Scenarios to explore global food security up to 2050: Development process, storylines and quantification of drivers

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Abstract

To guide policymaking, decision makers require a good understanding of the long-term drivers of food security and their interactions. Scenario analysis is widely considered as the appropriate tool to assess complex and uncertain problems, such as food security. This paper describes the development process, storylines and drivers of four new global scenarios up to the year 2050 that are specifically designed for food security modelling. To ensure the relevance, credibility and legitimacy of the scenarios a highly participatory process is used, involving a diverse group of stakeholders. A novel approach is introduced to quantify a selection of key drivers that directly can be used as input in global integrated assessment models to assess the impact of aid, trade, agricultural and science policies on global food and nutrition security.

Keywords: Scenarios, food security, participatory scenario building, integrated assessment.

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1 Introduction

The question on 'how to feed the world in 2050' has received increasing attention from policymakers, the media and scientists since the surge in food prices in 2007/2007. Understanding long-term food and nutrition security is a complicated because it is determined by the interaction of a wide number and highly uncertain drivers that operate at the household (e.g. income and education), national (e.g. agricultural and social protection policies) and global (e.g. climate change and trade policy) levels (see Laborde et al., 2013 for an analytical framework).

Due to the complex nature of food security, it is not surprisingly that projections for global food production, food prices and food security indicators (e.g. undernourishment and child malnutrition) differ widely across studies. For example, according to the FAO (Alexandratos and Bruinsma, 2012 p. 7) global food production needs to be increased with 60 per cent in 2050 (compared with 2005/2007) to feed the global population, while Tilman et al. (2011) find that an increase of 100-110 per cent is required. Similarly, a review of 12 global scenario studies (Dijk van and Meijerink, 2014) finds a highly diverse range of projections for food prices (ranging from 18 to 973 US$ per ton for maize, 86 to 771 US$ per ton for paddy rice and 41 to 708 US$ for wheat), undernourishment (ranging from 2.8 to 6 percent of global population) and child malnutrition (ranging from 50 to 189 million children) in 2050. The review concludes that the outcomes are difficult to compare due to differences in (1) assumptions on scenario drivers; (2) design of the models that are used to generate food security indicators and (3) reporting of results.

To formulate effective policies to ensure global food and nutrition security, and to understand their impact and trade-offs, decision makers need to have a good understanding of the main drivers that affect food security and how they interact. This demands high-quality scenario assessment studies that capture the complexity and uncertainty associated with food security and are built upon uniform, consistent and comparable assumptions.

This paper describes the development process, storylines and drivers of four new global scenarios up to the year 2050 that are specifically designed for food security modelling. It is part of the FP7 FOODSECURE project, which aims to assess global food and nutrition security by means of scenario analysis and modelling. The FOODSECURE storylines and drivers presented in this paper will be quantified by means of a number of well-known global integrated assessment models.[2] The models will also be used to assess the impact of aid, trade, agricultural and science policies on global food and nutrition security.

The structure of the paper is as follows. Section 2 presents brief background information on the definition of scenarios and possible types. Section 3 describes the methodology that is used to derive the storylines and related quantified drivers. It explains some of the methodological choices such as the type of scenario, the

[2] Three different models (combinations) will be used to quantify the scenarios: (1) MIRAGE (International Food Policy Research Institute, IFPRI), (2) GLOBIOM (International Institute for Applied Systems Analysis, IIASA) and (3) MAGNET-IMAGE (LEI Wageningen UR and the Netherlands Environmental Assessment Agency, PBL).

stakeholder engagement process and participatory approach, and the method to quantify important drivers. Section 4 presents the results, including the four scenario storylines and figures of main drivers. A discussion of the process and outcomes is given in Section 5, followed by conclusions.

2 Scenarios: definition and types

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) as well as national and regional level assessments.

A number of definitions are given for scenarios in the literature. The Millennium Ecosystem Assessment defines scenario 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). Scenarios provide a means of dealing with complex and uncertain issues such as future global food security, which depend on the interplay of a large number of driving forces. Scenarios have been useful in helping policy-makers to think about how the future might unfold and guide the formulation of policies that are dependent on future expectations. A common approach in large global integrated assessments is to develop creative storylines, often using participatory methods with stakeholders that are subsequently modelled to analyze the relationship between drivers and quantify the impact of policies. There is a long history of using scenario analysis in climate and environmental studies, but it is only recently that this approach is being used to assess future food and nutrition security.

Several typologies have been proposed to group scenarios in the literature (e.g. van Notten et al., 2003). Borjeson et al. (2006) (but also see Berkhout et al., 2002; and Reilly and Willenbockel, 2010) provide a typology that is based on the three principal questions that users may want to pose about the future: What will happen?, What can happen? and, How can a specific target be reached?, These questions translate into a typology of three major classes of scenarios that deal with probable, possible and preferable future states, respectively.

The first class, *projections,* include baseline scenarios that describe the future state of a system with no policy changes. They are also referred to as 'business-as-usual' and 'reference' 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 centered 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 analyze 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.

The second class, *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, a number of 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 matrix in which the dimensions form the axes. 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 picture of different futures is particularly useful to guide strategic decisions or inform policies in situations of rapid and irregular change when the future is difficult to predict. Explorative scenarios can be used to analyze and compare the impact of policy decisions in the context of different futures.

The final class, *normative scenarios* are designed to support vision building. They involve the creation of stories or pathways 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.

3 Methodology

This section describes the methodology that is used to develop the scenarios. After a short discussion on the choice for the type of scenarios that are developed and the participatory approach, it elaborates on the stakeholder engagement process and the methodology to quantify key drivers.

