Global Environmental Change 65 (2020) 102198

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Co-designing global target-seeking scenarios: A cross-scale participatory process for capturing multiple perspectives on pathways to sustainability

Ana Paula D. Aguiar [a,b,c,*], David Collste [a,d], Zuzana V. Harmáčková [a,c], Laura Pereira [e,f], Odirilwe Selomane [a,e], Diego Galafassi [a], Detlef Van Vuuren [g,h], Sander Van Der Leeuw [i]

[a] Stockholm University, Stockholm Resilience Centre, Kräftriket 2B, 104 05 Stockholm, Sweden
[b] National Institute for Space Research (INPE), Av. dos Astronautas 1758, CEP: 12227-010 São José dos Campos, SP, Brazil
[c] Global Change Research Institute of the Czech Academy of Sciences, Belidla 986/4a, 603 00 Brno, Czech Republic
[d] Centre D'Etudes et de Recherches sur le Développement International (CERDI-CNRS), Université Clermont-Auvergne, 65 Boulevard F. Mitterrand, 63000 Clermont-Ferrand, France
[e] Centre for Complex Systems in Transition, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa
[f] Centre for Food Policy, City University of London, London, UK
[g] PBL Netherlands Environmental Assessment Agency, Postbus 30314, 2500 GH The Hague, The Netherlands
[h] Utrecht University, Copernicus Institute for Sustainable Development, Postbus 80.115, 3508TC Utrecht, The Netherlands
[i] ASU-SFI Center for Biosocial Complex Systems, Arizona State University, 1031 S. Palm Walk Tempe AZ 85287 USA

ARTICLE INFO

Keywords:
Target-seeking scenarios
Pathways
Sustainable Development Goals
Cross-scale analysis
Food system transformation
Three Horizons

ABSTRACT

The United Nations 2030 Agenda catalysed the development of global target-seeking sustainability-oriented scenarios representing alternative pathways to reach the Sustainable Development Goals (SDGs). Implementing the SDGs requires connected actions across local, national, regional, and global levels; thus, target-seeking scenarios need to reflect alternative options and tensions across those scales. We argue that the design of global sustainability-oriented target-seeking scenarios requires a consistent process for capturing multiple and contrasting perspectives on how to reach the goals, including the perspectives from multiple scales (e.g. local, national, regional) and geographic regions (e.g. the Global South). Here we propose a novel approach to co-design global target-seeking scenarios, consisting of (a) capturing global perspectives on pathways to the SDGs through a review of existing global scenarios; (b) a multi-stakeholder process to obtain multiple sub-global perspectives on pathways to sustainability; (c) an analysis of convergences, and crucially, divergences between global and regional perspectives on pathways to reach the SDGs, feeding into the design of new target-seeking scenario narratives. As a case study, we use the results of the 2018 African Dialogue on The World in 2050, discussing the future of agriculture and food systems. The identified divergent themes emerging from our analysis included urbanization, population growth, agricultural practices, and the roles of different actors in the future of agriculture. The results challenge some of the existing underlying assumptions of the current sustainability-oriented global scenarios (e.g. population growth, urbanisation, agricultural practices), indicating the relevance and timeliness of the proposed approach. We suggest that similar approaches can be replicated in other contexts to better inform the process of sustainability-oriented scenario co-design across scales, regions and cultures. In addition, we highlight the implications of the approach for scenario quantification and the evolution of modeling tools.

1. Introduction

Future scenarios can be used as tools to expand our understanding of the drivers and consequences of sustainability challenges across scales. Scenarios are defined as plausible stories about how the future may unfold; they can be conveyed in words, numbers, and maps, often combining quantitative and qualitative elements (Ferrier et al., 2016; Raskin et al., 2005). They have a particularly central role in

* Corresponding author at: Kräftriket 2B, 104 05 Stockholm, Sweden.
E-mail addresses: anapaula.aguiar@su.se (A.P.D. Aguiar), david.collste@su.se (D. Collste), diego.galafassi@su.se (D. Galafassi), Detlef.vanVuuren@pbl.nl (D. Van Vuuren), vanderle@asu.edu (S. Van Der Leeuw).

https://doi.org/10.1016/j.gloenvcha.2020.102198
Received 23 May 2020; Received in revised form 7 October 2020; Accepted 21 October 2020

international science-policy fora such as the IPCC (Intergovernmental Panel on Climate Change) and the IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services Global Assessment). Conclusions derived from global environmental scenarios often influence international agreements and foster action at multiple levels, e.g. in the case of the IPCC scenarios and the Paris Agreement (UNFCCC, 2015). Importantly, the quality of the policy advice derived from scenarios vitally depends on the quality of the underlying scenario building process.

Historically, the majority of global environmental scenarios were exploratory (asking "*Which futures might unfold under specified conditions and what are their implications?"*). However, there has been a growing attention to target-seeking/normative sustainability-oriented scenarios (asking *"What future do we want and how do we get there?"*) (Ferrier et al., 2016; Wollenberg et al., 2000). Target-seeking scenarios thus capture both information on the desired "end-point" of future development and ways how to reach it, given the current conditions. Recently, interest in the development of sustainability-oriented target-seeking scenarios on the global level has been catalysed by the United Nations 2030 Agenda and its Sustainable Development Goals (SDGs), as well as the Paris Agreement (Gao and Bryan, 2017; Kok et al., 2018; Rogelj et al., 2018a; Sachs et al., 2019; van Vuuren et al., 2015).

Closely related to target seeking scenarios is the concept of pathways, which outlines the courses of events and actions towards the desired targets. This concept has become very popular in the sustainability arena, even though it has often been used with different meanings (Demeritt et al., 2011; Fazey et al., 2016; Geels and Schot, 2007; Leach et al., 2010; Rosenbloom, 2017; Swart et al., 2004; Turnheim et al., 2015). While the global scenario community sometimes uses the terms pathways and target-seeking scenarios interchangeably (Rogelj et al., 2018b; Turnheim et al., 2015), here we distinguish the two concepts. We consider pathways as "alternative trajectories of intervention and change, supported by narratives, entwined with politics and power" (based on (Leach et al., 2010)). In our specific context of reaching sustainability goals, pathways consist of different strategies which might be adopted by different actors for moving from the current situation towards a desired future vision or set of specified targets. They are courses of events and actions that build on each other, from short-term to long-term change. In our understanding, target-seeking scenarios represent multiple alternative pathways to sustainable futures, as for example the three Roads to Rio scenarios (Kok et al., 2018; van Vuuren et al., 2015).

Since an infinite number of possible alternative pathways and their combinations exist, the crucial challenge in designing target-seeking sustainability-oriented scenarios is how to select which pathways should be represented in individual scenarios and in their coherent sets (Alcamo, 2008). For instance, one could ask which alternative options of consumption patterns, technological innovations, regulatory measures, etc., should be represented in a desired future? The selection of alternative pathways is not well covered in the scenario literature and represents an important gap.

The selection of specific pathways to be represented in target-seeking scenarios is inherently value-laden and requires considerations for multiple values, world views, voices and overcoming potential power asymmetries and tensions between them (Leach et al., 2018). Thus, a consciously deliberate process is needed to elicit multiple perspectives on pathways to sustainable futures. Such different perspectives may also arise due to different regional and cultural contexts. Furthermore, contrasting perspectives on desirable sustainability pathways may be held by actors from different scales – local, national, regional, and global. This is particularly problematic for the implementation of SDGs, vitally requiring to connect actions across scales. Target-seeking scenarios to support SDG implementation must therefore allow for the representation of relevant divergences disputed across groups of actors and scales.

Meanwhile, global sustainability scenarios are developed with limited participation. For instance, the globally widely used Shared Socioeconomic Pathways (SSPs) narratives were initially drafted in a single workshop involving mostly modelling experts from the Global North (O'Neill et al., 2017). Several other global scenario processes have also underrepresented views from the Global South (e.g. in the case of the modelling groups contributing to the IPCC 1.5°mitigation scenarios (Rogelj et al., 2018a). These processes of scenario development do not account for the diversity of views discussed above and have been designed solely through a top-down process, incorporating the opinions of selected experts while excluding other relevant actors from different scales (Alcamo, 2008).

To fill these gaps, we use an innovative approach to design narratives for global target-seeking scenarios, incorporating multiple perspectives from across scales and regions. The approach is centred around the analysis of convergences, and crucially, divergences between global and regional perspectives about pathways to reach the SDGs. Specifically, the identified divergences then guide the selection of pathways to represent in the design of new global sustainability-oriented target-seeking scenarios. We present the results based on a case study undertaken within the 2018 African Dialogue on the World In 2050 (Aguiar et al., 2019), in which several of the current assumptions of sustainability-oriented scenarios were contested.

2. Material and methods

2.1. Case study

The 2018 African Dialogue on The World in 2050, held in Kigali in October 2018, was a two-day multi-stakeholder workshop discussing how *transforming agriculture and food systems* can contribute to reaching the SDGs in Sub-Saharan Africa. The Dialogue was organized with financial support from the Swedish International Development Cooperation Agency (SIDA), through SwedBio at Stockholm Resilience Centre (https://swed.bio/). Its participatory process was designed to provide insights to practitioners, policymakers, and scenario builders about alternative pathways to sustainable futures, capturing convergences and divergences across different groups of actors and scales. The Dialogue was organised in the context of "The World in 2050" (TWI2050) - an initiative bringing together a large network of researchers to develop a new generation of target-seeking scenarios designed to represent multiple pathways for achieving the SDGs within the planetary boundaries (TWI, 2019, 2018).

The Dialogue assembled forty participants from eleven different countries and included representatives of national governments, UN organizations, civil society, local communities, academia, and research. The stakeholders were selected based on their expertise in themes related to African agriculture and agro-biodiversity, social and economic development strategies, spatial planning, research-development-innovation, conservation and resource management. The complete report on the Dialogue process, list of participants and results are available online in (Aguiar et al., 2019) and a separate paper focusing on the workshop process (Collste et al., 2019).

In this case study, we designed alternative narratives to inform new global target-seeking scenarios by comparing sustainability pathways represented in global scenarios with the regional pathways to the SDGs emerging from the 2018 African Dialogue, as follows.

2.2. The research approach

Our approach consisted of three phases (Fig. 1), detailed in the following subsections:

First, we analysed and synthesized current **global perspectives on pathways to achieve the SDGs** based on a literature review of model-based global scenarios (Section 2.2.1).

Second, in order to capture **multiple regional perspectives on pathways to achieve the SDGs**, we developed and applied a participatory target-seeking scenario process adapted to the SDG context, based on the Three Horizons pathways approach (Collste et al., 2019;

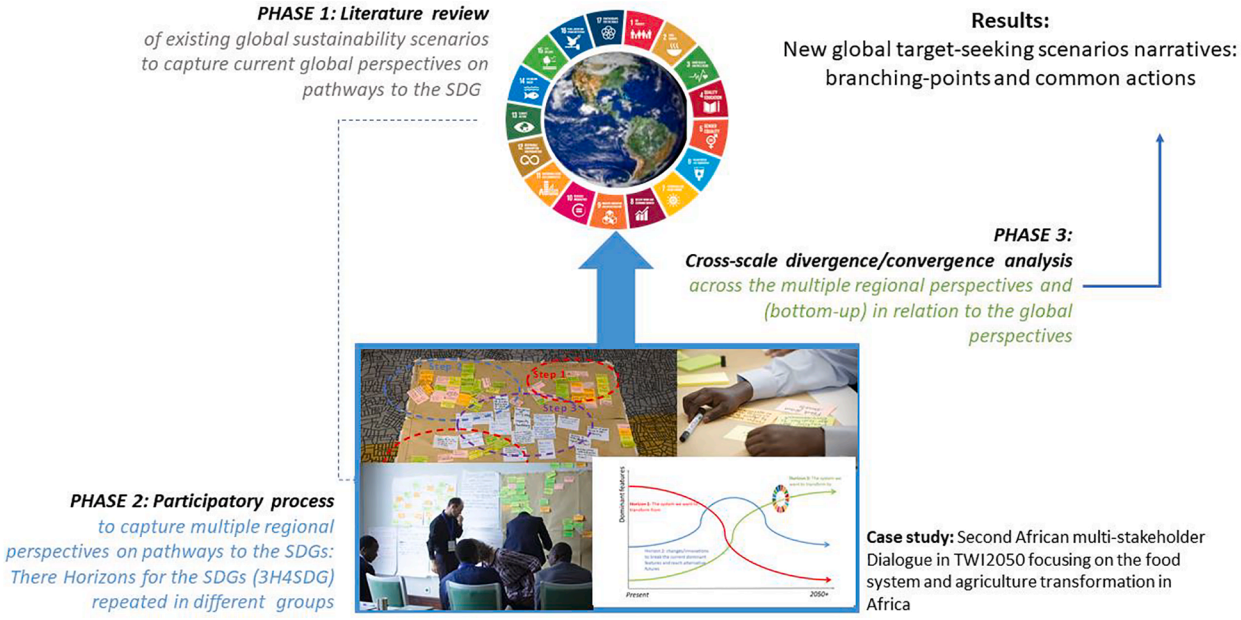


Fig. 1. Schematic representation of the research approach.

