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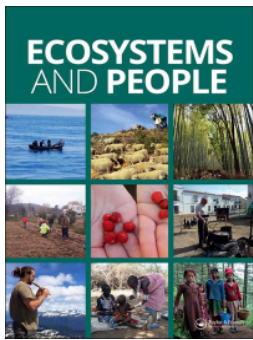
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Advancing a toolkit of diverse futures approaches for global environmental assessments

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ABSTRACT

Global Environmental Assessments (GEAs) are in a unique position to influence environmental decision-making in the context of sustainability challenges. To do this effectively, however, new methods are needed to respond to the needs of decision-makers for a more integrated, contextualized and goal-seeking evaluation of different policies, geared for action from global to local. While scenarios are an important tool for GEAs to link short-term decisions and medium and long-term consequences, these current information needs cannot be met only through deductive approaches focused on the global level. In this paper, we argue that a more diverse set of futures tools operating at multiple scales are needed to improve GEA scenario development and analysis to meet the information needs of policymakers and other stakeholders better. Based on the literature, we highlight four challenges that GEAs need to be able to address in order to contribute to global environmental decision-making about the future: 1. anticipate unpredictable future conditions; 2. be relevant at multiple scales, 3. include diverse actors, perspectives and contexts; and 4. leverage the imagination to inspire action. We present a toolbox of future-oriented approaches and methods that can be used to effectively address the four challenges currently faced by GEAs.

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1. Introduction

Can enough healthy food for all be provided while sustaining the biosphere? What role do different technologies and actors play in achieving this goal? Can globalisation enhance inclusion and respect for bio-cultural diversity? How do abrupt events affect sustainable trajectories of development, and how do we anticipate their adverse impacts? These and other sustainability questions are complex and interconnected, and answering them requires bridging diverse sources of experience and knowledge (Tengö et al. 2017). The challenge of bridging diverse ways of knowing is particularly pertinent in the context of global environmental assessments (GEAs), which have become an established feature of the global knowledge landscape and find themselves in a unique position to shape sustainable development

trajectories globally (Jabbour and Flachsland 2017). By GEAs, we refer to ‘largescale, highly deliberative processes where experts are convened to distill, synthesize, interpret and organize existing scientific knowledge (on environmental issues) to inform decision-making’ (Jabbour and Flachsland 2017, p. 193).

GEAs are important for supporting governance processes and are uniquely positioned to influence environmental decision-making in a context of sustainability challenges. GEAs such as those published by the IPCC (Intergovernmental Panel on Climate Change), IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) and the Global Environment Outlook (GEO) facilitated by the United Nations Environment Programme (UNEP), aim to synthesize, distill and communicate existing information

in ways that are relevant to decision makers and can help governments to achieve consensus when negotiating complex international accords and agreements (e.g. the Paris Climate Agreement and the United Nations 2030 Agenda for Sustainable Development) (Jabbour and Flachsland 2017). Towards that end, they aim to establish the current knowledge about the state of the environment, explore possible future trajectories, and discuss specific interventions that could be taken to achieve better outcomes.

The increasing interconnectedness and accelerating pace of societal and environmental changes in the Anthropocene present novel challenges to GEAs ability to achieve those goals (Steffen et al. 2015). Policy-makers are facing ever more complex decisions and are requiring different kinds of information from GEAs to navigate this complex decision-making environment (Jabbour 2019) leading to widespread calls for a more integrated, contextualized and goal-seeking evaluation of different policies, geared for multi-scale decisions and action (Kowarsch et al. 2017; Jabbour and Flachsland 2017). At the same time, GEAs have become increasingly solutions oriented, moving the focus beyond the assessment of current trends (*what is happening*) towards exploring and identifying the transformations to achieve more sustainable futures (*how to change*) (Asrar et al. 2019).

This shift in intention and direction for GEAs is especially relevant in the context of the Sustainable Development Goals (SDGs) and other global social and environmental targets. The international community set the ambition to achieve a broad range of globally accepted and integrated social, economic and environmental targets for 2030. However, while the need for systemic and transformative change across all scales is recognized, the question of *how* to achieve the integrated set of targets is still under discussion, and GEAs have the ability to make important contributions to answering this question.

