International Environmental Modelling and Software Society (iEMSs)
7th Intl. Congress on Env. Modelling and Software, San Diego, CA, USA,
Daniel P. Ames, Nigel W.T. Quinn and Andrea E. Rizzoli (Eds.)
http://www.iemss.org/society/index.php/iemss-2014-proceedings

Enhancing the policy relevance of scenarios through a dynamic analytical approach

Céline Guivarch[a,b], Vanessa Schweizer[c,d], Julie Rozenberg[b]

a Ecole des Ponts ParisTech, Champs-sur-Marne, France (guivarch@centre-cired.fr)
b Cired, 45bis avenue de la belle Gabrielle, 94736 Nogent-sur-Marne, France (rozenberg@centre-cired.fr)
c National Center for Atmospheric Research (NCAR), Boulder, CO, USA
d Centre for Knowledge Integration, University of Waterloo, Waterloo, ON, Canada (vanessa.schweizer@uwaterloo.ca)

Abstract: We present a new dynamic analytical approach for studying scenarios produced by an integrated assessment (IA) model. Our approach involves the analysis of a large number of scenarios, which can better address three principal shortcomings of how uncertainty is traditionally handled in IA scenario studies. The shortcomings are all a result of the prevailing practice of investigating a small number of scenarios and include (1) the ad hoc nature of exploring vast socioeconomic uncertainties with only a small number of scenarios; (2) the conventional representation of alternative scenario typologies as "parallel universes" or "diverging universes", which provide little insight on possible socioeconomic conditions that could lead to bifurcations or trend reversals. These shortcomings may inhibit the policy relevance of IA scenario studies. As an analytical approach that may improve the situation, we describe and demonstrate a dynamic method for analysing large numbers of scenarios and provide an example application using the framework for Shared Socioeconomic Pathways (SSPs), which are new socioeconomic scenarios being developed for future climate change research. We systematically tested alternative assumptions for an IA model parameters to generate a database of scenarios and classified them as consistent with each of the five SSP typologies. We then develop a visualization of their evolution through the SSP typology space dynamically over the years 2001-2090. We found that the dynamic analytical approach can reveal the influence of socioeconomic conditions that change the scenario typology classification of individual scenarios over time. Explanations for such scenario behaviour could be highly policy relevant.

***Keywords**:* large number of scenarios; dynamic approach.

1. BACKGROUND

In environmental change research, dominant approaches for using scenarios involve selecting a small number of scenarios (EEA 2009, Rounsevell and Metzger 2010) 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 (Lloyd and Schweizer 2013, Schweizer and Kriegler 2012). 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 (e.g. Lempert 2013), or the analysis is tasked with uncovering less biased scenarios (this from a statistical perspective, e.g. Morgan and Keith 2008). 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[1]. 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.

2. METHODOLOGY

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 that were derived systematically rather than through only a few contrasting cases (Rozenberg et al. 2014; orders of magnitude more have been explored by Schweizer and Kriegler 2012, Schweizer and O'Neill 2014). 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 (Waisman et al., 2012). Imaclim-R endogenizes the evolution in energy demand and represents the links between the evolutions in technical systems, consumptions behaviors and economic growth.
We generate a database of scenarios by systematically varying assumptions for values of 7 groups of model parameters (or scenario drivers):

1. Parameters regarding economic growth of the leader country (3 alternatives: low, medium or fast)
2. Parameters regarding the convergence of low-income countries (3 alternatives: low, medium or fast)
3. Parameters on the rigidities of labour markets (2 alternatives: low rigidities or high rigidities)
4. Parameters on the availability of coal and unconventional liquid fuels (2 alternatives: low availability or high availability)
5. Parameters regarding energy consumption behaviours (2 alternatives: energy-sober or energy-intensive)
6. Parameters regarding induced energy efficiency (3 alternatives: slow globally; fast in rich countries but slow catch-up in low-income countries; fast globally)
7. Parameters on the availability of low carbon technologies (2 alternatives: low availability or high availability).

The combinations of these alternative assumptions generated 432 scenarios.

