilibrium model that was developed for projecting global food supply, food demand and food security into the future but has been extended to analyse the relationship between water availability and food. Here, results presented in Nelson et al. (2010) are discussed, the most recent scenario exercise investigating the impact of climate change on global food security to 2050. Three scenarios are quantified with IMPACT. First, a pessimistic scenario that assumes the lowest of the four GDP growth rate scenarios from the MA and the 'high variant' of the UN *Population Prospects.* Second, a baseline scenario based on World Bank projections for GDP and the UN 'medium variant' for population growth. Third, an optimistic scenario, incorporating the highest of the four growth rates from the MA and the UN 'low variant'. These socio-economic drivers are combined with a range of climate change projections to derive the impact on food security for a large number of countries.

3.8 Global Environmental Outlook 5 (GEO-5)

Since 1997, the United Nations Environmental Programme (UNEP) has produced Global Environment Outlook (GEO) reports that examine the interactions between environment and society. Whereas in GEO 3 and 4, explorative scenarios were used to assess future environmental change, GEO 5 applies a normative scenario approach. More specifically, the report looks at two different storylines. The 'Conventional world' scenario assumes a business-as-usual trajectory up to 2050. In contrast, the 'Sustainable world' scenario, depicts an alternative world that is consistent with the current understanding of sustainability reflected by internationally agreed goals and targets on sustainable development, such as the United Nations Convention of Climate Change, FAO World Food Summit Plan of Action and UN Millennium Development Goals. The IMPACT model was used to quantify the scenarios.[7]

3.9 Shared Socioeconomic Pathways (SSPs)

As part of the IPCC Fifth Assessment Report (AR5) it was planned to develop a new set of scenarios to replace and update the existing SRES scenarios for the assessment of climate change. In contrast to the SRES scenarios in which socioeconomic storylines (and emissions estimations) and climate change scenarios were developed in a linear chain, it was decided to opt for an alternative approach in which both types of scenarios are developed in a parallel process (Moss et al. 2010). Already four so-called Representative Concentration Pathways (RCPs) that describe essential input for climate change models (e.g. radiative forcing, emissions of greenhouse gasses and land use change) have been completed and are currently been implemented and compared in climate change modelling exercises (D. van Vuuren et al. 2011; D. P. van Vuuren, Riahi, et al. 2012).

In a recent meeting of experts a start was made to develop the storylines of the Shared Socioeconomic Pathways (SSPs) and define essential elements that should be described, and for which quantitative data should be constructed (O'Neill et al. 2011). Preliminary narratives were developed for basic versions of five SSPs (Figure 5) which are framed along two tendencies that are important for formulation of climate change policy: challenges to mitigation and adaptation (See Arnell et al. 2011 for a discussion on the design structure of the SSPs). At the moment, the basic SSPs are revised and

[7] The GEO 5 report also presents quantitative results for both scenarios generated by the Threshold 21 World model (T21), which comprises several sectoral models integrated into a global model. This model, however, is not able to produce food security indicators and therefore its results are not discussed.

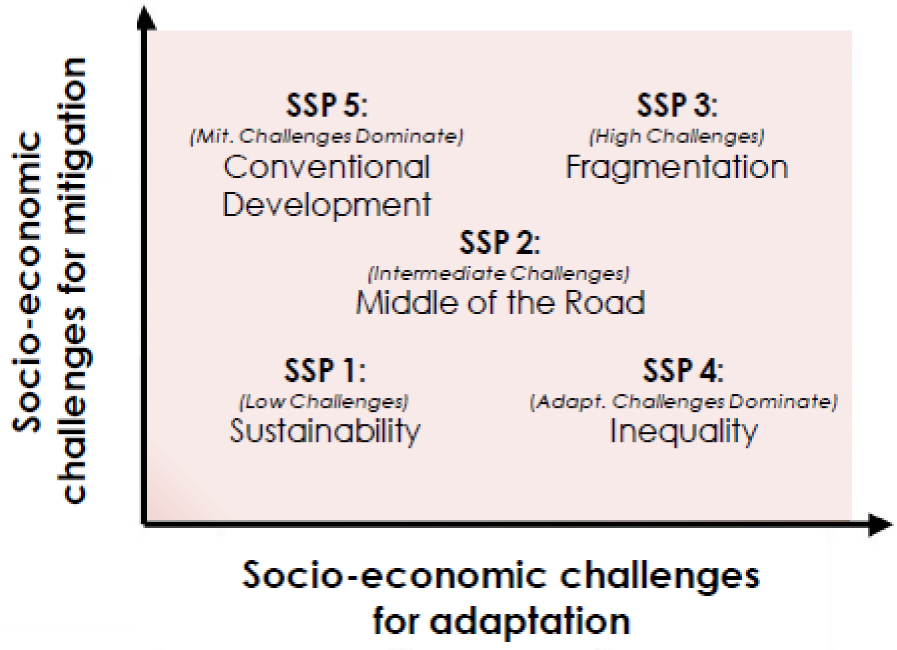
refined, and quantification of a subset of elements (among others population and economic growth) is underway. It is expected that final SSP narratives will be ready by the end of 2012.[8]

The basic SSPs as currently available can be summarised as follows:[9]

