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Stakeholder-designed scenarios for global food security assessments

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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 'wicked problems', such as ensuring global food security, that are characterized by a high level of complexity and uncertainty. This paper describes the development process, storylines and drivers of four new global scenarios that are specifically designed to explore global food security up to the year 2050. To ensure the relevance, credibility and legitimacy of the scenarios, they have been developed using a participatory process, involving a diverse group of stakeholders. The scenarios consist of storylines and a scenario database that presents projections for key drivers, which can be used as an input into global simulation models.

1. Introduction

The question on 'how to feed the world in 2050' has received increasing attention from policy makers, the media and scientists since the surge in food prices in 2007/2008 (FAO, 2009). To progress on this question and propose solutions, policy makers need insights into the future development of food availability, access, utilization and stability (FAO, 1996) as well as the underlying drivers, such as population growth, economic development and technical change, which jointly determine the state of future global food security.

Understanding long-term food security is a complicated issue because it has all the characteristics of a 'wicked problem' (Wilkinson and Eidinow, 2008). Wicked problems are public problems that are characterized by a high level of complexity, uncertainty and systemic challenges that impact across local to global scales. They are seemingly intractable because the influence of many social and political actors as well as biophysical factors and are described as 'messy' because there is no consensus on what is exactly the problem (Rittel and Webber, 1973). The consequence is that different perceptions of stakeholders will lead to diverse and often opposing definitions of the problem.

Traditional policy planning based on historical trends is not appropriate to explore the options to address the challenges posed by wicked problems. A more suitable methodology is the use of a scenarios that envisage a number of contrasting futures that diverge from the historical trend (Wiebe et al., 2018). Scenario analysis has become the standard approach to assess wicked problems, including climate change (Nakicenovic et al., 2000), ecosystem change (Millennium Ecosystem Assessment, 2005) and environmental challenges (UNEP, 2007) but only recently emerged as a tool to assess global food security (IAASTD, 2009). Most recent studies use the Shared Socio-economic Pathways (SSPs) (O'Neill et al., 2014), originally designed for climate change assessments, to quantify global food demand and supply scenarios (Valin et al., 2014; Hasegawa et al., 2015).

This paper describes the development process, storylines and drivers of four global scenarios that were developed in collaboration with stakeholders to assess global food security. As such, they can be considered as an alternative to, and can be contrasted with, the SSPs, which were largely developed by the research community. The scenarios are part of the FOODSECURE project (www.foodsecure.eu), which aims to assess global food security by means of scenario analysis and modelling. The FOODSECURE storylines and drivers presented in this paper have been quantified by means of a number of global integrated assessment models and used as a basis for developing and testing policies that contribute to global food security (see Doelman et al., 2019; Kuiper et al., 2019; Van Meijl et al., n.d. in this special issue).

The structure of the paper is as follows. Section 2 presents brief background information on the definition of scenarios and possible scenario types. Section 3 describes the participatory approach that was

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used to develop the scenario narratives. Section 4 summarizes the method that was used to quantify the global projections for the main scenario drivers. Section 5 presents the results, including the four scenario storylines and projections for key main drivers. Section 6 presents a discussion of the main findings and compares the FOODSECURE scenarios with other recent scenario exercises. Section 7 provides conclusions.

2. Scenarios: definitions and types

A number of definitions have been given for scenarios in the literature. The Millennium Ecosystem Assessment defines scenario as a "plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technology change, prices) and relationships." (Millennium Ecosystem Assessment, 2005, 547). 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. It has been demonstrated that scenarios can be a tool to inform science and policy (Chaudhury et al., 2013), can guide the formulation of policies that are dependent on future expectations and can support the building of capacity for strategic planning (Vervoort et al., 2014). A common approach in large global integrated assessments is to develop creative storylines, often using participatory methods with stakeholders that are subsequently modeled to analyse the relationship between drivers and quantify the impact of policies (Alcamo, 2008).

Several typologies have been proposed to group scenarios in the literature (e.g. Notten et al., 2003; IPCC, 2019). Börjeson et al. (2006) provide a typology based on the three principal questions that users may want to pose about the future: What will happen?, What can happen? 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, or 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 has been made. Examples are the OECD Environmental Outlook to 2050 (OECD, 2012) and the EU Reference Scenario 2016: Energy, Transport and GHG Emissions Trends to 2050 (Capros et al., 2016).

The second class, or explorative scenarios, are designed to give room to 'out of the box' thinking; they typically involve the development of a set of rich narratives that describe possible polar world views. 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 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. Explorative scenarios can be used to analyse and compare the impact of policy decisions in the context of different futures. Well known examples are the Millennium Ecosystem Assessment (2005) and the IPCC SRES scenarios Nakicenovic et al. (2000).

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 decision points to reach a specific vision of the future. An example is the UNEP Global Environmental Outlook UNEP (2012).

We decided that the exploratory scenario type was 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 does not seem appropriate. The exploratory scenario approach - which defines four polar future worlds - is better suited to deal with the high level of uncertainty and complexity that characterizes future global food security outcomes.

