The Future in Anthropocene Science

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Conflict of Interest

None.

Data Availability and Code Availability

All data used in this analysis is found in the article.

Abstract

The Anthropocene is the present time of human-caused accelerating global change, and new forms of Anthropocene risk are emerging that society has hitherto never experienced. Science and policy are grappling with the temporal and spatial magnitude of these changes, as well as the diminishing margin between science and policy itself. However, there is a gap in the transparency — and perhaps even in the awareness — of the profound role that Anthropocene science plays in shaping the structure and possibility of our future world. In this work, we explore three broad categories of Anthropocene science, including international energy scenarios, climate change projections, and the possibility of social collapse. These cases exemplify three key features of Anthropocene science: worlding capacity, values shaping what is possible, and refusal to consider all options. We discuss how Anthropocene science modulates new risks and systematically, though perhaps inadvertently, entrains certain social-ecological futures. We find that clarity in these three attributes of Anthropocene science could enhance its integrity and build trust, not least in the arena of public policy. We conclude with recommendations for improving the interpretability and scope of Anthropocene science in the context of a growing urgency for accurate information to inform our collective future.

1 Introduction

1.1 The Anthropocene context

The scale and scope of human driven environmental change in the twenty first century is without precedent (Masson-Delmotte et al., 2021). Humanity is unequivocally a planetary force changing the entire Earth system, leading to the recognition of our present time of the Anthropocene — the human epoch (Zalasiewicz et al., 2017). Over the next 50 years, global climate will be pushed well outside humanity's evolutionary experience (Steffen et al., 2015). Critical ecosystem services (that provide food, fiber, reliable water, etc.) are directly threatened by these changes (IPBES, 2019). Moreover, such changes will be permanent, at least as far as humanity is concerned (Clark et al., 2016). The planetary boundaries concept has emerged as a touchstone for understanding where key thresholds in the Earth system may exist, and the extent to which humanity has or has not pushed past these thresholds (Rockström et al., 2009). Currently, five of the nine planetary boundaries have been transgressed beyond what is considered a dynamically stable state (Persson et al., 2022; Wang-Erlandsson et al., 2022).

In an effort to make sense of the new types of risks that emerge in the Anthropocene, Keys et al (2019) introduced the notion of Anthropocene risk (Keys et al., 2019). This introduction primarily arose from a recognition that the stationarity of the Earth system is no longer a relevant baseline against which to consider future events (Milly et al., 2008), and the reality that many framings of systemic risk do not explicitly point to humanity as the culprit. Anthropocene risks are driven by anthropogenic changes in the Earth system, are characterized by globally intertwined social-ecological systems, and they give rise to complex cross-scale interactions from local to global, and from immediate to deep time.

In the midst of Anthropocene risks, much of humanity is rightly aiming to improve their quality of life, which is subsequently contingent on an intact and functioning Earth system (O'Neill et al., 2018). Globally, the notion of sustainable development has informed coordinated policies, most recently in the form of the United Nations Sustainable Development Goals (SDGs) (Sachs et al., 2020). The 17 integrated and comprehensive SDGs are stratified into more than 100 targets and indicators, which are then tailored to country and development specific contexts. The SDGs include topics focused on human health (e.g., SDG2, SDG3), economic well-being (e.g., SDG1, SDG8), and ecological conservation (e.g., SDG14, SDG15).

Despite the ambition of the SDGs, there is an irreconcilable conflict between scientific inquiry into the transgression of Earth system boundaries and the industrially-derived models of development informing global development policy (Hickel, 2019). All aspirational models of successful development, at least at the national scale, are rooted in highly extractive and carbon intensive activities (Fanning et al., 2020). Equally important, is the recognition that the rich world is simultaneously responsible for much of the acceleration of the Anthropocene, and it became rich through the historical disposition of land and resources of communities globally

(Byravan & Rajan, 2010; Callahan & Mankin, 2022). Additionally, concepts of sustainable development are necessarily normative, as the social notions and values that compose its definition—those related to ideas of nature, equity, quality of life, material wealth—are contextually and culturally specific (Anderson, 2016; Inoue & Moreira, 2016; Lafferty & Langhelle, 1999; Langhelle, 1999; Okereke, 2007). The political and ethical aims of sustainable development—including the goal of a high quality of life for all—are critically important. To make this goal possible, however, culturally-specific work is needed alongside more extensive legal and political changes to chart the radical transitions of nearly all industrial sectors that such goals will require (IPCC 2022).

And yet, destabilization of both Earth and social systems in the Anthropocene is already visible in the present day. For example, the number of hours that can be worked outdoors by a person under safe temperatures have been steadily decreasing over the past three decades. These decreases are not distributed equally around the world, such that countries with very low human development have seen the greatest impacts while countries with high human development have seen fewer impacts. Yet the interconnectedness of our modern economy connects distant parts of the planet in tightly coupled feedbacks (Guillén, 2015). Likewise hunger and food insecurity are, for the first time in decades, on the rise (United Nations, 2022). Moreover, the mismatch of policies that are commensurate with the challenge of transforming our world are equally visible (Ripple et al., 2022). For example, global fossil fuel production is unequivocally misaligned with the trajectory that would be necessary for sustainable energy sector transformations (SEI et al., 2021). The inevitable outcome is an increased turbulence in the rhythms of planetary, ecological, social, economic, and political realities (Homer-Dixon et al., 2015). This turbulence creates a discontinuity, such that the future cannot be reasonably approximated based on either the past or the present (Albert, 2020).