Most GEAs both assess the current state of the environment and look to potential futures. Scenario development is a key element of the latter, with GEAs using scenarios to explore possible futures (exploratory scenarios) and pathways towards achieving a set of policy goals (normative or target-seeking scenarios). Often, GEA scenario building takes the form of qualitative storylines quantified through the use of Integrated Assessment Models (IAMs). Such 'top-down scenarios' are model-based and quantitative, and follow a deductive path starting with the consideration of one or more interventions, along with other assumptions on drivers of change (e.g. technological innovations) and trace the causal chains expected by their implementation through a set of linked system models (e.g. human, economy, energy, land use, agriculture) to assess projected outcomes on, for example, climate and biodiversity (Van

Vuuren et al. 2011; Riahi et al. 2017; Weyant 2017). These model-based scenarios have been instrumental in pointing the international community to the existential crises of climate change and global biodiversity loss, how the two are interrelated, and broad strategies to address these changes (van Beek et al. 2020).

However, whilst IAMs are likely to remain important tools in upcoming GEAs, the changing and diversifying needs of GEAs requires scenarios to be expanded beyond top-down, quantitative approaches (Chan et al. 2020). A bottom-up perspective on the future offers benefits for the assessment of aggregate scenarios that are grounded in local realities and include existing practical action that can be appropriately scaled. This inductive approach engages a broad range of scientific and action-oriented knowledge, perspectives and visions of a desirable world in the future and the ways to get there, including pathways to achieve long-term sustainability goals (e.g. the SDGs) (Raudsepp-Hearne et al. 2019). Linking top-down and bottom-up approaches to multilevel scenario development provides an opportunity for global processes to inform local actions and for taking account of local actions in global agreements (Pereira et al. 2019a).

In this perspective, we focus on the role of different futures approaches in making environmental assessment scenarios more salient to the needs of decision-makers at multiple scales around the world. We elaborate on how to make the next generation of GEA scenarios more useful by confronting four key challenges: surprise, scale, diversity, and imagination. We conclude by outlining a toolbox of various futures approaches that can be combined and reconfigured in different ways to address the diversifying needs of GEAs.

2. The evolution of environmental scenarios and the need for the next generation of scenario approaches for GEAs

Scenarios describe a set of possible future conditions, usually in order to develop strategies and options that consider future uncertainties (Van Vuuren et al. 2012). They have been used extensively over the last sixty years, including in business and military communities (Wack 1985; Bradfield et al. 2005), in political and conflict resolution communities (Kahane 2002) and in sustainability research with an early influential application being the Limits to Growth study (Meadows et al. 1972).

Over the past three decades, scenarios that combine quantitative modelling with narrative storylines have provided a powerful tool for GEAs to develop scientifically informed analysis of plausible futures and the potential consequences of different actions. The Millennium Ecosystem Assessment (MA) used

scenarios to investigate possible futures for ecosystem services (Millennium Ecosystem Assessment 2005). The MA scenarios built on previous efforts such as the Special Report on Emissions Scenarios (SRES) by the IPCC (Nakicenovic et al. 2000), the work of the Global Scenario Group (Raskin et al. 2002) and GEO-3 (UNEP 2002), but added emphasis on the importance of social-ecological systems for human well-being (Bennett et al. 2005). The MA included local and regional scenarios, but these were not integrated with the global scenarios (Lebel et al. 2005). More recently, the Representative Concentration Pathways (RCPs) (Van Vuuren et al. 2011) and Shared Socioeconomic Pathways (SSP) (O'Neill et al. 2017) were developed to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation for IPCC assessments, and have subsequently been used to address other environmental issues such as biodiversity loss (Kim et al. 2018; Chaplin-Kramer et al. 2019). While these scenarios have helped scientists and decision-makers to conceive plausible pathways at global levels, they need elaboration to continue to be useful (O'Neill et al. 2020; Pielke and Ritchie 2021).

Most GEAs make use of top-down scenarios quantified by Integrated Assessment Models (IAMs), and as such have particular strengths and weaknesses. These models provide a coherent assessment framework that includes different subsystems of the human-Earth System (e.g. the economy, energy, ecosystems, etc.) and their interactions via explicit causal links. As such, IAMs can assess impacts of changes in key drivers and analyze trade-offs between social, economic, institutional and ecological developments. Furthermore, they may sometimes be able to address the system inertia that plays a big role in preventing environmental improvements (Hamilton et al. 2015). The ability to simulate system linkages explicitly and quantitatively is both a strength and a weakness of such 'top-down' oriented scenarios. On the one hand, quantifying system dynamics forces scenarios to be internally consistent and plausible. On the other, it constrains their ability to represent disruptive innovations (technological, economic or social) or the consequences of abrupt and persistent shifts in the structure and function of different subsystems (e.g. ecological regime shifts, see Rocha et al. 2018) and social imaginaries that include factors like arts, politics, gender, and lifestyle (Bendor 2018). Such features of IAM-quantified scenarios mean that these scenarios are relatively silent on underlying transformative changes in governance or economic systems, or the roles of different societal actors in change processes (Hajer et al. 2015). Additionally, the link between global insights generated from GEAs and local decision-making is often weak and poses a major challenge for the science-policy interface

(Kok and Veldkamp 2011; Vervoort et al. 2014; Frame et al. 2018).