3. Participatory scenario and storyline development process

Alcamo and Henrichs (2008) present four criteria to evaluate the quality of scenarios: (1) relevance; (2) credibility; (3) legitimacy, and; (4) creativity. Involving stakeholders in the design of scenarios will positively contribute to address and fulfill these criteria. For this reason, we decided to adopt a strong participatory approach to guide the design of the storylines and inform the quantification of key drivers (described in the next section).

The FOODSECURE scenarios were developed during two two-day meetings and two webinars that took place in 2013 and 2014. The process was designed and facilitated by a company specialized in stakeholder engagement processes and participatory scenario development using a structured approach (Text S1). The events brought together around 19 different stakeholders with a diverse set of backgrounds. An effort was made to invite a balanced set of stakeholders, which equal representation taking into account affiliation and gender. The same group of stakeholders were invited for all events to ensure continuation of the process although in some cases new participants from the same organizations replaced their colleagues.

The process to develop the scenarios consisted of the 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' in their scenario. The selected key drivers included: population growth, technical change, lifestyle and consumption patterns and income inequality. During group and plenary discussions, stakeholders selected the final two axes that define the scenario logic: (in)equality and sustainability were chosen as most significant dimensions. The storylines were further developed in subsequent rounds of structured assignments and group work followed by plenary sessions for discussion. The results were subsequently used as a basis to quantify several key drivers.

After the two workshops, the scenario support team refined the storylines and driver quantification. To validate the results, two webinars were organized, which made it possible for stakeholders to comment on the scenario narratives and the quantification of the drivers. The recommendations from the stakeholders were incorporated in the final version of the FOODSECURE scenario storylines and driver database.

4. Quantification of scenario drivers

To assess global food security and analyse the impact of policies, the FOODSECURE scenarios were designed to be used as for global integrated assessment models that require projections and parametrization of exogenous driving forces. The most important are: (1) population growth (also including urbanization), which is a key driver of global food demand (Kearney, 2010); (2) economic development (measured by Gross Domestic Product, GDP) and income change (measured by GDP per capita), which are strongly associated with (the change in) diets (Cirera and Masset, 2010) and (3) technological change (i.e. agricultural productivity measured by crop yield and livestock conversion efficiency), which is a key driving force of agricultural production (Foley et al., 2011; Ray et al., 2013).

Several approaches have been proposed in the literature to 'translate' stakeholder-proposed storylines into numerical series (Vliet et al., 2010). Two approaches that have been regularly used in the

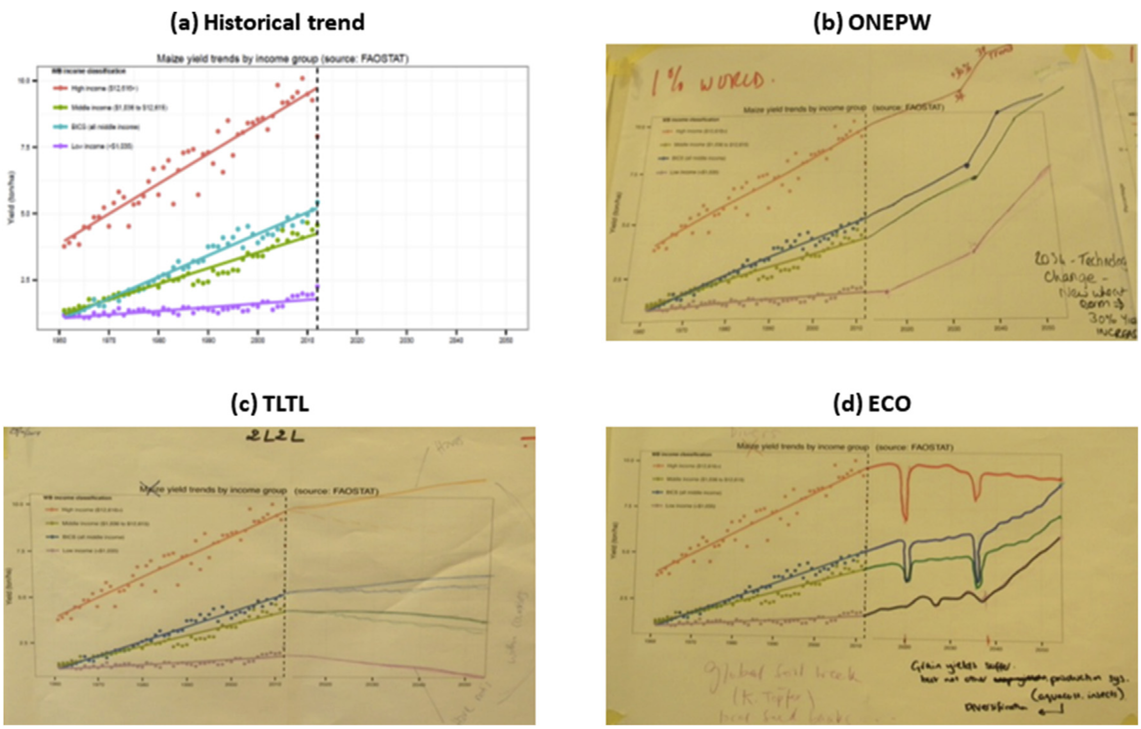


Fig. 1. Example of participatory trend mapping with maize yield projections. (a) Historical maize yield trends for four country income categories shared with the stakeholders. (b–c) Results from the participatory trend exercise prepared by stakeholders that show scenario specific maize yield projections for three scenarios: 1% World (ONEPW), Too Little Too Late (TLTL) and Ecotopia (ECO). The diagram for the Food For All but Not Forever (FFANF) scenario is presented in Text S1.