In the Anthropocene, then, we have entered a context with unprecedented environmental conditions combined with uncertain trajectories of human societies, and these factors complicate our models and projections about the habitability of the Earth system and the expected life of ecosystem services needed for diverse populations into the future. As we attempt to produce knowledge about the Earth focused on improving human well-being, Anthropocene scenarios have become one of the most useful and powerful forms of knowledge creation able to guide the actions and decisions of global governments and institutions in the present. Our study examines the particular strengths and intricacies of producing Anthropocene scenarios, and it proposes new methodologies and interpretive practices that must accompany this form of knowledge creation.

1.2 Tasks for 21st century Anthropocene science

To understand the Anthropocene, and the inevitable turbulence arising, the scientific community actively explores the future with conceptual and empirical models, i.e., simplified representations used for the purposes of understanding something (D. H. Meadows, 2008). Scenarios can be understood as pathways along which key variables of interest are allowed to change in testable, interpretable, and perhaps trustworthy ways. In addition to modeling the Earth system, scientists have now recognized the need to model human actions at a meta-scale. While the task of modeling large-scale, cultural dynamics and behavioral patterns has not been a component of nearly any mainstream scenario process of Earth system science in the past, developing "social climate models" is now becoming a component of Anthropocene science (Moore et al., 2022).

These demands create a unique agenda for Anthropocene science, which is related to but distinct from Earth system science. Recently launched in 2022, the new academic journal "Anthropocene Science" provides a clarifying definition of the emerging field: "Anthropocene Science is defined as a transformative human-environmental science based on traditional and modern knowledge systems, technologies, applications, and nature-friendly practices ingrained in ethics, plural values and positive behavioral changes for planetary stewardship" (Abhilash et al., 2021). Simply, Anthropocene science can be described as the science that studies the new conditions of the Earth system in which humanity is a forcing agent.

Distinguishing Anthropocene science from Earth system sciences is instructive. While the practices of Earth system sciences align more directly with scientific standards of disinterested/objective practice, Anthropocene science is overtly tasked with answering questions about humanity's survival and providing guidance for human actions and interventions. Anthropocene science requires value-based determinations and produces more prescriptive claims. Such statements are necessarily shaped by normative frameworks and social values—notions of community, economy, ethics, etc.—that are folded into the models for future scenarios, often without critical reflection or framing. While Anthropocene scenarios combine projections and interpretive decisions in different ways for different questions and audiences, their epistemological dimensions remain poorly articulated in the science itself. As a result, critical blindspots exist in many such scenarios where the values that guide their creation, exploration, and implementation are unstated and invisible to the end users, if not unstated and invisible to the scenario creators themselves (Pulkkinen et al., 2022) (Fig1, 'Refusal to look').

The stakes for how Anthropocene science and science-informed scenarios are produced, circulated, and acted upon could not be higher. The future trajectory of the Earth system now depends directly on what humans decide to do now (Clark et al., 2016; Steffen et al., 2018), and human decisions in the present are being influenced and guided by the scenarios and knowledge claims this field of inquiry is producing. In other words, Anthropocene scenarios – given the interpretive content they contain and proliferation of authoritative institutions producing them – are themselves becoming a worlding activity, in which the separation between the production and implementation of such information is steadily eroding (Fig 1, 'Worlding potential'). This merging of scientific analysis and prescriptive action is made more consequential by virtue of both the accelerating changes of the Anthropocene and the acceleration of this worlding process.

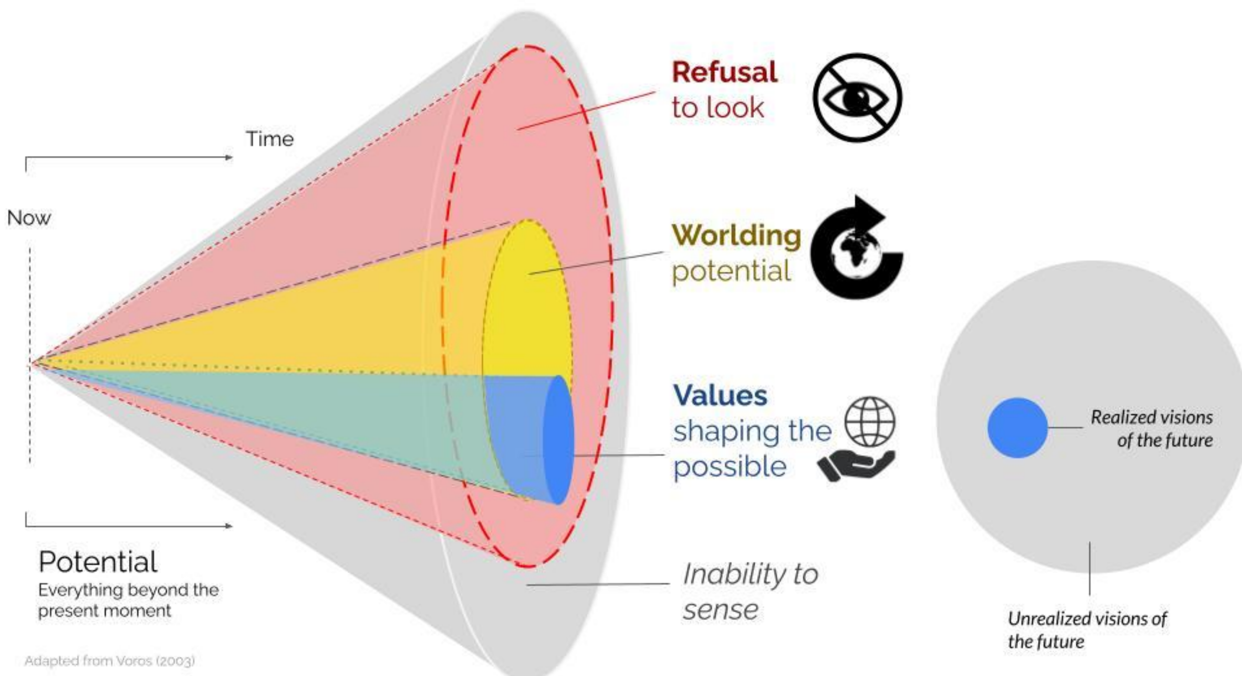


Figure 1. The three Anthropocene Scenario Challenges (i.e., A) worlding potential, B) values shaping possibility space, and C) refusal to look at certain possibilities) modulate the type and character of the scientific questions that are asked and answered (futures cone adapted from (Voros, 2003).