3.1 Type

On the basis of the scenario typology described above, it was decided that the exploratory scenario type is the most appropriate tool to assess future global food security. As we are mainly interested in the long-run view (up to 2050), using projections with only a single baseline scenario to represent the future is not appropriate. The exploratory scenario approach, which define four polar future worlds are better suited to capture the high level of uncertainty and complexity that is involved in an assessment of long run global food security, which is influenced by the interaction of a wide range of drivers. Similar to exploratory scenarios, normative scenarios are also designed for long run assessments. However, because of their backward looking approach they cannot easily be used to assess the impact of present policy shocks on future change. A key aim of the FOODSECURE project is conducting impact analysis and assessing trade-offs between several policy domains that affect food security (e.g. trade, aid, environmental and technology policies). Exploratory scenarios are better able to do this than normative scenarios.

3.2 Stakeholder participation

Alcomo and Henrichs (2008) present four criteria to evaluate the quality of scenarios: (1) relevance; (2) credibility; (3) legitimacy, and; (4) creativity. All four criteria are related to the need for participatory stakeholder engagement, in particular in cases where scenarios are created for policy makers and other non-scientist end users. As the prime aim of the FOODSECURE scenarios is to support policy making in the food security domain it is important that the scenarios fulfill the four quality criteria. For this reason, a strong participatory approach has been adopted to guide the design of the storylines and inform the quantification of drivers, which specifics are outlined in the two following sections.

3.3 Scenario development process

The Stakeholder Integrated Research (STIR) approach, which has recently been applied and tested for the development of climate change scenarios (Gramberger et al., 2014) is used to guide engagement with the various stakeholders in the scenario development process. STIR consists of the following five features (Figure 1):

Participatory integration of stakeholders in the research process: The aim of STIR is to make stakeholder engagement an intrinsic part of the scientific project and to create useful outputs that can be applied by the scientific community and stakeholders alike. To this end, STIR promotes an iterative process between stakeholders and scientist in which dialogue and co-creation of knowledge are central. This is different from a consultative process in which stakeholders are asked for feedback on research without participating in the creation of outcomes themselves.

Prospex CQI-method for stakeholder identification and selection: To optimize the stakeholder engagement process, STIR stresses the need for a process to identify and select stakeholders. One approach to organize such a process is the Prospex CGI-method that consists of: (C) Defining a set of criteria and categories for stakeholder groups that are influencing the topic of research or are affected by it; (Q) Setting a specific minimum quota for all kinds of categories (i.e. affiliation, gender and nationality), and; (I) Identifying individuals that fit the categories.

Design and facilitation of the stakeholder engagement process: In order to establish a dialogue between stakeholders and scientist, stimulate co-creation of knowledge and promote a truly participatory process, STIR emphasizes the need for detailed process design (i.e. designing the participatory process before the start of the engagement process) and professional process facilitation (i.e. ensuring that all stakeholders participate equally and that the desired outcomes are obtained in time).

Specified method for stakeholder-science data transfer: To use methodologies that ensure the data created by stakeholders (often qualitative) is usable in the scientific analysis (often quantitative). In the context of scenario development, STIR often applies the Storyline-And-Simulation approach (SAS), (Alcamo, 2008a),

which links qualitative scenario development with quantitative modelling through a number of iterative steps.

Stakeholder evaluation and compatible scientific set-up: To ensure direct and measurable feedback, stakeholders are asked to evaluate the scenario building process, preferably by means of written anonymous surveys after each activity or workshop. A compatible scientific setup means that stakeholder engagement processes are organized in such a way that they can be easily linked with the scientific research, for example organizing separate stakeholder engagement processes for each region that is analyzed.

[FIGURE 1 about here]

The basis for the development of the FOODSECURE scenarios were two two-day workshops and two webinars (Table 1) during which a participatory process was organized with stakeholders to create the four FOODSECURE scenarios. The stakeholders were selected using the CQI-method to ensure that the background of stakeholders was balanced. The workshops brought together around 20 different stakeholders, drawn from international organizations (e.g., OECD and FAO), national institutions, the EU, international non-governmental organizations (e.g., Oxfam and Action contre le Faim), universities and the private sector. The participants comprised policy makers, researchers, experts in scenario analysis and high level representatives from business with an interest in food security issues. The workshops were professionally designed and facilitated following the STIR approach by a company specializing in stakeholder engagement processes. The same stakeholders were invited for both workshops to ensure continuation of the process. In some cases, new participants from the same organizations replaced previous ones if these were unable to attend the second workshop. At the end of each workshop, all participants were asked to fill out a questionnaire for evaluation.

The process to develop the scenarios consisted of two three main steps: (1) the development of the scenario logic and storylines, (2) the quantification of key drivers, and (3) the validation of results. For the first step, the participants were organized in groups and asked to come up with a list of key driving forces and uncertainties that influence global food security. Throughout the workshops, participants stayed in the same scenario group, which enabled them to become ‘experts’ of their scenarios. Key drivers that were selected included: population growth, technical change, lifestyle and consumption patterns and income inequality. During group discussions, the list was used to select the two axes that define the scenario logic. In subsequent rounds of structured assignments and group work followed by plenary sessions for discussion, the storylines were further developed. The results were subsequently used as a basis to quantify several key drivers that are required as an input into the models (see below for more information).

After the two workshops, the scenario support team refined the storylines and assigned numerical values to the projections for a number of key drivers. In order to validate the results, two webinars were organized, which made it possible for stakeholders to comment on the scenario narratives and quantification of the drivers. The recommendations were incorporated in the last version of the scenarios.

