The Carbon Budget Accounting Tool ('CBAT')

'CBAT is an interactive device to support policy responses to climate change (including the review and implementation of NDCs), developed by the Global Commons Institute'.

Explanatory Note

CONTENTS

1. What CBAT does back to 'contents'

CBAT is an interactive device, which enables users to set from within credible ranges:

- The future budget for human carbon emissions;
- Feedback effects and
- Climate sensitivity

And then from the interplay of those (over the 100-year period from 2010 and 2110 and each of the years in between) to observe corresponding projections for:

- Average global temperature rise;
- Sea-level rise;
- Ocean acidification;

And within that the future interplay of: -

- Various time-frames for the international convergence of *gross* and *per capita* emissions, showing the interdependence of national emission reductions with the need to remain within a pre-determined global carbon budget,
- The transition from high-carbon to low-carbon sources of energy and
- The economic growth and climate change damages arising.

This makes CBAT an essential tool not only for 21st Century policy-makers, but for all those needing to confront their futures in a rapidly changing world.

CBAT also has a role in determining liability for historic emissions by helping to understand the future consequences of those emissions. From a legal perspective, it helps determine the current responsibilities of different actors to take preventative action. It would, for example, have assisted the court in the *Urgenda* case[1].

2. What CBAT is and is not back to 'contents'

CBAT is a 'policy tool' rather than a 'scientific model' which supports:

- Interrogation of scientific projections with a view to
- Precautionary, risk-based policy development under conditions of uncertainty.

CBAT examines critical relationships between increases to the carbon budget and the increasing risks of positive feedback effects that accompany those increases, as it enables users to control key variables in existing climate modeling (the future carbon budget, feedback effects and climate sensitivity) and examine the resulting outcomes.

So CBAT is best understood as both a heuristic device and a cognitive map. It is an approach to problem solving that is not intended to predict perfectly what is going to happen, so much as help to shape risk-averse decisions in the short-term against the longer term goal of UNFCCC-Compliance. So its use is particularly appropriate where:

a) A perfect model is not available; and
b) Practical policies need to be implemented regardless - precisely the circumstances relating to current climate change policy making.

3. Practical advantages of CBAT back to 'contents'

The absence of an agreed carbon budget (corresponding to the Paris Agreement commitment to limit warming to 1.5 or 'well below' 2 degrees Celsius), and scientific debate uncertainty regarding the strength of feedback effects and climate sensitivity, create severe practical difficulties not only for policy-makers but for all those who need to understand the consequences of different volumes and rates of carbon emissions, such as:

[1] *The Urgenda Foundation v. Kingdom of the Netherlands, District Court of the Hague [2015] HAZA c/09/00456689, June 2015* in which a Dutch Court ordered the Dutch Government to increase the ambition of its emission reduction targets

- the inhabitants of climate vulnerable regions of the world;
- developers of climate sensitive infrastructure and housing;
- providers of disaster relief;
- the insurance industry;
- companies and governments concerned with potential liabilities;
- investors in energy projects; and
- Courts of law.

CBAT helps overcome these difficulties by enabling users to test the consequences of different carbon budgets that are linked to user-control-arrays that cover the key areas of scientific uncertainty. Uncertainty regarding feedback effects, for example, may lead to their omission from scientific modeling altogether, resulting in models that are potentially misleading from a policy-making perspective.

CBAT confronts users with the significance of feedback effects and climate sensitivity, and allows for user choices within the full range of scientific debate. Consequently it allows users to adopt a pragmatic, risk-based approach to scientific uncertainty and even controversy. By amalgamating the input of different variables into trend-path-arrays, CBAT stays relevant to evidence of the changing rates of climate in future.

CBAT can also be used retrospectively to test assumptions, once emissions and atmospheric concentrations of carbon become known (as from 2010). Overall, it provides a basis for structured dialogue between policy-makers and scientists about scientific methods, risk assumptions and collective, precautionary decision-taking.

4. The Four CBAT Domains back to 'contents'

CBAT consists of the following four 'domains':

Domain 1 ('Contractions and Concentrations') enables users to set carbon budgets, feedback effects and climate sensitivity separately and then observe corresponding path-projections for globally averaged atmospheric carbon concentrations, temperature, sea-level rise and ocean acidification. Users can set and see the path-projected consequences to 2110 and also spot-detail for any year between 2010 and 2110 simultaneously. Domain one underpins all four CBAT domains and all four of these domains should be read in concert.