In this work, we articulate how numerous societal decisions in the present are being influenced and guided by Anthropocene scenarios. Anthropocene scenarios require numerous interpretive decisions about how to model aggregated human behaviors and cultural forces that are relevant to the Anthropogenic drivers that affect the planetary system. At the same time, Anthropocene science is being called on to provide prescriptive pathways for human action to explicitly inform policy decisions in the present. Given these demands, Anthropocene science and policy now interact with an exigency and reciprocity than seems exceptional in comparison to the broader science-policy interface. We claim that a limited set of normative perspectives are dominantly privileged in Anthropocene science, and, consequently, certain futures are entrained while many alternatives are omitted (Fig1, 'Values shaping the possible'). We argue that foundational assumptions, situated perspectives, normative frameworks, and interpretive decisions informing the future scenarios of Anthropocene science require explicit framing and critical reflection in the science itself.

2. Scenario case studies

Here, we discuss three examples of Anthropocene scenarios, and discuss the specific topics of worlding potential, values shaping the possible, and the refusal to look at certain potential futures.

2.1 Case Study: International Energy Agency fossil fuel forecasts

The International Energy Agency (IEA) is an independent, intergovernmental institution that produces data and projections to inform political and economic decisions regarding the energy sector. The United Nations, national policy directors, banks, corporations, and oil companies themselves all rely on the IEA's key publications, such as the World Energy Outlook, to inform strategic decision-making and financial investments (Hatch, 2021). Given the authoritative status of the IEA, the statements and projections it publishes about the energy sector influence financial investments in energy and directly shape the trajectory of the sector itself. The impact of the interpretive decisions made by the IEA when crafting their projections was clear in 2021, when a major shift in the IEA's modeling choices resulted in a new projection that caused a reciprocal rupture in the fossil fuel industry.

Since its founding in 1974 to 2020, the IEA had primarily based their projections of future fossil fuel demand on historical trends of energy demand, or "business-as-usual" energy practices, combined with expected future population increases, industry growth, and more. Such projections rely on many normative assumptions and modeling choices regarding social inputs, such as assumptions about the timescales of technological transition, the continued lack of legal consequence for the environmental externalities of fossil fuel extraction and use, a continued social and political tolerance of the fossil fuel industry, and a conservative picture of human behavior change (Gies, 2017). In other words, it makes normative assumptions about the legal, political, and social conditions that underwrite the fossil fuel industry's current markets and practices. Indeed, the IEA's projections have long been criticized for essentially green lighting the unchecked expansion of fossil fuel development, by presenting authoritative projections about increasing future fossil fuel demands, which encourage fossil fuel investments without critically situating the normative political and legal assumptions their projections make regarding the industry (Beer, 2021; Hook et al., 2021; Smith, 2021).

In 2021, however, the IEA made an intentional decision to work with a different set of foundational assumptions for their key projections. In what was described in the press as "a stunning evolution," the IEA created its projections by backcasting from the SDGs, which had immediate economic and legal effects (Beer, 2021). Rather than extrapolating from historical trends, the IEA worked back from the aspirational state of planned decarbonization of the energy sector. With this change in the modeling practice, a very different conclusion was reached from the analysis (Fig 2). Referencing their 2050 net zero emissions roadmap published in May 2021, the IEA publicly declared: "There is no need for investment in new fossil fuel supply in our net zero pathway. Beyond projects already committed as of 2021, there are no new oil and gas fields approved for development in our pathway, and no new coal mines or mine extensions are required" (International Energy Agency, 2021).