We utilized the new framework for Shared Socioeconomic Pathways (SSPs; O'Neill et al. 2014, Ebi et al. 2014), which are to be combined with Representative Concentration Pathways (RCPs; van Vuuren et al. 2011). SSP and RCP combinations enable comprehensive analyses of greenhouse gas mitigation effort as well as vulnerability to a changing climate (van Vuuren et al. 2014). 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 (Figure 1). 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

[1] Probabilistic scenario approaches are an improvement to the comparison of a few deterministic cases. However, concerns about overconfidence (Morgan and Henrion 1990) for the ranges and probability distributions of parameters may remain.

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 to map the scenarios into the SSP space (Figure 2).

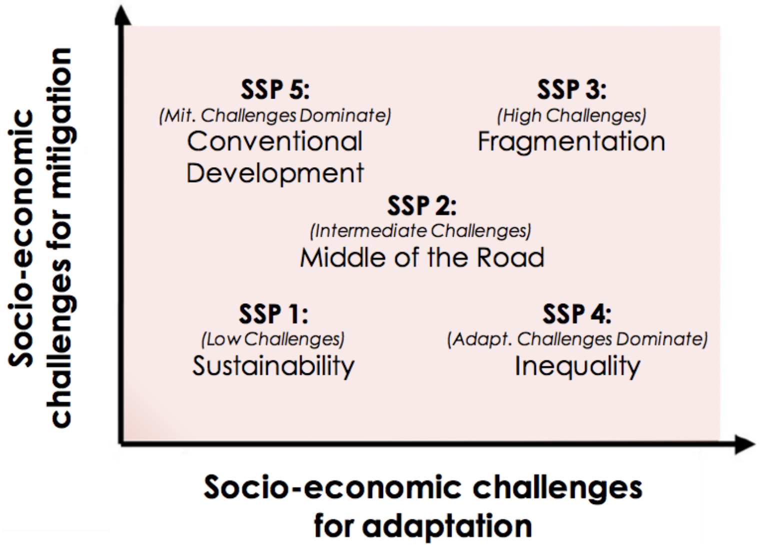

Figure 1. The SSP scenario space and five scenario typologies (from O'Neill et al. 2011).

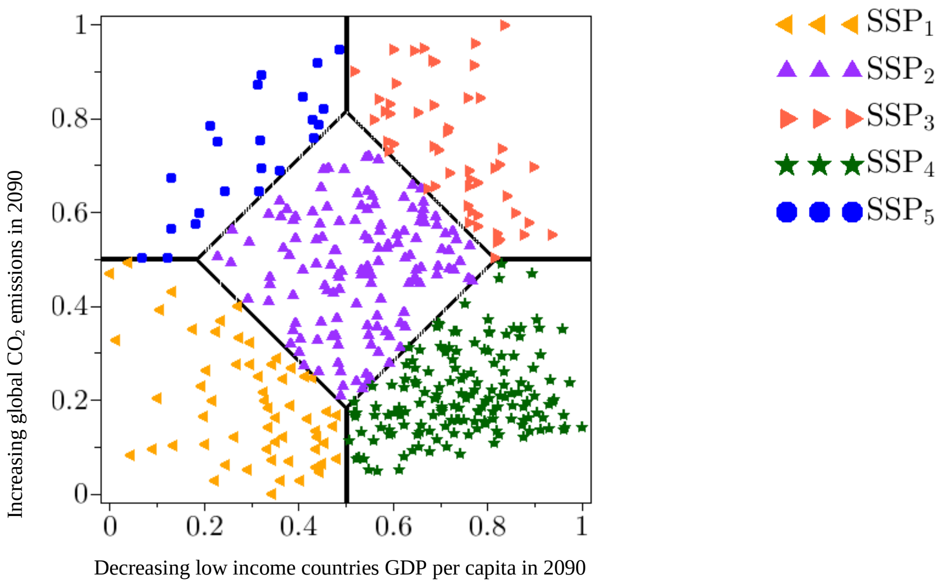

Figure 2. Mapping of 432 IMACLIM-R scenarios into the SSP scenario space.

3. RESULTS

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 2025) retained its classification over the long-term (through 2090) (Figure 3).