[TABLE 1 about here]

3.4 Quantification of scenario drivers

To assess global food security and analyze the impact of policy shocks, the scenarios will be numerically assessed by means of economic and biophysical models. These models have global coverage and therefore require a large amount of information on several exogenous driving forces and parameters. The most important are projections for population growth (also including urbanization), economic development and technological change (i.e. agricultural productivity in terms of crop yield).[3] Several approaches have been proposed in the literature to 'translate' stakeholder-proposed storylines into numerical series (van Vliet et al., 2010). One approach that has been used frequently in the development of climate change scenarios is "fuzzy set theory" (Alcamo, 2008b; Kok et al., 2014), in which scenario trends are first described in linguistic form by stakeholders after which a translation key is used to derive numerical values. Disadvantages of fuzzy set theory are the requirement of prior expertise and knowledge to be able to propose realistic values of the drivers and parameters that are needed by the models. It is therefore difficult and costly to apply fuzzy set theory in practice. For this reason, we applied a novel approach to derive the future trends of main drivers, which we term 'participatory trend mapping'

3.4.1 Participatory trend mapping

In workshop 2, after the first draft of the scenario storylines were finalized, stakeholders were asked to discuss future trends of key drivers that are consistent with the proposed narratives. In particular, scenario groups were asked to graphically illustrate the trend of the six key drivers up to 2050.[4] Each group was given a set of figures that depict the historic trend of the drivers over the last five decades (see

Figure 2a for an example). As the development of drivers is expected to differ across different types of countries, historical information was depicted for four different income groups using the World Bank classification: high income countries ($12,616 per capita or more), middle income countries ($1,036 to $12,615 per capita), low income countries ($ 1,035 per capita or less) and BRICS.[5] By means of these figures the stakeholders obtained a broad idea about past trends. Next, the stakeholders were asked to continue the trend line up to 2050 for each of the drivers in such a way that they are consistent with

[3] Other drivers and parameters that are needed are, among others, change in consumer preferences, trade tariffs, biofuel directives and land use parameters. On the basis of the raw scenario storylines, these variables can be quantified, but this is still work in progress. In a next version of the paper a table will be added which also presents information on these variables per scenario.

[4] Population growth, GDP per capita, cereal yield, nominal rate of assistance, meat consumption and land use. The decision was made to use GDP per capita instead of GDP for the participatory trend mapping exercise because this measure is easier to compare across countries and therefore easier to grasp by stakeholders. GDP projections are then calculated as the product of GDP per capita and population projections.

[5] In practice, historical trends were presented for the BICS countries, excluding Russia because it was not possible to construct historical series for Russia before 1989, when the USSR dissolved. We do not expect this has had any impact on the trend mapping by stakeholders. In the final quantification of the drivers, Russia was considered as a BRICS country.

the scenario storylines but at the same time are still realistic in comparison to historical developments (see

Figure 2b). This exercise stimulated the scenario groups to re-evaluate the scenario consistency, resulting in meaningful discussions and, some occasions, a revision of the scenario storyline.

[FIGURE 2 about here]

3.4.2 Estimation and extrapolation of trends

The diagrams with the stakeholder trends for each of the drivers together with qualitative information from the storylines formed the basis for the actual quantification of the drivers that was done by the research team. Depending on the driver, several approaches have been used for the quantification:

GDP and population growth. Consistent and realistic GDP and population projections cannot simply be created by extrapolating existing trends but require that certain historical patterns and theoretical assumptions are taken into account. For example, in case of population growth, projections need to take in to account present demographic structures, migration and education (UNDESA, 2012). In case of GDP growth, long-run studies on historical growth demonstrate that countries exhibit patterns of "catching up, forging ahead and falling behind" (Abramovitz, 1986; Maddison, 2001; Fagerberg and Verspagen, 2002), strongly depending on the rate of innovation at the technological frontier and the capacity and speed with which lagging countries are able to absorb new technologies and catch up. Constructing high-quality projections is therefore a complex, costly and specialist undertaking. For this reason, we decided not to create new projections but instead build on, and extent, the quantification of drivers from previous scenario studies. This is not uncommon and has, for example also been used by Westhoek et al. (2006) to prepare scenarios for the assessment of land use change in Europe. The existing projections are subsequently combined with the trends as proposed by the stakeholders to arrive at the final dataset.

Our main source of scenario projections for GDP and population are the recently completed Shared Socio-economic Pathways (SSPs) (Kriegler et al., 2012; O'Neill et al., 2012). To create the projections for the FOODSECURE scenarios, we compared the SSP storylines and projections for GDP per capita and population with the FOODSECURE scenarios and trends that are proposed by the stakeholders to identify similarities and discrepancies. It proved to be relatively straightforward to match both scenario studies on the basis of the broad narrative. Nonetheless, as would be expected, important differences remain that need to be taken into account. In particular, the assumptions on population growth for several scenarios and country

income groups differ substantially. On the other hand, GDP per capita trends are very similar between comparable SSP and FOODSECURE scenarios.

To bring the SSP projections for GDP and Population in line with the FOODSECURE narratives, the SSP trends where re-scaled up or downwards, depending on the storyline. In most cases SSP2, the Business-as-usual scenario was taken as a reference. Different scaling factors were used for each of the four country income groups. Finally, the projections for GDP per capita and population are combined to derive the GDP series at the country level.

Crop yield and livestock feed conversion efficiency. The SSPs do not provide projections for crop yield and livestock feed conversion efficiency growth, the indicators that are normally used to model technical change in crop and livestock sectors in global assessment models. Therefore, a different approach was used to construct projections for these indicators. Crop scientist, who analysed long-term historical crop yield patterns have pointed out that yield growth generally exhibits a linear trend (Fischer and Edmeades, 2010; Hafner, 2003). In a recent article, Grassini et al (2013) investigated past yield trends of 36 regions and concluded that "yield projections based on linear models, with breakpoints and plateaus to reflect the linear nature of the crop yield gains (Grassini et al., 2013 p. 9) should be used to derive future food production projections. Nonetheless, in previous assessments, modelers tend to use using compound growth rates to construct yield projections, which will result in too optimistic scenarios (Grassini et al., 2013; WRI, 2013).