- The Sustainability SSP describes a world that makes relatively good progress towards sustainability, with sustained efforts to achieve development goals, while reducing resource intensity and fossil fuel dependency. Elements that contribute to this are an open globalised economy, rapid development of low-income countries, a reduction of inequality (globally and within economies), rapid technology development, low population growth and a high level of awareness regarding environmental degradation.
- The Middle of the Road SSP is a business as usual scenario. In this world, trends typical of recent decades continue, with some progress towards achieving development goals, reductions in resource and energy intensity at historic rates, and slowly decreasing fossil fuel dependency.
- The Fragmentation SSP describes a world, which is separated into regions characterized by extreme poverty, pockets of moderate wealth and a bulk of countries that struggle to maintain living standards for a strongly growing population. Regional blocks of countries have re-emerged with little coordination between them. Countries focus on achieving energy and food security goals within their own region. The world has de-globalized, and international trade, including energy resource and agricultural markets, is severely restricted. Population growth in this scenario is high as a result of the education and economic trends.
- The Inequality SSP features a highly unequal world both within and across countries. A relatively small, rich global elite is responsible for much of the emissions, while a larger, poorer group contributes little to emissions and is vulnerable to impacts of climate change, in industrialized as well as in developing countries. Governance and globalization are effective for and controlled by the elite, but are ineffective for most of the population.
- The Conventional development SSP stresses conventional development oriented toward economic growth as the solution to social and economic problems through the pursuit of enlightened self-interest. The preference for rapid conventional development leads to an energy system dominated by fossil fuels, resulting in high GHG emissions and challenges to mitigation. Lower socio-environmental challenges to adaptation result from attainment of human development goals, robust economic growth, highly engineered infrastructure with redundancy to minimize disruptions from extreme events, and highly managed ecosystems.

[8] Personal communication with Thom Kram, Netherlands Environmental Assessment Agency (4 July, 2012).
[9] See O.Neill (2011) et al. for elaborate summaries and full versions of the narratives. They also present a table with brief descriptions of SSP elements and directions.

Figure 5: Five SSPs for which basis narratives have been developed



Source: O'Neill et al. (2011)

4 Scenario assumptions and implications for food security

4.1 Key driving forces

The heart of a scenario exercise consists of the assumptions made about the drivers of the system under analysis. Although many driving forces have been used in scenario studies, global exercises almost always describe the future trajectory of three major socio-economic indicators: population growth, economic growth and technological change. Table 3 summarises the assumptions of these drivers for the studies under review. Regarding technological change, assumptions on yield are presented, which are the most relevant for a food security perspective. In addition, and for similar reasons, a fourth driver is listed – annual expansion in crop area. For all studies, population growth is an exogenous driver for which data are commonly taken from the UN Population projections. Economic growth, yield and land use change can be exogenous, endogenous or a combination, depending on the storyline and modelling approach (see Annex 1). Here, only final results are shown as presented in the studies.

Assumptions about global population vary between 7.9 and 11.3 billion people in 2050. For the baseline (business-as-usual) scenario, the projection lies around 8.2-9.2 billion people and seems to have been scaled up in the more recent assessments. Global GDP growth ranges from 0.9 to 3.2 per cent per year and baseline projections are around 2.5-3.1 per cent annually.

Table 3: Key drivers assumptions (global level) by scenario

Scenario exercise	Scenario	Population in 2050 (billion)	GDP growth (% per annum)	Cereal productivity (% per annum)	Crop area increase (% per annum)
SRES	A1F2	8.7	3.6	[1]	-
	A2	11.3	2.3	[1]	-
	B1	8.7	3.1	[1]	-
	B1	9.3	2.8	[1]	-
MA	Global orchestration	8.1	-	1.0	0.01
	Techno garden	8.8	-	~0.9	0.11
	Adapting mosaic	9.5	-	~0.6	0.23
	Order from strength	9.6	-	0.5	0.34
CAWMA	Pessimistic rainfed	8.9	2.2	1.4/0.7 (rainfed/irrigated)	0.14/0 (rainfed/irrigated)
	Optimistic rainfed	8.9	2.2	0.4/0.6 (rainfed/irrigated)	1.06/0 (rainfed/irrigated)
	Expanding irrigated areas	8.9	2.2	0.4/0.7 (rainfed/irrigated)	0.56/0.66 (rainfed/irrigated)
	Improving irrigation performance	8.9	2.2	0.4/1.5 (rainfed/irrigated)	0.66/0.18 (rainfed/irrigated)
	Trade	8.9	2.2	1.2/1.7 (rainfed/irrigated)	0.44/0 (rainfed/irrigated)
	Optimistic	-	2.2	1.1/1.1 (rainfed/irrigated)	0.32/0.78 (rainfed/irrigated)
IAASTD	Reference scenario	8.2	3.1	1.02	0.18/0.06 (rainfed/irrigated)
	High AKST	-	3.1	1.43	-
	High AKST High	-	3.3	1.63	0.15/0.08 (rainfed/irrigated)
	Low AKST	-	2.9	0.61	-
	Low AKST Low	-	2.9	0.41	0.21/0.05 (rainfed/irrigated)
WAT 2050	Baseline	9.2	3.1*	0.7/0.6 (rainfed/irrigated)	0.2
Agrimonde	Agrimonde GO	8.8	-	0.87	0.41
	Agrimonde 1	8.8	-	0.14-0.98	0.78
IMPACT 2050	Pessimistic	10.4	0.9	[3]	-
	Baseline	9.1	2.5	[3]	-
	Optimistic	7.9	3.2	[3]	-
GEO 5	Conventional worlds	-	-	-	0.23
	Sustainable worlds	-	-	-	-0.05

Note: All figures are transformed to annual growth rates or 2050 levels to make outcomes comparable across studies; [1] See Parry et al. (2004) for yield change maps; [2] From Alexandratos (2006); [3] For CSIRO A1B climate change scenario. See Nelson et al. (2010) for other climate change scenarios.

Source : Parry et al. (2004); Carpenter et al. (2005); de Fraiture et al. (2007); McIntyre et al. (2009); Bruno and Paillard (2009); Nelson et al. (2010); Reilly and Willenbockel (2010) Alexandratos (2011) and UNEP (2012).