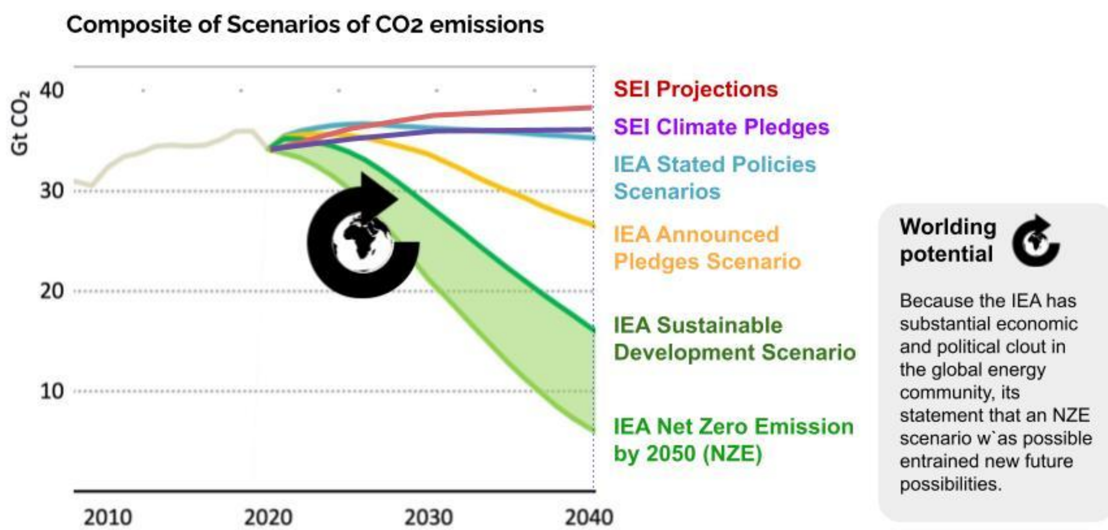


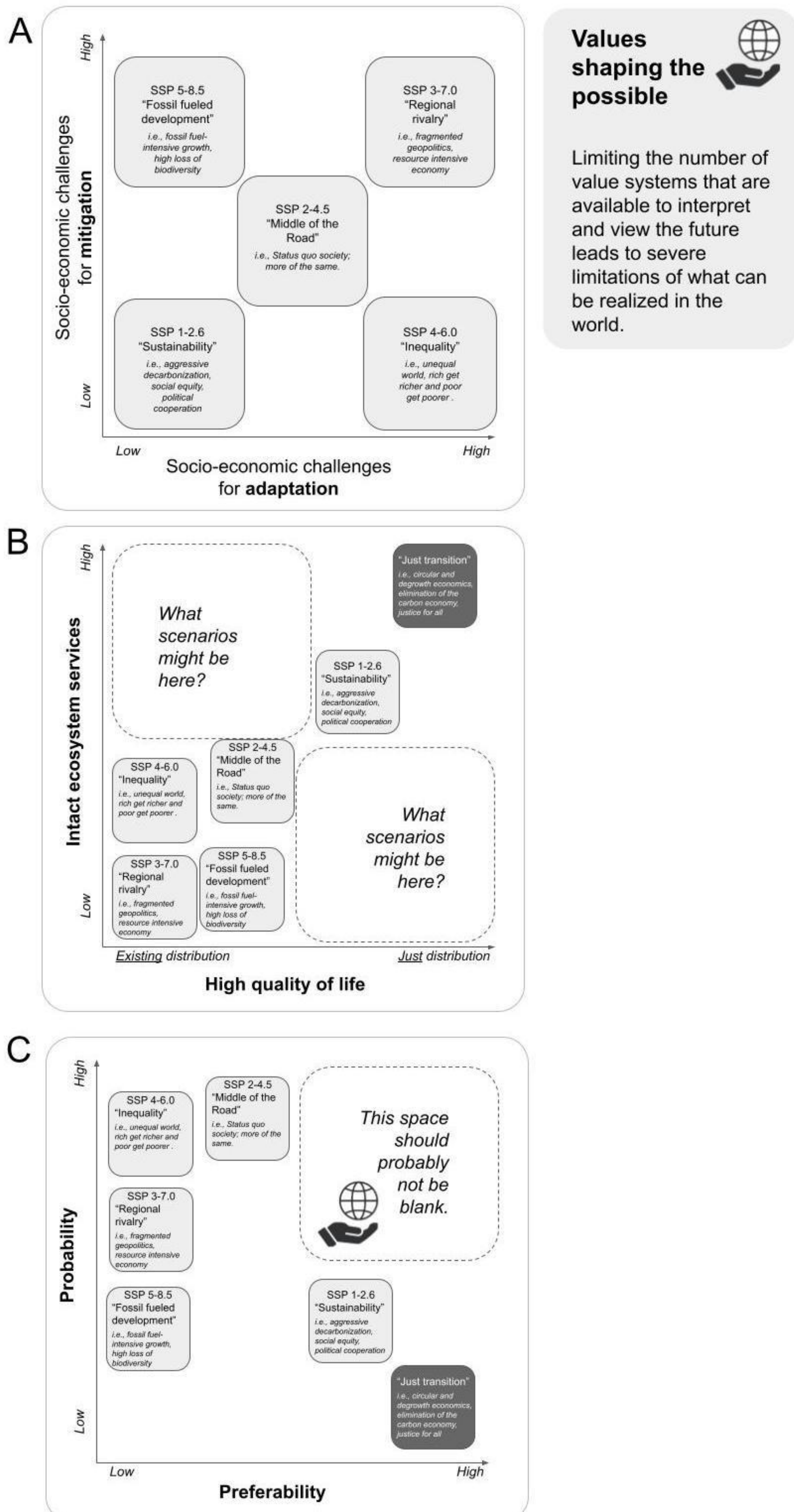
Figure 2. Comparison of IEA scenarios of potential annual carbon emissions, compared against projections of carbon emissions based on planned fossil fuel production. The worlding icon (from Fig 1), indicates the demonstrated potential for IEA to change the international perspective of the potential for a future low-carbon economy. Adapted from (SEI et al., 2021).

With much coverage in the mainstream press, this statement marked not only a change in the IEA's analysis but a fundamental reversal in mission for an "organization that has spent four decades working to secure oil supplies for industrialized nations" (Smith, 2021). Rather than bolstering continued fossil fuel development, the IEA's announcement had immediate consequences upon publication for gas prices, investments, and social-political support of the fossil fuel industry (Beer, 2021; Hatch, 2021; Smith, 2021). With this report, the IEA recast the fossil fuel industry in the present by amending the interpretive decisions that shaped its statements about the future of the industry. Most significantly, these projections further eroded fossil fuel corporations' social license to operate under business-as-usual practices. The IEA's report was published weeks after a Dutch court in The Hague (the site of the U.N.'s International Court of Justice) ordered Shell Oil to reduce is carbon emission by 45% by 2030. It was described as a "cataclysmic day for oil companies," that is "basically changing ... what Shell is at the core" (Carrington, 2021; Oroschakoff et al., 2021).