Sharpe et al., 2016) (Section 2.2.2).

Third, we conducted a structured cross-scale analysis of **convergences, and divergences** between the regional and global perspectives. Combining the convergent and divergent themes, we built the narratives for a new generation of target-seeking scenarios (Section 2.3).

2.2.1. *Capturing global perspectives: a literature review*

In the first phase, we reviewed and compiled existing sustainability-oriented scenarios from recent global environmental assessments, such as the 1.5 IPCC Special Report (Rogelj et al., 2018b), the IPBES Global Assessment (Chan et al., 2019), and The World in 2050 report (TWI, 2018). We focused particularly on scenarios representing pathways to achieve multiple sustainability goals – explicitly addressing agriculture and food system themes.

The analysis consisted of (a) uncovering the general assumptions and their alternatives addressed by the core global scenarios discussed in these assessments, (b) connecting those to existing typologies of scenarios (Hunt et al., 2012; van Vuuren et al., 2012a), pathways and narratives (Geels et al., 2015; Luederitz et al., 2017; Scoones et al., 2018), and (c) analysing the implication of such assumptions and alternatives for Africa.

2.2.2. *Three Horizons for the SDGs (3H4SDG)*

To uncover multiple regional perspectives about pathways to the SDGs, we adapted the Three Horizons framework (Sharpe et al., 2016) to the SDG context, creating a novel approach "3H4SDG" (Aguiar et al., 2019; Collste et al., 2019). This approach combines elements of previous works in sustainability science (Lundquist et al., 2017; Pereira et al., 2018a) and multiscale participatory processes (Aguiar, 2015; Folhes et al., 2015). As an in-depth description and discussion of the 3H4SDG approach requires a substantial space and is beyond the scope of this study, we provide only its brief summary and refer the reader to a related report available online in (Aguiar et al., 2019) and a separate paper detailing the participatory workshop process and the participants' feedback (Collste et al., 2019).

3H4SDG focuses on identifying a desirable vision of the future (a system we want to transform to), the undesirable features of the current system (a system we want to transform from), and necessary changes to shift from the current undesirable features to the desirable vision. The approach allows to explore the pathways to the SDGs in a holistic, integrated way by avoiding siloed discussions on individual goals or clusters of goals. This is in line with the 2030 Agenda resolution according to which the SDGs are "universal and indivisible" (UN General Assembly, 2015). Furthermore, 3H4SDG exposes the participants to recent global scenario studies, their underpinning premises and assumptions, enabling a cross-scale discussion. Finally, it promotes the emergence of multiple and alternative pathways by applying the process in parallel in small groups of stakeholders, "opening-up" to include non-dominant voices and narratives from different levels (Leach et al., 2007). Importantly, an essential part of the process is that each group takes notes of any divergent ideas that emerged within the group, across groups and also between their regional perspectives and the global scale perspectives. In the case of the African Dialogue case study, participants were divided into four regionally-focused sub-groups.

The key characteristic of the future visioning approach applied in the 3H4SDG approach is that participants are invited to think about their desired futures without imposing any previous assumptions on them, e.g. in terms of what type of economic and political development is realistically feasible (e.g., based on researchers' beliefs and values, or worldviews about political or economic systems). The rationale behind this approach is that if bound with specific limitations or assumptions (e.g. the prioritization of economic profitability), participants' exploration of futures is restricted and may inhibit uncovering potentially key or transformative elements (Raudsepp-Hearne et al., 2019). Thus, we have intentionally left the visions open to further plural explorations of their feasibility. At later stages of scenario building processes, the explorations of feasibility can take place e.g. through modelling efforts and through further societal deliberation of the pathways and their potential outcomes (beyond the scope of this study).

2.2.3. *Cross-scale analysis of convergences and divergences*

In order to compare the regional and global perspectives, we drew on the multi-scale scenario literature. We followed the conceptual approach to link scenarios across geographical scales proposed by (Zurek and Henrichs, 2007). We developed our method assuming **complementarity** of information across scales and **comparability** of treatment given to certain *themes* within the focus of analysis (Zurek and Henrichs, 2007). Our selection of themes is based on a bottom-up/top-down analysis. The analysis differs from previous cross-scale scenario analyses in Africa (Mason-D'Croz et al., 2016; Nilsson et al., 2017) as our

goal is primarily to inform the global scale based on the regional perspectives. Most previous work focuses on the top-down re-scaling of global scenarios for regional and local use (for example, (Mason-D'Croz et al., 2016)). We adopt a balanced bottom-up/top-down process to operationalize the cross-scale comparison, as detailed below.

The process of analysing convergences and divergences started from a bottom-up perspective, situating the multiple regional perspectives derived from the 3H4SDG approach within the global ones. This process was adopted in order for the cross-scale analysis not to be bounded or dominated by the narratives underpinning the existing global scenarios. The analysis focused on convergences and divergences on three levels: (1) *within different 3H4SDG groups, (2) between the 3H4SDG groups* and (3) *with respect to the global scale*. Convergent themes were those mentioned in more than one group and/or stressed to be important by the participants. Divergent themes included the ones identified by the participants during the participatory process or by authors of this paper during the analysis phase. Finally, the resulting themes were organized following a categorization to social, technological, environmental, ecological, and political dimensions (Schultz, 2015).

Based on the identified convergent and divergent themes, we extracted insights to inform the design of global-scale sustainability scenarios (Fig. 2). The convergence analysis provided information on common premises and actions that are perceived to be consensus parts of all pathways to sustainability, thus enriching sustainability-oriented scenarios narratives. The divergence analysis was then used to explore multiple alternatives of sustainability pathways. Each divergent theme was considered a potential pathway bifurcation (**branching point**) which may be combined when designing new scenarios.

In this phase of the process, we also **related the divergent themes to issues prominent in current debates in scientific literature and policy arenas** (e.g. on the land-sparing vs land-sharing debate, Phalan, 2018a). This approach allowed us to put the divergent elements from the participatory process into a broader perspective from the literature and embrace elements currently non-dominant in target-seeking scenario narratives and broader societal discussions (Sharpe et al, 2016; Chan et al, 2020; Geels, 2011). Thus, the approach reflected our presumption that target-seeking scenarios need to capture plural and contested views, explore alternatives and compare their outcomes, fostering the debate about possible pathways at multiple levels. In sum, we translate the divergent themes into branching points through the lens of scientific literature contextualizing the stakeholder views.

3. Results

3.1. Global perspectives: review of global scenarios representing sustainable pathways

The need for transformation of food systems has been largely discussed at the global scale in influential scientific literature and reports (FAO, 2017; Foley et al., 2011; Gordon et al., 2017; Willett et al., 2019). Although several quantitative modelling exercises have explored different aspects of the food and agriculture systems transformations (for instance, (Erb et al., 2016; Gerten et al., 2020; Muller et al., 2017; Obersteiner et al., 2016; Schader et al., 2015)), to date the core example of global integrated target-seeking scenarios aiming at achieving *multiple* goals (including human development, food, biodiversity, climate) is the Roads from Rio + 20 study (Kok et al., 2018; PBL, 2012; van Vuuren et al., 2015), implemented using the IMAGE IAM (Integrated Assessment Model). Three scenarios represent alternative pathways for achieving the defined targets under alternative assumptions. For instance, the adoption of "land sharing" or "land sparing" (Phalan et al., 2011; Tscharntke et al., 2012) representing two alternative strategies for conciliating agricultural production and biodiversity conservation.

More recently, multiple IAM groups have focused on developing scenarios to represent pathways to achieve the Paris Agreement, relying on the new IPCC scenario framework based on SSPs (O'Neill et al., 2017; Riahi et al., 2017; van Vuuren et al., 2012b). The SSPs represent five different development trajectories for societal trends elaborated in storylines and quantified in models. These storylines can be combined with different assumptions about climate policy to form a larger context of socioeconomic development and extent of climate change (Kriegler et al., 2014). Although the SDGs were not targeted in the development of

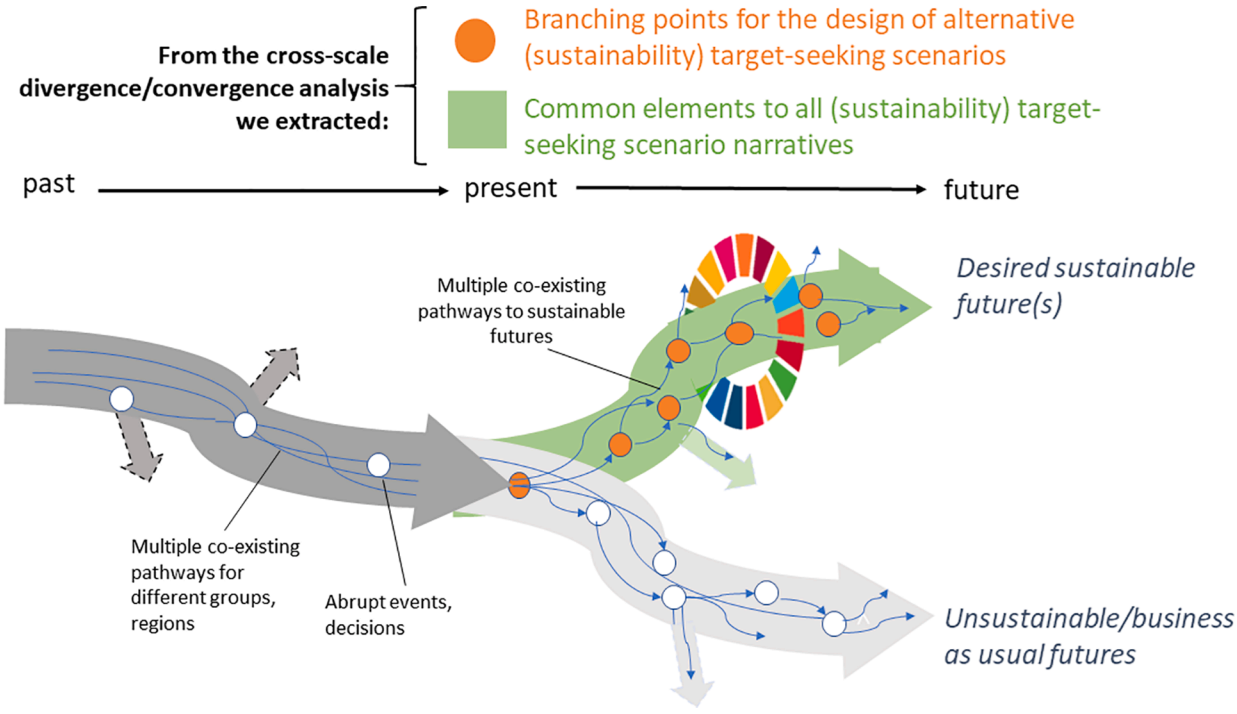


Fig. 2. Divergent themes providing insights for branching points of alternative scenarios; convergent themes providing information about narratives underlying all new scenarios (Source: prepared by the authors based on (Fazey et al., 2016; Roy et al., 2018).

the SSPs (Zimm et al., 2018), SSP1 ("Sustainability") assumptions combined with stringent climate policy (aligned to keep the average increase in temperature below 1.5 or 2 °C) is widely considered a scenario exploring a route towards a more sustainable future (e.g. SSP 1-1.9; (Rogelj et al., 2018a)). Current global IAMs are not able to represent all aspects of the SDGs, but they capture some of the key trade-offs and synergies among certain goals, mainly in relation to the food-water-energy nexus (Van Soest, under review, (TWI, 2018)).

One of the key foci of these recent studies, in line with the Paris Agreement, has been to explore how to reconcile climate change mitigation options with other goals, such as producing enough food for a growing population. Such scenarios usually rely on a "scarcity narrative" (Lambin and Meyfroidt, 2011; Scoones et al., 2019): the need to feed a growing population without further destroying nature, under the double threat of climate change and competing land uses (for climate mitigation, for instance). Examples of such studies based on the SSPs include the "integrated SDGs" scenario (Parkinson et al., 2019), and the "lifestyle change" scenario (van Vuuren et al., 2018), combining elements of SSP1 and 2, and SSP1-1.9 (Rogelj et al., 2018a).