4.2 Implications for food security

4.2.1 IPCC Special Report on Emissions Scenarios (SRES)

Parry et al. (2004) quantify cereal production, cereal prices and food security in each of SRES scenarios under three conditions: no climate change (reference scenario), climate change with CO2 fertilization effects and climate change without CO2 fertilization effects.[10] In the reference case of no climate change and increasing yields due to technological change, it is found that in all scenarios, particularly in A2, cereal prices will rise following a rise in demand that is caused by rising global incomes and the associated consumption of more meat. In the A1FI and B2 worlds, food prices rise up to 2050 but decrease afterwards as a consequence of a slowdown in population growth. A1, B1 and B2 show a decline in the global number of people at risk of hunger (defined as the population with an income insufficient to either produce or procure their food) throughout the century because the rise in cereal prices is offset by an increase in global purchasing power. In contrast, in the A2 scenario growth is lower and income equality remains, the number of people at risk remains unchanged at around 800 million.

Under the assumption of climate change (with and without CO2 fertilizer effects), cereal production reduces substantially in all scenarios. Accordingly, food prices increase considerably with more than threefold in A1FI and A2 and less than half in B1 and B2, in comparison to no climate change by 2080 under no CO2 fertilisation effects. The number of people at risk of hunger are highest in A2 (double the reference scenario of no climate change), primarily because the number of poor is highest in this scenario, followed by the B2, B1 and A1FI scenarios (see Table 5). For the case of CO2 fertilisation, cereal prices increases in all scenarios. Figures for hunger are more ambiguous and exhibit improvement up to the year 2050 but deteriorate thereafter (see Parry et al. 2004; Easterling et al. 2007 for details).

4.2.2 Millennium Ecosystem Assessment (MA)

For each of the MA scenarios, three food security related indicators are presented: cereal prices (wheat, maize and rice), food availability in kcal/capita/day and child malnutrition, all produced by the IMPACT model. In all four MA scenarios, total and per capita food production increase and reach similar levels by 2050. Nonetheless, difference in driving forces result in considerable variation food price changes, calorie availability and child malnutrition. In the Global Orchestration, the demand for cereals and meat is increasing rapidly due to the combined effect of high economic growth, trade liberalisation and urbanisation. Despite higher yields, induced by large investments in research and development, prices for wheat and maize (mainly used as animal feedstock) are increasing, while the price of rice is declining. Per capita calorie availability is highest, and malnutrition the lowest, in comparison to the other three MA scenarios.

The Order from Strength scenario is characterised by protectionist trade policy, high population growth and low levels of agricultural productivity change. As food production is not sufficient to fulfil demand, and trade is hampered, global food prices rise considerably. The effect is that calorie consumption only improves slightly by 2050 and child malnutrition is the highest among all four scenarios.

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[10] Climate change will also lead to rising atmospheric CO2 concentration, referred to as CO2 or carbon fertilization, which can increase yields and make plants more stress-resistant against warmer temperatures and drought. Some studies point out that this effect even counterbalances the negative effect of climate change on crop yield in some areas, resulting in net positive yields.

The Techno garden scenario resembles the Global Orchestration scenario with respect to the food security outcomes. Also in this case, global income growth, (medium) population growth, trade liberalisation and investment in yield improvement are central leading to similar patterns of food prices increase, calorie consumption and child malnutrition.

Finally, the Adapting Mosaic scenario stresses local approaches to food production and conservation, with limited investment in yield improvement and fewer opportunities for trade. Although global incomes are lower, population growth still results in increasing demand for food and, hence, high food price increases. Overall, food security outcomes are slightly better than those observed in the Order from strength scenario.

4.2.3 Comprehensive Assessment of Water Management in Agriculture (CAWMA)

In the baseline scenario, crop water consumption is expected to increase by 70 to 90 per cent in 2050. This estimate also accounts for the likely improvements in water productivity. At the same time, the demand for water in domestic and industrial uses is expected to double over the same period as a consequence of urbanisation.

The ‘optimistic rainfed’ scenario assumes that successful institutional reform, well-functioning markets and credit systems, mechanization, improved use of fertilizers and high-yielding varieties, and rapid adoption of water-harvesting techniques will lead to a 80 per cent reduction in the yield gap (the difference between actual and potential yield). The model simulation shows that the growth in production is more than sufficient to feed the domestic population in in almost all regions.

In contrast, the ‘pessimistic rainfed’ scenario expects that technical change is limited and improvements in infrastructure and institutions will not take place. Only if the area in rainfed production increases with 53 per cent, global food supply will be sufficient to meet demand. This expansion is feasible but is expected to cause negative environmental consequences. However, countries where a growth in crop area is not possible will have to increase food imports, potentially leading to higher food prices. In this scenarios, the risk of food insecurity, in particular for poor countries is the highest due to lower levels of food availability and accessibility.

In the ‘expanding irrigated areas’ a growth in irrigated area causes a modest increase in irrigated and rainfed yields – between 20 and 35 per cent over 50 years. As a result, food security and incomes of small scale farmers in Sub-Saharan Africa and Asia are enhanced become largely food self-sufficient but the pressure on freshwater sources increases. The expansion of irrigated areas requires substantial investment in water infrastructure is required from public and private funds.

In the improving irrigation performance it is assumed 75-80 per cent of the yield gap can be closed by increasing the performance of existing irrigation schemes. This will be achieved through a combination of institutional reform and better motivation of farmers, water managers to improve productivity of land and water, and improved water allocation mechanisms. Yield improvements and food self-sufficiency will mainly come about in South Asia where the scope for improving irrigation performance is largest. Effects are much smaller in Sub-Saharan Africa where agriculture is mostly rainfed.