Several alternative methodologies exist to develop scenarios ranging from participatory to expert-driven and from global to local levels (Van Vuuren et al. 2012a; Wiek and Iwaniec 2014; Oteros-Rozas et al. 2015). There are many examples of scenarios developed for and with local and regional decision-makers, and other stakeholders, that are aligned with their interests and needs (Biggs et al. 2007; Oteros-Rozas et al. 2015). They often engage in creative exercises that can enable radical and inspiring visions of the future, as well as drawing on imaginative tools for articulating these stories, including art (Bendor et al. 2017; Galafassi et al. 2018), multimedia (Hajer and Pelzer 2018), science fiction prototyping (Merrie et al. 2018) and role-playing games (Villamor and Van Noordwijk 2016). However, the scalability of these local insights into global context, and transferring them from one region to another, is challenging because they are not designed with such upscaling and transferability in mind.

Given the increased scale, speed and connectivity of changes in the Anthropocene making the world generally more unpredictable (Nyström et al. 2019), GEAs face certain challenges in how to provide decision-makers with insightful information about potential futures that draw on the strengths of all the above approaches. Based on the authors' combined interdisciplinary experience across multiple GEAs over the past 2 decades including those of the IPCC and IPBES, the 2005 Millennium Ecosystem Assessment, and UNEP's GEO, we propose that GEAs will need to address the following four challenges, acknowledging that these may not be exhaustive and other challenges may arise:

- (1) Anticipate unpredictable future conditions (Surprise);
- (2) Be relevant across multiple scales and decision-making levels (Scale);
- (3) Include diverse actors, perspectives and contexts (Diversity); and
- (4) Leverage creativity to inspire action (Imagination).

Whilst significant in themselves, these become major challenges when, as in the case of GEAs, they need to be addressed together to provide a full assessment of options to address complex social-ecological problems. In the next section, we describe each challenge and related literature, and then outline recent developments in futures-oriented approaches (not just scenarios) that together have the potential to address the challenges. In section 4, we outline how this toolbox of futures approaches can help identify which approaches are most suitable for specific questions, thus allowing for

the most appropriate suite of tools to be combined for a new generation of GEA scenarios.

3. Four key challenges and ways to address them

Surprise: Anticipating complex dynamics and unpredictable future conditions

Scenarios describe possible futures. However, the longer scenarios stretch into the future, the more difficult these futures become to describe. This is because aspects of the future are emergent and cannot all be known in advance, resulting in surprises (Bennett et al. 2021). Surprises occur in the form of unexpected behaviours or nonlinear, rapid events (Schneider 2004), and history has many examples of such ‘black swans’ – which are events that come as a surprise and often have major effects (Taleb 2007). Some recent examples include the financial crash of 2008 (Schweitzer et al. 2009; Haldane and May 2011) and the Arab Spring (Gause 2011), which were largely unexpected, but had significant implications for global geo-politics. The 2020 COVID-19 crisis shows that, even though the risk of a pandemic was well known, the complexity of the global socio-economic system makes the response to the virus outbreak largely unpredictable. Similar dynamics can be expected in addressing sustainability challenges that GEAs assess. For example, the extent and intensity of human impacts on various ecosystems (IPBES 2019) reduces the capacity of these ecosystems to absorb these impacts, leading to unanticipated, often nonlinear, behavior in social-ecological systems (Filbee-Dexter et al. 2017).

Surprises are inherently difficult to identify in advance and to represent quantitatively because the mechanisms (e.g. emergent behaviours, cross-scale dynamics etc.) that give rise to surprise are also challenging to foresee and difficult, if not impossible, to capture within contemporary modeling capacities (Planque 2016). Scenario analysis in GEAs therefore tends to assess the system’s response to predetermined and quantifiable surprises, rather than exploring the possibility for truly surprising events to emerge in the future. Models that rely on the representation of system behaviour based on past observations may not be fit for purpose in these cases as, by definition, surprise events will behave very differently from the past. This is illustrated by the uncertainties in models used to project climate change (Shiogama et al. 2016; Soden et al. 2018) and biodiversity loss (Thuiller et al. 2019). Moreover, surprise is not limited to changes in conditions or parameters defining modelled scenarios, but could emerge in the form of unpredicted transformation within the system, rendering the model itself obsolete. In order to account for surprise, GEAs need to move beyond models that rely mainly on the representation of system behaviour based on past observations. Surprise

