Decision making under uncertainty – Climate sensitivity and 2 degree target

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Huge uncertainty in Equilibrium Climate Sensitivity
There remain huge uncertainties related to almost all aspects of climate change, including science, technology and economy.

- We are not sure of the future impacts of climate change whether there exists a particular temperature increase level (threshold) above which our society cannot tolerate.
- We are not sure whether and when unknown innovative technologies will emerge.
- We are not sure of the cost of mitigation and adaptation.
- We are not sure of the extent the global surface temperature will increase when the CO2 concentration will double.

The last one is the uncertainty of the equilibrium climate sensitivity (ECS), one of the most crucial uncertainties surrounding climate change.

ECS is defined as “the change in global mean surface temperature at equilibrium that is caused by a doubling of the atmospheric CO2 concentration” in IPCC 5th Assessment Report (AR5). Since its 1st Assessment Report in 1990, and until 2001, IPCC has provided an assessment of ECS which ranged between 1.5 to 4.5°C, with the best estimate of 2.5°C. In its 4th Assessment Report (AR4), the ECS was changed as ranging between 2.0 to 4.5°C, with a best estimate increasing to 3.0°C, while in AR5, the ECS was changed back to its previous levels of 1.5 to 4.5°C. In AR5, IPCC provided no guidance on a best estimate, as experts could not reach consensus (see Table 1 below).

Table 1: Changes in Equilibrium Climate Sensitivity and Best Estimates in IPCC Reports

<table>
<thead>
<tr>
<th>IPCC Report</th>
<th>Published in</th>
<th>Climate sensitivity</th>
<th>Best estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Assessment Report</td>
<td>1990</td>
<td>1.5 – 4.5 °C</td>
<td>2.5 °C</td>
</tr>
<tr>
<td>2nd Assessment Report</td>
<td>1995</td>
<td>1.5 – 4.5 °C</td>
<td>2.5 °C</td>
</tr>
<tr>
<td>3rd Assessment Report</td>
<td>2001</td>
<td>1.5 – 4.5 °C</td>
<td>2.5 °C</td>
</tr>
<tr>
<td>4th Assessment Report</td>
<td>2007</td>
<td>2.0 – 4.5 °C</td>
<td>3.0 °C</td>
</tr>
<tr>
<td>5th Assessment Report</td>
<td>2013</td>
<td>1.5 – 4.5 °C</td>
<td>Not shown</td>
</tr>
</tbody>
</table>

Accurately speaking, AR5 describes the ECS as likely in the range of 1.5 to 4.5°C (high confidence), extremely unlikely for the ECS to be less than 1°C (high confidence), and very unlikely it would be greater than 6°C (medium confidence). In this context, “likely”, “extremely unlikely” and “very
unlikely” means probability of $\geq 66\%$, $\leq 5\%$ and $\leq 10\%$ respectively. This means that the range between 1.5 and 4.5°C has a probability $\geq 66\%$, while a wider range between 1°C and 6°C would expand the probability to $\geq 85\%$; even in this case, there still remains $\leq 15\%$ probability for ECS to be less than 1°C or more than 6°C. This simply shows the uncertainty surrounding temperature increases at doubling atmospheric CO$_2$ concentrations.

There are several methodologies to estimate ECS. The typical ones are AOGCM (Atmosphere–Ocean General Circulation Model), observation-based energy balance model (called as “instrumental” in AR5) or through paleoclimate reconstructions. ECS based on AOGCM in AR5 remains almost unchanged from AR4; it was 2 to 4.5°C (with a probability of 66\% for the range) and the best estimate was 3.2°C. For the past 15 years since 1998, however, global temperature did not increase as AOGCM anticipated (so-called “hiatus” phenomenon, see Figure 1 below). An increasing number of literatures since AR4, based on observed temperature changes, i.e. that took the hiatus into account, showed lower ECSs with a mean value was lower than 3°C. For example, among 13 studies that appeared between AR4 and AR5, only one showed its median value at 3°C while all others showed lower median value (AR5). Taking these into consideration, AR5 changed the likely range of ECS from 2.0–4.5°C to 1.5–4.5°C. In addition, as it was impossible for experts who rely upon different methodologies to agree on a best estimate, AR5 failed to identify one (another reason of failure was that there is no established definition of the best estimate).