In the ‘trade’ scenario countries with abundant water resources and production capacities (i.e. North America, Brazil and Argentina, Europe) increase agricultural trade to water-short countries (i.e. the Middle East and North Africa and to India, Pakistan, and China). The scenario analysis shows that global food demand can be satisfied by means of trade without worsening water scarcity or requiring expensive irrigation infrastructure. Increasing the dependence on foreign trade for food products is, however, a potential high-risk and high cost strategy, in particular for developing countries who might be faced with food price spikes and limited availability of foreign exchange to pay for the imports.

Finally, the ‘optimistic’ scenario emphasises an optimal mix of water-related interventions that differ across regions to fulfil global food demand. In South Asia considerable investments are made in irrigation infrastructure and improvement while in Sub-Saharan Africa rainfed smallholder agriculture is targeted. Global average rainfed cereal yield increases by 58 per cent and rainfed water productivity improves by 31 per cent. For irrigated yield the increase is by 55 per cent while water productivity improves by 38 per cent. Negative impacts on ecosystems are mitigated by means of regulation.

4.2.4 International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD)

Under the Reference scenario global food production increases with 1.2 per cent per year for the period 2000-2050 as a result rapid economic growth, slowing population growth and increased diversification of diets composed of more wheat and rice. Despite a growth in crop area and yield, developing countries, in particular Sub-Saharan Africa, are not able to fulfil domestic demand and experience an increase in food imports. Global prices of cereals are expected to increase substantially, making food more expensive and slowing down the calorie intake in developing countries. Overall, global food security improves and childhood malnutrition is projected to decline from 149 million children in 2000 to 99 million children in 2050.

In the High AKST and High AKST High scenarios, agricultural productivity is raised, which results lower food prices and more food consumption, in particular in developing regions where food becomes more affordable. As these regions are not able to fulfil domestic demand imports of both cereals and meat increase in comparison to the reference scenario. Both scenarios show global improvements in calorie intake and child malnutrition numbers, but the impact is more pronounced in the High AKST High scenario.

The reverse pattern is observed in the Low AKST and Low AKST Low scenarios, where declining levels of investment in agriculture and support services lead to higher food prices and shrinking food trade volumes. This contributes to deterioration in global food security; especially in Sub-Saharan where average daily kilocalorie availability per capita is expected to fall below the generally accepted minimum of 2,000 calories. In the Low AKST scenario child malnutrition slightly improves in 2050 vis-à-vis the 2000 figure while in the Low AKST Low scenario it is worsened.

4.2.5 FAO World Agriculture Towards 2050 (WAT)

Alexandratos (2011) reviews the projection for global food production and consumption in the WAT 2030/2050 (Alexandratos 2006) with FAO data that are used for the six-monthly *Food Outlook* and the latest version of the annual *OECD/FAO Agricultural Outlook 2009-2018*, which incorporate the effects of the on-going economic crisis and increasing demand for biofuel resources. It is concluded that the original projections, but disregarding biofuels, are still broadly valid for aggregate country and commodity groups. Hence, biofuel production (and climate change which also was not addressed in the WAT 2030/2050) needs to be addressed in the next WAT analysis.

In contrast, the projections of food consumption and numbers undernourished in developing countries were found to be outdated in view of recent developments, and were revised in line with the estimates of per capita consumption and prevalence of undernourishment published in the most recent version of FAO’s *State of Food Insecurity in the World*. The revised projection indicate that average food consumption per capita measured in kcal/person/day is lower and undernourishment is higher, both in absolute and as percentages of the population, in almost all developing regions. This also implies that the rate at which undernourishment is expected to decline will be slower and MDG 1 of halving the number of undernourished in developing countries will only be achieved just before 2050, compared to just after 2030 in the pre-crisis projection.

4.2.6 Agrimonde

Under the Agrimonde GO rapid economic growth, free trade and increase in agricultural productivity make it possible to meet the steep increase in the demand for food. The global availability of food calories per day en per capita rises in all developing regions and child malnutrition is reduced by 40 per cent. At the same time the diet in these countries has shifted towards a higher consumption of meat, creating obesity problems.

Agrimonde 1 describes a radically different future in which growth mainly takes place in developing countries and technologies related to renewable energy and ecological intensification have diffused on a large scale. To ensure food availability international trade in food and agriculture will increase. The scenario highlights the potential negative effects of protectionism and underscores the importance of trade but at the same time it acknowledges regulation might be required to protect smallholders in developing countries from cheap subsidised imports. Biodiversity and ecosystems are largely preserved but due to high prices and demand for food deforestation is not entirely stopped. The agri-industrial complex is characterised by small and medium firms, especially in developing countries. To reach this future, structural change is needed in the worldwide pattern of food consumption. Global diets converge to about 3000 kcal/per capita/day, which means that for example in the OECD countries calorie intake declines with 1000 kcal/capita/day.

4.2.7 International Food Policy Research Institute (IMPACT 2050)

A high number of plausible futures are simulated in the IMPACT 2050 study. In total 15 scenarios – three socio-economic scenarios times' five climate futures – are analysed. Four climate scenarios capture combinations of dry, cool, wet and warm environments while the fifth reflects a perfect mitigation scenario which implies present climate conditions continue in the future. On top, the baseline scenario is used as a reference to investigate the effect of yield improvements and irrigation efficiency. The study finds that in all scenarios food prices are expected to increase between 2010 and 2050 due to the combined effect of population and income growth, and negative effect of climate change on yields.

Food availability in developing countries, measured in the availability of daily kilocalorie improves in the baseline and optimistic scenarios (0.4 and 4.7 per cent, respectively) and declines in the pessimistic scenario (-8.3 per cent). The number of malnourished children decreases in all three scenarios but the decline is much less in the pessimistic scenario (-1.8 per cent) than in the baseline (-25.1 per cent) and the optimistic (-45.9 per cent) scenarios. Overall climate change causes an increase of between 8.5 and 10.3 per cent in the number of malnourished children relative to the perfect mitigation scenario. Simulations show that an increase in agricultural productivity leads to a less rapid increase in food prices and a reduction in the number of malnourished children. Improvements in irrigation efficiency have positive effects on food security in South Asia and middle income countries where much of the agricultural area is irrigated but are less relevant for low income regions where agriculture is largely rainfed.

