# Quantifying Greenhouse Gas Emissions by their Climate-Change Impact Potentials

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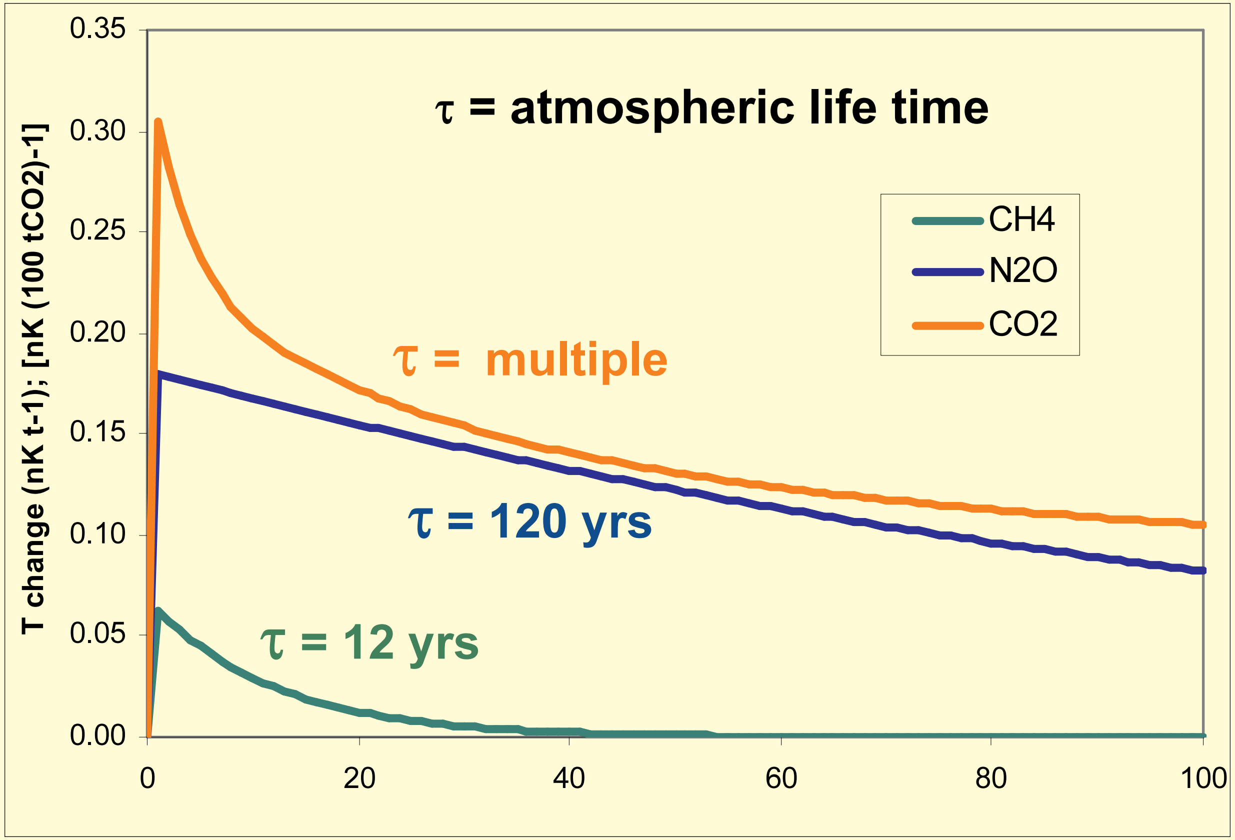
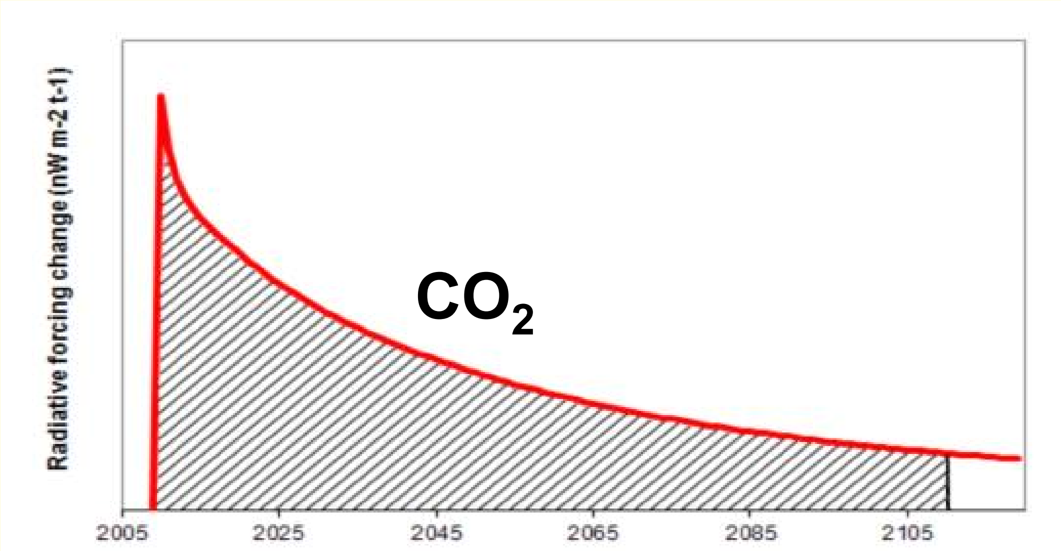
# Three gases with very different atmospheric life times

