Multi-century scenario development and socioeconomic uncertainty

Brian O'Neill
National Center for Atmospheric Research (NCAR)

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Introduction

The social cost of carbon (SCC) sums the damages resulting from a unit emission of CO2 today over the infinite future. As a result, this quantity depends in principle on socio-economic and climate conditions over all future time. In practice, SCC calculations are truncated over a finite period, and different factors can change the relevance of damages that occur in the very long term. On the one hand, future damages are discounted, which makes damages far in the future contribute less to the net present value than those that occur in the nearer term. On the other hand, assumed growth in the size of the economy and damages that increase in proportional terms with the amount of warming will tend to increase the contribution of damages far in the future relative to those in the nearer term. Thus the contribution of damages that occur beyond 2100 – and therefore the importance of socio-economic conditions beyond 2100 – to the net present value of damages from a current emission are ambiguous. The contribution of long-term damages to the specific calculations carried out in the Interagency Working Group report on the social cost of carbon (IAWGSCC, 2010; hereafter the "SCC report") are not specified, so it is unclear how important long-term socio-economic assumptions are to these calculations. For the present purposes we assume they are relevant, at least in some scenarios. Since the SCC calculations in the report are carried out to the year 2300, I focus on socio-economic futures over this time period.

The scenario variables for which long-term assumptions are made in the SCC report include population, GDP, CO2 emissions, and non-CO2 forcing. I focus on the first three, and compare the assumptions made in the report to those available in the literature, for both the 2000-2100 and 2100-2300 time periods. The quantitative scenarios used in the report are based on a set of scenarios drawn from EMF-22, a recent model comparison exercise carried out by the Energy Modeling Forum. The report describes the five scenarios it selected as follows: "EMF BAU scenarios represent the modelers' judgment of the most likely pathway absent mitigation policies to reduce greenhouse gas emissions, rather than the wider range of possible outcomes. Nevertheless, these views of the most likely outcome span a wide range" (IAWGSCC, 2010, p. 16). It is worth noting, however, that typical practice in EMF exercises is not necessarily to use the most likely socio-economic futures, but rather those that are well suited to the particular exercise, or most convenient. There is no guarantee that their likelihood has been judged in any way. In addition, there is no guarantee that they span the range of uncertainty in the literature, and as we will see in the comparison, they typically do not.

Population

The SCC report's population scenarios, based on the EMF scenarios, span a range of 8.7-10.4 billion people globally by 2100. In comparison, the most recent long-term projections from the United Nations (UN, 2004) and the International Institute for Applied Systems Analysis (IIASA, Lutz, 2008) span ranges of 5.5 – 14 billion and 4.5 – 12 billion, respectively. Ranges of population assumptions employed in emissions scenarios contained in the AR4 scenario database are similarly wide (although cover the low end of this range less well). Thus, the SCC report clearly spans an overly narrow range of population assumptions in 2100, and can be characterized as essentially clustering around a single medium population assumption.

The report extends the projections to 2300 by assuming growth rates in 2100 linearly decline to zero, producing a global population size in 2300 of 8-10.9 billion. Both the UN (UN 2003) and IIASA (Lutz and Scherbov, 2008) have carried out illustrative long-term projections to 2300. In neither case do these institutions identify a most likely long-term outcome; rather, both emphasize that the projections are intended to be illustrative of the consequences of different assumptions about fertility and mortality. The UN produces three projections that differ only in terms of fertility rates, which are assumed to converge to levels between 1.85 and 2.35 births per woman in the long term. This relative narrow fertility range produces a range of global population size of 2.3 – 36.4 billion people in 2300. IIASA considers uncertainty in both fertility and mortality, and assumes that fertility converges to levels between 1.0 and 2.5 births per woman, based on various lines of reasoning regarding determinants of fertility behavior. These assumptions produce a range of global population size of between 40 million and 47 billion people in 2300. Thus the SCC report essentially does not consider uncertainty in long term population size at all, since the range of outcomes it considers vary by a factor of 1.4 between low and high projections, while those in the demographic literature vary by a factor of more than 1000.

It is also worth noting that other dimensions of population beyond total size are likely important for impacts and damages, including age structure. In the IIASA projections, by 2300 age structures vary widely as well. The proportion of the population aged 80+ increases from a few percent at present to between 20% and 65% by 2300, indicating a completely unprecedented demographic structure.

GDP

The global GDP scenarios adopted in the SCC report, based on EMF models, range from a global economy of $268-$397 trillion (in 2005 US $). In comparison, the scenarios in the AR4 database range from $136 – $677 trillion, a range spanning a factor of 5 versus the range of a factor of 1.5 assumed in the SCC report.