4.2.8 Global Environmental Outlook 5 (GEO-5)

In the Conventional Worlds scenario population growth and economic growth will lead to a substantial increase in cereal prices from USD 150 per tonne in 2005 to USD 202 per tonne in 2050. As a result there is only a marginal improvement in global food security measured by calorie availability and the number of malnourished children. Under the normative Sustainable Worlds scenario, economic growth is expected to be higher in developing countries and population growth lower. Combined with higher investment in agricultural research and development, this will contribute to a 15 per cent rise in cereal yields by 2050 in comparison to the baseline and a decline in cereal prices of 39 per cent over the same period. The Sustainable World scenario assumes that there is full access to safe drinking by 2050, and all girls have access to secondary schooling by 2030. These two assumptions, together with the decrease in food prices contribute to a drastic improvement in average calorie consumption and child malnutrition.

5 Discussion

5.1 To what extent has food security been addressed in existing global scenario exercises?

In order to assess the extent of which food security has been addressed in the in reviewed scenarios it is useful to present 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).

Table 5 summarises the food security outcomes for each of the scenario studies and individual scenarios. The majority of studies provide three indicators of food security: food prices (in most cases for cereals), calorie availability (in kilocalorie per person per day) and child malnutrition (in absolute numbers or percentage).[11] In addition, some studies present data on the number of people at risk of hunger (SRES), prevalence of undernourishment (in absolute number or percentage) (WAT 2050) as well as broad qualitative statements on food accessibility and availability under different scenarios (CAWMA). These indicators only partially cover the dimensions of food security and predominantly focus on food availability and accessibility, while utilisation is hardly addressed (apart from the very basic indicator of child malnutrition) and stability is completely omitted. To measure food utilisation, micro-level data is required that describe household and individual income, expenditure, diet diversity and food intake, which is not easily available for many countries and regions. For the same reason, the scenario studies are also not able to present outcomes on poverty related issues for which the same type of data is needed. All the studies have a long term focus and therefore are not able 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.

This result is also for a large part caused by the type of models used in the assessments, which 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

[11] Calorie availability is often used as a measure for food consumption. This might be misleading as it refers to the amount of food available for human consumption. It is an average measure based on aggregate data, commonly estimated by the FAO Food Balance Sheets. In reality food consumption at the household level can different and depends on household income and wastage and losses of food in the household.

consumption side (household income and composition of the diet) and short to medium term effects (i.e. shocks and cyclical effects).[12] This issue will (partially) be addressed in the Food Secure project by introducing household level data and analysis in the macro-economic CGE models.

A similar observation was made by Wood et al. (2010), who meticulously mapped the causal linkages between environmental change and food security that are emphasised in three major global environmental assessments: MA, IPCC Fourth Assessment and GEO-4 (Figure 6): *"Data, knowledge and expertise gaps are even more apparent with regard to processes influencing the non-supply-related food security outcomes (witness the lack of impact pathway arrows reaching outcomes other than production, distribution, exchange and affordability). 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" (p. 59).*

5.2 Treatment of climate change and biofuels

Two major global processes are expected to have major influences on future agricultural development and food security. First, climate change will affect yields due to the combined impact of temperature change, precipitation, CO2 fertilisation, extreme weather events and sea-level rise. Second, the depletion of fossil resources and the transition towards a bio-based economy in which natural resources are increasingly used to fulfil the demand for food, feed fuel and functional materials. Only two of the scenarios studies (Parry et al. 2004; Nelson et al. 2010) explicitly incorporate the impact of climate change on food security outcomes. Overall climate change has negative impact on food security indicators although when CO2 fertilisation is taken into account the effect is ambiguous. None of the studies incorporates the potential impact of increasing demand for biofuels and biomaterials on food security. The version of the IMPACT model in Nelson et al. (2010) incorporates some very basic assumptions about biofuel production but is far from able to capture all the dynamics that are part of the shift to a bio-based economy. It is essential that the scenarios analysis and model quantification take into account the shift towards a bio-based economy.

5.3 What can be learned from these scenarios in terms of achieving an agriculture system that ensures food security for all, economic growth, and is sustainable?

It is not easy to derive simple conclusions for future food security from the various scenario studies because of the diversity in underlying assumptions, storylines, (combination of) models and indicators. To structure the discussion it is useful to apply the scenario typology developed by Van Vuuren et al. (2012). Table 4 groups the individual scenarios to that have been reviewed into archetypes scenarios. For example, both the SRES A1 scenario and the IMPACT 2050 Optimistic scenario assume overall high economic development, low population growth, rapid technological change and a reactive approach to towards environmental protection. Hence, they can be classified as Economic optimism scenarios. Similarly, the MA Techno Garden and the GEO-5 Sustainable world scenarios belong to the group of Global sustainable development scenarios because of their strong emphasis on sustainability and global governance. However, not all scenarios fit one-to-one with the proposed typology. In particular the scenario studies that apply projections with What if? questions, such as the CAWMA and a lesser extent IAASTD, tend to experiment with policies while keeping driving forces constant and therefore often fall 'in between' archetype scenarios. The classification the MA Global

[12] This probably also explains the popularity of the IMPACT model – used in half of the scenario studies – which is probably one of the few global models able to compute child malnutrition figures and food price change for a large number of crops and livestock.

Orchestration scenario is also problematic as it shares features of the Economic optimism and Reformed market archetypes.

Table 4: Classification of existing scenarios.