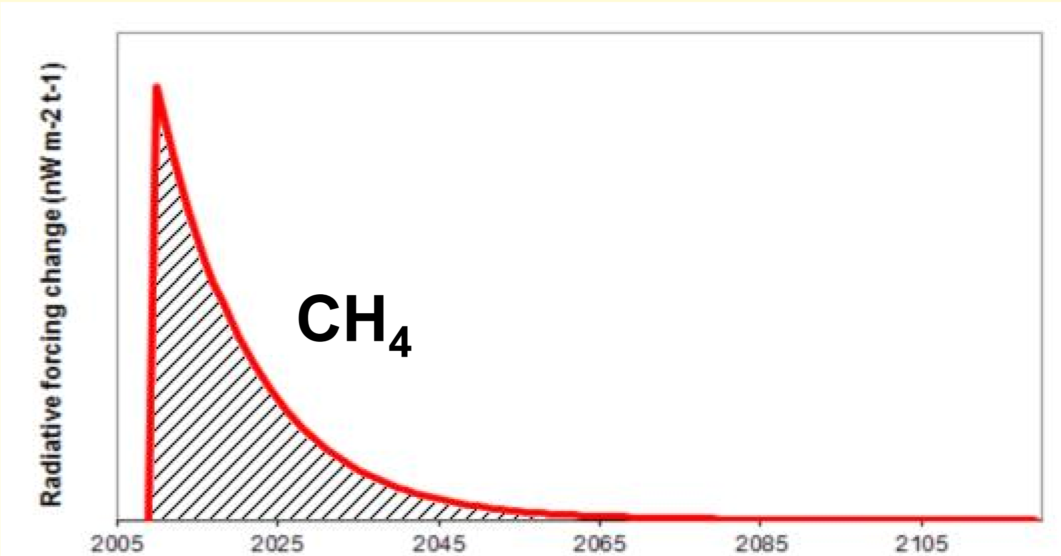



**Key points:**
Different greenhouse gases have different atmospheric lifetimes. The atmospheric lifetimes of methane and nitrous oxide can be described with first-order decay kinetics of 12 and 120 years, respectively. $CO_2$ is described with multiple decay constants for different fractions of emitted $CO_2$. These different turn-over times affect their respective climatic impacts.

## How to quantify their respective contributions?

# Calculating Greenhouse Warming Potentials




**Key points:**
Greenhouse Warming Potentials are calculating by integrating the radiative forcing of a unit of a specified gas over the following 100 years. The radiative forcing of different gases is then expressed relative to that of $CO_2$.

**Assessing the relative importance of different gases should start with a fundamental question:**

# Which aspect of climate change impacts us most?

## 1) Instantaneous climatic conditions?

- Heat damage
- Severe weather
- Food production

## 2) Rate of climate change?

- Ecological mal-adaptation
- Socio-economic institutions

## 3) Cumulative climate change?

- Sea level rise

**Different proposed metrics address one or the other of these impacts**

# Which aspect of climate change impacts us most?

**1) Instantaneous climatic conditions?**

**"Global Temperature Potential"**
**"2 degree target"**

**2) Rate of climate change?**

**No proposed metric**

**3) Cumulative climate change?**

**"Greenhouse Warming Potentials"**

## A proposal

**A new metric that is explicitly based on a calculation of climate-change impacts from different gases and at different times.**

# Climate Change Impact Potential

# (C-CIP)

# The Steps

1) Use the three impact types defined above

2) Give equal weight to each impact type

3) Sum impacts over the next 100 years under BaU scenario

4) Add marginal extra unit of GHG. Express change in summed impacts relative to that of 1 extra kg$CO_2$ emitted in 2010

5) CCIP gives weight of each unit of a different gas relative to that of $CO_2$.

# The three types of impacts

## Start by calculating perturbations

1) Instantaneous climatic conditions.