Figure 1 Observed globally averaged combined land and ocean surface temperature anomaly 1850–2012, Source: IPCC/AR5/WG1/Figure SPM.1(a)
Global negotiations are based on ECS of 3°C

Policymakers (not scientists) have politically agreed that the global surface temperature increase should be limited to below 2°C since pre-industrialization (the so-called 2°C target). No policymaker knows for sure at what concentration level of CO₂-equivalent such target could be achieved because of the wide range of ECS. Under the circumstances and in order to achieve a 2°C target, global leaders at the last G7 Summit (June 2015) supported to share with the rest of the world to reduce GHG emissions in the upper end of 40–70% from 2010, by 2050. The figure comes from the following Table 2 (originally in AR5). As shown in the table, to limit temperature increase below 2°C “throughout the 21st century” with a probability of ≥66% (likely), global emissions in 2050 should be reduced by 41–72% in comparison to those in 2010.

Table 2: Relationship between CO₂eq. concentrations, emissions reductions and temperature changes

<table>
<thead>
<tr>
<th>CO₂eq Concentrations in 2100 [ppm CO₂eq] Category label (concentration range)</th>
<th>Subcategories</th>
<th>Change in CO₂eq emissions compared to 2010</th>
<th>Temperature change (relative to 1850–1900)</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 (430-480)</td>
<td>Total range</td>
<td>-72– -41%</td>
<td>1.5–1.7°C (1.0–2.8)</td>
</tr>
<tr>
<td>500 (480-530)</td>
<td>No overshoot of 530 ppm CO₂eq</td>
<td>-57– -42%</td>
<td>1.7–1.9°C (1.2–2.9)</td>
</tr>
<tr>
<td></td>
<td>Overshoot of 530 ppm CO₂eq</td>
<td>-55– -25%</td>
<td>1.8–2.0°C (1.2–3.3)</td>
</tr>
<tr>
<td>550 (530-580)</td>
<td>No overshoot of 580 ppm CO₂eq</td>
<td>-47– -19%</td>
<td>2.0–2.2°C (1.4–3.6)</td>
</tr>
<tr>
<td></td>
<td>Overshoot of 580 ppm CO₂eq</td>
<td>-16–+7%</td>
<td>2.1–2.3°C (1.4–3.6)</td>
</tr>
</tbody>
</table>

The above table is an extract from Table SPM.1 from AR5 WG3 that shows information including the relationship between CO₂eq. concentrations and temperature changes in 2100 and necessary emissions reductions to achieve each concentration (temperature) target. The range of temperature change in 2100 illustrates differences between the emissions pathways of the scenarios in each category. The range of temperature change in the parentheses includes in addition the carbon cycle and climate system uncertainties.

Readers might wonder how these figures in Table 2 are calculated given the huge uncertainty surrounding ECS. In AR4, the same kind of table was shown, but the table clearly stated that the calculations were made using the best estimate ECS of 3°C. To obtain emissions reduction figures in the above table, we need one particular figure of ECS. In the footnotes of AR5/Table SPM.1, it is stated that to evaluate CO₂eq concentration the MAGICC (Model for the Assessment of Greenhouse Gas Induced Climate Change) was used, and temperature change in 2100 was calculated based on median estimate of the model calculations. The table was silent on the median estimate of the MAGICC model but after scrutinizing the text of AR5 and referring to literatures suggested in the
text, we found that 3°C was used to obtain the figures in Table 2. This means that if we are to stay below 2°C through 21st century with ≥66% chance with ECS of 3°C, global emissions must be reduced between 41–72% relative to 2010. As a result, the G7 declaration of 40–70% global emissions reduction by 2050 is based on the assumption that the best estimate of ECS to be 3°C regardless of the fact whether the leaders might have realized this or not.

As explained already, lowering a range of ECS in AR5 came from the fact that most recent literatures based on observation-based energy balance model showed lower ECS. It is, therefore, natural to think that the best estimate (or most likely value) of ECS is also lower than 3°C. What if it is, for example, 2.5°C instead of 3°C?