development of climate change scenarios are ‘fuzzy set theory’, in which scenario trends are first described in linguistic form by stakeholders after which a translation key is used to derive numerical values (Kok et al., 2015) and ‘fuzzy cognitive maps’ (Jetter and Kok, 2014), which use flow diagrams to structure and quantify relationships. A disadvantage of both approaches is that they often require prior expert knowledge in order to propose realistic values that can be used as an input into the models. This makes it often difficult and time consuming to apply the approaches in practice. For this reason, we explored a novel alternative approach, which we termed ‘participatory trend mapping’, to derive and quantify future trends of main drivers.

After the first draft of the scenario storylines was finalized, stakeholders were asked to think about the development of key drivers consistent with the proposed storylines. Each group was given a set of figures that depict the historical trend of several key drivers for the last five decades (Fig. 1a). As the development of drivers is expected to differ across different types of countries, historical information was depicted for four country income groups using the World Bank classification: high-income countries, middle-income countries, low-income countries and BRICS (i.e. Brazil, Russia, India, China and South Africa). The stakeholders were subsequently asked to continue the trend line up to 2050 for each of the drivers in such a way that they were consistent with the scenario storylines but at the same time were still realistic when compared with the historical trend (Fig. 1b–d). This exercise stimulated the scenario groups to re-evaluate the scenario storylines and logic, resulting in meaningful discussions and, in some occasions, a revision of the scenario storyline. The diagrams with the stakeholder proposed trends for each of the drivers, combined with qualitative information from the storylines, was the basis for the actual quantification of the drivers performed by the research team.

In order to make consistent and realistic driver projections, it is important to consider historical patterns as well as theoretical relationships. For example, in case of population growth it is essential to consider changes in fertility, mortality, migration and education on future trends (KC and Lutz, 2017). In case of GDP per capita growth, long-run studies on historical economic growth demonstrate that economic development strongly depends 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 (Fagerberg and Verspagen, 2002; Dellink et al., 2017). Constructing high-quality projections is therefore a complex, resource-intensive and specialist undertaking. For this reason, we decided to use population and GDP projections of a previous scenario studies as a starting point and adapt them to the storylines proposed by the stakeholders. A similar approach was used by Westhoek et al. (2006) and Kok et al. (2018), who prepared scenarios for the assessment of land use and climate change in Europe, respectively.

Our main source of scenario projections for population and GDP were the Shared Socio-economic Pathways (SSPs), which were also developed recently (Kriegler et al., 2012; O'Neill et al., 2017). We started with comparing the SSP storylines and projections for population and GDP per capita with the FOODSECURE storylines and driver patterns proposed by the stakeholders and identified similarities and discrepancies. Next, for each of the FOODSECURE scenarios and country income group combinations, matching SSP projections for population and GDP per capita were selected. In several cases, we decided to scale the SSP projections up- or downwards to match the trends described in FOODSECURE scenario storylines. The scaling factors where chosen in such a way that consistency was ensured both within (i.e. relative trends of different income groups in the same scenario) and between (i.e. relative trends of the same income group in different scenarios) scenarios. Details of the approach are provided in Text S2. Finally, national projections for GDP per capita and population were combined to create the GDP projections presented below.

The SSP Database (2016) does not provide harmonized projections for crop yield and livestock feed conversion efficiency growth, the indicators that are normally used to model technical change in the crop and livestock sector in global assessment models. Hence, we used another approach to construct projections for these indicators. Crop scientists, 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). Grassini et al. (2013) investigated past yield trends in 36 regions and concluded that yield projections based on linear models should be used to derive future food production projections. This contradicts with previous assessments, which used compound growth rates to construct yield projections, resulting in overly optimistic scenarios (Grassini et al., 2013; World Resources Institute, 2013). In conformity with the agronomic literature, we used linear instead of compound growth rates to project a baseline for future yield of eight crop groups at broad regional levels. The baseline was 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 and clearly depicted in some of the diagrams that resulted from the participatory trend mapping exercise (e.g. see Fig. 1).

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; Pradhan et al., 2013), which are defined as the amount of feed required by per livestock category. For the FOODSECURE scenarios we used livestock feed conversion efficiencies from Herrero et al. (2014) and Fricko et al. (2017), which were computed for three livestock sectors (cattle, pigs and poultry and dairy cattle) at the broad regional level. We decided to use the same business as usual scenario for all four FOODSECURE scenarios as projections are based on biophysical ceiling values which are unlikely to increase dramatically in the future.