$$P_y = T_y - T_{1900}$$

2) Rate of climate change

$$P_y = (T_y - T_{y-100}) / 100$$

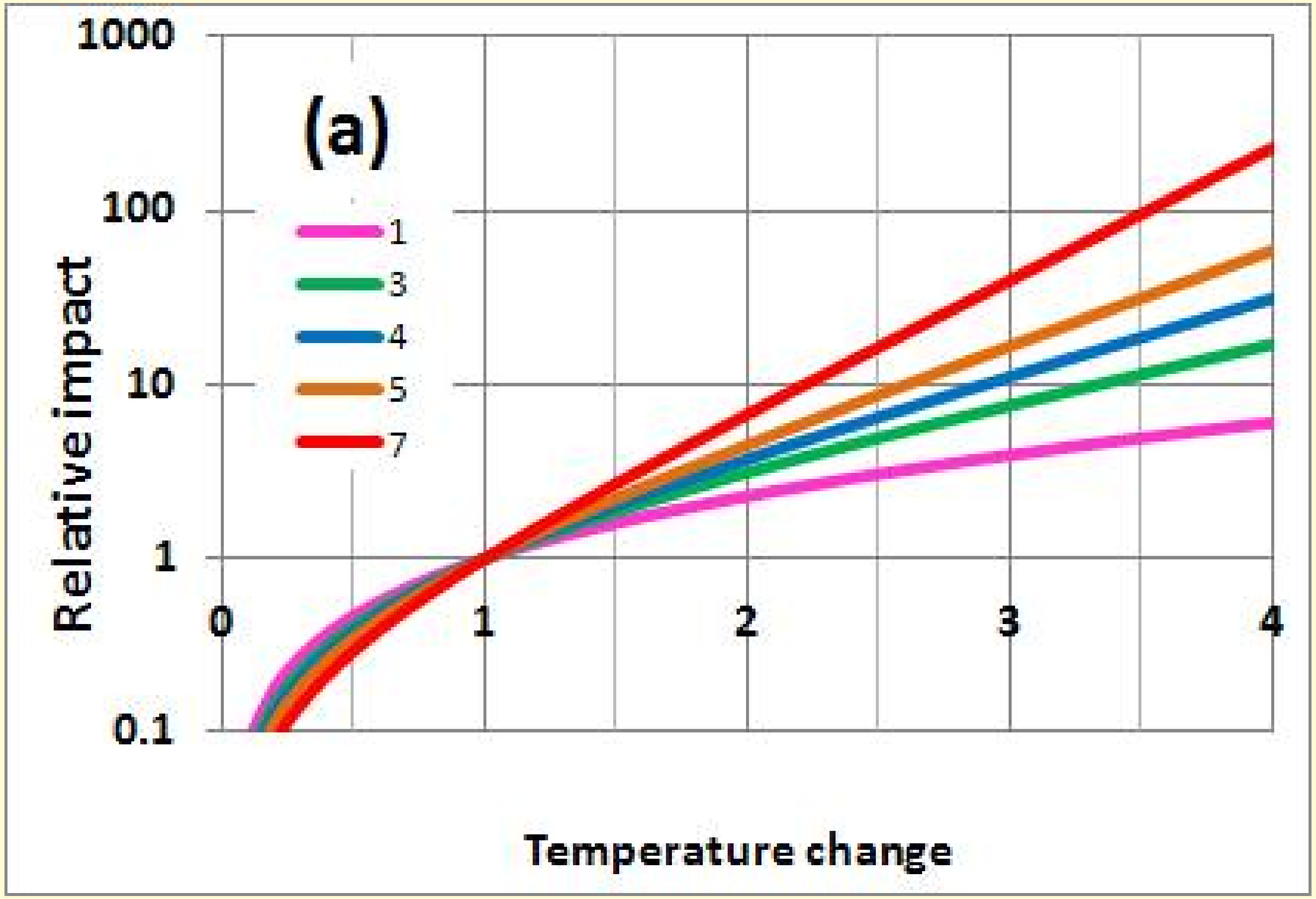
3) Cumulative climate change

$$P_y = \sum_{1900}^{y} (T_i - T_{1900})$$

$P_y$ is the perturbation calculated for year 'y'. T is temperature, $T_y$ the temperature in year y and $T_{1900}$ is the temperature in 1900 – taken to be the pre-industrial temperature.
For cumulative climate change, we sum the temperature anomalies for each year from 1900 to the year of interest, y.
In the next slide, impacts are calculated from these perturbations.

# Perturbation-impact relationship

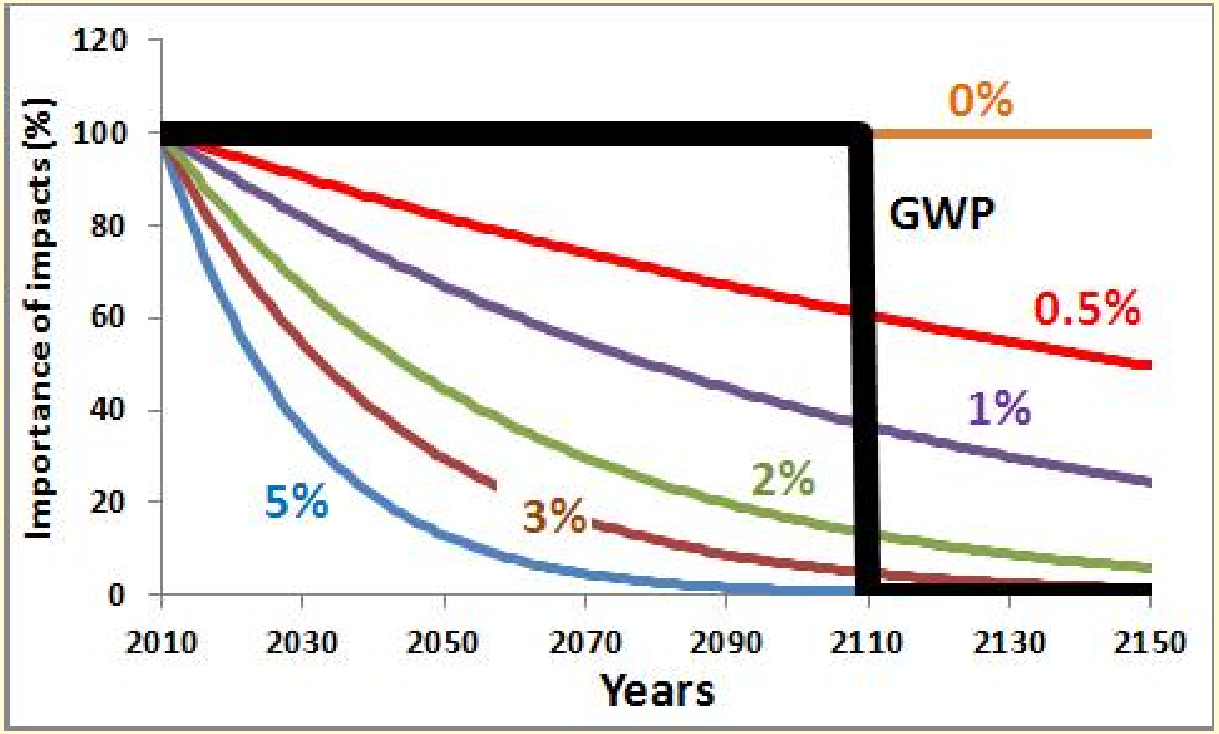
## Do impacts scale linearly with perturbation?