Beyond 2100 it is difficult to put the SCC assumptions in perspective given the dearth of long-term GDP scenarios in the literature. The SCC approach is to assume that growth rates of global GDP decline linearly to reach zero in 2300, based on the idea that "increasing scarcity of natural resources and the degradation of environmental sinks available for assimilating pollution from economic production activities may eventually overtake the rate of technological progress". While this is a plausible assumption, it is only one of many possible scenarios, and leads to a range of about $750 - $2200 trillion by 2300.

In contrast, an illustrative exercise by Tonneson (2008) applies a range of different growth rates to current GDP to project growth over the next 300 years. The growth rates are based on data for GDP per capita over the past 180 years, defining three scenarios by selecting the slowest and fastest periods of growth over this time span as well as the overall average growth rate. I combine these per capita growth rates with the projected population growth from the UN and IIASA scenarios, and with current estimated per capita GDP, to produce illustrative long-range GDP projections. They span a range in 2300 from around $100 trillion to around $1 million trillion – a range of a factor of 1000, far wider than the range of a factor of 3 covered by the SCC scenarios.

CO2 emissions

The range of CO2 emissions assumed in the SCC report result in emissions of 13-81 GtCO2/yr. The AR4 database includes emissions scenarios that range from -14 to 109 GtCO2/yr, which is somewhat larger but of the same order of magnitude as the SCC range.

Beyond 2100, the report assumes that rates of decline in the carbon intensity of GDP are maintained through 2300. This is based on the assumption that "technological improvements and innovations in the areas of energy efficiency and other carbon reducing technologies … will continue to proceed at roughly the same pace that is projected to occur towards the end of the forecast period". As in the GDP case, this is a plausible assumption but only one of many possibilities. It produces a range of emissions in 2300 of about 10 to 102 GtCO2/yr. In the scenario literature, scenarios for emissions beyond 2100 that are based on socio-economic assumptions (rather than simple extrapolations) are scarce. A point of comparison, however, is provided by the emissions underlying the Representative Concentration Pathways (RCPs), which are concentration and forcing scenarios that are providing the basis for climate modeling simulations for the IPCC Fifth Assessment Report (Moss et al., 2010). The RCPs cover a similar range of emissions as the SCC report through 2100, and then decline to low levels by 2300 (less than 10 GtCO2/yr), so the SCC report covers a wider – and higher – range of emissions outcomes than will be assumed in climate model simulations for AR5.

Discussion and conclusions

In summary, the comparisons carried out here show that the assumptions regarding population and GDP pathways in the SCC report cover an overly narrow range of uncertainty over the entire time horizon, but especially in the long term (beyond 2100). In contrast, the range of emissions pathways through 2100 is reasonably consistent with the range found in the literature. Beyond 2100 the emissions range is wider and higher than the range found in the RCP extensions, although the RCP pathways were not designed to reflect uncertainty in very long term emissions. The comparison is instructive however in that the global average temperature projected from the RCPs reaches 8 degrees or more by 2300, and therefore the SCC pathways will result in temperature increases even higher than this.

There are several caveats to these conclusions that must be kept in mind. First, uncertainty ranges in literature may themselves be too conservative. While the very long term population projections in the literature have been constructed with an eye toward bounding assumptions that are reasonably well grounded, the long term GDP projections were constructed in a back of the envelope style that may underestimate actual uncertainty, and for CO2 emissions no similar exercise was found in the literature at all. Second, we have only examined uncertainty in very aggregate socio-economic variables such as global population size and global GDP, but future impacts will depend perhaps more strongly on additional dimensions of these variables, such as the regional and spatial distribution of people and production, and the sectoral composition of production. It is difficult to interpret what particular levels of GDP per capita in the long term even mean: what types of economic activities, relying on what types of technologies, might be taking place 300 years in the future, and how will this affect impacts? Do current damage functions apply even approximately to the socio-economic conditions that would obtain in the very long term? Finally, we have ignored the potential for catastrophic impacts and their implications for socio-economic conditions, despite the fact that some SCC emissions pathways could lead to more than 8 degrees C in warming over this time period.

Based on these conclusions, and taking into account these caveats, we make the following recommendations for future versions of the SCC report:

1. Demonstrate the influence of key sources of uncertainty on SCC calculations, including the contribution to the SCC from different time periods.
2. Drop the use of a range of best estimates as a characterization of uncertainty, which under-estimates uncertainty, and consider a substantially wider range of socio-economic futures, through 2100 and 2300.
3. Consider simpler approaches to calculating damages in the very long term, when uncertainty is highest, such as the use of generic economic sectors and damage types
4. Improve the characterization of uncertainty in SCC results and reconsider the use of probabilistic outcomes, since the probabilities reflect uncertainty in only some parts of the calculation and are highly conditional on assumption regarding other components, such as the socio-economic pathways.
5. Consider linking to evolving work on RCPs and socio-economic scenarios that are consistent with them.

References

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