	Economic optimism	Reformed markets	Global sustainable development	Regional competition	Regional Sustainable development	Business-as-usual
SRES	A1		*B1*	A2	*B2*[a]	*B2*[b]
MA		*Global Orchestration*	Techno Garden	Order from Strength	*Adopting Mosaic*	
CAWMA	*Trade*		*All other scenarios*			
IAASTD			*High AKST High; High AKST*	*Low AKST Low; Low AKST*		Baseline
WAT 2050						Baseline
Agrimonde		*Agrimonde GO*	Agrimonde 1			
IMPACT 2050	Optimistic			*Pessimistic*		Baseline
GEO-5			Sustainable worlds			Conventional worlds
SSPs	Conventional development		Sustainability	Fragmentation *Inequality*		Middle of the road

Source: Van Vuuren et al. (2012) and classification of additional scenarios by author.
Note: Italics are used to indicate that scenarios are not completely consistent with the group in which they are classified. [a] Storyline; [b] Quantification.

Outcomes are broadly similar for scenarios that belong to the same archetype. The baseline scenarios only foresee a (slight) improvement in global food security outcomes up to 2050. Food prices are expected rise because increasing demand and lower yield growth and international food trade expands. As food becomes less affordable, food consumption (calorie availability) only increases marginally. The number of children that suffer from malnutrition declines with around one third because of income effects and better support services. Under 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, under the Global sustainable development scenario family food availability and accessibility improve drastically. 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, which ensures that food price increases in the future are limited. The main difference is that these processes are guided by strong global governance and therefore lead to more equitable and sustainable world. Finally, in the Regional competition, and to a lesser extent, the Regional sustainable development scenarios, perspectives for global food security are negative. Food availability is hampered by trade protection and limited investment in agricultural productivity and food accessibility is reduced as a consequence of lower economic growth.

5.4 New scenario development or re-using old scenario exercises?

One of the questions that has been raised during the planning of Work Package 5 is whether there is a need to develop new scenarios from scratch or, alternatively, if it is possible to re-use and, if needed, modify existing storylines and quantifications from the scenarios studies that have been discussed in this report. The advantage of the former is that new scenarios will be developed in a participatory manner with stakeholders from the scientific community, academia, civil society and government. A key outcome of a stakeholder process is to enhance the legitimacy of the scenarios and to create ownership and awareness among the potential users of the scenarios, which can facilitate its acceptance and support decision making (Alcamo & Henrichs 2008). The advantages of the latter is that: (1) resources that would be used for the development of new scenarios can be used for other purposes, such as the deepening of the vision and road mapping exercises, and (2) modelling teams do not have to go to the painstaking and costly process of quantifying the main drives of the new scenarios. That is *if* such quantification has already been done in one of the existing scenario studies.

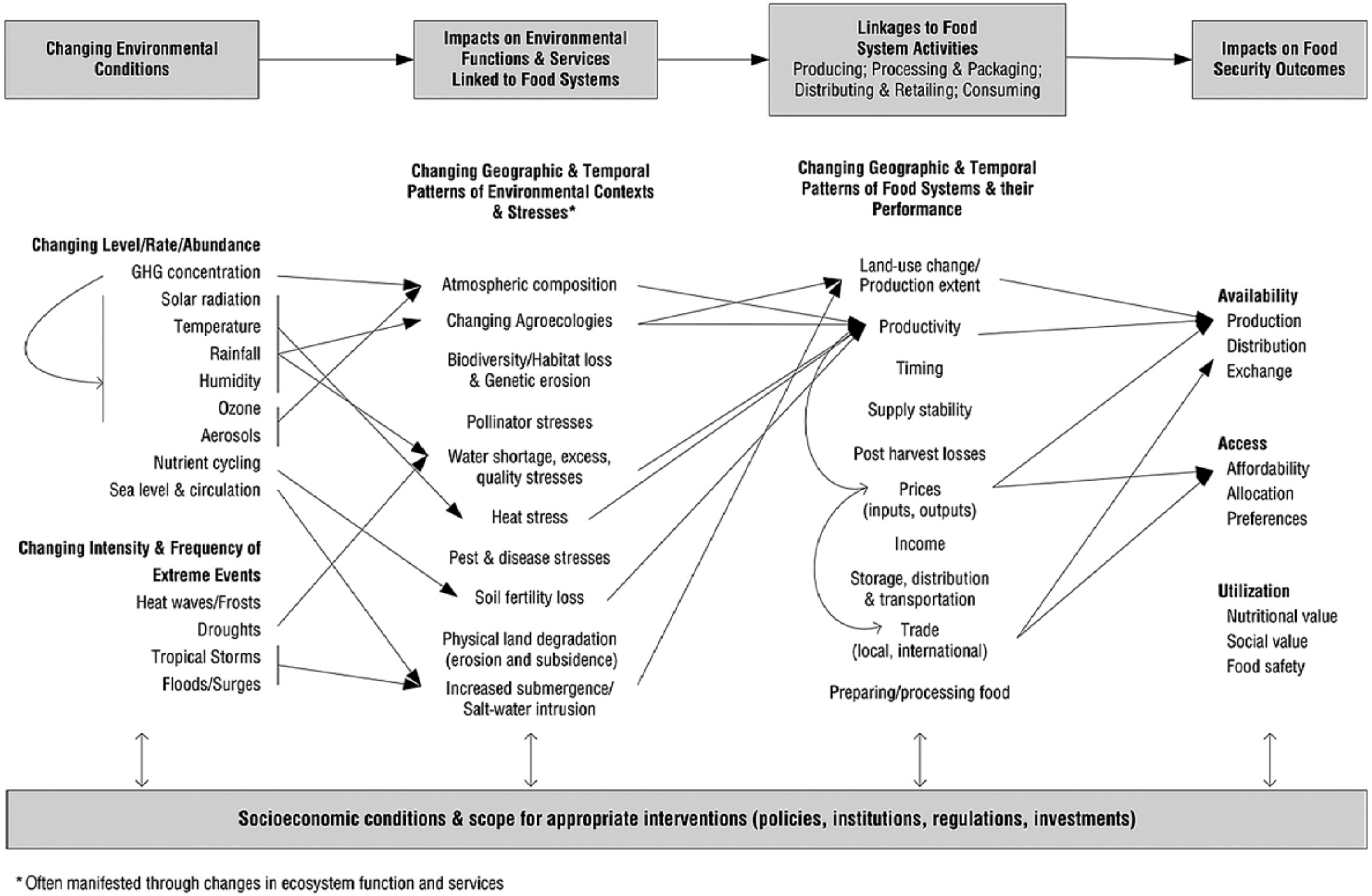
On the basis of the findings of the report it can be concluded that it is probably more efficient to build upon existing scenario exercises rather than going through a new process of scenario formulation because of the following reasons. First, as has been shown by Van Vuuren et al. (2012) and underscored by Table 4 above, one can distinguish a number of archetype scenarios that present a comprehensive picture of possible future worlds. It is unlikely that the scenario exercise in the Food Secure project will result in radically new views on the future but rather will resemble one or more archetypes highlighted by the typology.