Climate change impacts increase more than proportionately with the underlying perturbations, here illustrated for the specific case of temperature. This graph gives 5 possible curves illustrating the steepness or severity of climate-change impacts for different perturbations.

The work reported here uses the blue line that assumes that a three-fold larger perturbation (say, 3° instead of 1°C), has ten times the impact of the smaller perturbation. The same severity term is used for all three types of impacts.

# Discounting the Future?
## What discount rate to apply?




**Key points:**
Should future impacts be treated with the same importance as near-term impacts? This usually expressed through discount terms applied to future impacts, illustrated here for different possible discount rates. It also shows the approach adopted for calculating GWPs, which is to apply a 0 discount rate for the length of the assessment period, which then abruptly changes to ignoring any impacts beyond that point. That approach has also been adopted in the present work.

# So, to calculate CCIPs

1) Take an emission scenario and calculate the sum of each of the base impacts over 100 years – RCP 6

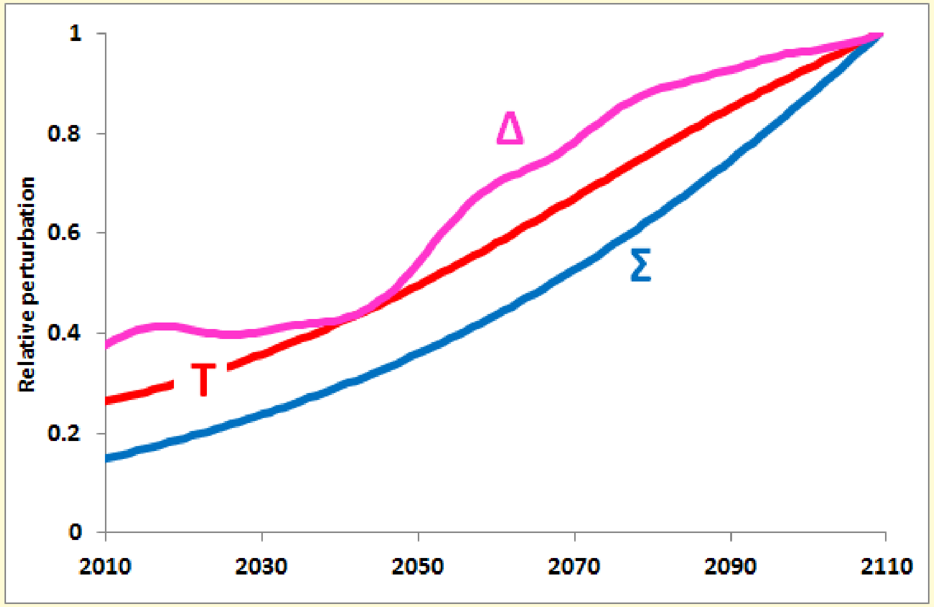
2) Add 1 kg$CO_2$ in 2010 and calculate the change in impacts for all years over 100 years.

3) Add 1 kg of a different gas, or $CO_2$ in a different year, and compare the impact change with that of $CO_2$ emitted in 2010.