events will be very different from the past, and so in order not to project more certainty than is deserved, more diverse tools are needed (Carpenter et al. 2009; Saltelli et al. 2020). Tools that engage creative thinking can be employed to help overcome this constraint, including narrative-based scenarios (Bennett et al. 2003; Reilly and Willenbockel 2010). Narratives can more easily incorporate imagination and are not bounded by knowledge of systemic relationships and other constraints (Merrie et al. 2018).

Developments that could help address this challenge

The Story and Simulation (SAS) approach suggested by Alcamo (2008) is a useful starting point for connecting the benefits of narratives with the constraints of models. Such approaches that combine qualitative narratives with quantitative simulations have been used in various model-based scenario development activities (e.g. SRES by Nakicenovic et al. 2000). Storylines on their own have also been proposed as a specific approach to representing uncertainty even in biophysical aspects of climate change (Shepherd et al. 2018). Models can serve as a potential check on assumptions embedded in qualitative narratives (Booth et al. 2016) by assessing whether particular relationships do in fact lead to the emergent futures expected, or whether there are potential unexpected constraints or other effects. Similarly, narratives can also serve as a check for assumptions embedded in models by assessing their applicability in particular contexts. By integrating narrative and quantitative based approaches in this way, scenarios can help explore a broader range of different possible eventualities (Alcamo 2008).

A complementary intervention to ensure that quantitative modelling and simulation does not constrain the role of surprise in the scenarios is through the use of wild cards. A wild card is ‘a future development or event with a relatively low probability of occurrence but a likely high impact’ (Steinmüller 2004, p. 195). Wild cards have four main uses in scenarios: 1) to estimate the susceptibility of a scenario to external disruptions, 2) to compensate for potential weak points in the conceptual framework of a scenario, 3) to help recognize alternatives and be open-minded in regard to unexpected developments and, finally, 4) to counteract certain widespread faults in scenario design, such as a shortage of imaginative capacity, the predominance of wishful thinking or a fixation on catastrophic scenarios (Steinmüller 2004). Incorporating wildcards into scenario processes can help make the resulting output more robust to the uncertainties of the future, but is also important future capacity building techniques that force participants and those engaging with the scenarios to entertain potentially radical ideas about how the future could unfold. With this in mind, they can be used to assess opportunities for enabling transformative change within the system (Walsh et al. 2015).

Scale: Incorporating actionable information across multiple scales and decision-making levels

Although a growing body of literature has identified the challenges and possibilities associated with developing cross-scale scenarios (Biggs et al. 2007; Kok et al. 2007; Zurek and Henrichs 2007; Mistry et al. 2014; Mason-D’Croz et al. 2016; Rosa et al. 2017), the literature has mostly focused on re-scaling global scenarios to fit regional and local applications (Kok et al. 2016; Häyhä et al. 2016; Mason-D’Croz et al. 2016; Palazzo et al. 2017). Most scenario work has created consistent, coherent or comparable scenarios at smaller scales, representing downscaled approaches to multi-level scenarios, but there is little work in upscaling bottom-up insights. Such downscaling exercises are mainly useful for providing the implications of the global context to national or local decision-makers, without considering local contexts. In contrast, bottom-up approaches that aggregate dynamics driving change at local scales into higher-scale scenarios are less common (Pilli-Sihvola et al. 2015; De Toledo et al. 2017; Hsu et al. 2019). The creation of global scenarios based on bottom-up approaches is limited to a few examples, such as the Seeds of Good Anthropocenes initiative (Pereira et al. 2019d), and the MIT Climate Co-Lab (Malone et al. 2017).

Additionally, current bottom-up approaches tend to focus on aggregating local, present-day practices, and less on exploring future local visions or pathways. Addressing this gap can offer opportunities to highlight potentially transformative changes that are locally driven, which would otherwise be missed by ignoring context. It may also attract new coalitions of actors and locally successful paradigm-breaking technologies and practices. Moreover, the local scope allows participatory scenarios to have concrete narratives and storylines that can feature the interest and experience of specific actors and governance systems. Scale challenges are also horizontal, requiring understanding of how changes in different places around the world impact each other (e.g. telecoupling effects) (Lenzen et al. 2012; Liu et al. 2016). Addressing horizontal challenges highlights the impacts of an intervention in one distant place on another, or the impacts of increased demand for materials from one place on another. Overcoming these scaling and interdependency challenges requires the use of top-down and bottom-up approaches in a complementary way.