Second, and perhaps more important, at the end of 2012, the storylines of the SSPs, the socioeconomic scenarios that are prepared for the IPCC Fifth Assessment are expected to be completed. These storylines will replace the existing SRES scenarios that are widely accepted and used for climate change analysis and, as has been shown above, the assessment of food security. The SSPs are expected to become the predominant storylines for climate change assessment in the coming five to ten year. At the same time, many of the modelling groups that are participating in Food Secure are already experimenting with the quantitative underpinning of the SSPs within the Agricultural Model Improvement and Intercomparison Project (AgMip).[13] In fact, to enhance the modelling, researchers in the project have begun to develop so-called Representative Agricultural Pathways (RAPs) which cover indicators that are of importance to agriculture (O'Neill et al. 2011).[14] In sum, there already is, or soon will be, a set of high profile global scenarios (storylines and quantification) that can, with some adaptation, easily be used for the analysis in the Food Secure project.

One could argue that the omission of part of the participatory scenario development process might negative influence the acceptance and impact of the food security scenarios and outcomes. However, this will be partially compensated by the fact that the SSPs are part of a high-level process and therefore are not expected to be questioned by the stakeholders. At the same time, it is probably still very useful to organise a workshop with stakeholders to reflect on the food security aspects of the SSPs. In addition, the legitimacy of the Food Secure project can also be enhanced by organising additional events with stakeholders (e.g. vision and road mapping workshops) for which more resources will then become available.

[13] http://www.agmip.org/ [Accessed 10 July, 2012].
[14] To be confirmed by Hans van Meijl, IFPRI and other modelling teams.

Figure 6: Food security impact pathways in major global environmental assessments studies



Source: Wood et al. (2010).

Table 5: Food security projections and outcomes

Scenario exercise	Scenario	Cereal price (per annum) %	Global people at risk of hunger	Child malnutrition (million)	Calorie availability (kcal/person/day)	Prevalence of undernourishment (% of population/million)	Food availability and food accessibility
SRES[1]	A1F2	~0.79	208	-	-.	-	-
	A2	~1.03	721	-	-	-	-
	B1	~0.44	240	-	-	-	-
	B2	~0.56	348	-	-	-	-
MA	Global Orchestration	Maize: 0.62; Wheat: 0.25; Rice: -0.91	-	65	3580	-	-
	Techno Garden	Maize: -0.23; Wheat: -0.24; Rice: -0.56	-	105	3270	-	-
	Adapting Mosaic	Maize: 0.81; Wheat: 0.79; Rice: 0.84	-	145	2970	-	-
	Order from Strength	Maize: 0.34 ; Wheat: 0.40 ; Rice: 0.72	-	184	3010	-	-
CAWMA	Pessimistic rainfed	Increase	-	-	2970	-	Under pressure
	Optimistic rainfed	-	-	-	-	-	Improves
	Expanding irrigated areas	-	-	-	-	-	Improves
	Improving irrigation performance	-	-	-	-	-	Improves in certain regions.
	Trade	-	-	-	-	-	Improves but with high risk
	Optimistic	-	-	-	-	-	Improves
IAASTD	Baseline	Maize: 0.92; Wheat: 1.12; Rice: 0.50	-	99	~3000	-	-
	High AKST	Maize: -1.29; Wheat: -0.39; Rice: -0.73	-	66	~4000	-	-
	High AKST High	Maize: -2.37; Wheat: -1.16; Rice: -1.43	-	44	~4500	-	-
	Low AKST	Maize: 3.82; Wheat: 3.17; Rice: 1.95	-	126	~2500	-	-
	Low AKST Low	Maize: 5.64; Wheat: 4.64; Rice: 2.94	-	189	~2000	-	-
WAT 2050	Baseline		-	-	3047/2966 (world/developing countries)	4.8/370[2]	-
Agrimonde	Agrimonde GO	-	-	-	3588	-	-
	Agrimonde 1	Limited price volatility due to regulation.	-	-	3000	-	-
IMPACT 2050	Pessimistic	Maize: 1.83; Wheat: 1.16; Rice: 1.45	-	155	2443	-	-
	Baseline	Maize: 1.76; Wheat: 1.09; Rice: 1.10	-	117	2769	-	-
	Optimistic	Maize: 1.58; Wheat: 0.91; Rice: 0.68	-	84	3141	-	-
GEO 5	Convential Worlds	1.17	-	115	2823[2]	-	-
	Sustainable Worlds	0.06	-	50	3213[2]	-	-

Note: All figures are transformed to annual growth rates or 2050 levels to make outcomes comparable across studies. [1] No climate change scenario data; [2] Developing countries; [3] Average of four climate change scenarios.