We incorporate the recommendations of crop scientists, and use linear instead of compound growth rates to project a baseline for future yield of eight crop groups. The baseline is combined with breakpoints and plateaus to model the introduction of radical technologies (sharp rise in yield) and dramatic impact of climate change (sharp decrease in yield) that were proposed by the stakeholders in several of the scenarios. The results are presented in the next section.

In contrast to crop yield, there is much less information available on the past and future trajectories of livestock feed conversion efficiencies (e.g. Bouwman et al., 2005; Wirsenius et al., 2010), which are defined as the amount of feed required by per livestock category (e.g. dairy, ruminant meat, pork and poultry). For the FOODSECURE scenarios we use livestock feed conversion efficiencies from INRA/DLA (2012), which are computed for three livestock sectors (cattle, pigs and poultry and dairy cattle). Historical projections are inferred from the mass balance of the global food system by means of the Agricultural Representative Identity based Pathways and Emissions (AgRIPE) framework combined with findings from Bouwman et al. (2005). Projections for a Business as Usual scenario matching FAO projections (Alexandratos et al., 2006) generated by the GLOBIOM model up to 2050. We decided to use the baseline scenario for all four FOODSECURE scenarios because of the projections are based on biophysical ceiling values which are unlikely to increase.

4 Results

4.1 Scenario logic

Figure 3 shows the four FOODSECURE scenarios and their position in the scenario matrix. The stakeholders decided to organize the scenarios around two axes that highlight two major uncertainties: (1) lifestyle and use of natural resources ranging from a sustainable to an unsustainable world and (2) equality, with the two polar views of an equal and a highly unequal world. Together, they define for different scenarios: *1% World (ONEPW)*, *Ecotopia (ECO)*, *Too little, too late (TLTL)* and *Food for all but not forever (FFANF)*. The storylines of the four scenarios are summarized below. All scenarios describe a world in the year 2050.

[FIGURE 3 about here]

4.2 Storylines

4.2.1 1% world (ONEPW)

In the *1% world*, global wealth is very unequally distributed. An elite group of 'new rich' that constitutes around one per cent of total population control the major corporations that dominate the majority of markets and own most natural resources. Many of these resources, in particular water and land are located in developing countries, which has increased the scarcity of resources in these countries considerably. Authority and power are shifted from the government to elite. Governments have cut budgets and reduced the expenditures in public services, which are mostly replaced by private services mainly geared towards the needs of the elite. The elite are highly educated and trained and order to protect their assets they invest in research and development to create private solutions for climate change and natural disasters. The result are a number of path-breaking technologies to overcome the problems of climate change, reduce pollution and waste and protect the environment. Other technological advances have resulted in much higher crop yield to ensure the efficient and low-cost production of food. A lot of the advanced technology put in place requires minimum skill levels from employees handling the technology.

4.2.2 Ecotopia (ECO)

The *Ecotopia* scenario assumes an equal society, in which all are educated and wealth is equally distributed. Free movement of people is guaranteed. Local policies support development of rural areas. Trade policies will be aligned to food and nutrition security and stable ecosystems. The global population has access to sustainable diets. Water and food choices and basic needs will be covered. All food is safe and there are new sources of food available and socio-cultural aspects are respected in the diet. The concept of "prosumers" is introduced, where consumers of food are at the same time also producers of food. New agricultural production technologies are developed that focus on sustainability and zero waste. Urban agriculture is highly developed and aquaculture is sustainable. New and diversified renewable energy sources are applied that replace conventional fossil fuel energy sources. Environmental and agricultural innovations are accessible for everybody due to its open source nature.

4.2.3 Food for all but not forever (FFANF)

The last 30 to 40 years in the *Food for all but not forever* scenario, have been characterized by rapid economic growth and employment growth. Growth has been accompanied by more intensive multilateral international co-operation that has led to the free movement of goods and people, better health and education systems, more democracy and eradication of hunger. Wealth is more equally distributed because countries have adopted taxation systems to equalize incomes and property within societies. At the same time, climate change has worsened as a consequence of the use of more and cheaper fossil fuels and less renewable resources as well as the movement to intensive but polluting agricultural systems. Consumption and growth are more important that sustainability in the mindset of the global population.

In 2050, poverty has been reduced and society has become more equal but the environment is on the brink of catastrophe. Over the last five years, the global economy is severely suffering from climate-induced disasters such as hurricanes, floods and droughts. The overuse of pesticides and fertilizers has substantially decreased soil fertility on all continents across different ecosystems. The rainforest has largely been destroyed and replaced by farm land. Food production systems have intensified to the point that pandemics have broken out in the life stock sector.

4.2.4 Too limited, too late (TLTL)

In the *Too limited, too late* scenario, several new financial crises have resulted in a sharp decrease in economic growth. This has sparked national political crises, which has given room for opportunistic behavior. Governance at the international level has also worsened. All of this has led to an unequal society which exists of “haves” and “have nots”, which gap widens over time. At the same time the effects of climate change, caused by uncontrolled depletion of (fossil) natural resources, have destructive effects, leading to biodiversity loss, an increase in natural disasters, and disputes about water. Only the small minority of the “haves” benefit from food that is produced in a very unsustainable way, while the majority suffers from food and nutrition security. A selected group (elite) hold power and protect their interests.