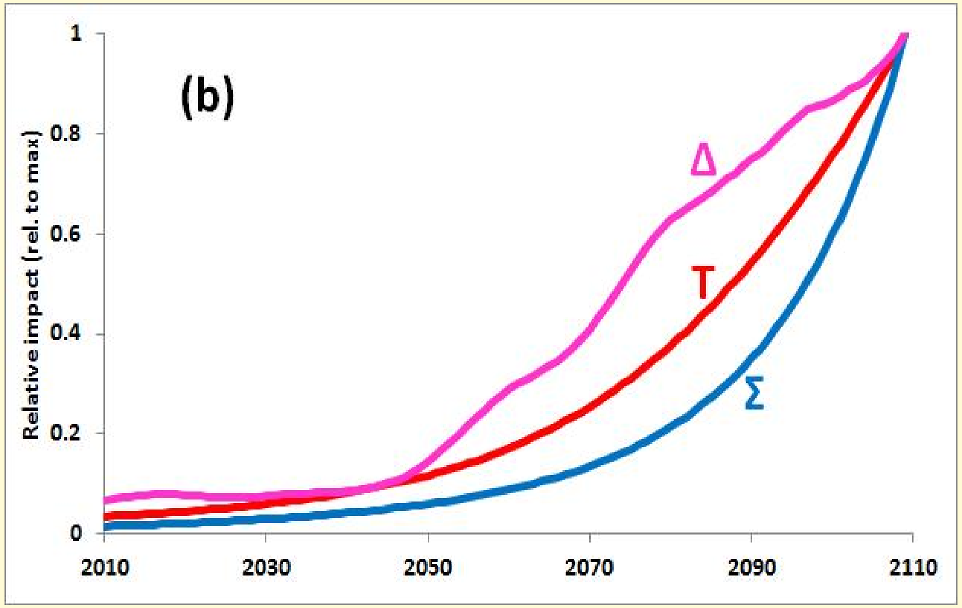
**DONE!**

# The base impacts 2010-2109

## Perturbation



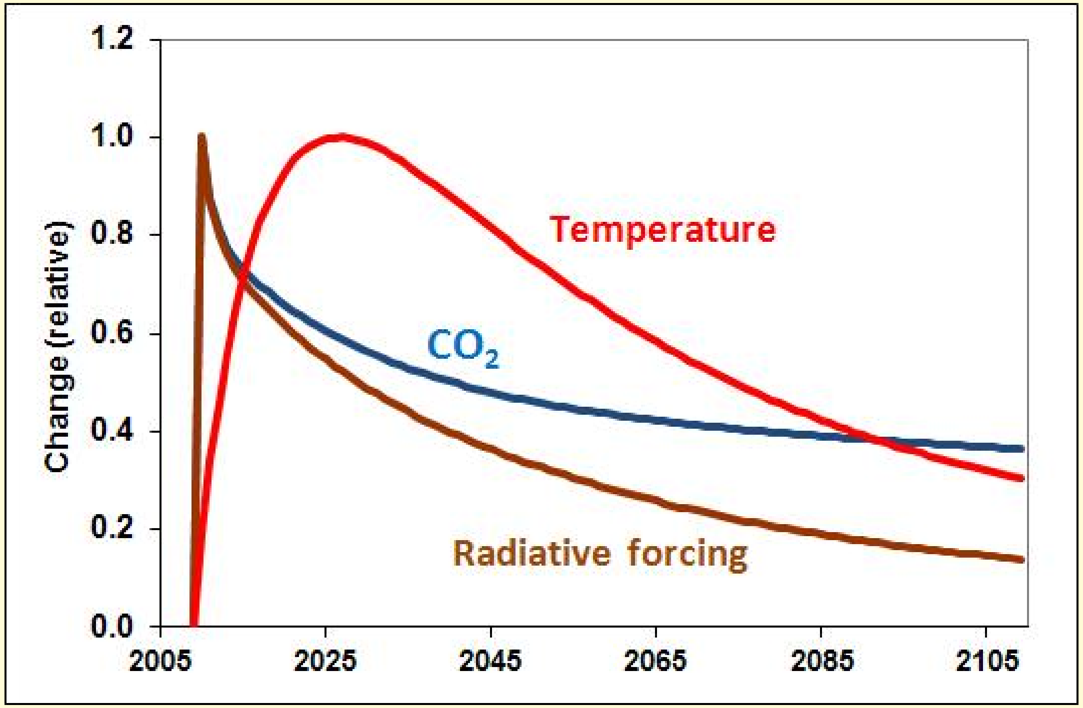

## Impact




**Calculations under RCP 6, using the combined forcing of $CO_2$, $CH_4$ and $N_2O$**

**Key points:**
Perturbations and impacts under the three impact types are calculated for the next 100 years. This has been done here under the RCP 6 scenario (as being the scenario to represent the most realistically most likely future). Perturbations (on the left) are then calculated as described above, leading to impacts (right panel). All values have been normalised to the highest values calculated over the next 100 years. T gives instantaneous temperature impacts, Δ gives rate of change impacts, and Σ gives cumulative temperature impacts. Under RCP 6, the most severe impacts of all three impact types are calculated to occur at the end of the 100-year period. Impacts increase sharply towards the end, especially for cumulative temperature impacts.

