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Reinvigorating the scenario technique to expand uncertainty consideration

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Abstract Scenarios are widely used for long-term climate and energy analysis. However, in the great majority of studies with a handful of scenarios or scenario categories, both scenario developers and users capture only a subset of future uncertainties. We propose three focal points for reinvigorating the scenario technique to expand uncertainty consideration: (1) to ensure that scenario developers embrace an increased space of multidimensional uncertainties, (2) to facilitate the process of scenario users capturing this space, and (3) to evaluate and iteratively revise the improvement progress. If these focal points are adopted, scenario studies in climate and energy analysis shall not simply stop after producing scenarios, but shall continue with techniques to facilitate elicitation of user-specific insights, as well as evaluation of both scenarios and scenario techniques.

1 Introduction

The complexity of long-term climate and energy analysis originates in numerous multidimensional uncertainties and incomplete knowledge meaning that forecasting techniques become barely relevant (Craig et al. 2002; Lempert 2013; Morgan and Keith 2008). Scenarios—as

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pictures of plausible future realities that reflect coupled natural, built environment and socio-economic uncertainties—are widely used for considering uncertainty and risk.

Due to these multidimensional uncertainties there are an infinite amount of plausible scenarios that could be constructed. In order to narrow down the amount of scenarios to tractable numbers, scenario axes (van't Klooster and van Asselt 2006) or story-and-simulation approach (Alcamo 2008) are often used. However, such approaches only enable analysis of several fragmented segments of the multidimensional space. As a result, some potentially important uncertainties may remain unacknowledged by both scenario developers and even more so by scenarios users, leading to an incomplete picture for decision-making. We propose three focal points for reinvigorating the scenario technique to expand uncertainty consideration.

2 Focal points for reinvigorating the scenario technique

2.1 Ensuring that scenario developers embrace an increased range of uncertainties

Large numbers of climate and energy scenarios already exist. The IPCC Fifth Assessment Report (IPCC 2014) grew into a mega-report with more than 1'200 scenarios. Multi-model multi-scenario comparisons, pioneered by Energy Modeling Forum (EMF 2014), are increasingly adopted beyond EMF. If open source modeling and crowdsourcing trends prevail (Bazilian et al. 2012), the amount of climate and energy scenarios will increase even further. All these scenarios provide separate pieces of the multidimensional space of future developments. Analysis of such comprehensive scenario ensembles offer means to embrace uncertainty. The on-going efforts towards creating scenario databases, depicting many scenarios and applying descriptive statistics methods represent a good start, but new techniques could generate an even richer understanding.

The concept of exploratory modeling provides a useful framework. Bankes (1993) distinguished between using simulation models as exploratory and consolidative. The latter regards models as consolidating all relevant information together into a single package that, once validated, can serve as a surrogate for the real world. For instance, consolidative models are often used to make predictions. In contrast, the former uses models to map assumptions to consequences, without necessarily privileging any particular set of assumptions, and aims to make arguments based on such mappings. For instance, McJeon et al. (2011) ran an energy-economic model over thousands of combinations of technology assumptions to identify those most strongly associated with the high cost of stabilizing atmospheric carbon dioxide concentrations. Rozenberg et al. (2014) ran an integrated assessment model thousands of times to identify the most important uncertain drivers explaining differences in challenges to climate adaptation and mitigation. Lemoine and McJeon (2013) used many model runs to examine robustness of 450 and 500 ppm carbon targets to uncertainty in climate damage and costs. More recently, large scenario ensembles were analyzed dynamically to extract insight into socio-economic conditions that could lead to bifurcations or trend reversals (Guivarch et al. 2014).

Consolidative modeling can also scan over a wide range of uncertainty, often to implement stochastic methods (Kann and Weyant 2000). Monte Carlo technique randomly samples input parameter values from their respective probability distributions. A climate or energy model is then run repeatedly with these sampled values in order to produce probability distributions of the outcomes of interest. New and Hulme (2000) used such an approach to generate probabilistic forecasts of future temperature and precipitation in the UK. Stochastic optimization and, when probability distributions of input parameters are not known, robust optimization identify optimal strategies under this uncertainty. For example, Bistline and Weyant (2013) looked for optimal electricity system decisions under technological and policy uncertainties.