In general, there are several elements that can make scenarios more likely to be consistent with the 1.5 °C target. The default case mostly has scenarios that show (almost) full de-carbonization of the energy system, energy efficiency, reduction of non-CO_2 emissions and negative emissions based on reforestation and bio-energy-with-carbon-capture-and-storage (BECCS). However, there are other elements that are discussed within the scenario literature that make it more likely to meet the 1.5 °C target, including lower population, strong urbanization, medium to high economic growth, low (food) consumption and a nature restored world with highly concentrated and technological food production. These elements can also help to reach the goals schematically represented in Fig. 3. For the agriculture and food system this implies:

- *From the consumer side:* transition towards healthier and environment friendly **diets** (e.g. less red meat), emphasis on education, reducing **population growth**, an energy transition to renewable sources like bio-energy and high urbanization.
- *For food production:* a **land-constrained** scenario for food production due to competition with large-scale reforestation and biofuels. Strong emphasis on technical solutions, mainly sustainable **intensification** and better management practices, aligned to the land saving approach. One key component is 'sustainable intensification' with yield increases estimated from 50% to almost 100% (TWI, 2018). Such pathways also imply less waste throughout the process.
- All these studies explicitly or implicitly assume (but do not model or detail) a series of assumptions regarding the **governance** of such large-scale transformations in different geographical contexts and also what people themselves consider to be a desirable and sustainable future.

Following the classification of scenario archetypes in (van Vuuren et al., 2012a), most scenarios reviewed in this section largely follow the *Global Sustainable Development archetype*, which entails: strong orientation towards environmental protection and reducing inequality, based on solutions found through global cooperation, lifestyle change and more efficient technologies. The only exception is the "Decentralized Solution" from the Roads to Rio + 20 study mentioned above, which follows a *Regional Sustainability archetype*. This Regional Sustainability archetype entails regional solutions for current environmental and social problems, usually combining drastic lifestyle changes with decentralized governance and agro-ecological approaches for agriculture (with higher land claims for agriculture). Furthermore, international institutions decline in importance, due to a shift towards local and regional decision-making structures and institutions.

What do these dominant narratives imply for Africa?

Fig. A.1 illustrates SSP1 land cover impacts for Africa. Under the assumption that the livestock sector intensifies substantially, and food losses and dietary preferences for animal products are reduced, SSP1 projects a considerable reduction in grazing land. Abandonment of grazing lands takes place in relatively productive areas, leading to a high potential for bioenergy production and cropland expansion. When considering additional mitigation measures, the level of deforestation in Sub-Saharan Africa is significantly reduced, resulting in a considerable increase of forest areas. According to (Doelman et al., 2018), in the

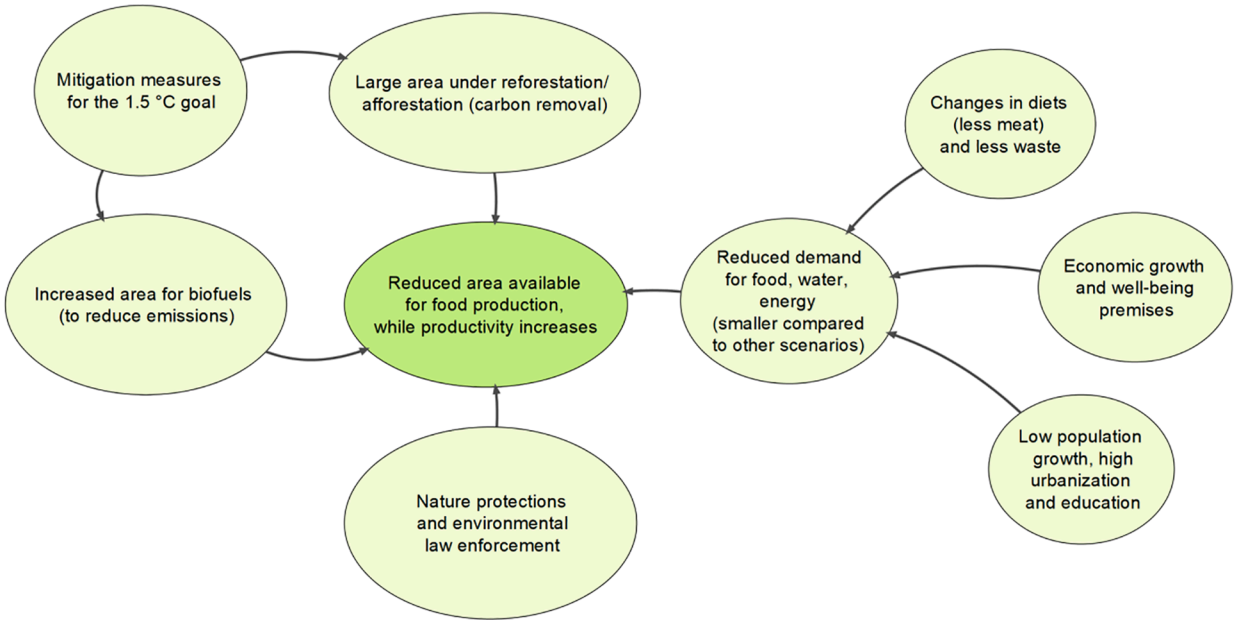


Fig. 3. Conceptual diagram representing how the assumptions underlying the current 1.5 °C. mitigation scenarios (in light green) affect land availability for food production (in darker green). Although such scenarios assume lower population growth than other scenarios, there is still an inherent assumption about the need to double current agricultural productivity, as land for food production is restricted due to competing large scale restoration and biofuels expansion projects inherent in climate mitigation (source: prepared by the authors). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

mitigation scenario, agricultural demand in Africa cannot be fulfilled within the region, requiring high levels of imports from other regions. This is in direct conflict with notions of self-sustainability and sovereignty aspired by many regions of the world, including Africa. This is particularly pertinent considering that the emergence of shocks such as COVID-19 can disrupt supply chains, and dependence on imports can lead to vulnerability to these shocks (Kummu et al., 2020).

Key underlying assumptions of the SSPs are population and urbanization dynamics, which vary considerably among them (Kc and Lutz, 2017). For instance, the population estimates in 2100 for the different SSPs range from 7 billion in SSP1 (lower than the current population of 7.6 billion) to almost 13 billion. The effectiveness of the SSP1 scenario in limiting environmental pressure depends on these very low population growth assumptions (in addition to relatively low consumption and strong technology development). This is illustrated in Fig. A.2 for low-income countries. In Africa, the very low population growth assumptions in SSP1 are combined with an increase in the urban to rural ratio from 37% currently to 90% in 2100. This places a significant expectation on countries to urbanize, and somewhat writes-off rural areas as part of the livable solution to sustainability. The two factors are interconnected, as SSP1 projections rely on premises of women's education and urbanization to reduce fertility rates (Abel et al., 2016; Jiang and O'Neill, 2017; Kc and Lutz, 2017).

3.2. Convergent and divergent themes emerging from the 3H4SDG approach: the 2018 African Dialogue results

Using the 3H4SDG pathways approach during the 2018 African Dialogue, three different pathways emerged from the groups that were focusing on local to regional issues (*Ubuntu*, *Prosperous and Peaceful East Africa* and the *Urugendo* pathways), while another pathway (*Rainbow* pathway) emerged from a group focusing on African wide continental concerns. Appendix B presents a synthesis of the individual pathways. Appendix C summarizes the divergences identified by the participants during the Dialogue. An in-depth description of the individual pathways is also provided in (Aguiar et al., 2019; Collste et al., 2019).

3.2.1. Convergences and divergences within and between regional pathways

From the **convergence** analysis **between the regional pathways**, the themes that emerged were: a strong emphasis on education/skills, youth, women and population empowerment, the consolidation of cooperatives and cooperation between farmers, the need for infrastructure, generating and sharing of reliable data, structuring of local to global markets, financing and insurance for agriculture, independence from foreign donors, regional cooperation, transparency and accountability of governments – and not least, political will. (Aguiar et al., 2019) details such convergences in the context of the SDG implementation, grouping them in four categories: Empowerment (youth, women and population), Partnerships for change, Environment and Knowledge, Technology and data sharing.

From the **divergences** identified by the participants within and **between regional pathways** (Table C.1), five themes emerged (detailed in the following section): *(i) Population growth; (ii) Consumption patterns; (iii) Actors involved in agriculture in the future; (iv) Dominant agricultural practices; (v) Role of the state and private sector in governance*. Interestingly, the African Continent group, when compared to the sub-regional groups, emphasized more aspects related to regional cooperation, including data generation and sharing, and the importance of alliances for change (across Africa and with other continents). The African Continent group also brought some concerns usually expressed in global scenarios (such as changes in meat consumption) not addressed by the other groups, as discussed below.

3.2.2. Divergences with respect to the global scale

The divergences between the pathways on the **regional and global level** mirrored some of the themes identified above, including *(i) Population growth; (ii) Consumption patterns; (iii) Actors involved in agriculture in the future; (iv) Dominant agricultural practices; (v) Role of the state and private sector in governance*. In addition, they concerned: *(vi) Urbanization* and *(vii) Globalization (markets for food and land mitigation)*.

I. **Population growth:** The issue of population growth (and measures to control it) caused divergences in all the groups. Some viewed population growth as a threat to the natural resources and food security, while others emphasized it as an opportunity to create new markets, a larger work force and innovative youths – reflecting the different angles of this debate in society. The *Prosperous and Peaceful East African* pathway story mentions this as an open issue: *"… whether we should limit population or find ways to see it as an asset"*. In spite of this, all groups integrated some level of family planning, and gender empowerment in their pathways.

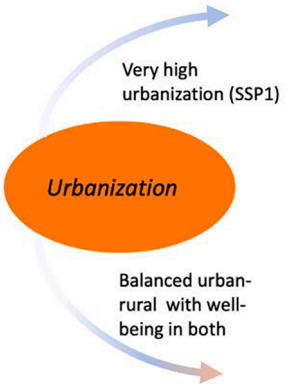
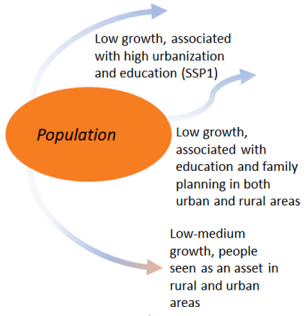
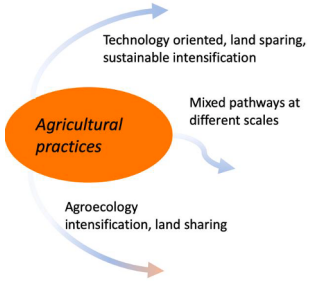
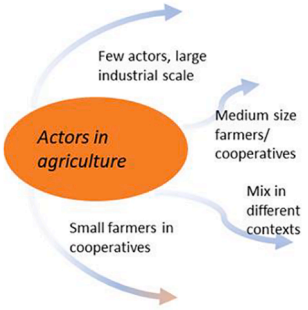
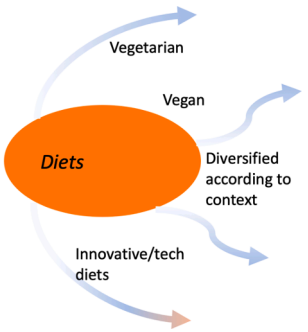
II. **Consumption patterns:** Some participants argued in favour of a meat-free diet and justified this by the potential negative environmental consequences of meat production, such as greenhouse gas emissions and land consumption. Others argued against a meat-free diet and justified this by the need for meat protein, especially for the malnourished and children, the importance of herding in the livelihoods of pastoralists, and cultural attachments (Nori and Scoones, 2019). Changes toward healthier and more environmentally friendly diets are one of the key assumptions of the sustainability-oriented global scenarios, based on international reports like EAT Lancet (Willett et al., 2019). A considerable reduction in the consumption of meat can lead to a significant reduction in greenhouse gas emissions and area required for agriculture (van Vuuren et al., 2018).

III. **Actors involved in agriculture in the future:** The Ubuntu pathway tells a story of small-scale farmers organized in well-structured cooperatives, providing enough food for themselves, for the local markets, but also exporting to the continent and the world (and oriented towards agroecology). However, the role of small-scale farmers in the future was also contested, for instance: "*there have been many debates about whether small-scale agriculture is viable or [whether] we should encourage large-scale commercial (industrial) farming. Whether agriculture should be commercial/market-oriented, or community-oriented*". There was also a discussion about whether intensification of production is a source of more income for the small-scale farmers, or not. Some participants argued that higher volumes of production lead to lower prices, calling for larger farms. All groups emphasized the importance of strengthening cooperatives of smallholder farmers, the diversification of products and use of modern techniques combined with indigenous knowledge.

IV. **Dominant agricultural practices:** A core divergence that emerged from the comparison across groups relates to the debate around agroecology versus sustainable agricultural intensification (SAI) as pathways to a sustainable agriculture (Duru et al., 2015; Garnett et al., 2013; Godfray and Garnett, 2014; Pereira et al., 2018b; Struik and Kuyper, 2017; Tomlinson, 2013; Tscharntke et al., 2012). Current dominant global sustainability scenarios largely rely on a land sparing, high technological sustainable intensification approach. There were also disagreements inside and across groups about the adoption of GMOs (Genetically modified organisms) (Bawa and Anilakumar, 2013) and about the use of biofortified seeds, followed by a discussion on their actual need - as compared to improved diets and crop varieties. These debates opened up some of the critical alternative pathways currently in play within the continent.