Domain 2 ('Contraction and Convergence') assumes the rational and equitable distribution of any remaining carbon budget requires countries with high *per capita* emissions to reduce their emissions faster than those with lower emissions. Domain two shows how different budgets and different rates of emission 'convergence' within those budgets, project different inter-national distributions of the carbon budget across different regions of the world over the period 2010 to 2110. Users can select different dates and rates for the *start* and *finish* of international convergence of *gross* and *per capita* emissions over time.

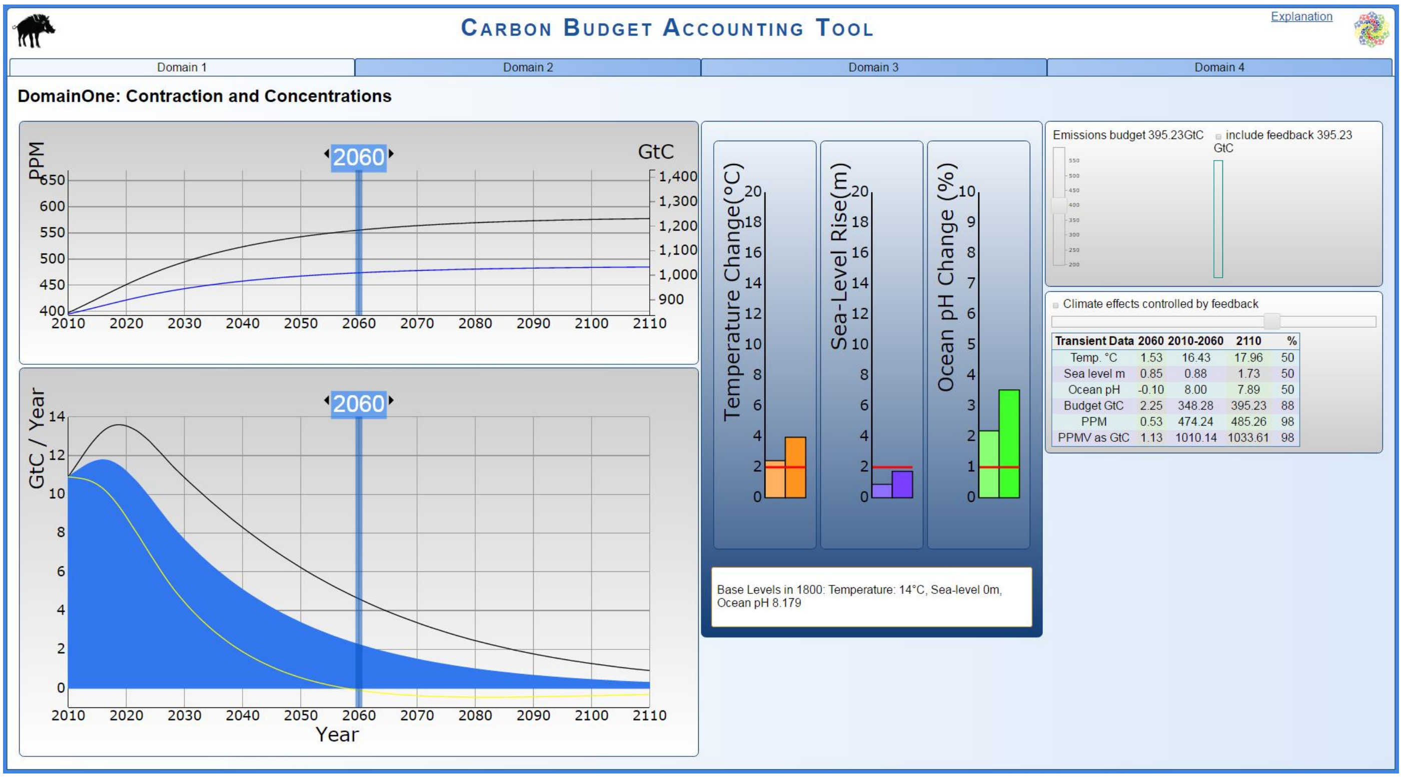
Domain 3 ('Contraction and Conversion') shows how the rate of demand for clean sources of energy is tied to different rates of global carbon contraction budgets over the period 2010 to 2110. CBAT's 'clean energy' model simply distributes future demands evenly as between *wave*, *water*, *solar*, *wind* and *Earth/Bio*. There is separate control for *nuclear* energy's share of future demand, as it is assumed that a contribution from nuclear may be relevant.