Source : Parry et al. (2004); Carpenter et al. (2005); Easterling et al. (2007); de Fraiture et al. (2007); McIntyre et al. (2009); Bruno and Paillard (2009); Nelson et al. (2010); Reilly and Willenbockel (2010) Alexandratos (2011) and UNEP (2012).

6 Conclusions

This study reviews eight important scenario studies (and an upcoming assessment), in particularly looking at the implications for food security under different futures. It finds that the studies only deal with two of the four dimensions of food security: food availability and food accessibility, while food utilisation and stability are hardly covered. This is mainly caused by the nature of the models, which have well developed models to simulate bio-physical and market dynamics but with very limited capacity to analyse the household and individual part of food demand and food security. Furthermore, the transition towards a bio-based economy is not specifically addressed by the studies. This major global change process already has contributed to an upward pressure on prices and is expected to continue doing so in the future to come. Climate change is dealt with in two of the studies and is expected to affect negative effects on food security.

It is also shown that the scenarios studies could be classified using a set of archetype scenarios with comparable assumptions and outcomes. Macro-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.

Finally, the question was discussed if it is necessary to undertake an additional scenario design exercise for the Food Secure project. It is concluded there exists a set of high profile scenarios in the form of the Shared Socioeconomic Pathways that are currently being developed in the context of the IPCC Fifth Assessment. These scenarios will be completed by end of 2012 and can therefore serve as a starting point for the scenario analysis in Food Secure. Moreover, several of the modelling teams are active in AgMIP and therefore are already familiar with the quantitative data that underlies the SSPs.

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Annex 1: Overview of models and drivers by scenario study

Scenario study	Model	Model type	Main endogenous drivers	Main exogenous drivers
SRES	BSNAT	Crop model	Yield	Climate, land cover
	IBLS	Computable general equilibrium	Emissions, climate, agricultural production, demand, prices and trade, GDP	Population, productivity, climate
MA	IMAGE 2.2	Integrated assessment	Energy, land use, emissions, climate	Population, GDP
	AIM	Integrated assessment	Land cover, emissions, water use	Population, productivity
	IMPACT	Multi-market partial equilibrium	Agricultural production, demand, prices and trade, child malnutrition	Population, GDP, agricultural productivity
	WaterGap	Hydrology	Water use, water stress	Population, GDP, climate, land cover
	ECOPATH/ECOSIM	Biophysical	Marine ecosystem, biomass	Marine species mortality, fisheries catch
CAWMA	WATERSIM	Linked multi-market partial equilibrium and hydrology	Agricultural production, demand, prices and trade, water use	Population, GDP, agricultural productivity, diet
IAASTD	IMPACT-WATER,		Agricultural production, demand, prices and trade, child malnutrition	Population, GDP, agricultural productivity
	SLAM	Livestock allocation	Ruminant area and density	n.a.
	IMAGE 2.4	Integrated assessment	Energy, land use, emissions, climate	Population, GDP
	GTEM	Computable general equilibrium	n.a.	n.a.
	WATERSIM	Partial equilibrium with water module	Food and water supply and demand	n.a.
	GLOBIO3	Dose-response biodiversity model	Biodiversity indicators	n.a.
	ECO-OCEAN	Marine biomass balance	Marine ecosystem	n.a.
WAT 2050	FAO World food model combined with expert knowledge	Multi-market partial equilibrium	Agricultural production, demand, prices and trade	Population, GDP, agricultural productivity
Agrimonde	Agrobiom	Biomass	Calorie balances	
IMPACT 2050	IMPACT-WATER	Multi-market partial equilibrium	Agricultural production, demand, prices and trade, child malnutrition	Population, GDP, agricultural productivity
GEO 5	IMPACT-WATER	Multi-market partial equilibrium	Agricultural production, demand, prices and trade, child malnutrition	Population, GDP, agricultural productivity

Annex 2: Web sources for scenario studies

IPCC Special Report on Emissions Scenarios (SRES)

http://www.ipcc.ch/ipccreports/sres/emission/index.htm [Accessed 8 July, 2012]
http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml [Accessed 8 July, 2012]

Millennium Ecosystem Assessment (MA)

http://www.maweb.org/en/Index.aspx [Accessed 8 July, 2012]

Comprehensive Assessment of Water Management in Agriculture (CAWMA)

http://www.iwmi.cgiar.org/assessment/ [Accessed 8 July, 2012]

International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD)

http://www.agassessment.org/ [Accessed 8 July, 2012]

FAO World Agriculture Towards 2030/2050 (WAT)

Source: http://www.fao.org/economic/esa/esag/en/ [Accessed 27 June, 2012]

Agrimonde

http://www.cirad.fr/en/publications-resources/publications/studies-and-documents/agrimonde
[Accessed 8 July, 2012]
http://www.international.inra.fr/press/what_challenges_must_we_face_to_feed_the_world_in_2050
[Accessed 8 July, 2012]

International Food Policy Research Institute (IMPACT 2050)

http://www.ifpri.org/book-775/climate-change [Accessed 8 July, 2012]
http://www.ifpri.org/climatechange/ [Accessed 8 July, 2012]

Global Environmental Outlook 5 (GEO-5)

http://www.unep.org/geo/geo5.asp [Accessed 8 July, 2012]

Shared Socioeconomic Pathways (SSPs)

http://sedac.ciesin.columbia.edu/ddc/ar5_scenario_process/parallel_nat_scen.html [Accessed 10 July, 2012]

FOODSECURE

FOR POLICIES THAT MATTER

The FOODSECURE project in a nutshell

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

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SEVENTH FRAMEWORK PROGRAMME