In 2050, there is no international cooperation and the whole UN system has dissolved. A select elite group holds the power and protects their interests, while the majority of people are poor with limited access to food, health and education. There is monopolized access to knowledge and technology: the rich have access to modern technologies, the poor have no access. The whole ecosystem is collapsed, natural resources are depleted and biodiversity has been largely lost.

4.3 Key drivers

4.3.1 Population growth

Population growth is an important driver of global food demand and, thus, food security. The UN medium projection for global population expects that total population will peak at 9 billion in 2050 and will slowdown thereafter (UNDESA, 2012). However a very recent re-assessment of the data, for the first time including a probabilistic projections, point out that the world population can be expected to increase from the current 7.2 billion people to 9.6 billion in 2050 and eventually reaching 10.9 billion in 2100 (Gerland et al.,

2014). The main reason for the continued global population growth is an increase in the projected population of Africa. These findings demonstrate that future population growth is still very uncertain and confirms the need to use scenario analysis to assess the impact on global food security.

Figure 4 depicts the population projections for the four country groups by scenario. Apart from the high income group, population growth is expected to be highest in the *1% World* scenario. *Too limited, too late* projections are in the middle for all country groups, while the results for *Food for all but not for everyone* and *Ecotopia* are at the bottom of the scale (except for high income group where population growth is the highest). An important assumption in the *1% World* scenario is that population growth in the high income, medium income and BRICS countries is relatively high. In the *Food for all but not forever* scenario, migration plays a prominent role. It is assumed that people have possibility and are willing to migrate from poor to rich countries. The result is high population growth in high income countries and low population growth in the other country groups. The *Too little, too late* scenario assumes that population growth in the high income countries, BRICS and middle income countries is slowing down, while expansion continues in the Low income countries. Finally, in the *Ecotopia* scenario, the storyline indicates that poverty is decreasing in developing countries and educatio and health systems are improving, leading to a stagnation in population growth.

[FIGURE 4 about here]

4.3.2 Macro-economic development

GDP and GDP per capita growth are core measures of economic growth and development and, hence, strong drivers of food demand and supply. Comparing scenarios, GDP per capita growth is highest in the *Food for all but not forever* scenario and lowest in the *Too late, too litle* scenario (except for the high income group), while the *Ecotopia* and *1% world* are located in the center (

Figure 5). The *Food for all but not forever* scenario sketches a world with rapid growth and growing equality but with an implosion of the global economy in 2045, which is clearly reflected in the figure. In contrast, the *Too late, too limited* scenario foresees a fragmented world that is characterised gobal income divergence and relative low levels of development. The *1% world* ONEWP projects increasing inequality but with relative high growth in all regions. In particular in the high income countries because of innovations that are mainly applied in the location where the elite live. GDP per capita growth in other regions is expected to be lower because of the rise in global inequality. The main theme of the *Ecotopia* scenario is a sustainable and more equitable world with income per capita levels that converge.

[FIGURE 5 about here]

4.3.3 Crop yield

It has frequently been argued yield gaps need to be closed in order to produce sufficient food for the global population in 2050 (Licker et al., 2010; Foley et al., 2011; Mueller et al., 2012) and that present rates of crop yield are not sufficient to achieve this (Ray et al., 2013). Assumptions on yield are therefore an important element of any scenario study that aims to assess future global food security.

Figure 6 shows both the historical yield trend and the yield projections for each of the four scenarios by country income group. The figure shows the results for maize and other grains but similar information is available for seven other crop groups.

The yield projections are quite diverse across scenarios. An important part of the storyline in the *1% World* is rapid technological advancement (e.g. the new breeds and cultivation techniques) occurs at specific points in time (around mid-2030) resulting in breakpoints in the crop yield projections. Innovations emerge in high income countries but diffuse with a lag to other regions. By 2050 yields have increased about 30 percent in comparison to the base year 2010. The *Too late, too little* scenario assumes crop yield is going down in low-income regions because of the impact of environmental catastrophes, resulting from climate change. The middle-income countries reach a sort of plateau, while the yield in high-income countries goes up but at a slower rate because of more resilient agricultural systems. In the *Food for all but not forever* scenario, yield is increasing rapidly in all regions because of the international diffusion of knowledge and more intensive production approaches. However after around 2030, yield growth reaches a plateau and eventually collapses because of the negative impact of climate change around 2045. The *Ecotopia scenario* foresees the existence of open source technologies that rapidly diffuse internationally. As a consequence, the low-income countries will close a large part of the yield gap. The crop yield in high-income countries will slightly decrease or stagnate, because yields have reached the biophysical maximum potential.

[FIGURE 6 about here]

5 Discussion

5.1.1 Scenario development process

The actual scenario development process that was implemented diverted from the original planning in two ways. First, following Kok et al. (2011), the initial idea was to use an existing set of scenarios (so-called 'fast-track' scenarios), as a basis for the FOODSECURE storylines to speed up the process and leave more room for the quantification of drivers. More specifically, it was foreseen to use the newly developed SSP scenarios as a starting point and ask stakeholders to add or refine food security related components. However, during the process, stakeholders raised the concern that the SSPs did not cover all plausible futures and are too strongly geared towards climate change, and are therefore not able to adequately take into account the relevant aspects of future food and nutrition security. To accommodate their concerns, we decided to go through a full scenario development process of defining key uncertainties and develop the scenario logic from the bottom up. The lessons that can be drawn from this is that stakeholders are likely to be unwilling to accept scenarios that have been created for a different subject and purpose and therefore, researchers and scenario developers should be careful in using existing storylines as basis for scenario development

Second, it was planned to use the SAS approach to introduce a feedback loop between the storylines developed by stakeholders and quantitative model results that are based on them. Unfortunately, because of

the aforementioned change in the scenario planning process the storylines were not completed after the first workshop, which made it impossible to use them as input for the model simulations. Given the available resources, it was not possible to organize additional workshops and the iteration between stakeholder-determined storylines and expert-driven model runs had to be omitted. The consistency check between storylines and model results will now be done by researchers only, which is a clear shortcoming in the participatory scenario building process.