Developments that could help address this challenge

Much can be learnt here from the work on multi-scale assessments of social-ecological systems that conduct an assessment at two or more discrete scales, and cross-scale assessments, which deliberately look for cross-scale interactions (Scholes et al. 2013). Achieving coherent analysis across multiple

scales is dependent on the rationale for why the specific scales were chosen and a consideration of the scale-related properties of the phenomena being assessed, paying attention to the ways in which information and control pass between scales (Scholes et al. 2013). The most common approach is for global scenarios to provide the framing and boundaries for local and regional scale scenarios. For example, Zipper et al. (2020) employed the planetary boundary concept from (Rockström et al. (2009) to calculate fair shares and define a local safe operating space to guide sustainable water management at local and regional levels. The holistic approach they used allows for considering physical, political, commercial and socio-economic aspects of water availability, demand, access, etc at sub-national to global level. Another innovative approach is proposed by Aguiar et al. (2020) to co-design new and alternative narratives for top-down (target-seeking) global scenarios. Through a multi-stakeholder process capturing multiple sub-global perspectives on pathways to sustainability, the approach seeks to surface convergences, and crucially, divergences between global and regional perspectives on pathways to reach the SDGs to develop new global narratives that better reflect core debates and tensions in the society.

In developing global scenarios, specific attention can also be paid to identifying and incorporating known and potential cross-scale effects, such as cascading financial, disease or supply chain shocks between highly connected places. In contrast, local and regional scenarios can include an initial step that reviews and scans the broader global context for potential effects that could reshape local dynamics and incorporate these into local storylines. This can help prevent local scenarios from being overly specific and missing larger-scale transformative changes such as the emergence of new technologies or shifting values that can fundamentally reshape local dynamics. For example, the bottom-up Manoa mash-up scenarios developed for southern Africa specifically included the potential effects of emerging technologies such as artificial meat production and CRISPR gene editing technology to consider their effects on the regional environment, economy and society (Hamann et al. 2020). Comparisons of scenarios developed using similar frameworks or goals can provide useful insights between different places and across scales, and highlight where there are major differences in key driving forces and the ways in which they play out (e.g. GEO-6 and IPBES sub-global assessments). For the biodiversity community, the development of the Nature Futures framework is intended to provide such a coherent structure for cross-level scenario development and comparison (Pereira et al. 2020).

Diversity: Including diverse actors, perspectives and contexts

Potential future scenarios and pathways will be based on combining existing with new and emerging initiatives (Arthur 2011). Diversity of experiences and examples adds more nuance, detail, creativity, and transformative potential to scenarios by incorporating a wider range of existing solutions, proven practices and tested technologies (Bennett et al. 2016). Diversity can also refer to the need to include a variety of actors and their perspectives (Pereira et al. 2019b). For example, global scenario studies that assess the potential impact of reducing global meat consumption (e.g. Springmann et al. (2018) often have little consideration for biocultural context – suitability of crops and livestock production is not necessarily exchangeable.

A bottom-up, inclusive approach that includes indigenous and local knowledge and encourages equal participation and iterative learning among diverse actors should allow for the emergence of alternative narratives to contrast with more generic, dominant ones (Leach et al. 2010; Luederitz et al. 2017), but is hard to do in practice (Scoones et al. 2020). Such joint learning among actors with diverse perspectives is associated with building the capacity for collective action and inspiring the necessary behavioural changes for transforming to sustainable futures (Norström et al. 2020). While this plurality of – often conflicting – perspectives is fraught with tensions and interpersonal dynamics, a well-facilitated social process can generate narratives that highlight potential points of conflict, actively seeking to understand their broader implications through analysis of different scenarios, and negotiating solutions that are well informed of the local context (Freeth and Drimie 2016; Van Kerkhoff et al. 2019).