# The biophysics of adding one unit of $CO_2$




**Key points:**

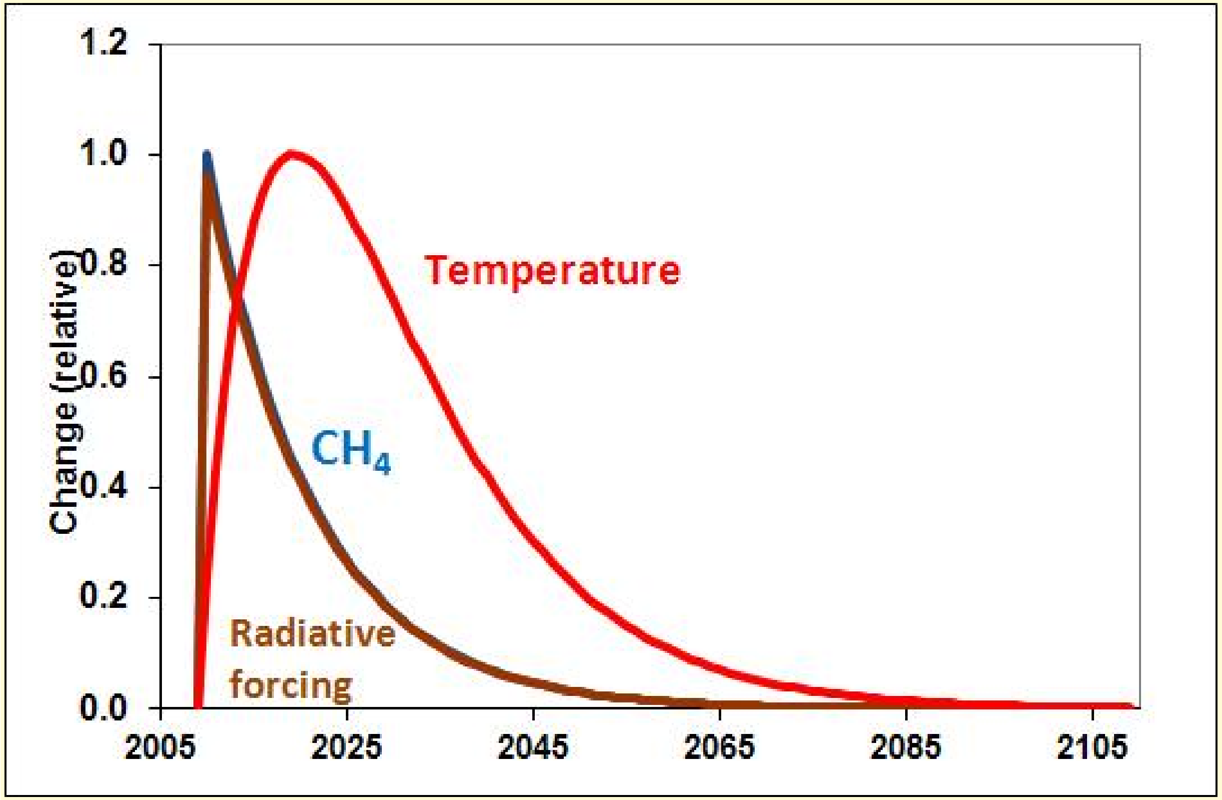
The graphs shows the biophysical consequences of adding one unit of $CO_2$ in 2010.

Some of the $CO_2$ added to the atmosphere is taken up by the oceans and the biosphere so that atmospheric $CO_2$ starts to decrease over time after the initial addition (the blue line).

Radiative forcing increases in line with higher atmospheric $CO_2$. However, if the background $CO_2$ concentration increases, as is expected over the next 100 years, the marginal radiative forcing of each individual molecule of $CO_2$ will progressively decrease, hence radiative forcing from $CO_2$ emitted in 2010 (the brown line), decreases more sharply than the $CO_2$ concentration.

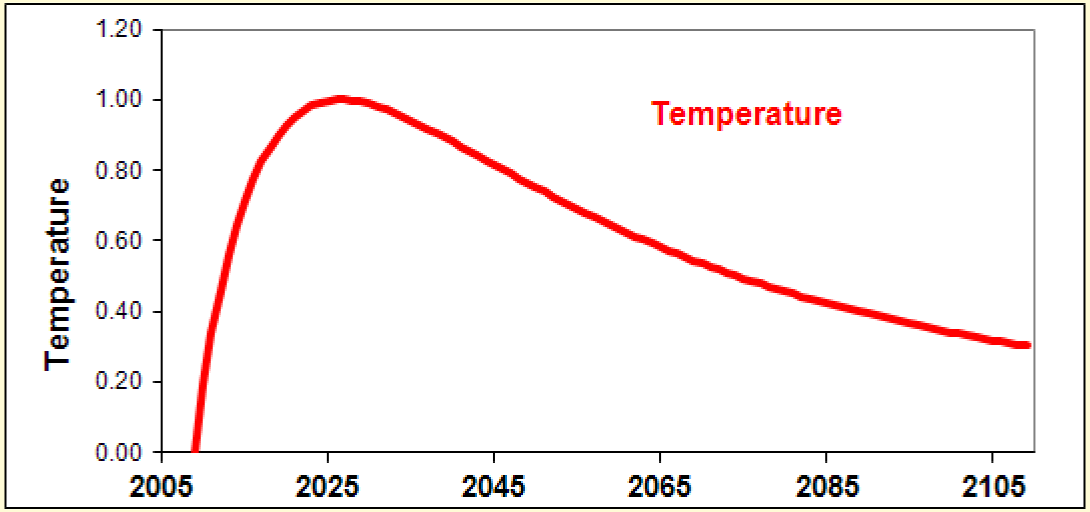
Temperature increases (the red line) then follow the increase in radiative forcing, but with a further delay due to the inertia in the global climate system (modelled here with a simple 10-year time constant).