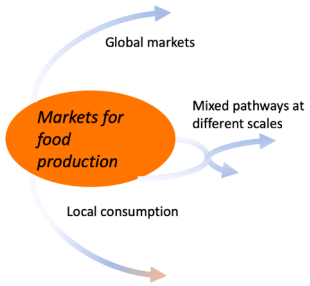
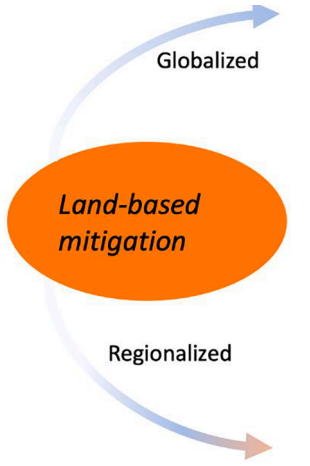
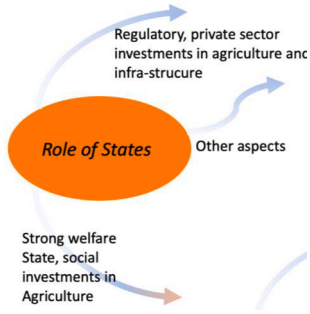
V. **Role of the state and private sector in governance:** Another of divergence relates to the role of the state and private sectors in promoting agriculture and human well-being. One of the groups wrote in their synthesis letter: "We still debate about whether to

Table 1
Pathway branching points and their alternatives, derived from the analysis of divergent themes. The branching points are linked to the STEEP categories.

Branching points and pathway elements to be combined in scenario design	
Social - Urban/rural relations: Current global sustainability scenarios rely on an assumption of a highly urbanized world. Alternative pathways requiring exploration include sustaining more balanced urban/rural relations, considering the existence of strong rural communities with a high quality of life in some contexts. Target-seeking scenarios also need to address the quality and type of urbanization (prosperity and services for all vs. current chaotic urbanization in the Southern hemisphere, mid-size cities vs. megacities) more explicitly. References for the debate: (Christiaensen and Todo, 2014; de Brauw et al., 2014; Güneralp et al., 2017; Jayne et al., 2014)	
Current global sustainability scenarios rely on the assumption of very low population growth associated with massive urbanization.	
Social – Population growth: Pathways requiring exploration based on this study include an alternative perception of the population in Africa as an opportunity (e.g. in terms of innovation, local markets), while focusing on excessive consumption (instead of population) as the actual sustainability issue. References for the debate: (Abel et al., 2016; Kc and Lutz, 2017; Scoones et al., 2018)	
Current global scenarios derived from SSP1 rely primarily on a global land sparing narrative, in which food is produced in the more suitable lands across the globe through highly technological and intensive production. The majority of the recent scenarios align with the "sustainable intensification" narrative (ref).	
Technology - Agricultural practices: The alternatives emerging from this study include agroecological intensification, or a mixture of sustainable intensification and agroecology in different contexts (similarly toto the pathways represented in the Rio + 20 scenarios). These alternatives could allow for a combination of land sharing and land sparing at different scales and in different contexts. Other pathway alternatives include different considerations of technical options, such as the use of GMO and its implications, and a range of practices related to agrochemical inputs and pesticides. References for the debate: (Bennett, 2017; Duru et al., 2015; Fischer et al., 2014; Garnett et al., 2013; Godfray and Garnett, 2014; Kremen, 2015; Pereira et al., 2018b; Phalan et al., 2011; Struik and Kuyper, 2017; Tomlinson, 2013; Tscharntke et al., 2012)	
Economy - Actors in agriculture: Current target-seeking scenarios tend to disregard the impacts of the options above on land distribution among different types of actors (large industrial companies, cooperatives, small and medium size farmers, etc.). Furthermore, they do not consider the impact of the alternative technical choices (e.g. use of fertilizers and pesticides) on health and livelihoods. Alternative pathways explored in this study branched around land tenure issues. These issues are strongly linked to rural/urban well-being and urbanization and highlighted the need for alternative scenarios to represent a range of possible futures for different types of farms, ranging from an extremely concentrated landscape (in a highly urbanized world, with very few large actors producing food) to a more balanced mix of actors and agricultural systems. Another key element is to consider cooperatives of small farmers as economic actors. References for the debate: (Christiaensen and Todo, 2014; de Brauw et al., 2014; Jayne et al., 2014; Pereira et al., 2014) Current sustainability scenarios largely rely on increase in low meat diets.	
Social - Consumer behavior and consumption patterns: Alternative pathways include multiple combinations of diets, depending on context and cultural background, beyond the meat-free narrative. Better practices for cattle raising, for instance, need to be considered to explore how to minimize the detrimental environmental impacts of the activities. References for the debate: (Rothgerber, 2015; Stehfest et al., 2009; Willett et al., 2019)	
Economic – Markets and globalization/food production:	

(*continued on next page*)

Table 1 (*continued*)

Branching points and pathway elements to be combined in scenario design	
Current sustainability scenarios rely mainly on a global sustainability archetype which assumes a globalized open market, including for food products. Alternative pathways include a broader range of narratives, including a primary focus on producing food for local/regional markets, instead of global ones. In addition, more sophisticated models need to explore the role of control over food supply chains - their control by a few global corporations versus more decentralized systems. References for the debate: (Geels et al., 2015; Luederitz et al., 2017; Stringer et al., 2020)	
Environment - Land-based climate change mitigation: Current sustainability scenarios rely mainly on the narrative of full de-carbonization of the energy system, energy efficiency, reduction of non-CO2 emissions and negative emissions based on reforestation and bio-energy-with-carbon-capture-and-storage (BECCS). Currently the dominant global narrative relies on a globalized approach to land allocation based on agricultural suitability and economic compensation through the REDD mechanism. Alternative pathways which need to be incorporated in global scenarios include a broader range of land-based mitigation options, from the current globalized approach to a more decentralized/distributed approach (each continent mitigates its own historical emissions, for instance) or even mixed options. References for the debate: (Doelman et al., 2018; Kok et al., 2018; Krause et al., 2018; van Vuuren et al., 2015)	
Current global sustainability scenarios mostly rely on the assumption of a globalized, connected word, largely aligned to the Global Sustainable Development archetype, which entails global cooperation, lifestyle change and more efficient technologies.	
Political – Governance & Role of the State and Private sector: Alternative roles of the state and the private sector in agriculture, and more broadly in the economy, need to be represented in pathways. For instance, the role of state and private sector in promoting agriculture and human well-being (welfare state versus liberal economies), the presence or absence of agricultural subsidies, including the trade implications of both. A related branching point relates to reaching the goals in democratic or autocratic political systems (e.g., China). References for the debate: (TWI, 2018)	

continue or discontinue subsidies and the role of government in supporting agriculture". As a related issue, the Rainbow group discussed the adequacy of having social democracy as the political ideology governing Africa. They solved this with a more general formulation "priority for social programs".

VI. **Urbanization:** The assumptions of increasing urbanisation underlying current sustainability scenarios (mainly the ones aligned with the SSP1) conflicted with the vision that emerged from some of the groups. The Ubuntu pathway, for instance, describes a future of strong rural communities. The Prosperous and Peaceful East Africa group wrote in their synthesis: "Urbanized world: There might be alternative ways of living rural" and "Are global models thinking we will all be [living in] Shanghai or New York?".

VII. **Globalization, food production and mitigation:** From the groups emerged a perspective of producing food for local markets as a priority, ensuring local food security. Only the excess would be commercialized regionally and then globally. This might provide an alternative perspective from those represented in the scenarios which assume global markets for commodities. As mentioned above, global scenarios rely on a global land sharing pathway, in which food is produced with high levels of productivity in the more suitable lands all over the world, thereby freeing land for restoration and biofuel production (both depicted as necessary to mitigate global emissions). Also related to this, climate adaptation was considered a major priority for Africa, but making space for climate mitigation through restoration and biofuels, such as illustrated in (Doelman et al., 2018), was mentioned by the participants.

Appendix D summarizes the convergent and divergent themes using a categorization into social, technological, environmental, ecological and political dimensions.

3.3. Using the results to co-design the narratives of global target-seeking scenarios

In the final step, we used (a) the identified **convergences** to define common assumptions and propose **consensus actions** that all the designed target-seeking scenario narratives should include, and (b) the identified divergent themes to provide insights into the **pathways' bifurcations (branching points)** that need to be considered when designing target-seeking scenarios representing alternative pathways to reach sustainability goals. When deriving the potential branching

Table 2
Example of creating new global scenario narratives through comparing existing global narratives with the branching points (derived from the divergences) and common elements (derived from the convergences) resulting from the study approach. We compare elements derived from Table 1 and from the SSP1 narrative (O'Neill et al., 2017). Legend: Orange – divergence, Green– general convergence.

SSP1 narrative element (O'Neill et al. 2015)		Alternative narrative 1 based on the branching points and common actions	Alternative narrative 2 based on the branching points and common actions
High and well-managed urbanization.		Balanced urban-rural population ratio with high quality of life in both rural and urban areas.	Mixed level of urbanization in different contexts favoring middle-size cities.
Low fertility and relatively low population growth.		Low to medium population growth, people seen as an asset in rural and urban areas.	Low population growth associated with education and family planning in rural and urban areas.
Low meat diets		Diversified diets according to context.	Innovative/tech diets.
Improvements in agricultural productivity; rapid diffusion of best practices		Agroecology intensification, land sharing.	Mixed land sharing/sparing pathways at different scales; sustainable intensification
Not explicitly captured in SSP1 (but implicitly few actors, highly efficient)		Medium and small farmers in cooperatives, reverse land concentration trend.	Mix of large and medium farmers, fewer small farmers/cooperatives in different contexts
High education and skills		Common to all sustainability narratives.	
High social cohesion		Common to all sustainability narratives.	
Not captured in SSP1		Research and extension combining traditional (e.g. indigenous, local) and science-based knowledge/evidence.	

points, we linked the identified divergences with insights from current debates in scientific literature and policy arenas on related themes.

Table 1 summarizes which branching points and resulting pathways we derived, based on the divergent themes identified through the participatory process and their comparison with the literature.

For instance, the divergent theme "Dominant agricultural practices" was closely related to the current land sparing/land sharing debate, which has been central to navigating conservation and agricultural production in the last decade (Bennett, 2017; Fischer et al., 2014; Kremen, 2015; Phalan et al., 2011; Tscharntke et al., 2012; Phalan, 2018a, 2018b). In addition, the same divergent theme was also closely related to the current societal debate on agricultural practices, especially on the concepts of "sustainable intensification", "agroecological intensification" and "ecological intensification" (Duru et al., 2015; Garnett et al., 2013; Godfray and Garnett, 2014; Struik and Kuyper, 2017; Tomlinson, 2013; Tscharntke et al., 2012). The links between the identified divergent theme and the evidence in the literature gave rise to the branching point "Technology - Agricultural practices" and its related pathway branches (Table 1). Available evidence illustrates that this branching point is underpinned by different world-views, divergent group interests and power asymmetries (Newell and Taylor, 2018; Scoones et al., 2018; Tittonell, 2014).

The divergent theme "Actors involved in agriculture in the future" was linked to the issue of land distribution and concentration, particularly the fate of small-scale farmers in the future (branching point "Economy – Actors in Agriculture"). This issue has been highly societally relevant and encumbered with strongly contesting visions, ranging from perspectives favouring medium to large-scale, market-oriented mechanized farming to the agroecological movement focusing on peasant's livelihoods (Meyfroidt, 2017; Samberg et al., 2016; Cabral et al., 2016; Jayne et al., 2016; Kuyper and Struik, 2014; Scoones et al., 2018; Burke et al., 2020; Nicholls and Altieri, 2018). Although recent literature has disputed the understanding of a linear relationship between productivity and property size, calling for more nuanced and region-specific considerations (Peters, 2013; Collier and Dercon, 2014; Kweka and Ouma, 2020; Rada and Fuglie, 2019), plurality in this theme has been generally absent from current global scenarios. In Africa, current trends indicate that medium-scale farms (10–100 ha in Africa) are likely to soon become the dominant form of farming in many African countries, with disputed perspectives on the economic benefits for smaller farmers (Jayne et al., 2016; Burke, Jayne, and Sitko, 2020). There is also an ongoing process of large-scale land acquisitions which might substantially alter the land distribution in the region (Bottazzi et al., 2016; Oberlack et al., 2016). The issue of land distribution and rural livelihoods is also closely linked to current heated debates such as the "Half Earth proposal" (Ellis and Mehrabi, 2019; Schleicher et al., 2019).