Developments that could help address this challenge

New thinking and approaches that recognize the interconnectedness of equity and sustainability as well as the multiple perspectives and dimensions involved in pathways to think these through are urgently needed (Leach et al. 2018). In participatory futures work, tools such as the Three Horizons can be employed as a means by which to hold these multiple views of transformed futures within one process (Sharpe et al. 2016). Such simple heuristics that allow for conflicting views to be equally appreciated and noted down in a process is one important way to ensure that diversity is maintained. For example, even when there is disagreement about the specifics of future visions or pathways, the heuristic allows for all of these to be captured by virtue of everyone's sticky note being included on the diagram, and so alternative viewpoints can literally be kept on the

same page without forcing a group to choose a specific option (See for an example Pereira et al. 2018; Raudsepp-Hearne et al. 2019; Falardeau et al. 2019). Learning from scenario processes that are explicitly designed to address conflicting perceptions offer insights as to possible methods for rating different pathway options, such as by employing multiple criteria as was done in the case of land use planning in the Argentinean Chaco where different scenarios were rated for sustainability and environmental justice (Zepharovich et al. 2020). Actively working to include marginalized voices in futures processes is vital to addressing current global inequities and ensuring that pathway diversity truly represents all possible alternatives- not just the conventional 'highways', but also the less recognised 'footpaths' that tend to be overlooked as they are the solution space offered by the most vulnerable (Leach et al. 2010).

Incorporating diversity into sustainability scenarios can also be facilitated by the development of systematic databases that capture both local conditions for sustainability as well as a selection of potentially transformative initiatives to achieve the SDGs. Crowd-sourced, on-line systems, such as the aforementioned Seeds of Good Anthropocenes and MIT Climate Co-Lab databases mobilise the involvement of thousands or tens of thousands of participants in the aggregation of local practices and scenarios. Such processes can be extended into applications for collecting data, such as with the Android application Urbanopoly that seeks to collect information on urban environments (Celino et al. 2012). Such systematically collected databases, designed for inclusivity across different local contexts in the world, can be used in a combinatorial and imaginative way and have the potential to bridge bottom-up and top-down scenarios. Inspiration can also come from generating a large number of interactive scenarios online (Dunagan 2012), using agent-based modelling that allows for quantitative incorporation of dynamics at the resolution of individual or groups of actors, and can be deployed up to the global scale (Rounsevell et al. 2014; Schulze et al. 2017; Lippe et al. 2019; Schlüter et al. 2019). Such bottom-up modelling approaches would benefit GEAs because they can quantitatively model emergent properties from individual and local activities, and would complement IAMs (Schlüter et al. 2019).

Imagination: Using creativity to inspire action despite conditions of complexity and uncertainty

Some scenario efforts primarily extrapolate existing trends rather than exploring the potential transformative changes based on new ways of thinking and doing (Pereira et al. 2019c). In the face of global sustainability

challenges, it is difficult to imagine all feasible alternatives and pathways into the future (Bendor 2018). For example, the impacts of the steam engine on society would have been impossible to imagine for a person living in a medieval village, despite the fact that the ‘seeds’ of this future had existed since Hero of Alexandria first captured the power of steam in the first century A.D. Unpacking the implications of how the future will unfold is not simply about being able to anticipate surprises, but is also about using the power of human creativity to imagine how possible future worlds may unfold; both utopian and dystopian. This important component is often neglected in assessments, but is increasingly being recognised as critical for improved decision-making about the future of the planet (Wyborn et al. 2020).

The use of scenario planning can broaden perceptions, reduce the propensity for bounded rational thinking and lead to development of innovative options (Bodin et al. 2016). Creative scenario co-development processes that promote imagination and create an opening for more empathetic responses offer important complementary tools within the suite of methodologies used in scenario development (Pereira et al. 2019c). Building such anticipatory governance capacities can enable more conducive environments to allow for the achievement of alternative transformation pathways that are required to meet the multi-generational challenges of global environmental stewardship and sustainable development (Vervoort 2018).

Developments that could help address this challenge

The ability to inspire imaginative thinking at larger scales should be a central focus when considering how bottom-up scenarios can be developed (Vervoort 2019). A key set of examples for such an approach comes from game-based digital structures for large-scale collectives of future storytellers with online groups of thousands or tens of thousands of players, such as World Without Oil (ITVS 2007), Superstruct (ITF 2008; Egan 2008), Foresight Engine (Dunagan 2012) and Fort McMoney (Dufresne 2013). UNEP and Sony PlayStation have also co-created an immersive virtual reality experience about climate change to challenge lack of awareness about the scale of individual emissions by allowing users to live a lifestyle compatible with limiting global warming to 1.5°C, above which the threats of climate change become increasingly devastating (Patterson and Barratt 2019). Such approaches combine structured scenario development with imaginative exploration of future narratives. They offer inspiration for the aggregation of local scenarios, as well as for creating local scenarios from initiatives as ‘pockets of the future in the present’. A new iteration

of this type of digital, game-based bottom-up approach integrates massively multi-player futuring with physical environments (cities) to create and connect thousands and potentially many more small scenarios as exemplified by the Utrecht2040 game (UU 2019).