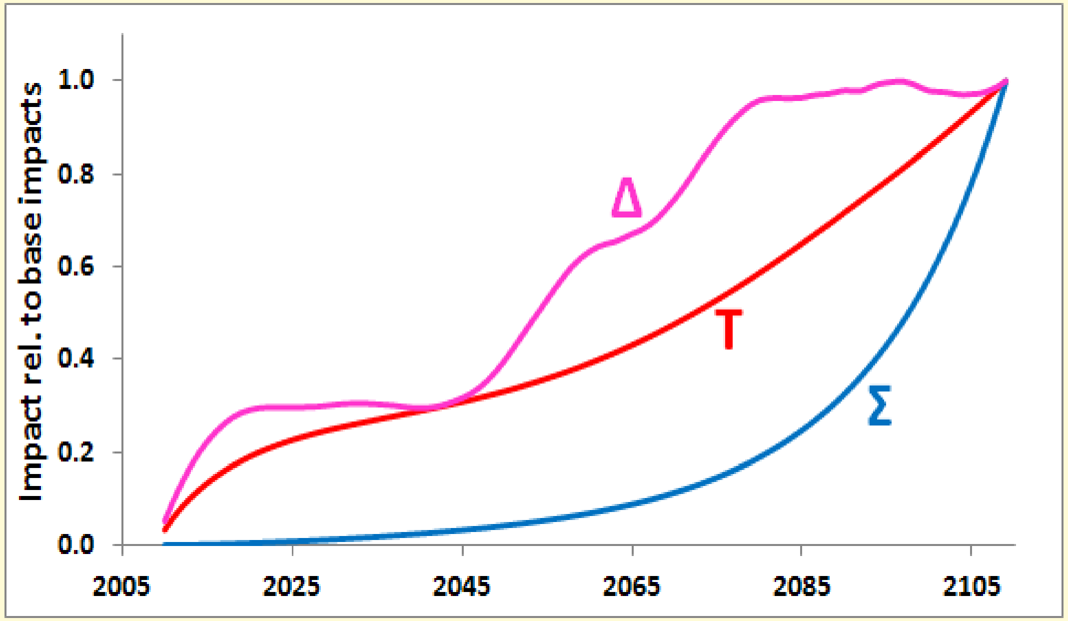
# The biophysics of adding one unit of $CH_4$




**Key points:**
This graphs shows equivalent changes as the previous graph, but for methane.
The patterns differ from those for $CO_2$ in that the decrease in gas concentration is much more rapid, and more complete, than for $CO_2$. Radiative forcing follows methane concentrations more closely because the RCP 6 scenario includes little change in the anticipated future methane concentrations.
Temperature then follows radiative forcing, but with the rapid disappearance of added methane, the temperature response also fades away, with little residual increase apparent at the end of the 100-year period