The identified branching points "Technology– Agricultural practices", "Economy – Actors in Agriculture" further relate to the issues of urbanization and food security (Pereira et al., 2014). In the case of Africa, urban realities are highly complex and challenge the common assumption in current global scenarios that urbanization will guarantee human development. Urban areas in Africa show high levels of

unemployment and a growth of informal settlements (slums) (Brelsford et al., 2017; Güneralp et al., 2017), usually not mirroring the "thriving cities and urban livelihoods" as often and uncritically considered in the Global North literature (e.g., (Ellis and Mehrabi, 2019)). At the same time, citizens continue to draw on local nature to satisfy basic needs (Balbi et al., 2019). Thus, it is vital for target-seeking scenarios to incorporate alternative perspectives on urbanization, as captured by the identified branching point "Social - Urban/rural relations".

Finally, the branching points were combined to design new sustainability-oriented target-seeking scenario narratives. Table 2 shows a possible combination of the branching points to design two new sustainability-oriented target-seeking narratives. As an illustration, we compare these new narratives to the SSP1 assumptions.

4. Discussion

The key contribution of this study is illustrating how a participatory process can inform the design of target-seeking scenarios, bridging scales and opening sustainability narratives to multiple perspectives. We structure the Discussion in four related topics; first, we discuss how the explored pathways embrace multiple perspectives reflected in the current societal and scientific debates. Second, we discuss the potential limitations of our approach, especially related to the participatory process. Third, we discuss the implications for the quantification phases of target-seeking scenario building. Finally, we discuss how the identified branching points can be used to provide insights in the evolution of different modeling approaches.

4.1. Embracing multiple perspectives in target-seeking scenario narratives across scales

Recent pathway research recognizes that it is vital to avoid imposing pre-existing assumptions on the process of exploration of sustainability pathways (Le Heron et al., 2016). These assumptions can be e.g. beliefs, paradigms of world-views held by the researchers or by a certain part of society in general. A key aspect of this thinking is that setting the boundaries of what comprises a realistic or unrealistic content of future pathways or judging where these boundaries are need to be avoided at the stage of eliciting participatory pathway narratives. Thus, in this study, we intentionally did not constrain participants' pathway exploration, in order not to restrain the emergence of potentially key, innovative or transformative elements (Le Heron et al., 2016). Also at the later stage of enriching the global-scale target-seeking scenario narratives with the identified branching points within this study, we intentionally refrained from setting such boundaries of what comprises a feasible pathway, leaving space to a plural representation of existing debates in science and society. We argue that setting such boundaries would, again, impose selected understandings of the global dynamics, and would thus proliferate the dominance of certain narratives. In our understanding, the explorations of pathway feasibility need to be left open for a wide range of potential users of the study results, be it through further qualitative deliberative processes, or quantitative modelling. In this respect, our results clearly unveil tensions between world views and value systems across different scales and contexts (Kostakis et al., 2016), and surface themes under-represented in existing global target-seeking scenarios.

4.2. Limitations of the research approach

In general, the design of holistic target-seeking scenarios requires to cover a wide range of themes. However, in case that target-seeking scenarios are enriched through complementary participatory processes, these can only cover a certain subset of themes at a time. For instance, our case study focused specifically on food and agricultural systems transformation in Africa and thus, some other themes and regional aspects were omitted, e.g. energy system transformation. Thus, the omitted aspects need to be added through complementary participatory processes in other regions and at other scales, or expert processes combined with literature review.

We developed the 3H4SDG participatory approach as a generic tool to be further adapted and improved in the future. Ideally, the participatory process would be repeated in multiple contexts, adding to the understanding of convergences and divergences across scales and socioeconomic and biocultural contexts. We expect that some convergences and divergences would be common across regions, for instance urbanization trends across the continents of the Global South (see (Nagendra et al., 2018)), while others might be context specific (e.g. the informal nature of significant parts of economies, (Gërxhani, 2004; Schneider et al., 2010), adding richness to the resulting scenarios. Importantly, balancing out diversity and manageability is key for the proposed type of participatory process.

As in all participatory processes, the depth and representativeness of information derived largely depends on the selection of the participants (Cvitanovic et al., 2019; Reed et al., 2013). For the proposed approach, the main criteria for stakeholder selection should be the diversity of perspectives on the issue under discussion. Although we believe we achieved this goal in our particular case study, the results could have benefited from e.g. a broader representativeness of gender and additional African sub-regions, as discussed in (Aguiar et al., 2019). We recommend that future applications of the process include additional types of interactions with stakeholders, e.g. discussing the convergent and divergent themes in a more structured way, and to combining them into new narratives in a participatory manner. Additional discussion of the participatory process, including the information on the reception of the process by the involved participants, is available in (Collste et al., 2019).

4.3. Quantifying the narratives

As a potential next step, the global target-seeking narratives resulting from our proposed approach and its pilot application in this study can be quantified on the global and regional levels – in a process similar to that used to quantify the SSPs (O'Neill et al., 2014; Riahi et al., 2017).

In general, building alternative quantitative scenarios around a qualitative narrative represents the most common approach for scenario construction, known as Story and Simulation (SAS) (Alcamo, 2008). Recently, new approaches, such as "scenario discovery", have been advocated (Carlsen et al., 2017) and applied to national (Gao and Bryan, 2017) and global scales (Lamontagne et al., 2018). In the scenario discovery approach, individual assumptions about drivers are combined in multiple ways, without requiring a predefined narrative. We argue that our approach to the identification of branching points can be easily adopted in scenario discovery, helping define the options that can be combined in this process. In any of these two cases (SAS or scenario discovery), multiple scenario exercises can then be explored to test whether different pathways do or do not lead to the desired goals.

Finally, we envision that the proposed approach to designing target-seeking scenarios does not necessarily have to be applied solely to feed into modelling on the global scale, e.g. by IAMs. It can also inform modelling at other scales, as it might not be possible for global models to capture the specificities of alternative pathways for different regions or countries. We argue that particularly to support the implementation of the SDGs, complementary models and scenarios representing alternative pathways need to be developed at multiple scales (Allen et al., 2017; Gao and Bryan, 2017). The approach can also be combined to complement ongoing cross-scale modelling initiatives (Schmidt-Traub et al., 2019). For instance, the approach can help explore the feasibility of global target-seeking scenario assumptions (e.g., about GDP or population growth) for different countries in a simulation environment. Similarly, it can serve the exploration of how individual countries' decisions contribute to the achievement of global goals (e.g., limiting the temperature to 2 °C, or protecting "Half Earth", (Ellis and Mehrabi, 2019;

Schleicher et al., 2019)).

4.4. Insights for evolving modeling tools based on societal needs

Existing computational models do not adequately represent alternative pathways across scales, including their broad sets of goals and targets (such as the SDGs) (van Soest et al., 2019). For instance, in our specific case, some of the branching points emerging from our analysis are not adequately represented in current models (e.g. alternative regimes of governance) (Table 1). Tackling this may require some of the following strategies; first improving existing computational models may be needed. This is particularly true for IAMs, initially developed to address climate-related concerns (van Soest et al., 2019). Second, representing pathways to multiple goals might require opening-up to multiple modelling approaches (Groeneveld et al., 2017; Lippe et al., 2019; Rounsevell et al., 2014; Schlüter et al., 2019; Schulze et al., 2017; van Vuuren et al., 2016), more adequate to different contexts and scales (Allen et al., 2017, 2016). Finally, the consideration of un-quantifiable, qualitative pathway elements needs to be embraced (Mallampalli et al., 2016; Harrison et al., 2013).

We argue that the results of the proposed approach can provide insights into necessary improvements in computational models, fostering their evolution. One clear example is the "Actors in agriculture" branching point, illustrating the need for modelling current and alternative patterns of land tenure among different types of actors and its implications for the SDGs in urban and rural areas. Although this is currently not feasible, spatial data at global scale are already becoming available to help enable this process (see, for instance (Samberg et al., 2016)). Another example is the "Agricultural practices" branching point and the representation of alternative agricultural management practices in models (Erb et al., 2016).

In case such modelling limitations cannot be overcome in the short term, target-seeking scenario processes involving quantification through models should transparently state which options are not being represented due to being considered less relevant and which due to the limitations in the modelling approaches or lack of data. This distinction is vital, given the potential importance of the resulting target-seeking scenarios for decision making. In such cases, branching points such as those identified in this study can enrich the narratives of alternative target-seeking scenarios and foster related discussions across scales.

In sum, quantitative scenarios are bounded by (1) the current scientific knowledge in different fields (e.g. agricultural management), (2) the breadth of perspectives encompassed by their narratives, and (3) the technical limitations of existing modeling tools to represent both. We argue that our approach can help to better bridge and shed light on these three aspects.

5. Conclusions

In this paper we propose an innovative approach to include multiple perspectives, including those from different regions, cultures and scales, in the design of global target-seeking scenarios. Unlike the exploratory scenarios, which are traditionally designed around major uncertainty axes (Alcamo, 2008), we argue that target-seeking scenarios should instead be designed around major tensions and debates in the society, including dominant and non-dominant perspectives.

The approach proposed in this study relies on capturing convergences and divergences between regional- and global-scale perspectives on pathways to sustainability through a structured participatory process and subsequent analysis. Our results illustrate that integrating multiple stakeholder perspectives on alternative sustainability pathways in designing global target-seeking scenario narratives is feasible and highly relevant, despite its challenges. This process can also contribute to the ongoing effort in IPBES aiming to generate new bottom-up sustainability-oriented scenarios for biodiversity and ecosystem services (Kok et al., 2017; Rosa et al., 2017).

Implementing the SDGs and achieving sustainability in the long run will require negotiations at multiple levels and navigating a plurality of values and solutions. Scientific discussions around the SDGs since their launch in 2015 have largely focused on technical aspects at the target level, such as monitoring and understanding target level interaction based on conceptual or empirical relationships between goals and targets (Nilsson et al., 2016; Pradhan et al., 2017; Reyers et al., 2017; Weitz et al., 2018). We agree with recent criticism (Scoones, 2019) about the need to maintain the holistic perspective on the goals aiming at their implementation (Stafford-Smith et al., 2017). We need to make the SDGs part of the planning discussions at multiple levels. *Society at large needs to feel ownership over the goals*, and approaches such as the 3H4SDG can contribute to that end. Although there have been some criticisms about the applicability and feasibility of the SDGs and their targets (Easterly, 2015; Horton, 2014; Lim et al., 2018; Winkler and Williams, 2017), the SDGs may be the best chance we have to engage people in a deep transformative process towards common sustainability goals. This is also applicable beyond the current SDGs, which are primarily a vehicle to express a desired future. As we demonstrated in this study, there is a richness that participatory approaches can bring to the discussion of pathways and to the design of new scenarios representing them. We therefore believe that advancing on cross-scale participatory scenario processes, linked to appropriate models at multiple scales, is a critical contribution that the scientific community can make to the global sustainability agenda.

CRediT authorship contribution statement

Ana Paula D. Aguiar: Conceptualization, Methodology, Investigation, Writing - original draft, Supervision, Writing - review & editing. **David Collste:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing. **Zuzana V. Harmáčková:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing. **Laura Pereira:** Conceptualization, Investigation, Writing - original draft. **Odirilwe Selomane:** Conceptualization, Investigation, Writing - original draft. **Diego Galafassi:** Conceptualization, Investigation, Writing - original draft. **Detlef Van Vuuren:** Conceptualization, Investigation, Writing - original draft. **Sander Van Der Leeuw:** Conceptualization, Investigation, Writing - original draft.

Declaration of Competing Interest

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

Acknowledgements

We thank the participants and facilitators of the 2nd African Dialogue on TWI2050: https://swed.bio/reports/the-second-african-dialogue-on-the-world-in-2050/ and the SwedBio team for the support.

Ana Paula D. Aguiar, Zuzana V. Harmáčková and Odirilwe Selomane have been supported by the GRAID programme at Stockholm Resilience Centre, funded by the Swedish International Development Agency (SIDA). Zuzana Harmáčková's work was supported by Global Change Research Institute of the Czech Academy of Sciences. David Collste has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie Grant Agreement No 675153 (ITN JD AdaptEconII).

The 2nd African Dialogue on TWI2050 was funded by the Swedish International Development Agency (Sida) through SwedBio.

We thank Marcel Kok (PBL) for valuable discussions during the writing process of this manuscript. We would like to sincerely thank our anonymous reviewers for their valuable comments.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloenvcha.2020.102198.

References

Abel, G.J., Barakat, B., Kc, S., Lutz, W., 2016. Meeting the Sustainable Development Goals leads to lower world population growth. Proceedings of the National Academy of Sciences 201611386.

Aguiar, A., 2015. Transition to sustainability: are participatory multi-scale scenarios a useful tool? GLP News - Newsl. Glob. L. Proj. 11.

Aguiar, A.P., Collste, D., Galafassi, D., Harmackova, Z.V., Houngbedji, K., Mesfin, M., Ndahiro, D., Pereira, L., Selomane, O., van der Leeuw, S., 2019. The Second African Dialogue on the World In 2050 - How to attain the SDGs within planetary boundaries: Agriculture and food systems. Report on a Multi-Actor Dialogue for TWI2050, 30 – 31 October 2018, Kigali, Rwanda. Sustainable Development Goals Center for Africa and SwedBio/Stockholm Resilience Centre at Stockholm University.