To facilitate the modelling of the scenarios, the driver projections were aggregated into 19 country groups that represent different global economic and regional blocks, and are used as units in the global simulation models (Text S2). All projections are stored in the FOODSECURE Scenario Driver Database (Van Dijk et al., 2019).

5. Results

Fig. 2 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. Depending on the scenario storyline, (in)equality can refer both to inter- and intra-national differences in

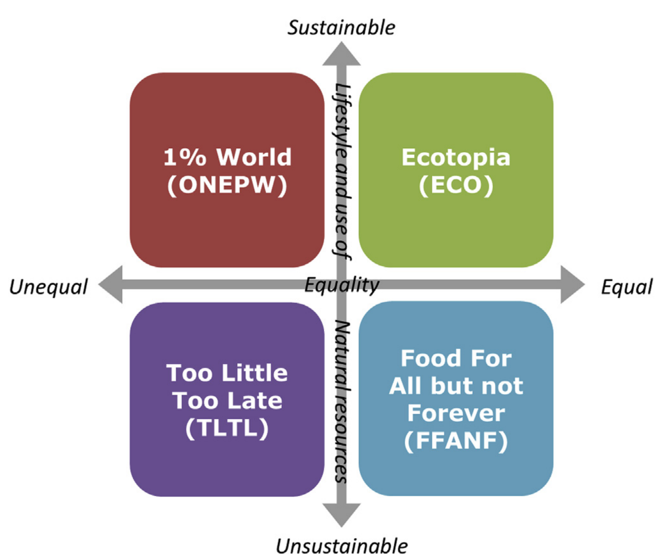


Fig. 2. FOODSECURE scenario matrix showing the two axes that define the scenario logic: (in)equality and sustainability, resulting in four different scenarios: 1% World (ONEPW), Ecotopia (ECO), Too little, too late (TLTL) and Food For All but Not Forever (FFANF).

Table 1
Key elements and drivers of the FOODSECURE scenarios.

Elements	ONEPW	ECO	FFANF	TLTL
Income per capita growth	High in HICs, medium in other regions: divergence	Low in HICs, high in other regions: convergence	Very high in all regions: convergence	Low in all regions: divergence
Inequality	Increased between and within regions	Reduced between and within regions	Strongly reduced, especially between regions	Increased, especially between regions
Population growth	Low in LICs, high in other regions	Low	Relatively low	Medium in HICs, low in other regions
Technical change	Very rapid	Rapid	Rapid	Slow
Crop yield growth	High: convergence	Stagnating in HICs, high in other regions: convergence	High but with eventual collapse: convergence	Low: divergence
Globalisation	Globally connected elites	Globally connected, local markets	Strongly globalised	De-globalizing, national focus
International cooperation	Strong between the elite	Strong	Medium	Weak
Use of natural resources	Sustainable, managed by the elite	Sustainable	Unsustainable	Unsustainable
Diet	Medium-meat diet	Low-meat diet	High-meat diet	Medium-meat diet
Food waste and losses	Low	Very low	High	Very high
Migration	Medium	Medium	High from low to high-income countries	Medium
Policy orientation	Toward the benefit of the elite	Toward sustainable development	Toward free markets and growth	Toward national priorities
Climate change impact	Low due to mitigation and adaptation technologies	Low due mitigation	High due to lack of mitigation	High due to lack of mitigation and adaptation

income. The combination of the two axis defines the four 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 briefly described below and Table 1 presents a comparison of key elements and drivers for each of the scenarios.

5.1. Storylines

5.1.1. 1% world (ONEPW)

The 1% World (ONEPW) is a combination of a sustainable but unequal world. In this scenario, global wealth is very unequally distributed both within and across countries. An elite group of 'new rich' – that constitutes around one per cent of total population – controls the major corporations dominating the majority of markets and owning most of natural resources. The greater part of the resources, in particular water and land, is located in developing countries. The scarcity of resources in these countries has increased considerably over the past forty years. Authority and power have been shifted from the government to the elite. Governments have cut budgets and reduced the expenditures in public services, which are mostly replaced by private services and are mainly geared towards the needs of the elite. To protect their assets, the elite have invested in research and development to create private solutions for global environmental problems, which have resulted in a number of path-breaking technologies to overcome the problems of climate change, reduce pollution and waste and protect the environment. Technological advances also include agricultural technologies that have resulted in an increase in crop yield to ensure the efficient and low-cost production of food. Food security is ensured for the elite in the 1% world scenario. The rest 99% of people are fed, since the quantity of food has been provided through high efficient and technologically advanced production systems. However, the nutritional quality of the staple food is insufficient, especially regarding micro nutrients.

5.1.2. Ecotopia (ECO)

The Ecotopia (ECO) scenario is a combination of a sustainable and equal world. It assumes an equal society both within and between countries, in which all people are well educated and wealth is equally distributed. Free movement of people is guaranteed. Local policies support development of rural areas. 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, which replace conventional fossil fuel energy sources. Environmental and agricultural innovations are accessible for everybody due to their open source nature. Trade policies are aligned to food security and stable ecosystems. The global population has access to sustainable diets. Water and food choices and basic needs are 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. In the Ecotopia scenario the problem of food insecurity has been solved by 2050.

