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Enhancing the policy relevance of scenarios through a dynamic analytical approach

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In environmental change research, dominant approaches for using scenarios involve selecting a small number and treating each as a distinct 'parallel universe'. Often, this is done for the purpose of contrasting projections, where alternatives are distinguished by different policy choices in comparison to a reference, or 'business as usual' case. However, a general shortcoming of this approach is that the wide variety of future uncertainties is inspected *ad hoc* leaving many uncertainties and potential risks un-investigated.

We suggest that the *ad hoc* nature of such studies constrains their policy relevance, since it can easily be argued that such studies are not comprehensive. Additionally, the practice of contrasting a few scenarios originates from a tradition where the analytical objective is to convey irreducible uncertainty, as multiple renditions of the future can be equally compelling. However, in order for sustainability science to retain its policy relevance, we argue that it is important for future-oriented research to move beyond basic heuristics. Instead, more value may come from adopting risk analytic perspectives, where the conditions for policy failure are identified, or the analysis is tasked with uncovering less biased scenarios. To this larger discussion, we add that more sophisticated scenario analyses could also potentially improve our scientific understanding of dynamics for complex systems. It is evident that such systems pose challenges for conventional scenario analysis, as it is virtually certain over multi-decadal time horizons that future reality will diverge from any long-term projections provided by some small number of scenarios. This is because discontinuities characterize the evolution of human and natural systems. Thus an analytical perspective that focuses on studying the conditions for such discontinuities may be a substantial improvement for the policy relevance of sustainability research.

In this article, we demonstrate a new dynamic approach to scenario analysis for sustainability science, which addresses the aforementioned shortcomings. The new approach is characterized by three main innovations. First, we explored more of the space of possible futures through hundreds of scenarios (432) that were derived systematically rather than through only a few contrasting cases. Second, we applied a time-varying scenario typology, which enabled the inspection of scenario evolutions. Through such an inspection, scenarios with particularly policy-relevant behaviour (such as desirable stability) were isolated. Third, statistical data mining techniques were applied to the policy relevant scenarios to uncover their common drivers. This yielded insights on particular conditions that were consistent with certain scenario behaviours.

We applied this three-part approach to socioeconomic scenarios for climate change research generated by an integrated assessment model, IMACLIM-R. We utilized the new framework for Shared Socioeconomic Pathways (SSPs), which are to be combined with Representative Concentration Pathways (RCPs). SSP and RCP combinations enable comprehensive analyses of greenhouse gas mitigation effort as well as vulnerability to a changing climate. The SSPs are a timely case and furthermore require that scenarios represent one of five types, which are defined by their relative socioeconomic *challenges to mitigation* or *challenges to adaptation*. Mitigation and adaptation challenges may co-vary (i.e. low, medium, or high challenges, which are SSPs 1-3), or they may not (i.e. high adaptation challenges coupled with low mitigation challenges (SSP4), or high mitigation challenges coupled with low adaptation challenges (SSP5)). In our analysis of scenarios with the SSP framework, we measured mitigation challenges by global CO2 emissions and adaptation challenges by the GDP per capita of low-income countries.

We developed visualizations of the evolution of the 432 scenarios from our database through the SSP typology space dynamically over the years 2001-2090, and found general patterns for the stability of each of the SSP types. We defined stability according to whether a scenario classified as a particular type of SSP in the short term (through 2020) retained its classification over the long-term (through 2090). A majority of scenarios (55%) are not stable according to that definition, which shows that, even in the absence of exogenous shocks, scenarios are not all diverging from the “middle-of-the-road” and bifurcations are common. SSPs where challenges to mitigation and adaptation co-varied were generally more stable than mixed-outcome SSPs. The SSP with low mitigation and adaptation challenges (SSP1) was the most stable, while the SSP with high-mitigation challenges and low-adaptation challenges (SSP5) was the least stable. Focusing on scenarios ending in the SSP1 domain, a “desirable” endpoint, we used the PRIM algorithm to uncover their main drivers. The analysis revealed energy-sober behaviors as a necessary condition. This driver allows to both a decrease of emissions (because energy consumption is lower) and an increase of growth (because lower basic needs for energy services and lower energy prices allow households to consume more final goods for a given budget, triggering a change of structure of the economy towards more labor-intensive sectors and amplifying the effect on GDP) compared to the “middle-of-the road”. Focusing on scenarios starting in the SSP5 domain, we used the PRIM algorithm to understand the main drivers behind the instability of these scenarios. We found most scenarios starting in the SSP5 domain drift over time and end in SSP2 or SSP4 domains. The latter are characterized by high growth drivers (labour productivity increase and catch-up), low coal availability, energy intensive behaviors and low energy-efficiency. These scenarios have a relatively high “potential” growth (due to fast convergence), and experience fast growth in the short term but growth is slowed over time by the conjunction of high energy prices and high energy demand. The high energy prices force the reduction in economic activity, hence a reduction in emissions through a volume/affluence effect. These scenarios are archetypes of the “carbon lock-in story” and its economic negative effect in the long-term.