Often such analyses report the resulting optimal policies or modeling outcome distributions, but do not provide the underlying model runs. Doing so could be useful, since these scans over uncertainty can be used for other purposes such as alternate decision frameworks. Hall et al. (2012) used the cases generated to optimize emission reduction strategies in the Nordhaus DICE model, a best-estimate joint probability distribution, and both robust decision-making and Info-Gap methods in order to find strategies robust when the probabilities are not known.

But even state-of-the-art models and large scenario ensembles may insufficiently cover the multidimensional space due to factors such as ignorance (Spiegelhalter and Riesch 2011) and unknown unknowns (Rumsfeld 2002). Climate analysis has advanced much further in expressing its confidence in scenarios and related insights, c.f. IPCC (2014). On the other hand, energy analysis has lagged behind. However, formal measures of confidence represent the minimum that can be done. Viewed in retrospect, quantitative scenario exercises generally miss surprises more often than qualitative ones (Postma and Liebl 2005; Van Notten et al. 2005), perhaps because the latter are less constrained by the analytics and give freer reign to the imagination. As one example, the Shell '1973 Scenarios' helped the company to foresee the possibility of a Middle East oil shock and to respond more swiftly than its competitors when a crisis struck in 1973. Such qualitative scenario techniques, as used by Shell (2012) or US National Academy of Sciences (White et al. 2013), could complement modeling-based scenarios in opening up the wider consideration of uncertainty. An iterative process of generating quantitative model-based scenarios and then using human "red teams" to suggest what the models might have missed, could help generate policy-relevant "surprise" scenarios (Lempert 2007).

2.2 Facilitating scenario users to consider this increased range of uncertainties

The number and diversity of scenario developers and users (Wilkinson and Eidinow 2008) involved in global and national analyses makes the co-development of scenarios to match the needs of specific users practically infeasible. A process in which scenario developers specify a predefined, narrow set of scenarios may not prove ideal, because no single best scenario set meets the needs of all users in all contexts. Instead, the scenario community could provide tools and services that enable users to summarize or otherwise extract a small number of particularly useful scenarios from large scenario ensembles. Visualization (McInerny et al. 2014; Shaw et al. 2009) and interactive techniques (Pidgeon et al. 2014; Wong-Parodi et al. 2014) help with clarity and accessibility of scenario information. Users could extract tailored subsets of scenarios using techniques and criteria such as:

- Most internally consistent scenarios, which include combinations of scenario elements that are expected to occur simultaneously. A systematic method for identifying such combinations, including qualitative scenario elements, is the cross-impact-balance technique (Weimer-Jehle 2006). Consistency scoring is determined by a collection of expert judgments on how each element is expected to directly influence the other elements. A combination of elements that evokes a set of direct influences reinforcing the original combination (rather than supporting an alternative one) is said to be self-consistent and is therefore deemed internally consistent. Schweizer and O'Neill (2014) applied cross-impact-balance to find socio-economic pathways for climate change research.

- Maximally diverse scenarios, which differ in their elements as much as possible and thus reveal the breadth of the scenario space. Modified distance-to-selected technique (Tietje 2005; Trutnevyte 2013) could be used for this purpose. After an initial scenario is chosen from the large scenario ensemble, the second scenario with the largest Euclidean distance from the first scenario is selected, using a distance metric that is of interest to scenario users. The third and further scenarios are sampled using harmonic means of Euclidian distances to so-far selected scenarios until a desired number of scenarios are gathered. Trutnevyte (2013), for example, sampled a small set of maximally diverse cost-optimal and near-optimal energy mixes in terms of deployed technologies.
- Most policy-relevant scenarios, such as those provided by scenario discovery, which is a technique for summarizing a large number of model runs into a small number of scenarios designed to be most relevant towards making a particular decision (Bryant and Lempert 2010; Lempert et al. 2003). Lempert (2013) used scenario discovery to identify scenarios that illuminate the vulnerabilities of proposed policies—that is, identify a small set of scenarios that best distinguish futures where a policy meets or misses its goals. Such scenarios emerge from a decision support process that begins with a proposed policy, tests the policy in a large set of model runs, and applies statistical cluster analysis to the model results to identify the conditions under which the policy fails. This information can then be used to identify and evaluate alternative policies that are robust over a wide range of futures.
- Scenarios that stimulate the analysis of surprises and discussion about the unthinkable outcomes, as discussed in the preceding.