Alcamo, J., 2008. Environmental Futures: The Practice of Environmental Scenario Analysis. Elsevier.

Allen, C., Metternicht, G., Wiedmann, T., 2016. National pathways to the Sustainable Development Goals (SDGs): a comparative review of scenario modelling tools. Environ. Sci. Policy 66, 199–207.

Allen, C., Sydney, U., Metternicht, G., Wiedmann, T., 2017. An Iterative Framework for National Scenario Modelling for the Sustainable Development Goals (SDGs): An Iterative Framework for National Scenario Modelling for the SDGs Indicator-based assessment for the SDGs -Arab SDG Report View project Developing an in. <https://dx.doi.org/10/gb44tr>.

Balbi, S., Selomane, O., Sitas, N., Blanchard, R., Kotzee, I., O'Farrell, P., Villa, F., 2019. Human dependence on natural resources in rapidly urbanising South African regions. Environ. Res. Lett.

Bawa, A.S., Anilakumar, K.R., 2013. Genetically modified foods: safety, risks and public concerns-a review. J. Food Sci. Technol. 50, 1035–1046.

Bennett, E.M., 2017. Changing the agriculture and environment conversation. Nat Ecol Evol 1, 18.

Bottazzi, P., Goguen, A., Rist, S., 2016. Conflicts of customary land tenure in Rural Africa: is large-scale land acquisition a driver of 'institutional innovation'? J. Peasant Stud. 43 (5), 971–988.

Brelsford, C., Lobo, J., Hand, J., Bettencourt, L.M.A., 2017. Heterogeneity and scale of sustainable development in cities. Proc. Natl. Acad. Sci. U. S. A. 114, 8963–8968.

Burke, W.J., Jayne, T.S., Sitko, N.J., 2020. Do medium-scale farms improve market access conditions for Zambian Smallholders? J. Agric. Econ. 71 (2), 517–533.

Cabral, L., Favareto, A., Mukwereza, L., Amanor, K., 2016. Brazil's agricultural politics in Africa: more food international and the disputed meanings of "family farming". World Dev. 81, 47–60. https://doi.org/10.1016/j.worlddev.2015.11.010.

Carlsen, H., Klein, R.J.T., Wikman-Svahn, P., 2017. Transparent scenario development. Nat Clim. Chang. 7, 613.

Chan, K.M.A., Agard, J., Liu, J., de Aguiar, A.P.D., Armenteras, D., Boedhihartono, A.K., Cheung, W.W.L., Hashimoto, S., Pedraza, G.C.H., Hickler, T., Xue, D., Selomane, O., Balint, L., Mohamed, A., 2019. Chapter 5: pathways towards a sustainable future. In: Díaz, S., Settele, J., Brondizio, E.S., Ngo, H.T., Guèze, M., Agard, J., Arneth, A., Balvanera, P., Brauman, K.A., Butchart, S.H.M., Chan, K.M.A., Garibaldi, L.A., Ichii, K., Liu, J., Subramanian, S.M., Midgley, G.F., Miloslavich, P., Molnár, Z., Obura, D., Pfaff, A., Polasky, S., Purvis, A., Razzaque, J., Reyers, B., Chowdhury, R. R., Shin, Y.J., Visseren-Hamakers, I.J., Willis, K.J., Zayas, C.N. (Eds.), IPBES Global Assessment on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany pp. xx–xx.

Chan, K.M.A., Boyd, D.R., Gould, R.K., Jetzkowitz, J., Liu, J., Muraca, B., Naidoo, R., Olmsted, P., Satterfield, T., Selomane, O., Singh, G.G., Sumaila, R., Ngo, H.T., Boedhihartono, A.K., Agard, J., Aguiar, A.P.D., Armenteras, D., Balint, L., Barrington-Leigh, C., Cheung, W.W.L., Díaz, S., Driscoll, J., Esler, K., Eyster, H., Gregr, E.J., Hashimoto, S., Hernández Pedraza, G.C., Hickler, T., Kok, M., Lazarova, T., Mohamed, A.A.A., Murray-Hudson, M., O'Farrell, P., Palomo, I., Saysel, A.K., Seppelt, R., Settele, J., Strassburg, B., Xue, D., Brondízio, E.S., 2020. Levers and leverage points for pathways to sustainability. People Nat. 2, 693–717.

Christiaensen, L., Todo, Y., 2014. Poverty reduction during the rural-urban transformation – the role of the missing middle. World Dev. https://doi.org/10.1016/j.worlddev.2013.10.002.

Collier, P., Dercon, S., 2014. African agriculture in 50 years: smallholders in a rapidly changing world? World Dev. 63, 92–101.

Collste, D., Aguiar, A.P., Galafassi, D., Harmáčková, Z., Pereira, L., Selomane, O., 2019. A cross-scale participatory approach to discuss pathways to the 2030 Agenda SDGs: the example of The World In 2050 African Dialogues. A Methodology paper on the The Three Horizons Framework for the SDGs (3H4SDG). https://dx.doi.org/10.31235/osf.io/uhskb.

Cvitanovic, C., Howden, M., Colvin, R.M., Norström, A., Meadow, A.M., Addison, P.F.E., 2019. Maximising the benefits of participatory climate adaptation research by understanding and managing the associated challenges and risks. Environ. Sci. Policy 94, 20–31.

de Brauw, A., Mueller, V., Lee, H.L., 2014. The role of rural-urban migration in the structural transformation of Sub-Saharan Africa. World Dev. 63, 33–42.

Demeritt, D., Dobson, A., Li, T.M., Leach, M., Scoones, I., Stirling, A., 2011. Pathways to sustainability: Perspectives and provocations. Environ. Plan. A 43, 1226–1237.

Doelman, J.C., Stehfest, E., Tabeau, A., van Meijl, H., Lassaletta, L., Gernaat, D.E.H.J., Neumann-Hermans, K., Harmsen, M., Daioglou, V., Biemans, H., van der Sluis, S., van Vuuren, D.P., 2018. Exploring SSP land-use dynamics using the IMAGE model: Regional and gridded scenarios of land-use change and land-based climate change mitigation. Glob. Environ. Change 48, 119–135.

Duru, M., Therond, O., Fares, M., 2015. Designing agroecological transitions; A review. Agron. Sustainable Dev. 35, 1237–1257.

Easterly, W., 2015. The SDGs Should Stand for Senseless, Dreamy, Garbled. Foreign Policy.

Ellis, E.C., Mehrabi, Z., 2019. Half Earth: promises, pitfalls, and prospects of dedicating Half of Earth's land to conservation. Curr. Opin. Environ. Sustainability 38, 22–30.

Erb, K.-H.-H., Lauk, C., Kastner, T., Mayer, A., Theurl, M.C., Haberl, H., 2016. Exploring the biophysical option space for feeding the world without deforestation. Nat. Commun. 7, 11382.

FAO, 2017. The future of food and agriculture – Trends and challenges. Food and Agriculture Organization of the United Nations, Rome.

Fazey, I., Wise, R.M., Lyon, C., Câmpeanu, C., Moug, P., Davies, T.E., 2016. Past and future adaptation pathways. Clim. Dev. https://doi.org/10.1080/17565529.2014.989192.

Ferrier, S., Ninan, K.N., Leadley, P., Alkemade, R., Acosta, L.A., Akçakaya, H.R., Brotons, L., Cheung, W.W.L., Christensen, V., Harhash, K.A., Kabubo-MarS, J., 2016. IPBES (2016): The Methodological Assessment Report on Scenarios and Models of Biodiversity and Ecosystem Services. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany.

Fischer, J., Abson, D.J., Butsic, V., Chappell, M.J., Ekroos, J., Hanspach, J., Kuemmerle, T., Smith, H.G., von Wehrden, H., 2014. Land sparing versus land sharing: moving forward. Conserv. Lett. 7, 149–157.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M., 2011. Solutions for a cultivated planet. Nature 478, 337–342.

Folhes, R.T., de Aguiar, A.P.D., Stoll, E., Dalla-Nora, E.L., Araújo, R., Coelho, A., do Canto, O., 2015. Multi-scale participatory scenario methods and territorial planning in the Brazilian Amazon. Futures 73, 86–89.

Gao, L., Bryan, B.A., 2017. Finding pathways to national-scale land-sector sustainability. Nature 544, 217–222.

Garnett, T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Bloomer, P., Burlingame, B., Dawkins, M., Dolan, L., Fraser, D., Herrero, M., Hoffmann, I., Smith, P., Thornton, P.K., Toulmin, C., Vermeulen, S.J., Godfray, H.C.J., 2013. Agriculture. Sustainable intensification in agriculture: premises and policies. Science 341, 33–34.

Geels, F.W., McMeekin, A., Mylan, J., Southerton, D., 2015. A critical appraisal of Sustainable Consumption and Production research: the reformist, revolutionary and reconfiguration positions. Glob. Environ. Change 34, 1–12.

Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Res. Policy 36, 399–417.

Geels, F.W., 2011. The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environ. Innov. Soc. Trans.

Gerten, D., Heck, V., Jägermeyr, J., Bodirsky, B.L., Fetzer, I., Jalava, M., Kummu, M., Lucht, W., Rockström, J., Schaphoff, S., Schellnhuber, H.J., 2020. Feeding ten billion people is possible within four terrestrial planetary boundaries. Nat. Sustainability 3, 200–208.

Gërxhani, K., 2004. The informal sector in developed and less developed countries: a literature survey. Publ. Choice. https://doi.org/10.1023/b:puch.0000044287.88147.5e.

Godfray, H.C.J., Garnett, T., 2014. Food security and sustainable intensification. Philos. Trans. R. Soc. Lond. B Biol. Sci. 369, 20120273.

Gordon, L.J., Bignet, V., Crona, B., Henriksson, P.J.G., Van Holt, T., Jonell, M., Lindahl, T., Troell, M., Barthel, S., Deutsch, L., Folke, C., Jamila Haider, L., Rockström, J., Queiroz, C., 2017. Rewiring food systems to enhance human health and biosphere stewardship. Environ. Res. Lett. 12, 100201.

Groeneveld, J., Müller, B., Buchmann, C.M., Dressler, G., Guo, C., Hase, N., Hoffmann, F., John, F., Klassert, C., Lauf, T., et al., 2017. Theoretical foundations of human decision-making in agent-based land use models–a review. Environ. Modell. Software 87, 39–48.

Güneralp, B., Lwasa, S., Masundire, H., Parnell, S., Seto, K.C., 2017. Urbanization in Africa: challenges and opportunities for conservation. Environ. Res. Lett. https://doi.org/10.1088/1748-9326/aa94fe.

Harrison, P.A., Holman, I.P., Cojocaru, G., Kok, K., Kontogianni, A., Metzger, M.J., Gramberger, M., 2013. Combining qualitative and quantitative understanding for exploring cross-sectoral climate change impacts, adaptation and vulnerability in Europe. Reg. Environ. Change 13, 761–780. https://doi.org/10.1007/s10113-012-0361-y.

Horton, R., 2014. Offline: why the sustainable development goals will fail. The Lancet. https://doi.org/10.1016/s0140-6736(14)61046-1.

Hunt, D.V.L., Lombardi, D.R., Atkinson, S., Barber, A.R.G., Barnes, M., Boyko, C.T., Brown, J., Bryson, J., Butler, D., Caputo, S., Caserio, M., Coles, R., Cooper, R.F.D., Farmani, R., Gaterell, M., Hale, J., Hales, C., Hewitt, C.N., Jankovic, L., Jefferson, I., Leach, J., MacKenzie, A.R., Memon, F.A., Sadler, J.P., Weingaertner, C., Whyatt, J. D., Rogers, C.D.F., 2012. Scenario archetypes: converging rather than diverging themes. Sustainable Sci. Pract. Policy 4, 740–772.

Jayne, T.S., Chamberlin, J., Headey, D.D., 2014. Land pressures, the evolution of farming systems, and development strategies in Africa: a synthesis. Food Policy 48, 1–17.