5.1.3. Food For All but Not Forever (FFANF)

The Food For All but Not Forever (FFANF) scenario is a combination of an unsustainable but relatively equal world. In this scenario consumption and growth are more important than sustainability in the mindset of the global population. The rapid economic and employment growth, accompanied by more intensive multilateral international cooperation, has led to free movement of goods and people, better health and education systems, more democracy and eradication of hunger. Wealth is more equally distributed and poverty has been reduced, since countries have adopted taxation systems to equalize incomes and property within societies. At the same time, the environment has deteriorated as a consequence of more and cheaper fossil fuels and a shift to intensive, but polluting agricultural systems. 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. In addition, the climate change problem has worsened and most recently the global economy is severely suffering from climate-induced disasters, such as hurricanes, floods and droughts. Food security is this scenario has been achieved, but in an unsustainable way.

5.1.4. Too Little Too Late (TLTL)

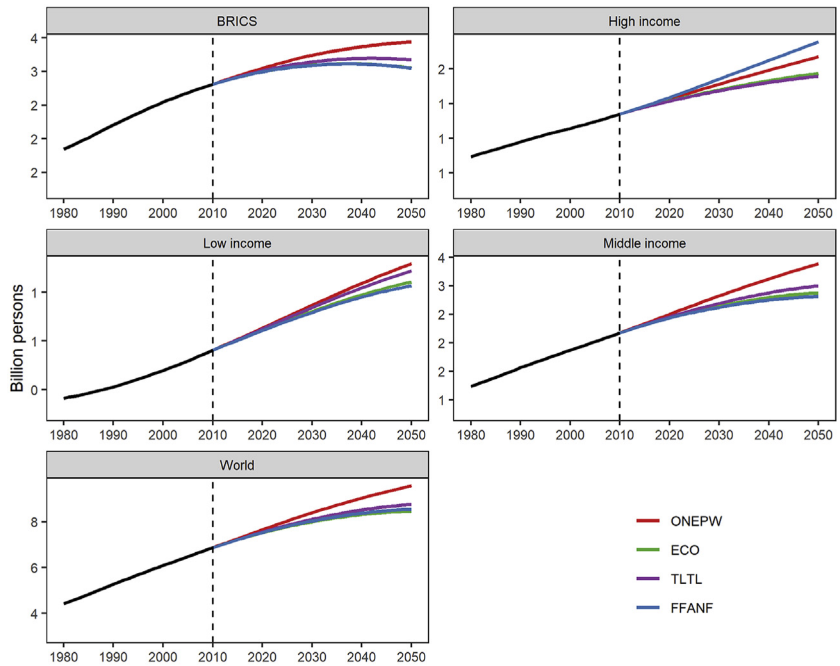
The Too Little Too Late (TLTL) scenario is a combination of an unsustainable and unequal world. In the TLTL scenario, several new financial crises have resulted in a sharp decrease in economic growth. This situation has sparked national political crises, which in turn have given room for opportunistic behavior. Governance at the international level has also worsened: in 2050, there is no international cooperation and the whole UN system has dissolved. All of this has led to an unequal society, which consists of the 'haves' and the 'have nots', with the gap between the two groups widening over time. A select elite group ('the haves') holds the power and protects own interests, while the majority of people (the 'have nots') is poor with limited access to food, health and education. There is monopolized access to knowledge and technology: the rich have access to modern technologies, while the poor do not. At the same time, the destructive effects of climate change, caused by uncontrolled depletion of (fossil) natural resources, has caused biodiversity loss, an increase in natural disasters, and disputes about water. Regarding food security, only the small minority of the 'haves' benefits from food produced in a very unsustainable way, while the majority suffers from food insecurity.

5.2. Drivers

Fig. 3(a-c) depict the projections for population, GDP per capita and crop yield growth by scenario and country income group. Population growth in the high income group is the highest in FFANF because migration plays a prominent role. It is assumed that people have possibility and are willing to migrate from poor to rich countries. The result of migration is high population growth in high income countries and low population growth in the other country groups. In the ONEPW scenario, population growth in the high income group (and medium-income and BRICS countries) is also high because the assumption is made that higher incomes make it possible to sustain larger families and households. The TLTL 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, driven by increasing differences in global income. Finally, in the ECO scenario, the storyline indicates that poverty is decreasing in developing countries and education and health systems are improving, leading to a stagnation in population growth.