**Lowering ECS and its implication to the 2°C target**

Rogelj et al. (2014) argued that “much lower values would postpone crossing the 2°C temperature threshold by about a decade for emissions near current levels” (case 1), or “alternatively would imply that limiting warming to below 1.5°C would require about the same emission reductions as are now assumed for 2°C” (case 2). The argument in case 1 is easily understandable. As emissions increased rapidly in the past, even for the scenario with the lowest ECS (1.7°C in this paper), temperature also increases rapidly and would only postpone crossing the 2°C temperature threshold by about a decade under BAU case. The paper also argues, the same emissions reduction scenario to achieve 2°C target would be able to limit the temperature increase below 1.5°C with the lowest ECS (case 2). But what the paper didn’t show was how different the emissions pathways would be to achieve 2°C target under different ECS (namely 3°C and 1.7°C). Our concern here is how emissions reduction scenarios to achieve 2°C target will be affected when ECS will be lowered by 0.5°C from 3°C to 2.5°C.

We have made our own study, by applying our energy-system model (RITE DNE21+) and also relying on MAGICC model, on the impact of lowering ECS by 0.5°C and its implication to achieving 2°C target. Refer to Figure 2 below.

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1 In this case, temperature increase in 2100 will be between 1.5 to 1.7°C (the range shows difference of emissions scenarios). But if we take uncertainties of ECS and other climate system into considerations, temperature increase in 2100 will be as wide as 1.0 to 2.8°C. This means there are possibilities that 40—70% reduction may not be enough to achieve the target or the reduction would be too much and may hurt sustainable economic growth seriously.
Figure 2: INDCs and 2°C target, difference by ECS (source: RITE)

The red bold line shows emissions pathway until 2030 taking into consideration of Intended Nationally Determined Contribution (INDCs) of major countries, including Japan that has yet to submit its pledge as of the end of June. Orange line shows the emissions pathway that limits the temperature increase below 2°C through the 21st century under ECS of 2.5°C. Both grey and blue lines show emission pathways until 2050 to achieve 2°C target based on ECS of 3°C. The former one temporally overshoots concentration of 530 ppm and temperature of 2°C during 21 century but stays below 2°C in 2100, and the latter does not overshoot both concentration of 500 ppm and temperature of 2°C.

The red bold line is drawn on the assumption that all INDCs will be implemented. We assume China’s emissions in 2030 to be 16.7GtCO$_2$-eq. based on CO$_2$/GDP improvement ratio of 65% and annual GDP growth ratio of 6.2%. The US pledge covers only until 2025 and comprises of two targets, i.e., 26% and 28% emissions reduction relative to 2005. We assume here that the 28% emission will be implemented by 2025, thereafter with a linear interpolation to 80% reduction in 2050.

Both grey and blue lines are emissions pathways to achieve 2°C target assuming ECS of 3°C. In case of grey line scenario, temperature temporally overshoots before 2100 and return to below 2°C in 2100, whereas temperature continues to stay below 2°C through 2100 in blue line scenario. It is clear that the emissions pathway taking into consideration of submitted and known INDCs (red bold line) is far from those two pathways (grey and blue) and almost impossible to achieve 2°C target, if ECS will be 3°C. On the contrary, orange line pathway is the one that will be able to achieve 2°C target provided that ECS will be 2.5°C. The pathway of current pledge (red bold line) is consistent with the orange line pathway. This means that there still remains chance to achieve 2°C target with current INDCs, if ECS will be 2.5°C.

Conclusion
It is clear from the above discussions that the impact of a mere 0.5°C difference in climate sensitivity is of critical significance for policy objectives, which is especially significant given the large
uncertainties of climate sensitivity. Policymakers should be aware that current climate negotiations are based on ECS of 3°C, but there exists broad range of uncertainty on ECS and experts are unable to agree on the value of best estimate. It is the scientific community’s role to try to narrow the uncertainty surrounding the range of ECS. If it is impossible for the experts to agree on a best estimate (or most likely value) of ECS, due to differences between methodologies (this happened in AR5 as explained earlier between AOGCM and observation-based energy balance model), it is also the scientific community’s role to present two best estimates based on two different methodologies as well as two kinds of possible pathways toward achieving 2 degree target.

It is our hope that negotiators will become well aware that their decision will be based on huge uncertainties surrounding climate change, especially uncertainty of ECS.