Imagination can be augmented in scenario approaches by using creative processes such as storytelling, or science-fiction prototyping (Milkoreit 2016; Merrie et al. 2018), and experiential futures and games (Candy and Dunagan 2017; Vervoort 2019). Using imagination as an approach offers possibilities to facilitate the creation of narratives and visions in visual and interactive ways (Milojević 2017; Moore and Milkoreit 2020). Models can potentially demonstrate the technical and economic feasibility of these imaginative transformation scenarios/pathways where applicable.

4. The toolbox

Having outlined the challenges and potential solutions for addressing these in the previous section, here we propose a toolbox of futures approaches that could be useful in GEAs depending on the specific outcome that they seek to achieve. We argue that harnessing the complementarities between top-down and bottom-up scenario approaches would be a substantial step towards a next generation of GEA scenarios that can better address the challenges of surprise, scale, diversity, and imagination. Developing ways to combine under-utilized and novel, but high potential scenario approaches in ways that make them more comparable, transparent, and accessible will allow for opportunities for closer integration with more traditional scenario approaches. A review by Muiderman et al. (2020) across research communities engaging with futures and anticipatory governance describes a typology of aims that generally underlie scenarios research. Three of these are relevant for GEAs: 1) risk assessment and mitigation; 2) exploring diverse, possible futures to enhance preparedness; and 3) collectively envisioning desirable futures. The first, risk assessment and mitigation provides insights to guide decision-making to reduce future risks, and it needs in particular to deal with the challenge of cross-scale dynamics and surprise. The second, exploring diverse, possible futures allows decisions to be made more robust by considering the future from many different, and surprising perspectives. The third, collectively envisioning desirable futures can potentially galvanise action to help create more positive futures. Core challenges for achieving this aim are engaging people’s imagination and embracing the diversity of their positive futures perspectives.

We organized scenario methods using the four challenges and three aims presented above to

Table 1. Summary of how different methods might offer unique and complementary contributions to multi-scale scenarios, based on different aims.

Main outcome	Risk reduction *surprise *scale	Preparedness *surprise *diversity	Action mobilisation *diversity *imagination
Approach	Aim 1: To assess risk of probable futures	Aim 2: To explore multiple possible futures	Aim 3: To co-create desirable futures
Top-down contributions (deductive)	<p>project probable futures using existing data</p> <p>generates a set of potential futures based on specific known drivers using basic rules, can generate complex, emergent patterns based on individual agent choices</p> <p>helps bring discounted or underestimated future risks to life</p>	<p>quantify scenarios of diverse futures</p> <p>draws on expert knowledge to generate a wide diversity of ideas about what futures could happen based on present drivers</p> <p>offers a range of plausible global scenario logics with clear assumptions</p> <p>can be developed with diverse participants informing agent choices rather than model assumptions in order to open up a more diverse potential futures based on actual decision-making behaviours</p> <p>allows users to pre-experience and practice for complex changes, challenge limited conceptualizations of futures experientially</p>	<p>quantify different solution-oriented pathways to achieve the same goal</p> <p>produces a range of what desirable goals for what the future could be, using available knowledge</p>
Bottom-up contributions (inductive)	<p>IAMs^a</p> <p>Expert-driven scenarios^{b,c}</p> <p>Scenario archetypes^d</p> <p>Agent-based modelling; Multi-agent simulation^{e,g}</p> <p>Gaming;</p> <p>Virtual Reality; Augmented reality;</p> <p>Experiential futuring^h</p> <p>Participatory scenariosⁱ</p>	<p>scenarios can be developed and tested for likelihood.</p> <p>generates possible futures from diverse perspectives and sectors</p> <p>represents highly diverse futures from different perspectives and sectors</p>	<p>co-creates desirable futures based on the perceptions of participants and what needs to be done to get there</p> <p>includes diverse actors in creating visions of the plurality of desirable futures</p>
Methods that can be adapted across multiple scales	<p>generates a desired end state for a plan that can be tested for feasibility</p> <p>produces a diversity of challenging futures based on science fiction concepts.</p>	<p>generates possible futures from diverse perspectives that are not necessarily based in present concerns</p>	<p>describes a diversity of radical science fiction inspired futures based on different notions of desirability</p>
Science fiction prototyping ^{k,l}			

Illustrative references: ^a(Van Vuuren et al. 2012b), ^b(Cork et al. 2005), ^c(O'Neill et al. 2017), ^d(Hunt et al. 2012), ^e(Sitas et al. 2019), ^f(Helbing and Balierti 2013), ^g(Lindkvist et al. 2020), ^h(Vervoort 2019), ⁱ(Oteros-Rozas et al. 2015), ^j(Wiek and Iwaniec 2014), ^k(Milkoreit 2016), ^l(Merrie et al. 2018).