The stark reversal of the IEA's energy projections resulted from the interpretive decisions it made in constructing their statements about the future of aggregate human behaviors. These choices were political as much as they were analytic. Energy scenarios are, in reality, highly interpretive and crafted extrapolations. As a result, the IEA's status as a leading authority, its resources for conducting comprehensive data analysis, and its network of relationships at the highest levels of government and finance (in other words it's *worlding capacity*), their statements spurred actions that directly impacted the future scenario they were claiming to describe. Given the increased feedback loops between aggregate human behaviors and the Earth system, the interpretive choices that shape future scenarios can have strong effects on the actual future of planetary conditions. While the IEA is beginning to acknowledge these choices, it is important to situate the IEA's claims alongside other forecasts of energy development that reflect neither the normative scenario lens of the IEA, nor the resultant magnitudes of fossil fuel extraction over the coming decades (SEI et al., 2021).

2.2 Case Study: Shared Socioeconomic Pathways

Scenarios have been a cornerstone of climate-change research for nearly half a century. They help explore how societal actions will drive future changes in climate and the impacts of these changes on society. The recently developed Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) framework represent the most comprehensive effort yet to explore future interactions among socio-economic and climate systems (Riahi et al., 2017). The SSPs are a set of storylines that describe plausible ways in which demographic, economic, technological, social, environmental and governance aspects of society will change over this century. In combination with a range of future emissions pathways encapsulated by the RCPs (van Vuuren et al., 2011), the SSP-RCP scenarios are deployed to determine both future emissions and the diverse societal costs that will be incurred and averted in achieving different climate targets. While many plausible future scenarios can be conceived, a limited set has been prioritized by the Intergovernmental Panel on Climate Change's Sixth Assessment Report. These five scenarios include, on the one end, a sustainably developing world with low levels of planetary warming (SSP1-RCP2.6) and, on the other, a world where unbridled fossil fuel use drives development and intense climate change (SSP5-RCP8.5) (Fig 3). To conceptually organize the SSPs, the original presentation of the SSPs requires a two-axis graph describing increasing challenges to climate change adaptation on the x-axis, and increasing challenges to climate change mitigation on the y-axis (Fig3a).


A
High
Low
Socio-economic challenges for **mitigation**
SSP 5-8.5 “Fossil fueled development”
i.e., fossil fuel-intensive growth, high loss of biodiversity
SSP 3-7.0 “Regional rivalry”
i.e., fragmented geopolitics, resource intensive economy
SSP 2-4.5 “Middle of the Road”
i.e., Status quo society; more of the same.
SSP 1-2.6 “Sustainability”
i.e., aggressive decarbonization, social equity, political cooperation
SSP 4-6.0 “Inequality”
i.e., unequal world, rich get richer and poor get poorer .
Low
High
Socio-economic challenges for **adaptation**
Values shaping the possible
Limiting the number of value systems that are available to interpret and view the future leads to severe limitations of what can be realized in the world.
B
High
Low
Intact ecosystem services
What scenarios might be here?
“Just transition”
i.e., circular and degrowth economics, elimination of the carbon economy, justice for all
SSP 1-2.6 “Sustainability”
i.e., aggressive decarbonization, social equity, political cooperation
SSP 2-4.5 “Middle of the Road”
i.e., Status quo society; more of the same.
SSP 4-6.0 “Inequality”
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What scenarios might be here?
SSP 3-7.0 “Regional rivalry”
i.e., fragmented geopolitics, resource intensive economy
SSP 5-8.5 “Fossil fueled development”
i.e., fossil fuel-intensive growth, high loss of biodiversity
Existing distribution
Just distribution
High quality of life
C
High
Low
Probability
SSP 4-6.0 “Inequality”
i.e., unequal world, rich get richer and poor get poorer .
SSP 2-4.5 “Middle of the Road”
i.e., Status quo society; more of the same.
This space should probably not be blank.
SSP 3-7.0 “Regional rivalry”
i.e., fragmented geopolitics, resource intensive economy
SSP 5-8.5 “Fossil fueled development”
i.e., fossil fuel-intensive growth, high loss of biodiversity
SSP 1-2.6 “Sustainability”
i.e., aggressive decarbonization, social equity, political cooperation
“Just transition”
i.e., circular and degrowth economics, elimination of the carbon economy, justice for all
Low
High
Preferability

Figure 3. Three conceptual arrangements of potential scenarios of climate change include, (A) the existing framework for the Shared Socioeconomic Pathways (SSPs), B) an alternative arrangement that incorporates planetary and human well-being, and C) an alternative framework that emphasizes normative preferability and scenario plausibility based on the inertia of social, political, and economic systems.