Comparing scenarios, overall GDP per capita growth is highest in the FFANF scenario and lowest in the TLTL scenario, while the ECO and ONEPW are in the middle range. The FFNAF scenario sketches a world with rapid growth and growing equality, but at the same time with an implosion of the global economy in 2045, which has a clear impact on the future developments in the scenario. In contrast, the TLTL scenario foresees a fragmented world that is characterized by global income divergence and relatively low levels of development. The ONEPW projects increasing inequality, but with relatively high growth in all regions, particularly in the high income countries. The high growth in income per capita in the high income countries occurs due to innovations that are mainly adopted in the regions where the elite resides. GDP growth in other regions is expected to be lower, because of the rise in global inequality. The main theme of the ECO scenario is a sustainable and more equitable world where GDP per capita in the high income nearly stagnates while other countries are catching up, leading to an convergence in income levels.

(a) Population



(b) GDP per capita

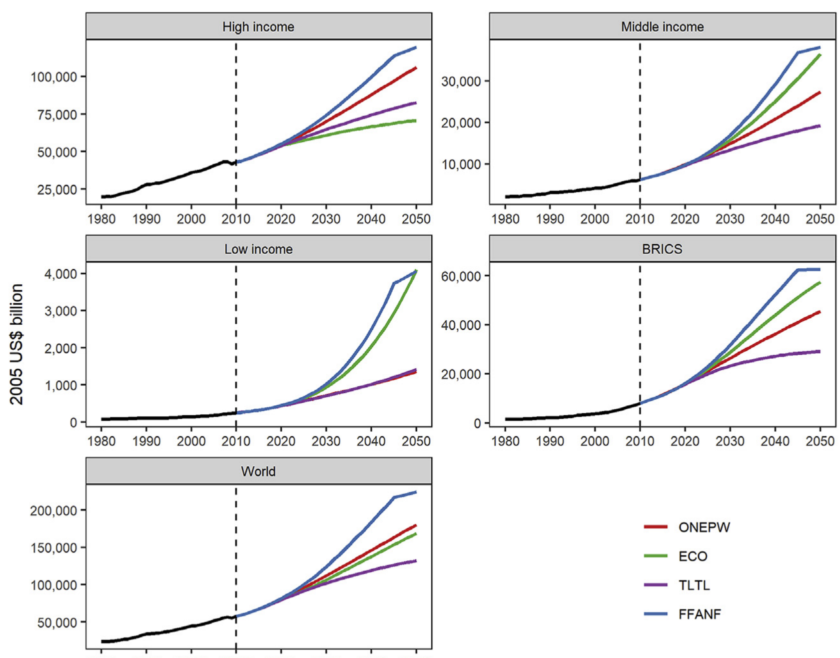


Fig. 3. GDP, population and crop yield projections by income group. Income groups were defined using the World Bank country classification: High income (> USD 12,616 per capita), Middle income (USD 1,036-USD 12,615 per capita), BRICS (i.e. Brazil, Russia, India, China and South Africa), Low income (< USD 1,035 per capita). (a) Population trends; (b) Gross Domestic Product (GDP) trends and (c) maize yield trends. Dashed line shows the historical linear trend for the period 1990–2012 and extrapolated up to 2050. Historical information from the World Development Indicators (population and GDP, www.wdi.worldbank.org) and FAOSTAT (maize yield, http://www.fao.org/faostat). Projections prepared by authors on the basis of stakeholder input (Van Dijk et al., 2019).

The yield projections are quite diverse across scenarios (note that the figure only presents the results for maize and other grains, similar projections are available for seven other crop groups). An important part of the storyline in the ONEPW is rapid technological advancement (e.g. new breeds and cultivation techniques) that 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. The TLTL scenario assumes crop yield is going down in low-income regions due to 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 increases, but at a slower rate, because of more resilient agricultural systems. In the FFANF scenario, yield is increasing rapidly in all regions due to the international diffusion of knowledge and more *(c) Maize yield*

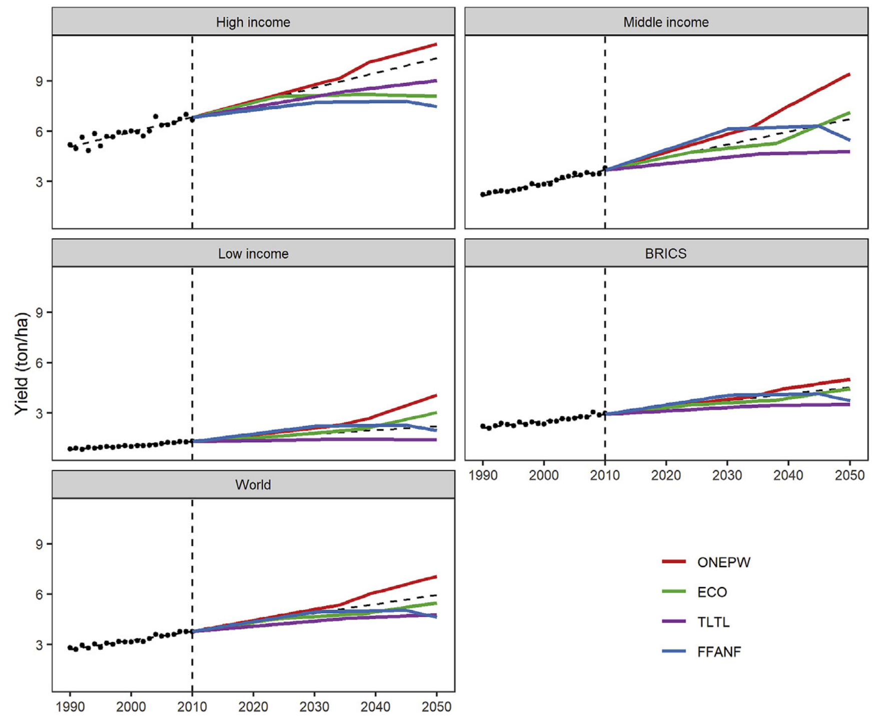


Fig. 3. (*continued*)