capture how the complementarity of approaches can be used to improve various aspects of environmental decision-making (table 1). We have divided these into more top-down (deductive) approaches and more bottom-up (inductive) approaches with a third category that can be used at multiple levels. Different scenario methods and tools can be used to achieve multiple aims whilst the same future methods can originate from alternative perspectives and be used for different purposes to produce a variety of results. Note that these methods are not mutually exclusive categories and that many futures outputs already cut across one or more methodological approaches (e.g. expert-driven scenarios that are also archetypes or participatory scenarios that make use of science-fiction prototyping). This preliminary toolbox is not exhaustive, and we urge futures experts to add and expand on the outline that we have proposed. Further development is necessary on approaches to bridge the bottom-up and top-down perspectives.

We hope the preliminary toolbox presented in table 1 will encourage researchers and practitioners to improve their scenarios practices and develop this toolbox further. We believe the approaches identified in this table could enable GEAs to maintain their existing functions, while better incorporating the diverse demands of sustainability policy, strategy and investment planning across scales and sectors. Given the urgency of sustainability challenges, we would recommend that rather than being seen as a starting point for policy engagement, GEAs offer the opportunity for promoting impactful cases and sustainability pathways that can be further enabled by transformative policies and investments at local, national, regional and global levels. Such an extended mandate is not a new suggestion (Hulme et al. 2011), but in this paper we offer a specific means by which to move in this direction, starting with identifying a package of tools to navigate the uncertainty of the future in different ways. This does not just mean integrating and combining approaches, but, it also means recognizing, and integrating different aims with which futures are explored, from risk assessment to navigating a wider range of plausible futures to imagining new, desirable future worlds (Muiderman et al. 2020).

Historically, the scientific communities that support the development of bottom-up and top-down approaches have been working independently of one another. To bridge this gap and to maximize the benefits of connecting diverse scenario approaches, GEAs can serve as a catalyst to develop the trans-disciplinary capacity required to think and work across issues, sectors and scales. As has been evident in writing this paper with an author group with a diverse set of expertise, differences in the perspectives of those working across disciplines and scales in GEAs run deep and require close collaboration and shared learning to be successful. This, in turn, means

that time and resources should be made available for such collaborative and participatory learning and innovation in developing GEAs and resulting information, as has been reinforced in the intergovernmental assessment community (Obermeister 2017; Vadrot et al. 2018). Furthermore, it requires a fundamental commitment by decision-makers and those actors calling for global environmental assessments to support such novel processes. The politicisation of assessments, including their negotiation, can often hinder more creative attempts to provide novel insights by the authors. However, there is indication that there is appetite for more novel approaches to allow for greater usefulness. The UNEP GEO-6 report was unique in its attempt to bridge more ‘bottom-up’ approaches with modelling (Asrar et al. 2019) and the Nature Futures Framework that has been developed by the IPBES task force on scenarios and models (Pereira et al. 2020) offer hope that more flexibility is possible.

5. Conclusion

Achieving global sustainability, including multilateral environmental agreements and their associated targets, requires urgent and large-scale transformations of current socio-economic systems and their governing policies (IPCC 2018; TWI2050- The World in 2050 2018; GSDR 2019; IPBES 2019; UNEP 2019). Global sustainability goals, such as those set by the SDG process and the Paris Climate Agreement, are mobilizing societal actors from local to global scales toward this end (Hsu et al. 2019). This has resulted in the need for research to answer the kinds of complex questions, such as those posed in the introduction. However, these are not straightforward projections into the future and as such, require new approaches to provide actionable information to decision-makers. Similarly, requests are being made of GEAs to be able to assess this research and thereby better inform stakeholders about how to enable transformations toward a sustainable future (Díaz et al. 2019).

GEAs are powerful tools in mobilising the international policy community towards taking coherent decisive actions towards a more sustainable future. However, in order to reach their full potential, they need to be able to offer clear options of how to move towards a diversity of better futures, grounded in actions from the local to the global. This requires a fundamental reconfiguration of how scenario analyses have been conducted in GEAs up to this point. This call to action for future research intends to engage a broad range of scientific and action-oriented knowledge, perspectives and opinions about towards a more just and sustainable future and potential pathways to get there. The implementation of the futures toolbox is a starting point to

provide relevant information for practitioners to make better informed decisions about how to achieve a sustainable future.

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