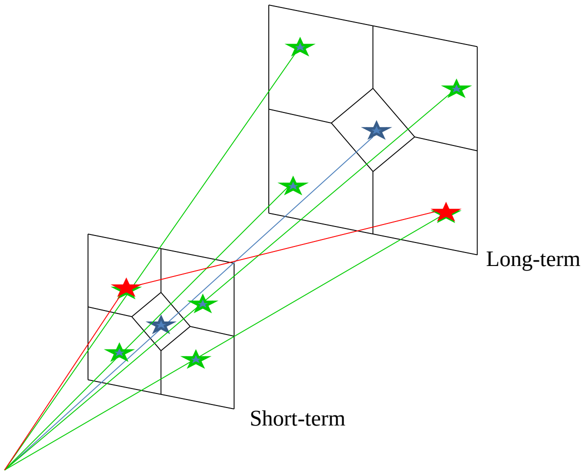

Figure 3: A scenario, classified as a particular type of SSP in the short term (through 2025), is stable if it retains its classification over the long-term (through 2090).

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.

	Leader growth	Low income countries catch up	Unconventional fossil fuels	Behaviors	Energy efficiency	Availability of low carbon technologies	Labour rigidities in low income countries
Stable 1		(Medium) or Fast		Energy sober	High or (mixed)		Low
4→1		(Medium) or Fast		Energy sober	High		High

Table 1: Main drivers of scenarios ending in the SSP1 domain.

Focusing on scenarios ending in the SSP1 domain, a “desirable” endpoint, we used the PRIM (Patient Rule Induction Method) 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”.

	Leader growth	Low income countries catch up	Unconventional fossil fuels	Behaviors	Energy efficiency	Availability of low carbon technologies	Labour rigidities in low income countries
5→2	Low or medium	Fast	High	(Energy intensive)			Low
5→4		Fast	Low	Energy intensive	Low or mixed		Low
Stable 5	High	Fast	High				Low

Table 2: Main drivers of scenarios starting in the SSP5 domain.

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.

7. REFERENCES

Ebi, K. L., Hallegatte, S., Kram, T., Arnell, N. W., Carter, T. R., Edmonds, J., Kriegler, E. (2014). A New Scenario Framework for Climate Change Research: Background, Process, and Future Directions. Climatic Change 122 (3): 363-372.

EEA. (2009). Looking back on looking forward: a review of evaluative scenario literature, European Environment Agency Technical Report 3/2009.

Lempert, R. (2013). Scenarios that illuminate vulnerabilities and robust responses. Climatic change 117 (4): 627-646.

Lloyd, E. A., Schweizer, V.J. (2013). Objectivity and a comparison of methodological scenario approaches for climate change research. Synthese, 1-40.

Morgan, M. G., Keith, D. W. (2008). Improving the way we think about projecting future energy use and emissions of carbon dioxide. Climatic Change 90 (3): 189-215.

Morgan, M. G., Henrion, M. (1990). Uncertainty: a Guide to dealing with uncertainty in quantitative risk and policy analysis Cambridge University Press. New York, New York, USA.

O’Neill, B. C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., van Vuuren, D.P. (2014). A New Scenario Framework for Climate Change Research: The Concept of Shared Socioeconomic Pathways. Climatic Change 122 (3): 387-400.

Rounsevell, M. DA, Metzger, M.J. (2010). Developing qualitative scenario storylines for environmental change assessment. Wiley Interdisciplinary Reviews: Climate Change 1 (4): 606-619.

Rozenberg, J., Guivarch, C., Lempert, R., Hallegatte, S. (2014). Building SSPs for Climate Policy Analysis: A Scenario Elicitation Methodology to Map the Space of Possible Future Challenges to Mitigation and Adaptation. Climatic Change 122 (3): 509-522

Schweizer, V.J., Kriegler, E. (2012). Improving environmental change research with systematic techniques for qualitative scenarios. Environmental Research Letters 7 (4): 044011.

Schweizer, V.J., O’Neill, B.C. (2014). Systematic Construction of Global Socioeconomic Pathways Using Internally Consistent Element Combinations. Climatic Change 122 (3): 431-445.

van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G.C., Kram, T., Krey, V., Lamarque, J.-F. (2011). The representative concentration pathways: an overview. Climatic Change 109: 5-31.

van Vuuren, D. P., Kriegler, E., O’Neill, B.C., Ebi, K.L., Riahi, K., Carter, T.R., Edmonds, J. (2014). A New Scenario Framework for Climate Change Research: Scenario Matrix Architecture. Climatic Change 122 (3): 373-386.