intensive production approaches. However, after around 2030, yield growth reaches a plateau and eventually collapses, due to the negative impact of climate change around 2045. The ECO 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 by 2050. The crop yield in high-income countries will slightly decrease or stagnate, since yields would have reached the biophysical maximum potential by 2050.

6. Discussion

6.1. Scenario development process

To speed up the process and leave more room for the quantification of drivers, the initial scenario development plan was to use an existing set of scenarios (so-called 'fast-track' scenarios (Kok et al., 2011), in this case the SSP scenarios) as a basis for the FOODSECURE storylines. 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 security. To accommodate these concerns, we decided go through a full scenario development process of defining key uncertainties and develop the scenario logic from the bottom up. The lesson 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. Therefore researchers and scenario developers should be careful in using existing storylines as basis for scenario development as these might be rejected by stakeholders.

Further, it was planned to use the Story-And-Simulation (SAS) approach (Alcamo, 2008) to introduce a feedback loop between the storylines developed by stakeholders and associated quantitative model results. 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 prepare model simulations in time for the second workshop. 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. As a result, the consistency check between storylines and model results has been solely done by researchers, which is a clear shortcoming in the participatory scenario building process.

6.2. 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 discussing and assessing a relative large number of driving forces with stakeholders in a relatively short time. 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, which directly provides numerical values, is that researchers still have to do the final translation from visual trends into numbers. This might introduce a bias and highlights the need for the validation of results by stakeholders after which the projections can still be revised. Nonetheless, we are of the opinion that participatory trend mapping is interesting and new new tool that can also be used in other scenario building exercises.

6.3. Comparison with other scenarios

Van Vuuren et al. (2012) (also see Van Vuuren and Carter, 2014) proposed a typology of six scenario 'families' that share perspectives on key uncertainties regarding future developments and, as a result, also have similar assumptions for different driving forces. The six identified families include: Economic Optimism scenarios, Reformed Market scenarios, Global Sustainable Development scenarios, Regional Competition scenarios, Regional Sustainable Development scenarios, and

Table 2
FOODSECURE scenarios and other scenario-based assessments mapped against 'scenario families'. Scenario families are sets of scenarios with similar perspectives on key uncertainties regarding future developments (Van Vuuren and Carter, 2014). FOODSECURE mapping added by authors. *indicates scenarios that are not completely consistent with the assigned scenario family.

Scenario archetypes	FOODSECURE	SSPs	IPCC-SRES	MA	UNEP GEO-3
Economic optimism	FFANF	SSP5	A1F1		Market first
Reformed markets	ONEPW*			Global orchestration	Policies first
Global sustainable development	ECO*	SSP1	B1	Techno garden	Sustainability first
Regional competition	TLTL	SSP3/SSP4	A2	Order from strength	Security first
Regional Sustainability			B2*	Adapting mosaic	
Business-as-usual		SSP2	B2*		

Business-as-usual scenarios. The FOODSECURE scenarios – together with other global scenario-based assessments – can be mapped against these scenario families (Table 2). Apart from the ONEPW and, to a lesser extent ECO, it is relatively straightforward to classify the FOODSECURE scenarios. We decided to allocate the ONEPW to the Reformed markets type because it also features rapid economic development and technological change as well as environmental protection. However, the fit is not perfect as inequality, a key element of ONEPW, is not captured and also the population trend is different. ECO shows many similarities with the Global sustainable development scenario family but also includes elements from the Regional sustainability group of scenarios, in particular the focus on local markets.

Fig. 4 compares the projections for population, GDP and yield with that of previous scenarios studies. It reveals that the FOODSECURE GDP projections are distributed evenly across the plausible range, while populations trajectories cover a smaller bandwidth. This can be partly explained by the fact that older assessments (e.g. the IPCC SRES scenarios) tend to have higher population projections than more recent assessments. The yield projections describe a wide range of possible pathways, even approaching the outermost projection in the sample of reviewed scenarios. Overall, the comparison shows that the FOODSECURE scenarios capture a wide range of possible future pathways, which are in range with the other global integrated scenario-based assessments without being too extreme.

7. Conclusions

This paper describes the development process and results from a participatory scenario exercise to construct a set of global scenarios for global food security analysis. The outcome of the process are four different scenarios that cover a large spectrum of possible futures that are relevant from a food security perspective. The FOODSECURE scenarios are defined along two axes: (in)equality, and (un)sustainable lifestyle and use of natural resources. They consist of a set of storylines and a database with projections of key drivers that can be used as an input into global assessment models for further quantification and analysis (e.g. Doelman et al., 2019; Kuiper et al., 2019; Van Meijl et al., n.d.).