Such approaches are currently being used, sometimes in collaboration with decision-makers (e.g., Groves et al. 2014), to design scenarios for specific applications. More expansively, one might imagine such approaches as enabling a shift from scenarios as products to scenarios as services. Traditionally, scenario exercises deliver scenarios as a product—that is, a small number of well-crafted static outputs meant to be useful for a wide range of applications. However, as the literature often notes, such scenarios may only be weakly connected to particular users' needs (Parson et al. 2007). At present, the IPCC and many other organizations providing climate services, host websites that offer large databases of model runs with future climate and socio-economic trajectories, often accompanied by a small number of static scenarios such as the Shared Socioeconomic Pathways (O'Neill et al. 2014). In the future, such organizations could also include portals on their websites that use methods such as scenario discovery and scenario diversity, to mine those large databases and enable users to identify a small number of scenarios customized to fit their needs.

2.3 Evaluation for iteratively revising the uncertainty treatment

Evaluation of the analytical diversity of scenario techniques is critical to enable success of the other two foci. Risk communication literature argues that without evaluation, information providers (scenario developers, in this case) cannot know (1) whether what they intend to say with their scenarios is in fact what is being heard and (2) whether these scenarios are what the audience wants and needs to know (Pidgeon and Fischhoff 2011). There is little evaluative evidence for scenarios (EEA 2009), meaning that the community may have been developing new scenarios on the basis of their own interpretations of the scenarios they find to be understandable and useful. For example, McMahon et al. (2015) showed that novice readers of one of the most used IPCC scenario graphs falsely interpreted the origin of a large share of uncertainty in global surface warming. These readers overestimated the uncertainty due to scientific knowledge and underestimated the socio-economic uncertainties and the role of human decisions.

Both scenario techniques and scenarios should thus be evaluated: (1) whether scenario users interpret the information as intended and (2) whether the produced scenarios match the users' needs. Lab-like behavioral experiments or structured interviews could be useful tools. Parker et al. (2014) tested several scenario discovery options in a lab-like fashion in order to grasp the scenario users' preferences for simplicity and accuracy. The aforementioned study by McMahon et al. (2015) used structured interviews to reveal the patterns regarding how user's interpret scenario graphs. Trutnevyte et al. (2011) observed the change in scenarios users' preferences for alternative futures before and after the scenario exercise. Wong-Parodi et al. (2014) proposed a general framework for assessing interactive decision aids in terms of knowledge gain, consistency of preferences, and active mastery of material. The multidimensionality of uncertainties and resulting possible futures in climate and energy research poses a particular challenge. Evaluation and iterative revision of scenario techniques is thus essential.

In addition to the lack of such elementary evaluation, the quality and impact of scenario development processes, techniques and resulting scenarios need to be evaluated as well. Girod et al. (2009) and van Vuuren et al. (2012) developed evaluation frameworks that include scenario legitimacy, saliency, and usability criteria. Another criterion that could be integrated in such frameworks is whether specific scenarios were followed up by a policy outcome, policy process, public debate, or follow-up scenario development.

The community would benefit if scenario developers more frequently conducted evaluations of their own scenarios. As the number of scenarios and scenario services proliferate, independent assessment of these scenarios and evaluation literature would prove useful.

3 Outlook: scenario studies should move beyond producing only scenarios

In this essay we proposed three focal points for reinvigorating the scenario technique to expand uncertainty consideration by both scenario developers and users and to sustain progress through evaluation. What this means in practice is that scenario providers shall not just produce scenarios. Scenario studies should come as packages of rich scenario ensembles, along with techniques to facilitate elicitation of user-specific insights and scenario subsets. The community as a whole should also focus more on evaluation of both scenarios and scenario techniques.

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