The SSPs were conceived as equi-probable pathways, even if the specifics of the worlds they represent may make some of them less desirable (e.g., SSP3). Similarly, given their path-dependence, some scenarios now seem less probable based on ongoing changes in the energy sector (e.g., SSP5-RCP8.5). Yet, the existing literature that explores future risks and opportunities in sectors as diverse as ecosystem conservation and water security, shows a preponderance of scenarios exploring the consequences of extreme pathways such as SSP5-RCP8.5. Exploring impacts of extreme climate change projected under the SSP5-RCP8.5 scenario is critical to understanding the full range of socio-ecological system sensitivities. However, within the logic of the SSP-RCP framework, this level of heating is achieved via a pathway that is improbable at least from anthropogenic greenhouse gas emissions alone ((Hausfather & Peters, 2020; Pielke & Ritchie, 2021)). The mischaracterization of this scenario as representing a business-as-usual future world has been widely discussed and has been traced to expediencies arising from the political, media and scientific spheres (Hausfather & Peters, 2020; Pielke & Ritchie, 2021). Scenario studies that compare an SSP2-RCP4.5 future against an SSP5-RCP8.5 one are common. These studies inevitably convey that the 'real' business-as-usual scenario (SSP2-RCP4.5), where the world breaches targets set under the Paris agreement, is preferable to one where extreme climate change results from an unlikely energy future.

There is also the additional dissonance introduced by the placement of the SSP5-RCP8.5 scenario in the quadrant representing high mitigation and low adaptation challenges. The implicit assumption that supports labeling SSP5-RCP8.5 as having "low adaptation challenges" is that given enough economic gains, it would be possible to adapt to a world that is 3 to 5 degrees Celsius warmer, even as studies warn of widespread and adverse impacts to natural systems, ecosystem services, and human health at those levels of global heating (Martens et al., 2022).

SSP1 on the other hand is outlined as an optimistic scenario where global sustainable development results in low challenges to adaptation and mitigation. The emphasis on the global adoption of sustainable growth pathways however sidesteps the question of environmental justice, which forms the primary axis along which nations of the Global South seek to parse global mitigation responsibilities (Althor et al., 2016). Developed nations have made the largest cumulative contributions to atmospheric greenhouse gas accumulations, whereas developing nations are expected to bear the brunt of climate change impacts (King & Harrington, 2018). This emphasis is even more striking given that the unprecedented adoption of sustainable lifestyles alone is not enough to limit warming to 1.5 or even 2 degrees (Rammelt et al., 2022). Meeting these targets requires the deployment of yet unproven negative emissions technology with consequences for land-based livelihoods (NASEM, 2019). For example, an SSP1-RCP2.6 world will see large losses in pasture land owing to a global decline in demand for meat and increases in areas under trees and BECCS (Bioenergy with Carbon Capture and Storage; (Dooley et al., 2018; Popp et al., 2017)). What does this assume about pastoral livelihoods, food traditions and food security of people in the Global South?

The SSP-RCP scenarios present complex descriptions and projections of future societal and climatic conditions. While they are presented and treated as value-free scientific objects, these scenarios were developed in part to ascertain challenges associated with meeting the goals of the Paris Agreement — a document that enshrines the global consensus on what constitutes a livable future world. Yet, none of the scenario storylines, and associated policy assumptions capture the political contestations (e.g., just transitions and Common but Differentiated Responsibilities) that lie at the heart of the Agreement, or entrain ideas of global transformation that deviate from global, extractive development (Hickel et al., 2021; Keyßer & Lenzen, 2021). These scenarios are indeed a work in progress and their current form reflects their authors' attentiveness to critiques of previous climate scenario development efforts and recent policy needs (Pedersen et al., 2022). Consequently, inferences drawn based on the use of these scenarios must acknowledge both their transitory nature and the particular worldviews they inadvertently entrench.

2.3 Case study: Limits to growth and societal collapse

The breakdown of systems — whether geophysical, ecological, or social — has been a latent theme in Anthropocene science for more than half a century. Notions of crisis and collapse have been employed to explore and explain the current phase of human society (Guillén, 2015; Homer-Dixon et al., 2015; Orlov, 2013; Raskin & Swart, 2020; Tainter, 1988). Many of these crises or collapse theories are rooted in the idea that contemporary, complex human societies require considerable energy (e.g., cheap abundant high-density energy, such as fossil fuels) to both (a) grow bigger and to (b) maintain existing complexity (West, 2018). Specifically, as societies become ever more complex, more and more of the available energy must be devoted to servicing the extant complexity, with less available for servicing additional growth. Following this framework, when the energy expenditure for maintaining complexity exceeds the supply of energy, collapse may occur (Homer-Dixon, 2010).

Early scenarios of collapse faced substantial skepticism (Bardi, 2011; Nordhaus, 1973). One of the earliest systems-based analyses of contemporary society projecting crisis and collapse in the mid-21st century, was the Limits to Growth (D. H. Meadows et al., 1972). Though the original work used relatively simple models, especially by today's standards of Integrated Assessment Models (van Beek et al., 2020), the trajectory of human development over the past 50+ years has followed closely the so-called "standard" run, akin to a business-as-usual scenario (D. L. Meadows & Randers, 2012). Importantly, this business-as-usual scenario forecasted a convergence of resource depletion and corresponding societal crisis somewhere between 2030 and 2060. Other work, using entirely different approaches, appear to have come to similar conclusions regarding a global crisis arising in the mid-21st Century (Johansen & Sornette, 2001). Contemporary reviews of the original Limits to Growth thesis, updated with data from the past 50 years, have shown that the original simulations remain robust and useful scenario analyses (Herrington, 2020). This is noteworthy in part because, so few contemporary integrated simulations of global society appear to depict mid-21st century crises. This absence of crisis in simulations may arise from assumptions about continued prosperity and economic growth (e.g. economic convergence) in the core set of integrated assessment models used to depict possible 21st century trajectories of human society (Buhaug & Vestby, 2019). This assumption of economic growth reflects a broader set of worldviews, and indeed latent values, regarding human society (Ritchie & Dowlatabadi, 2017).