5.1.2 Stakeholder evaluation

To guarantee relevance, credibility, legitimacy and creativity of the FOODSECURE scenarios, stakeholder participation has been central part of scenario development process. It is therefore, important to evaluate stakeholder satisfaction and find out if participants support the scenario outcomes. The questionnaire that was handed out after each workshop pointed out that the majority of participants were generally very satisfied with the facilitation, the content support and the practical arrangements. A few comments indicated that the overall process was less clear in the first workshop but it was nevertheless rated good or very good by 89,5% of the participants. The fact that the workshop process was adjusted during the workshop to accommodate the stakeholders' need for more discussion on new scenarios (as compared to the SSPs) had a very positive impact on stakeholder satisfaction, reflected in the 94,5% satisfaction rate (very good and good) with regards to the facilitation. A large majority (93%) agreed that the scenario-building process as a whole was useful in developing strategies for food and nutrition security.

5.1.3 Quantification of drivers

A novel approach – participatory trend mapping – was used to obtain projections for a number of important long-run drivers of food security. We found that this approach was very useful in quickly discussing a relative large number of driving forces with stakeholders. The use of pictures with historical trends proved a simple, intuitive and effective way of quickly informing stakeholders about indicators they were previously not familiar with and helped to generate realistic future trends. A positive side effect was that in several instances the mapping of drivers led to a renewed discussion about the internal consistency of the scenarios and consequential adjustment. A disadvantage of participatory trend mapping, in contrast with fuzzy set theory that directly provides numerical values, is that researchers still have to do post-processing to translate the trends into numbers. This might introduce a bias and highlights the need for the validation of results in which stakeholders have to opportunity to provide comments and after which projections can still be revised. Nonetheless, we are of the opinion that participatory trend mapping is interesting and useful new tool that can also be used in other scenario building exercises.

6 Conclusions

This paper describes the development process and results from a participatory scenario exercise to develop a set of global scenarios that can be used in conjunction with global impact assessment models to investigate the dynamics in long-run global food security. The outcome are four different scenarios that cover a large spectrum of possible futures, defined along two axes: (in)equality, and lifestyle and natural resources. A

number of conclusions can be drawn from our experience in building FOODSECURE scenarios. First, a participatory approach towards scenario development, involving a diverse group of stakeholders, combines with a professional management and planning of the process, leads to innovative and diverse scenarios. It is unlikely that the derived scenarios would also have resulted from an exercise that mainly involves scientists. Second, a fast-track approach towards scenario building is not without difficulties and risk. In this study, stakeholders were not convinced by the selected fast-track scenarios. The process was successfully adapted, yet the adaptation led to a substantial delay Finally, participatory trend mapping, a novel approach first tested in this paper, in combination with thorough validation, proved to be a useful tool to derive realistic trends of long-term driving forces.

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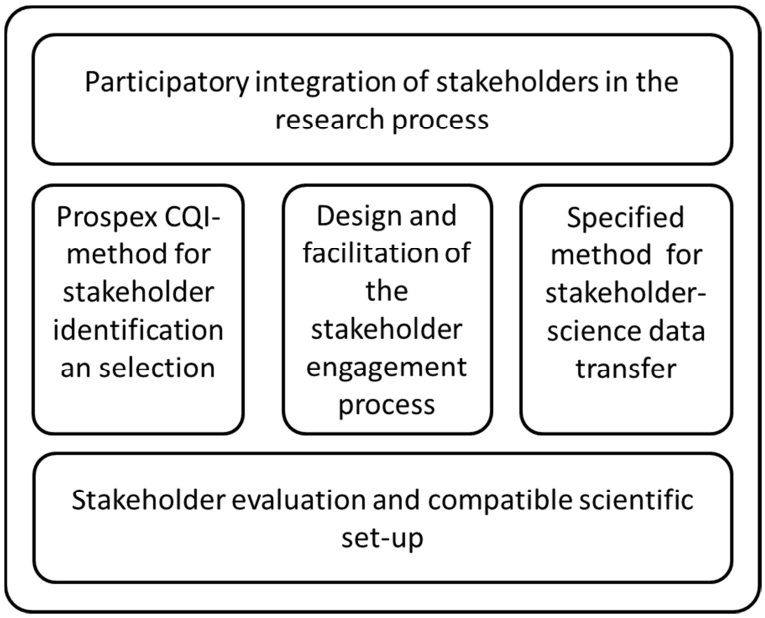
Figures and Tables

Figure 1: Stakeholder Integrated Research (STIR) features



Source: Gramberger et al. (2014)

Table 1: Overview of FOODSECURE stakeholder workshops and webinars

Event	Date and location	Participants	Main activity
Workshop 1	5-6 September 2013, Bruges, Belgium	19	(1) Qualitative scenario development
Workshop 2	27-28 February 2014, Prague, Czech Republic	16	(1) Finalization of storylines (2) quantification of key variables
Webinar 1	6 June 2014, online	2	(1) Validation of storylines (2) validation of quantification of key variables
Webinar 2	10 June 2014, online	8	(1) Validation of storylines (2) validation of quantification of key variables