A number of conclusions can be drawn from our experience in building the FOODSECURE scenarios. First, a participatory approach towards scenario development, involving a diverse group of stakeholders leads to the creation of innovative and diverse scenarios. This is underlined by the finding that at least one of the FOODSECURE

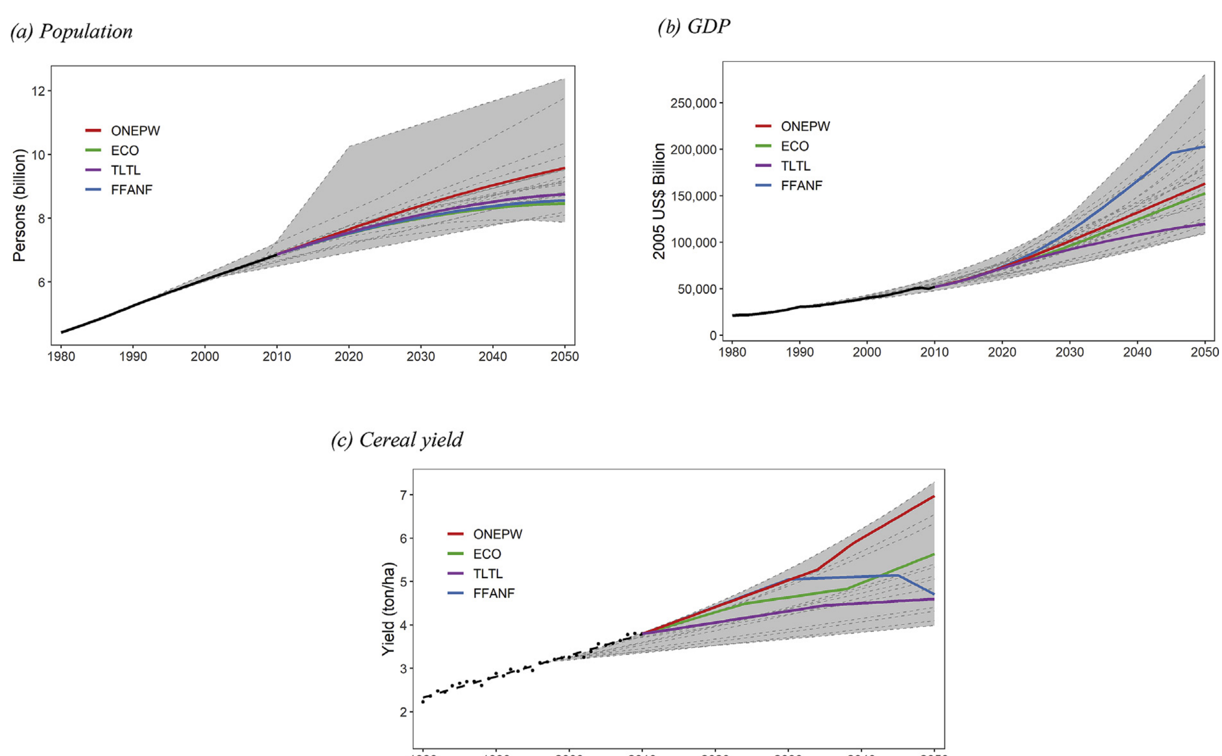


Fig. 4. FOODSECURE drivers compared with driver projections prepared by other studies. (a) Population projections; (b) Gross Domestic Product (GDP) projections; and (c) cereal yield projections. Historical information from the World Development Indicators (population and GDP, www.wdi.worldbank.org) and FAOSTAT (maize yield, http://www.fao.org/faostat). Apart from the FOODSECURE scenarios, figures include projections from 10 global studies described in Van Dijk and Meijerink (2014) and the SSPs (SSP Database, 2016).

scenario storylines has characteristics that are substantially different from the scenarios that can be found in the literature. Second, a fast-track approach towards scenario building, which aims to refine and adapt already existing scenarios is not without difficulties and risk. In this study, stakeholders were not convinced by the selected fast-track scenarios, which led to substantial delay and, eventually, the development of a complete new set of scenarios. 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 of global food security.

To explore and quantify the high level of uncertainty that is an inherent part of modelling global systematic challenges, such as food security, the common approach is to compare the results of various models over a range of scenarios (Rosenzweig et al., 2013; Warszawski et al., 2014). So far, there have been only a limited number of these exercises related to future food production and demand, and all of them used the Shared Socio-economic Pathways as a reference (Valin et al., 2014; Hasegawa et al., 2018). The FOODSECURE scenarios can be considered as an alternative to the SSPs, with (partly) different storylines and drivers. It would be an interesting exercise to compare and contrast the modelling of both sets of scenarios in order to obtain insights on the range of potential future food security outcomes as well as policies to address them.

Declaration of Competing interest

The authors declare that they have no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2020.100352.

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