Jayne, T.S., Chamberlin, J., Traub, L., Sitko, N., Muyanga, M., Yeboah, F.K., Anseeuw, W., et al., 2016. Africa's changing farm size distribution patterns: the rise of medium-scale farms. Agric. Econ. 47 (S1), 197–214.
Jiang, L., O'Neill, B.C., 2017. Global urbanization projections for the Shared Socioeconomic Pathways. Glob. Environ. Change 42, 193–199.
Kc, S., Lutz, W., 2017. The human core of the shared socioeconomic pathways: population scenarios by age, sex and level of education for all countries to 2100. Glob. Environ. Change 42, 181–192.
Kok, M.T.J., Alkemade, R., Bakkenes, M., van Eerdt, M., Janse, J., Mandryk, M., Kram, T., Lazarova, T., Meijer, J., van Oorschot, M., Westhoek, H., van der Zagt, R., van der Berg, M., van der Esch, S., Prins, A.-G., van Vuuren, D.P., 2018. Pathways for agriculture and forestry to contribute to terrestrial biodiversity conservation: a global scenario-study. Biol. Conserv. 221, 137–150.
Kok, M.T.J., Kok, K., Peterson, G.D., Hill, R., Agard, J., Carpenter, S.R., 2017. Biodiversity and ecosystem services require IPBES to take novel approach to scenarios. Sustainability Sci. 12, 177–181.
Kostakis, V., Roos, A., Bauwens, M., 2016. Towards a political ecology of the digital economy: socio-environmental implications of two competing value models. Environ. Innov. Societal Trans. https://doi.org/10.1016/j.eist.2015.08.002.
Krause, A., Pugh, T.A.M., Bayer, A.D., Li, W., Leung, F., Bondeau, A., Doelman, J.C., Humpenöder, F., Anthoni, P., Bodirsky, B.L., Ciais, P., Müller, C., Murray-Tortarolo, G., Olin, S., Popp, A., Sitch, S., Stehfest, E., Arneth, A., 2018. Large uncertainty in carbon uptake potential of land-based climate-change mitigation efforts. Glob. Chang. Biol. 24, 3025–3038.
Kremen, C., 2015. Reframing the land-sparing/land-sharing debate for biodiversity conservation. Ann. N. Y. Acad. Sci. 1355, 52–76.
Kriegler, E., Edmonds, J., Hallegatte, S., Ebi, K.L., Kram, T., Riahi, K., Winkler, H., van Vuuren, D.P., 2014. A new scenario framework for climate change research: the concept of shared climate policy assumptions. Clim. Change 122, 401–414.
Kummu, M., Kinnunen, P., Lehikoinen, E., Porkka, M., Queiroz, C., Röös, E., Troell, M., Weil, C., 2020. Interplay of trade and food system resilience: Gains on supply diversity over time at the cost of trade independency. Global Food Secur. 24, 100360.
Kuyper, Thomas W, Struik, Paul C, 2014. Epilogue: Global Food Security, Rhetoric, and the Sustainable Intensification Debate. Curr. Opin. Environ. Sustainability 8 (October), 71–79.
Kweka, Opportuna L., Ouma, Stefan, 2020. 'Changing beyond Recognition'?: reimagining the future of smallholder farming systems in the context of climate change. Geoforum. Elsevier Ltd.
Lambin, E.F., Meyfroidt, P., 2011. Global land use change, economic globalization, and the looming land scarcity. Proc. Natl. Acad. Sci. U. S. A. 108, 3465–3472.
Lamontagne, J.R., Reed, P.M., Link, R., Calvin, K.V., Clarke, L.E., Edmonds, J.A., 2018. Large ensemble analytic framework for consequence-driven discovery of climate change scenarios. Earth's Future 6, 488–504.
Le Heron, R., Lewis, N., Fisher, K., Thrush, S., Lundquist, C., Hewitt, J., Ellis, J., 2016. Non-sectarian scenario experiments in socio-ecological knowledge building for multi-use marine environments: Insights from New Zealand's Marine Futures project. Mar. Policy 67, 10–21.
Leach, M., Reyers, B., Bai, X., Brondizio, E.S., Cook, C., Díaz, S., Espindola, G., Scobie, M., Stafford-Smith, M., Subramanian, S.M., 2018. Equity and sustainability in the Anthropocene: a social–ecological systems perspective on their intertwined futures. Global Sustainability 1, e13.
Leach, M., Scoones, I., Stirling, A., 2010. Dynamic sustainabilities: technology, environment, social justice. Earthscan.
Leach, M., Scoones, I., Stirling, A., 2007. Pathways to Sustainability: an overview of the STEPS Centre approach, STEPS Approach Paper. STEPS Centre, Brighton, Brighton.
Lim, M.M.L., Jørgensen, P.S., Wyborn, C.A., 2018. Reframing the sustainable development goals to achieve sustainable development in the Anthropocene—a systems approach. Ecol. Soc. https://doi.org/10.5751/es-10182-230322.
Lippe, M., Bithell, M., Gotts, N., Natalini, D., Barbrook-Johnson, P., Giupponi, C., Hallier, M., Hofstede, G.J., Le Page, C., Matthews, R.B., Schlüter, M., Smith, P., Teglio, A., Thellmann, K., 2019. Using agent-based modelling to simulate social-ecological systems across scales. Geoinformatica 23, 269–298.
Luederitz, C., Abson, D.J., Audet, R., Lang, D.J., 2017. Many pathways toward sustainability: not conflict but co-learning between transition narratives. Sustainability Sci. 12, 393–407.
Lundquist, C.J., Pereira, H.M., Alkemade, J.R.M., den Belder, E., Carvalho Ribeiro, S., Davies, K., Greenaway, A., Karlsson-Vinkhuyzen, S.I.S.E., Kim, H., Lazarova, T., Pereira, L., Peterson, G., Ravera, F., van den Brink, T., Argumedo, A., Arida, C., Armenteras, D., Ausseil, A.-G., Baptiste, B., Belanger, J., Bingham, K., Bowden-Kerby, A., Cao, M., Nettleton-Carino, J., Van Damme, P.A., Devivo, R., Dickson, F., Dushimumuremyi, J.P., Ferrier, S., Flores-Diaz, A., Foley, M., Garcia Marquez, J., Giraldo-Perez, P., Greenhalgh, S., Hamilton, D.J., Hardison, P., Hicks, G., Hughey, K., Kahui-McConnell, R., Wangechi Karuri-Sebina, G., de Kock, M., Leadley, P., Lemaitre, F., Maltseva, E., de Mattos Scaramuzza, C.A., Metwaly, M., Nelson, W., Ngo, H., Neumann, C., Norrie, C., Perry, J., Quintana, R., Rodriguez Osuna, V.E., Röhrl, R., Seager, J., Sharpe, H., Shortland, T., Shulbaeva, P., Rashid Sumaila, U., Takahashi, Y., Titeux, T., Tiwari, S., Trisos, C., Ursache, A., Wheatley, A., Wilson, D., Wood, S., van Wyk, E., Yue, T.X., Zulfikar, D., 2017. Visions for nature and nature's contributions to people for the 21st century. NIWA Sci. Technol. Ser. 83, 67.
Mallampalli, V.R., Mavrommati, G., Thompson, J., Duveneck, M., Meyer, S., Ligmann-Zielinska, A., Druschke, C.G., Hychka, K., Kenney, M.A., Kok, K., Borsuk, M.E., 2016. Methods for translating narrative scenarios into quantitative assessments of land use change. Environ. Model. Softw. 82, 7–20.
Mason-D'Croz, D., Vervoort, J., Palazzo, A., Islam, S., Lord, S., Helfgott, A., Havlík, P., Peou, R., Sassen, M., Veeger, M., van Soesbergen, A., Arnell, A.P., Stuch, B., Arslan, A., Lipper, L., 2016. Multi-factor, multi-state, multi-model scenarios: exploring food and climate futures for Southeast Asia. Environ. Modell. Software 83, 255–270.
Meyfroidt, P., 2017. Mapping farm size globally: Benchmarking the smallholders debate. Environ. Res Lett.
Muller, A., Schader, C., El-Hage Scialabba, N., Brüggemann, J., Isensee, A., Erb, K.-H., Smith, P., Klocke, P., Leiber, F., Stolze, M., Niggli, U., 2017. Strategies for feeding the world more sustainably with organic agriculture. Nat. Commun. 8, 1290.
Nagendra, H., Bai, X., Brondizio, E.S., Lwasa, S., 2018. The urban south and the predicament of global sustainability. Nature Sustainability 1, 341–349.
Newell, P., Taylor, O., 2018. Contested landscapes: the global political economy of climate-smart agriculture. J. Peasant Stud. 45, 108–129.
Nicholls, C.I., Altieri, M.A., 2018. Pathways for the amplification of agroecology. Agroecol. Sustainable Food Syst. 42, 1170–1193.
Nilsson, A.E., Bay-Larsen, I., Carlsen, H., van Oort, B., Bjørkan, M., Jylhä, K., Klyuchnikova, E., Masloboev, V., van der Watt, L.-M., 2017. Towards extended shared socioeconomic pathways: a combined participatory bottom-up and top-down methodology with results from the Barents region. Glob. Environ. Change 45, 124–132.
Nilsson, M.A., Griggs, D., Visbeck, M., 2016. Policy: Map the interactions between Sustainable Development Goals. Nature 534, 320–322.
Nori, M., Scoones, I., 2019. Pastoralism, uncertainty and resilience: global lessons from the margins. Pastoralism 9, 10.
Oberlack, C., Tejada, L., Messerli, P., Rist, S., Giger, M., 2016. Sustainable livelihoods in the global land rush? Archetypes of livelihood vulnerability and sustainability potentials. Glob. Environ. Chang. 41, 153–171.
Obersteiner, M., Walsh, B., Frank, S., Havlík, P., Cantele, M., Liu, J., Palazzo, A., Herrero, M., Lu, Y., Mosnier, A., Valin, H., Riahi, K., Kraxner, F., Fritz, S., van Vuuren, D., 2016. Assessing the land resource–food price nexus of the Sustainable Development Goals. Sci. Adv. https://doi.org/10.1126/sciadv.1501499.
O'Neill, B.C., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., van Ruijven, B.J., van Vuuren, D.P., Birkmann, J., Kok, K., Levy, M., Solecki, W., 2017. The roads ahead: narratives for shared socioeconomic pathways describing world futures in the 21st century. Glob. Environ. Change 42, 169–180.
O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., van Vuuren, D.P., 2014. A new scenario framework for climate change research: The concept of shared socioeconomic pathways. Clim. Change 122.
Parkinson, S., Krey, V., Huppmann, D., Kahil, T., McCollum, D., Fricko, O., Byers, E., Gidden, M.J., Mayor, B., Khan, Z., Raptis, C., Rao, N.D., Johnson, N., Wada, Y., Djilali, N., Riahi, K., 2019. Balancing clean water-climate change mitigation trade-offs. Environ. Res. Lett. 14, 014009.
PBL, 2012. Roads from Rio + 20. Pathways to achieve global sustainability goals by 2050. Netherlands Environmental Assessment Agency.
Pereira, L.M., Cuneo, C.N., Twine, W.C., 2014. Food and cash: understanding the role of the retail sector in rural food security in South Africa. Food Secur. 6, 339–357.
Pereira, L.M., Hichert, T., Hamann, M., Preiser, R., Biggs, R., 2018a. Using futures methods to create transformative spaces. Ecol. Soc. 23.
Pereira, L.M., Wynberg, R., Reis, Y., 2018b. Agroecology: the future of sustainable farming? Environ.: Sci. Policy Sustainable Dev. 60, 4–17.
Peters, P.E., 2013. Land appropriation, surplus people and a battle over visions of agrarian futures in Africa. J. Peasant Stud. 40, 537–562.
Phalan, B., Onial, M., Balmford, A., Green, R.E., 2011. Reconciling food production and biodiversity conservation: land sharing and land sparing compared. Science 333, 1289–1291.
Phalan, B.T., 2018a. What have we learned from the land sparing-sharing model? Sustain. 10 (6) https://doi.org/10.3390/su10061760.
Phalan, B.T., 2018b. What have we learned from the land sparing-sharing model? Sustainability (Switzerland) 10.
Pradhan, P., Costa, L., Rybski, D., Lucht, W., 2017. A systematic study of Sustainable Development Goal (SDG) interactions. Earth's. Future.
Rada, N.E., Fuglie, K.O., 2019. New perspectives on farm size and productivity. Food Policy 84, 147–152.
Raskin, P., Monks, F., Ribeiro, T., van Vuuren, D., Zurek, M., 2005. Global Scenarios in Historical Perspectives, in: S. R. Carpenter E. M. Bennett, P.L.P., and M.B. Zurek (Ed.), Ecosystems and Human Well-Being: Scenarios. Volume 2: Findings of the Scenarios Working Group of the Millennium Ecosystem Assessment. Island Press, Washington, D.C., USA., pp. 35–44.
Raudsepp-Hearne, C., Peterson, G.D., Bennett, E.M., Biggs, R., Norström, A.V., Pereira, L., Vervoort, J., Iwaniec, D.M., McPhearson, T., Olsson, P., Hichert, T., Falardeau, M., Aceituno, A.J., 2019. Seeds of good anthropocenes: developing sustainability scenarios for Northern Europe. Sustainability Sci.
Reed, M.S., Kenter, J., Bonn, A., Broad, K., Burt, T.P., Fazey, I.R., Fraser, E.D.G., Hubacek, K., Nainggolan, D., Quinn, C.H., Stringer, L.C., Ravera, F., 2013. Participatory scenario development for environmental management: a methodological framework illustrated with experience from the UK uplands. J. Environ. Manage. 128, 345–362.
Reyers, B., Stafford-Smith, M., Erb, K.-H., Scholes, R.J., Selomane, O., 2017. Essential variables help to focus sustainable development goals monitoring. Curr. Opin. Environ. Sustainability. https://doi.org/10.1016/j.cosust.2017.05.003.
Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., Kc, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., Da Silva, L.A., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V.,

Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman, J.C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A., Tavoni, M., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: an overview. Glob. Environ. Change 42, 153–168.