Given the anticipated turbulence of the Anthropocene, increasing scientific attention may need to be focused on scenarios of cascading crises, social-ecological collapse, and socio-economic breakdown (Homer-Dixon et al., 2015; Scheffer & Carpenter, 2003; United Nations, 2022). Raskin and Swart (2020) identify the "continuity bias" (also called "normalcy bias" in disaster studies, e.g., Omer and Alon (1994)) in integrated global models that serve to emphasize "Conventional worlds" dominated by social, political, and economic forces that are familiar, such as the Shared Socioeconomic Pathways (Fig 4). However, Raskin and Swart argue that there is some evidence of a much broader set of scenarios including those that would lead to thriving ecosystems and societies (e.g., what Raskin and Swart call "Great Transitions", and what we call "Transformations"), as well as the potential for trajectories of crisis and collapse (e.g., what Raskin and Swart call "Barbarization", and what we call "Breakdown of systems").

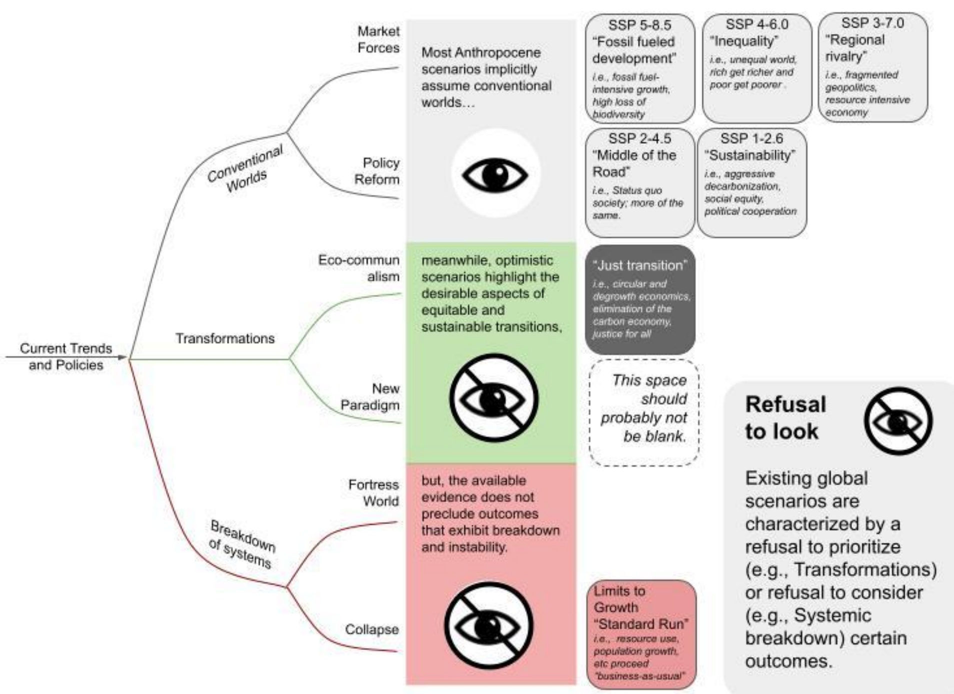

Figure 4. Adaptation of the Tellus Global Scenarios framework, including the three branches of 'conventional worlds', 'great transitions', 'and 'barbarization', along with the subsequent branches. We overlay this with examples of SSP climate scenarios, a proposed normative scenario (from Fig 2), and an additional example in the Barbarization branch using the "Standard Run" from (Herrington, 2020; D. H. Meadows et al., 1972; D. L. Meadows & Randers, 2012; Turner, 2008).

In this midst, surfacing the values and ethics that have hitherto implicitly shaped the structure and character of scenarios will become increasingly necessary. This is crucial to both recognize the constraints of what can be reasonably expected from a given scenario, as well as providing interpretive guardrails of how to appropriately use these ideas. For example, if a set of collapse scenarios depict human hardship in a way that requires trade-offs among different aspects of well-being, it will change the interpretation of these scenarios to know whether the scenario creators are coming from a perspective that values all of humanity equally, or perhaps views some groups of people as more important than others.

3. Discussion

3.1 Critical reflections on Anthropocene scenarios

When the worlding capacity of Anthropocene science is revealed, it becomes clear that ethically problematic outcomes may arise, both scientifically and in our material reality. For example, the IEA report detailed earlier, illustrates the surprising potency of powerful actors shaping our world based on claims about the future framed as fact. While undoubtedly the IEA's evidence is supportive of their scenarios, the claims they put forward are infused with a normative perspective about what should and should not happen in the future. More broadly, a challenge for Anthropocene science is that such normative perspectives are not typically made plain.

Yet, acknowledging the social values and interpretive decisions that shape scenario projections will enable more accurate and objective interpretation of their findings. A methodological disclosure of the social assumptions and preferences used to construct the models by which scenarios are produced will increase the impartiality of their findings (Fig 5). Acknowledging the interpretive elements of scenarios will simultaneously allow for an expansion of the conceptual possibilities that can enter into public discourse. For example, rather than working solely from assumptions about industrially derived habits as the endpoints of development, analysts could responsibly entertain a wider range of scenario possibilities precisely because these alternative social models will be made explicit as part of the framing. It is only by acknowledging the situated and locatable conditions of scenario statements that an impartial discourse and inquiry can proceed (Haraway, 1988).

Anticipating the potential for collapse locally, regionally, or globally would change the expectations we have for Anthropocene scenarios. Yet, systematically excluding these possibilities has hampered policy discourses in the present. It is imperative that the plausibility of scenarios is communicated in a way that is honest and reflects the best understanding that we have of both the past as well as the predictable features of the future. Given that it is now widely understood that "stationarity is dead" (Milly et al., 2008) and that the past no longer adequately predicts the future, we must cultivate a greater capacity for anticipation of crises and collapse.