Domain 4 ('Damages and Growth') projects climate change loss and damage rates, for a given carbon budget, feedback and sensitivity levels, in relation to constant GDP growth at 3% a year from 2010. In relation to that, the user can set the percentage of GDP that is climate-damages in 2010 (from 1% to 10%). In that context, if the carbon budget contracts too slowly, damage rates can rise faster than 'growth' and 'growth minus damages' unfold at rates where 'global economic collapse' is increasingly likely in relation to increasing delay with decarbonization.

5. User guide to the Domains back to 'contents'

- A 'Mouse-Hover' function reveals *names* for all features shown, in all charts in all Domains. For example, if the mouse hovers over blue mass in Domain 1 screen-left, a label saying, *"Budget Emissions Gt C"* is shown.
- Tabulated numbers are displayed on-screen in extensive detail, responding dynamically to *all combinations of user control-choices in Domains 1, 2 & 4*.
- The opening default in Domain One, shows the Carbon Budget in the UK Climate Change Act at 395 Gt C 2010 -2110, in other words the CBAT default is at the mid-point of its range of 'Emissions Budgets'.

Domain 1



Carbon Emissions Budgets – Contraction and Concentrations

In the lower left hand box is the 'Carbon Budget. It is expressed in Gigatonnes of Carbon (Gt C). When users move the 'Emissions Budget' slider up and down the scale on the right, we can see and set from an array of projections of budgets as 'path integrals' over time (2010-2110) within a range of approximately 200 to 600 GtC.

It is important to note that these are 'Budget Emissions' (from oil, coal, gas burning, flaring, cement-making and land-used changes; see Domain three) which we can directly control, as distinct from 'Feedback Emissions' (see below) which we can't.

Carbon Emissions as Atmospheric Concentrations

In the upper left hand box, the blue and black lines represent carbon emissions remaining in the atmosphere as 'Constant Airborne Fractions' ('CAF') of the emissions budget selected in the lower left hand box. These CAF lines are reference lines; the black line denotes CAF at 100%, the blue line CAF at 50%. All paths for the atmospheric concentrations of carbon are expressed both as parts per million ('PPM') Carbon Dioxide and also as the corresponding weight of Carbon only, in Gt C.

Rising atmosphere concentrations of carbon dioxide are simply the accumulation of a particular fraction of emissions. In recent history, CAF has tended to be a little under

50% of emissions (the *Fraction Retained*), meaning a little over 50% of carbon emissions has been re-absorbed (the *Fraction Returned*) by carbon sinks, such as forests and oceans. Feedback effects are now affecting the balance of these fractions.

Temperature, Sea Level Rise, Ocean Acidity.

The vertical bars in the middle are in left-hand/right-hand pairs. The right-hand bar is always set at 2110. The left-hand-bar shows all & any year between 2010 & 2110 in response to VBL (see below). The orange bars show projected *temperature* change; the purple bars show *sea-level rise*; the green bars shows *ocean acidification*.

In the emissions/concentrations charts on screen-left, there is a vertical blue line (VBL) with a date-year shown on it. When the user shifts this blue control-line left and/or right, it shows values for any given date in projections 2010 and 2110.
This in turn shifts the left-hand orange, purple and green bars to show projected temperature, sea-level and ocean acidification changes for the specified date, eventually moving to become the same as the right-hand bar reaches 2110.

Feedback Emissions (as distinct from Budget Emissions).

Now check the *'include feedback'* box in the top right hand corner. In the top screen-left 'concentrations' box you will see a set of three more lines, two grey and one red. In the lower screen-left emissions contraction box a corresponding set of three more lines, two grey and one red appear. The upper set represent feedback concentrations and lower set represent feedback emissions. Tonne for tonne, the carbon weight of these budget/feedback emissions and concentrations correspond in Gt C.

You can now move the 'Feedback Slider' up/down to set the level of feedback. This combines 'budget emissions' with 'feedback emissions' to combine the atmospheric CO2 concentrations. Note, the red line moves in the range available within the feedback slider at the budget slider position chosen, with corresponding results for Temperature, Sea-Level Rise and Ocean Acidification becoming evident.

Climate Sensitivity.