Rogelj, J., Popp, A., Calvin, K.V., Luderer, G., Emmerling, J., Gernaat, D., Fujimori, S., Strefler, J., Hasegawa, T., Marangoni, G., Krey, V., Kriegler, E., Riahi, K., Van Vuuren, D.P., Doelman, J., Drouet, L., Edmonds, J., Fricko, O., Harmsen, M., Havlík, P., Humpenöder, F., Stehfest, E., Tavoni, M., 2018a. Scenarios towards limiting global mean temperature increase below 1.5 °C. Nat. Clim. Chang. 8, 325–332.

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E., Mundaca, L., Seferian, R., Vilarino, M.V., Calvin, K., Edelenbosch, O., Emmerling, J., Fuss, S., Gasser, T., Gillet, N., He, C., Hertwich, E., Höglund Isaksson, L., Huppmann, D., Luderer, G., Markandya, A., McCollum, D., Millar, R., Meinshausen, M., Popp, A., Pereira, J., Purohit, P., Riahi, K., Ribes, A., Saunders, H., Schadel, C., Smith, C., Smith, P., Trutnevyte, E., Xiu, Y., Zickfeld, K., Zhou, W., 2018b. Chapter 2: Mitigation pathways compatible with 1.5°C in the context of sustainable development.

Rosa, I.M.D., Pereira, H.M., Ferrier, S., Alkemade, R., Acosta, L.A., Akcakaya, H.R., den Belder, E., Fazel, A.M., Fujimori, S., Harfoot, M., Harhash, K.A., Harrison, P.A., Hauck, J., Hendriks, R.J.J., Hernández, G., Jetz, W., Karlsson-Vinkhuyzen, S.I., Kim, H., King, N., Kok, M.T.J., Kolomytsev, G.O., Lazarova, T., Leadley, P., Lundquist, C.J., García Márquez, J., Meyer, C., Navarro, L.M., Nesshöver, C., Ngo, H. T., Ninan, K.N., Palomo, M.G., Pereira, L.M., Peterson, G.D., Pichs, R., Popp, A., Purvis, A., Ravera, F., Rondinini, C., Sathyapalan, J., Schipper, A.M., Seppelt, R., Settele, J., Sitas, N., van Vuuren, D., 2017. Multiscale scenarios for nature futures. Nat Ecol Evol 1, 1416–1419.

Rosenbloom, D., 2017. Pathways: an emerging concept for the theory and governance of low-carbon transitions. Glob. Environ. Change 43, 37–50.

Rothgerber, H., 2015. Underlying differences between conscientious omnivores and vegetarians in the evaluation of meat and animals. Appetite 87, 251–258.

Rounsevell, M.D.A., Arneth, A., Alexander, P., Brown, D.G., de Noblet-Ducoudré, N., Ellis, E., Finnigan, J., Galvin, K., Grigg, N., Harman, I., et al., 2014. Towards decision-based global land use models for improved understanding of the Earth system. Earth System Dyn. 5, 117.

Roy, J., Tschakert, P., Waisman, H., Halim, S.A., Antwi-Agyei, P., Dasgupta, P., Hayward, B., Kanninen, M., Liverman, D., Okereke, C., Pinho, P.F., Riahi, K., Rodriguez, A.G.S., Aragón–Durand, F., Babiker, M., Bangalore, M., Bertoldi, P., Choudhary, B.B., Cartwright, A., Djalante, R., Ebi, K., Ellis, N., Engelbrecht, F., Figueroa, M.J., Gupta, M., Haileselassie, A.M., Henrique, K.P., Huppmann, D., Huq, S., Jacob, D., James, R., Ley, D., Marcotullio, P., Massera, O., Mechler, R., Mehrotra, S., Newman, P., Parkinson, S., Revi, A., Rickels, W., Salili, D.H., Schipper, L., Schmidt, J., Schultz, S., Smith, P., Solecki, W., Some, S., Teariki-Ruatu, N., Thomas, A., Urquhart, P., Wewerinke-Singh, M., 2018. Sustainable Development, Poverty Eradication and Reducing Inequalities, in: Global Warming of 1.5 °C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change.

Sachs, J.D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., Rockström, J., 2019. Six Transformations to achieve the Sustainable Development Goals. Nature Sustainability 2, 805–814.

Samberg, L.H., Gerber, J.S., Ramankutty, N., Herrero, M., West, P.C., 2016. Subnational distribution of average farm size and smallholder contributions to global food production. Environ. Res. Lett. 11, 124010.

Schader, C., Muller, A., Scialabba, N.E.-H., Hecht, J., Isensee, A., Erb, K.-H., Smith, P., Makkar, H.P.S., Klocke, P., Leiber, F., Schwegler, P., Stolze, M., Niggli, U., 2015. Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. J. R. Soc. Interface 12, 20150891.

Schleicher, J., Zaehringer, J.G., Fastré, C., Vira, B., Visconti, P., Sandbrook, C., 2019. Protecting half of the planet could directly affect over one billion people. Nat. Sustainability 2, 1094–1096.

Schlüter, M., Müller, B., Frank, K., 2019. The potential of models and modeling for social-ecological systems research: the reference frame ModSES. Eco. Soc. https://doi.org/10.5751/es-10716-240131.

Schmidt-Traub, G., Obersteiner, M., Mosnier, A., 2019. Fix the broken food system in three steps. Nature 569, 181–183.

Schneider, F., Buehn, A., Montenegro, C.E., 2010. New estimates for the shadow economies all over the World. Int. Econ. J. https://doi.org/10.1080/10168737.2010.525974.

Schultz, W., 2015. Manoa: The future is not binary. APF Compass April, 22–26.

Schulze, J., Müller, B., Groeneveld, J., Grimm, V., 2017. Agent-based modelling of social-ecological systems: achievements, challenges, and a way forward. J. Artif. Societies Soc. Simul. 20.

Scoones, I., 2019. The SDGs: A new politics of transformation?.

Scoones, I., Smalley, R., Hall, R., Tsikata, D., 2019. Narratives of scarcity: framing the global land rush. Geoforum. https://doi.org/10.1016/j.geoforum.2018.06.006.

Scoones, I., Stirling, A., Abrol, D., Atela, J., Charli-Joseph, L., Eakin, H., Ely, A., Olsson, P., Pereira, L., Priya, R., van Zwanenberg, P., Yang, L., 2018. Transformations to Sustainability (No. 104), STEPS Working Paper. STEPS.

Sharpe, B., Hodgson, A., Leicester, G., Lyon, A., Fazey, I., 2016. Three horizons: a pathways practice for transformation. Ecol. Soc. 21.

Stafford-Smith, M., Griggs, D., Gaffney, O., Ullah, F., Reyers, B., Kanie, N., Stigson, B., Shrivastava, P., Leach, M., O'Connell, D., 2017. Integration: the key to implementing the Sustainable Development Goals. Sustainability Sci. https://doi.org/10.1007/s11625-016-0383-3.

Stehfest, E., Bouwman, L., van Vuuren, D.P., den Elzen, M.G.J., Eickhout, B., Kabat, P., Vuuren, D.P., Elzen, M.G.J., Eickhout, B., Kabat, P., 2009. Climate benefits of changing diet. Clim. Change 95, 83–102.

Stringer, L.C., Fraser, E.D.G., Harris, D., Lyon, C., Pereira, L., Ward, C.F.M., Simelton, E., 2020. Adaptation and development pathways for different types of farmers. Environ. Sci. Policy. https://doi.org/10.1016/j.envsci.2019.10.007.

Struik, P.C., Kuyper, T.W., 2017. Sustainable intensification in agriculture: the richer shade of green. A review. Agron. Sustainable Dev. 37, 39.

Swart, R.J., Raskin, P., Robinson, J., 2004. The problem of the future: Sustainability science and scenario analysis. Glob. Environ. Change 14.

Tittonell, P., 2014. Ecological intensification of agriculture—sustainable by nature. Curr. Opin. Environ. Sustainability 8, 53–61.

Tomlinson, I., 2013. Doubling food production to feed the 9 billion: a critical perspective on a key discourse of food security in the UK. J. Rural Stud. 29, 81–90.

Tscharntke, T., Clough, Y., Wanger, T.C., Jackson, L., Motzke, I., Perfecto, I., Vandermeer, J., Whitbread, A., 2012. Global food security, biodiversity conservation and the future of agricultural intensification. Biol. Conserv. 151, 53–59.

Turnheim, B., Berkhout, F., Geels, F.W., Hof, A., McMeekin, A., Nykvist, B., van Vuuren, D., 2015. Evaluating sustainability transitions pathways: Bridging analytical approaches to address governance challenges. Glob. Environ. Change 35, 239–253.

TWI2050, 2019. The Digital Revolution and Sustainable Development: Opportunities and Challenges. The World in 2050 Initiative.

TWI2050, 2018. Transformations to Achieve the Sustainable Development Goals. The World in 2050 Initiative, Laxenburg, Austria.

UNFCCC, 2015. The Paris Agreement. United Nations Framework Convention on Climate Change.

UN General Assembly, 2015. Transforming our world : the 2030 Agenda for Sustainable Development, 21 October 2015, A/RES/70/1.

van Soest, H.L., van Vuuren, D.P., Hilaire, J., Minx, J.C., Harmsen, M.J.H.M., Krey, V., Popp, A., Riahi, K., Luderer, G., 2019. Analysing interactions among sustainable development goals with integrated assessment models. Global Trans. 1, 210–225.

van Vuuren, D., Lucas, P.L., Häyhä, T., Cornell, S.E., Stafford-Smith, M., et al., 2016. Horses for courses: analytical tools to explore planetary boundaries. Earth Syst. Dyn. 7, 267–279.

van Vuuren, D.P., Kok, M., Lucas, P.L., Prins, A.G., Alkemade, R., van den Berg, M., Bouwman, L., van der Esch, S., Jeuken, M., Kram, T., Stehfest, E., 2015. Pathways to achieve a set of ambitious global sustainability objectives by 2050: Explorations using the IMAGE integrated assessment model. Technol. Forecast. Soc. Change 98.

van Vuuren, D.P., Kok, M.T.J.J., Girod, B., Lucas, P.L., de Vries, B., 2012a. Scenarios in Global Environmental Assessments: Key characteristics and lessons for future use. Glob. Environ. Change 22, 884–895.

van Vuuren, D.P., Riahi, K., Moss, R., Edmonds, J., Thomson, A., Nakicenovic, N., Kram, T., Berkhout, F., Swart, R., Janetos, A., Rose, S.K., Arnell, N., 2012b. A proposal for a new scenario framework to support research and assessment in different climate research communities. Global Environ. Change 22, 21–35.

van Vuuren, D.P., Stehfest, E., Gernaat, D.E.H.J., van den Berg, M., Bijl, D.L., de Boer, H. S., Daioglou, V., Doelman, J.C., Edelenbosch, O.Y., Harmsen, M., Hof, A.F., van Sluisveld, M.A.E., 2018. Alternative pathways to the 1.5 °C target reduce the need for negative emission technologies. Nat. Clim. Chang. 8, 391–397.

Weitz, N., Carlsen, H., Nilsson, M.A., Skånberg, K., 2018. Towards systemic and contextual priority setting for implementing the 2030 Agenda. Sustainability Sci. 13, 531–548.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J.A., Vries, W. de, Majele Sibanda, L., Afshin, A., Chaudhary, A., Herrero, M., Agustina, R., Branca, F., Lartey, A., Fan, S., Crona, B., Fox, E., Bignet, V., Troell, M., Lindahl, T., Singh, S., Cornell, S.E., Reddy, K.S., Narain, S., Nishtar, S., Murray, C.J.L., 2019. Food Planet Health: Healthy Diets From Sustainable Food Systems. Summary Report of the EAT-Lancet Commission. The EAT-Lancet Commission.

Winkler, I.T., Williams, C., 2017. The Sustainable Development Goals and human rights: a critical early review. Int. J. Hum. Rights. https://doi.org/10.1080/13642987.2017.1348695.

Wollenberg, E., Edmunds, D., Buck, L., 2000. Anticipating Change: Scenarios as a Tool for Adaptive Forest Management: A Guide. CIFOR.

Zimm, C., Sperling, F., Busch, S., 2018. Identifying Sustainability and Knowledge Gaps in Socio-Economic Pathways Vis-à-Vis the Sustainable Development Goals. Econ. Soc. https://doi.org/10/gf6358.

Zurek, M.B., Henrichs, T., 2007. Linking scenarios across geographical scales in international environmental assessments. Technol. Forecast. Soc. Change 74, 1282–1295.