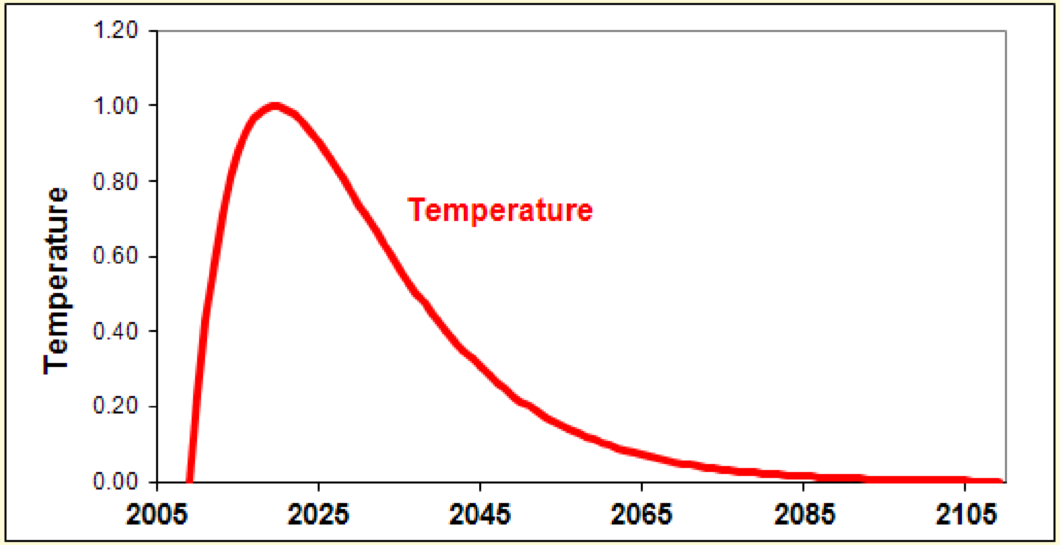
# Adding one unit of $CO_2$

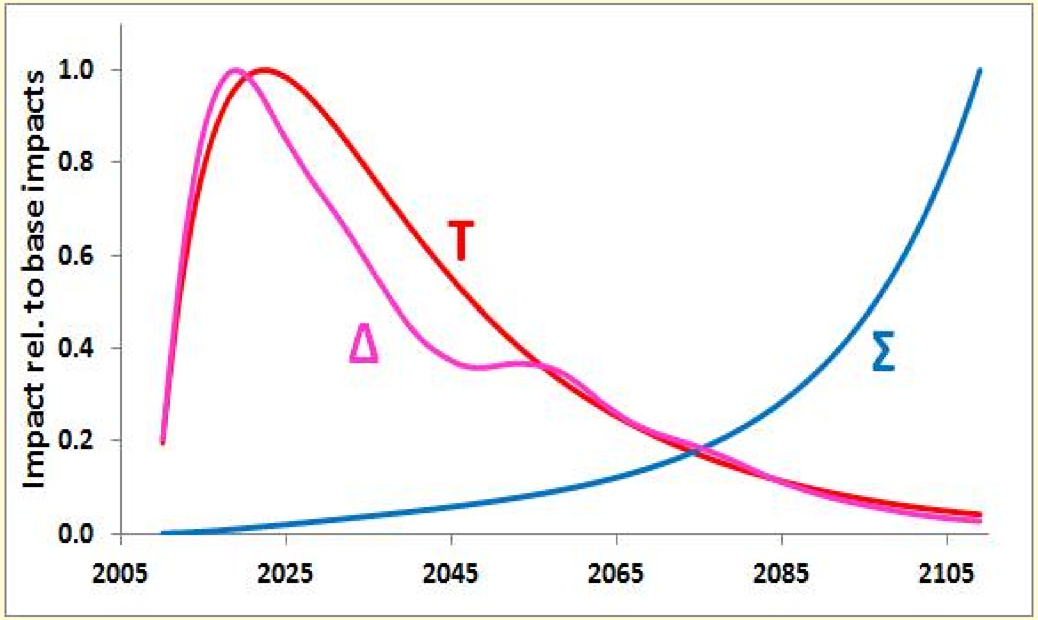



**Key points:**
The top graph shows the temperature change from adding one unit of $CO_2$ in 2010 as calculated previously. The bottom slide shows the respective impacts when that temperature increase is added to the background temperatures under RCP 6.
Instantaneous impacts (**T**) increase over time even though the underlying raised temperature diminishes. That increasing responsiveness is because any temperature increase has greater impact if it is added to temperatures that are already in a damaging range. The same pattern is even much more pronounced for cumulative temperature impacts (**Σ**), but less pronounced for rate of change impacts (**Δ**).

# Adding one unit of $CH_4$




**Key points:**
These graphs show the same patterns for a methane addition as the previous slide showed for $CO_2$. The key difference is that with methane's short longevity in the atmosphere, temperature increases from a 2010 emission are not sustained for very long, and there is little temperature effect 100 year after the initial emission. Even though temperature increases could significantly increase impacts by the end of a 100-year period, that effect cannot be realised if the temperature is no longer elevated. Methane's contribution is therefore restricted to the earlier period when it has less impact than the same temperature increase would have later in the century.

# CCIPs (under RCP 6) vs GWPs

| | GWP | Radiative Forcing | Inst T impacts | Cumulative T impacts | Rate of T change impacts | Average CCIP |
|---|---|---|---|---|---|---|
| $CH_4$(B) | 25 | 25 | 11 | 30 | 11 | 17 |
| $CH_4$(F) | 25 | 28 | 13 | 33 | 14 | 20 |
| $N_2O$ | 298 | 414 | 487 | 388 | 483 | 453 |

**$CH_4$(B) = Methane of biogenic origin; $CH_4$(F) = Methane of fossil origin**

**Key points:**
This slide shows relativities of methane and nitrous oxide relative to $CO_2$ for radiative forcing, the three separate types of impacts and their average, the CCIP.
The 100-year sums of radiative forcing calculated here are not the same as GWPs, because of some simplifications in the calculations here, and because GWPs are calculated on a background of constant GHG concentrations, whereas the calculations done here use RCP 6 to give a changing background concentration. This mainly affects $CO_2$ calculations and through that the ratio of different gases to $CO_2$.
Biogenically-derived methane causes less warming than fossil methane because the C molecule in methane would otherwise cause warming as $CO_2$. For biogenically derived methane, CCIPs are about 1/3 lower than GWPs, about ¼ less for fossil-derived methane, and 50% higher for nitrous oxide. In essence, CCIPs shift the emphasis from shorter- to longer-lived greenhouse gases.

# Conclusions

- Impact assessment should quantify impacts in detail, esp. cumulative vs instantaneous
- Current metrics are not based on a consistent underlying theory.
- Give (equal) weight to all impact types.
- Discount rate - use 0 discount rate over 100 years.
- CCIPs provide an index that can replace GWPs.
- CCIPs < GWPs for short-lived gases (i.e. $CH_4$).

*Thank you!*