Source: Authors

Figure 2: Example of participatory trend mapping for the Ecotopia scenario

(a) Trend (b) Projections by stakeholders

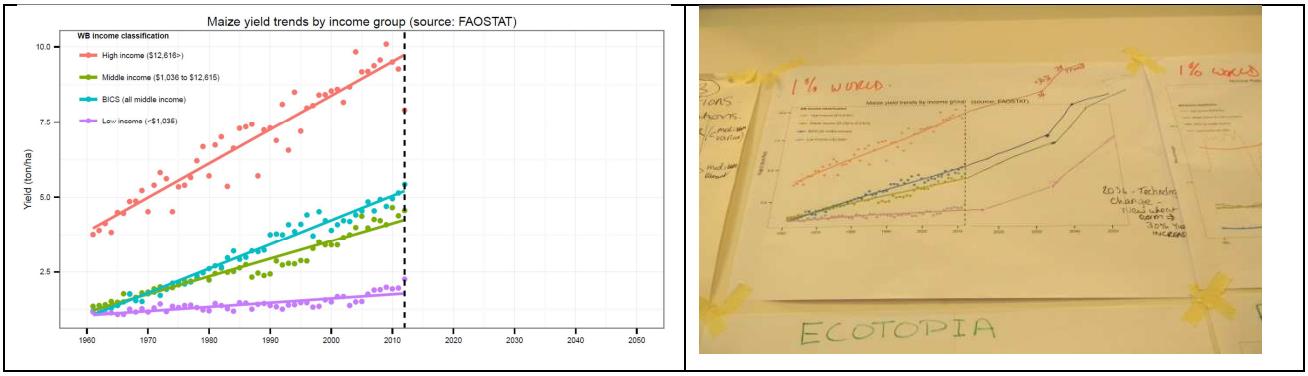


Figure 3: Scenario logic of the FOODSECURE scenarios

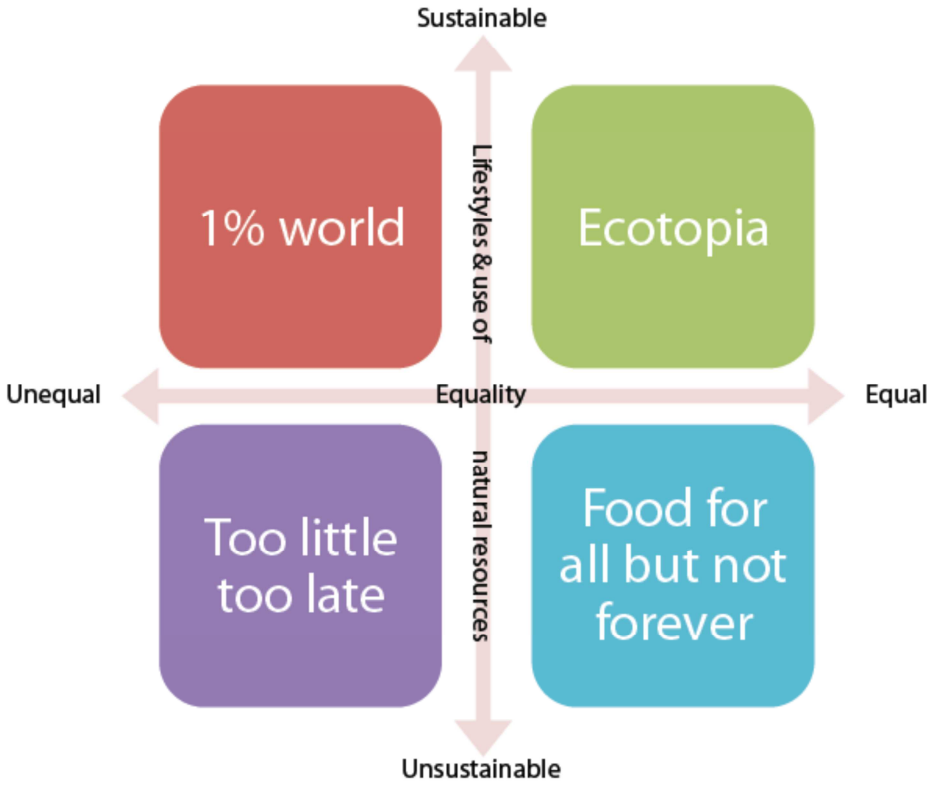