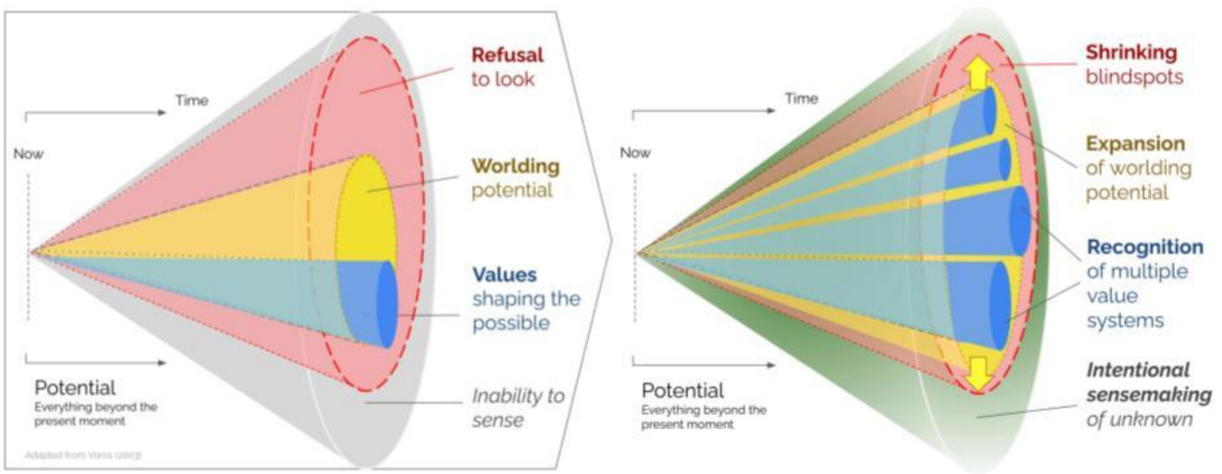

Figure 5: Updated futures cone of possibility, with a wider range of futures ultimately considered by recognizing multiple value systems, expansion of worlding potential, deliberate reduction of blind spots, and intentionally attempting to make sense of the unknown.

3.2 Recommendations for the future in Anthropocene science

This work illuminates several key under-discussed features of Anthropocene science, and we offer several recommendations that aim to enrich scenario scholarship. First, we recommend a methodological addition to Anthropocene scenario publications and research that articulates the normative dimension(s) of the scenario authors. Such an addition could also permit greater clarity in what the scenario is and is not examining. It is common in academic work to include a section on assumptions and limitations of research, and this includes scenario research. However, Anthropocene scenario science has yet to methodologically examine the assumptions it makes in modeling aggregate human behaviors and systems, such as in emerging "social-climate" system models. For example, if a scenario process excludes indigenous perspectives and knowledge systems, or it assumes a continuation of linear over circular economies, this should be clearly articulated and justified.

Second, we recommend transparent presentation of the creators, funders, and intended audiences of scenarios. Such a practice could make explicit the motivations that undergird the construction of our future reality. In practical terms, the scenarios that we have and that currently shape our reality are generally created by powerful individuals, organizations, and nations, and in general these sets of people are disinclined to upset the status quo. But the IEA powerfully demonstrated that a group with power can decidedly change the status quo narrative. For example, what would it mean to have globally relevant scenarios that are endorsed by organizations like the IPCC or others, which actually de-center capitalism? What would it mean to seriously include sets of degrowth-based economic projections to inform the next round of climate change futures?

Third, we recommend that Anthropocene science needs to truly grapple with the tension between our accelerating geophysical, social and technological world and the metaphorical bill that is coming due, in the form of ecological tipping points, ocean systems that can no longer absorb our waste, and geophysical trajectories from which we cannot turn back. For Anthropocene science to deliver useful information it will need to confront the incompatible reality of our economic systems and the biogeophysics of our world. This means radically changing if not transforming the types of assumptions that structure large scale scenarios of the future. This means challenging underlying economic paradigms, which structure in a mathematical sense, the types of realities that models can produce. This is not to say that our economic systems have not delivered prosperity in the past or the present. But we ought to recognize that many of our current economic systems have also delivered society to our present-day calamities.

4. Conclusions

In this work, we argue that Anthropocene science must function differently in our world. This is a massive scale effort, because it requires transforming not just the philosophy of scenario production, but the personnel, infrastructure, and institutions that perform this science. This requires scaling-up new disciplines that merge novel economic thinking such as circular and degrowth economics, with the most cutting-edge science around ecological and geophysical stability. And this is not a task for one or two academic departments around the world. This is a task that requires buy-in from the highest levels of government and international organizations, both to legitimize and to structure efforts such that they are cooperative and complementary (Homer-Dixon et al., 2022). Such a task acknowledges both the necessity and complexity of integrated assessment modeling and that large knowledge gaps exist, in part, because of the specialization that is required in designing, running, and analyzing scenarios that are already in existence. It could be that it is time to invigorate existing integrated assessment models with new specializations that are needed to broaden the scope and inclusion of the ideas that are incorporated into the models. Finally, we call for a further expanded scope for interdisciplinary Anthropocene scenario science. While our small group of authors represent a broad range of perspectives including sustainability, atmospheric science, ecology, and the environmental humanities, more voices must be heard. Likewise, we hope that this perspective inspires new communities of scholarship to contribute and possibly feel legitimacy as they enter debates and dialogues about the future of humanity.

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