Figure 4: Population by scenario and income group: 1980-2050

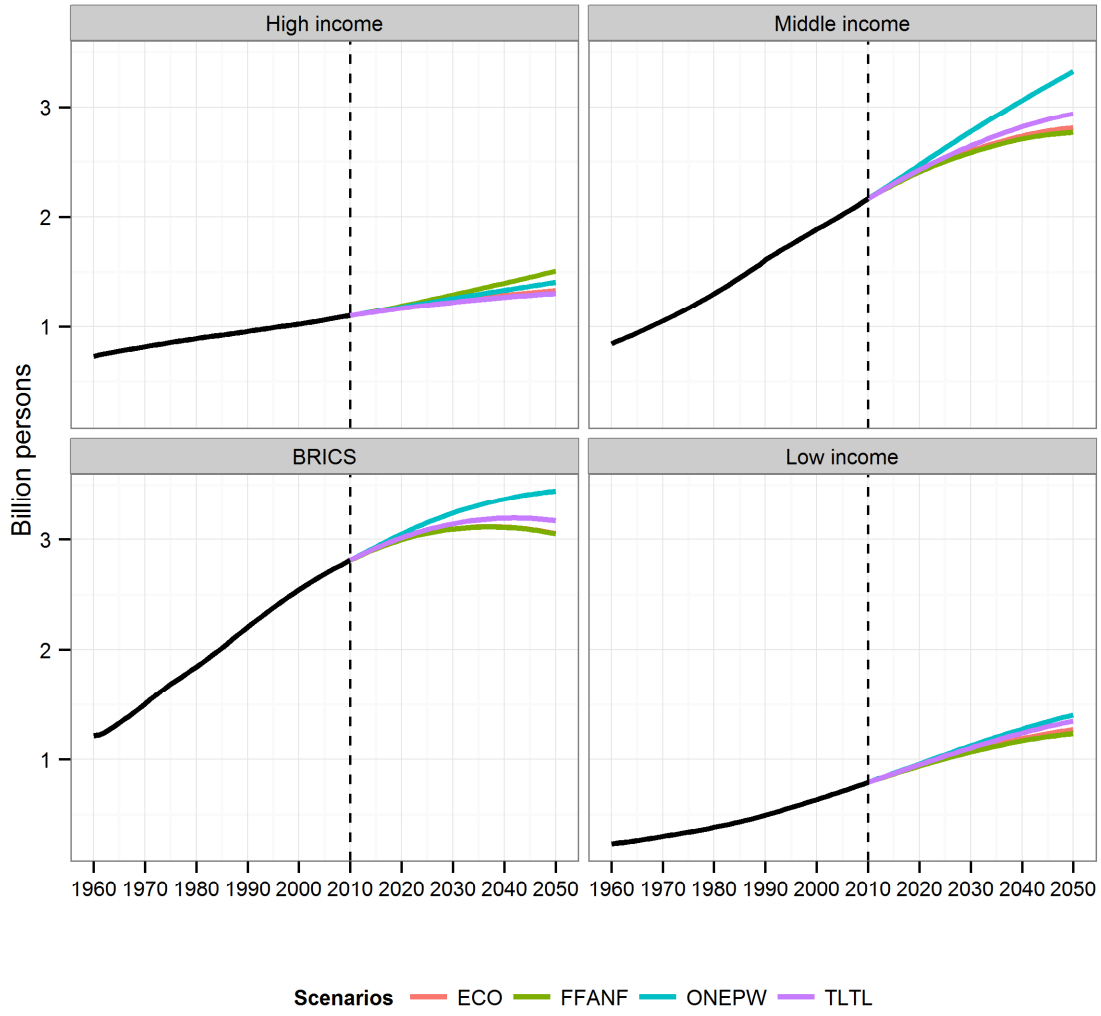


Figure 5: GDP by scenario and income group: 1980-2050

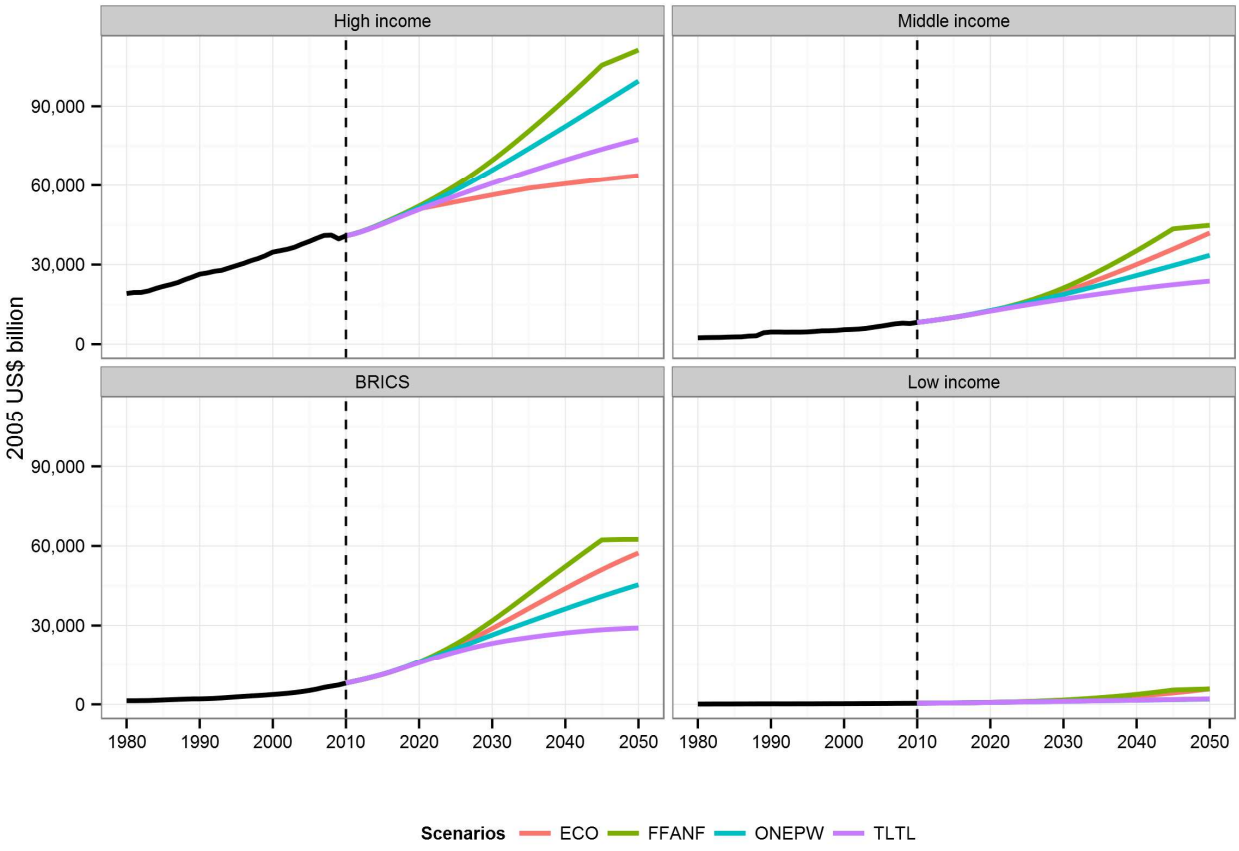


Figure 6: Maize and other grains yield by scenario for representative region income groups: 1990-2050