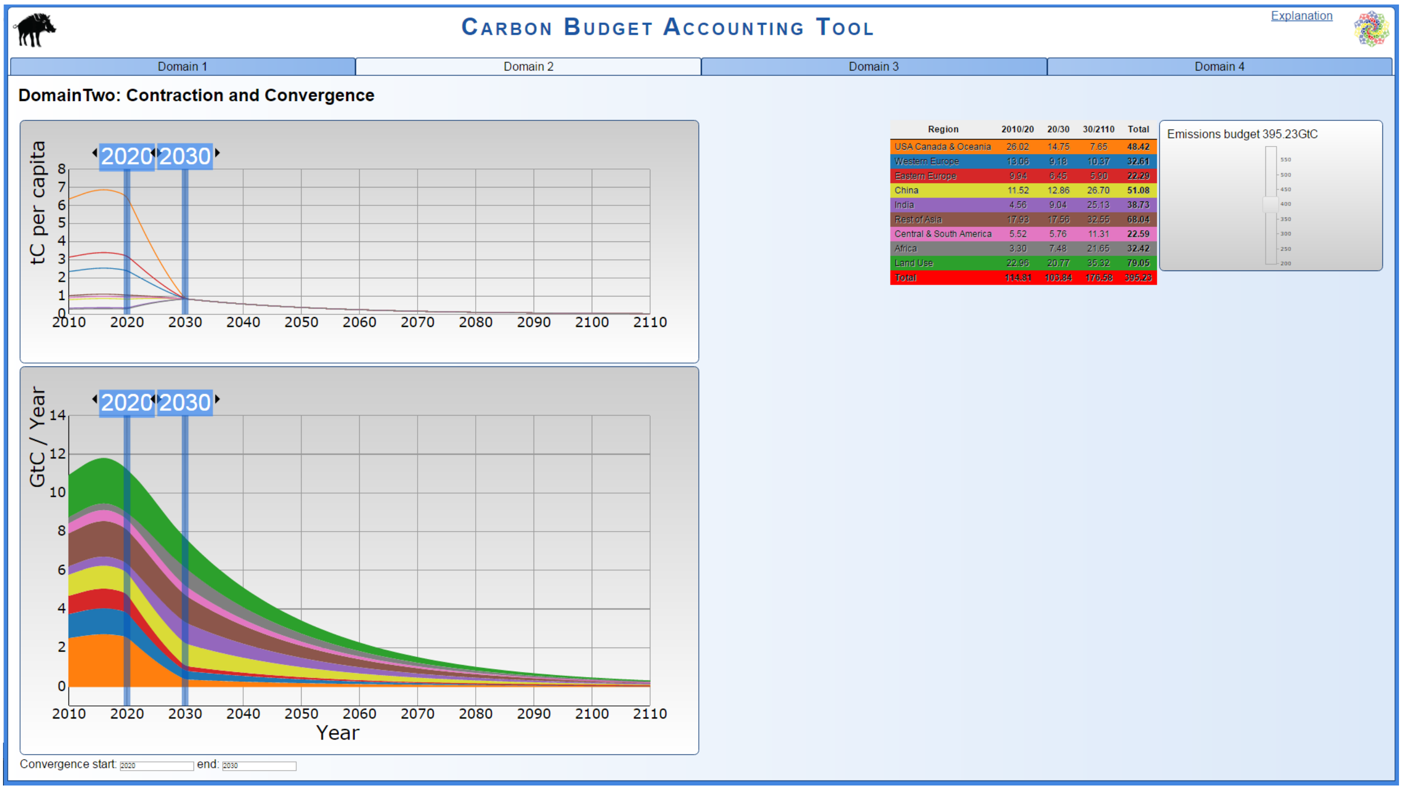
Now move the horizontal slider in the right hand box left and right. This controls climate sensitivity over a high/low range 1.5° to 7.8° C. Estimates for this value have been rising. The higher the sensitivity level selected, the higher the corresponding consequences for Temperature, Sea-Level Rise and Ocean Acidification become.
A check-box also enables sensitivity to be coupled to or uncoupled from feedback.

As previously, you can slide the blue bar on the left hand side to left and right, for projections for a given date in any carbon budget scenario between 2010 and 2110.

Reflecting how bigger (heavier slower) carbon budgets lead to higher temperatures and stronger feedback effects, note how with increases to the carbon budget, the available range for feedback effects tends to rise upwards in relation to CAF 50% (i.e. the blue line in the top left hand box), while with decreases to the carbon budget, the available range for feedback effects tends to fall downwards in relation to CAF 50%.

Domain 1 provides the calculating basis for analysis in all other CBAT domains.

Domain 2



Carbon Emissions Budgets – Contraction and Convergence

The budgets in Domain 2 correspond with the budgets in Domain 1.
Resetting the Budget in any of the four Domains, resets it in all four Domains.

Set the global emission budget with the slider in the box on the right-hand side.
This carbon budget is regionally sub-divided into: -

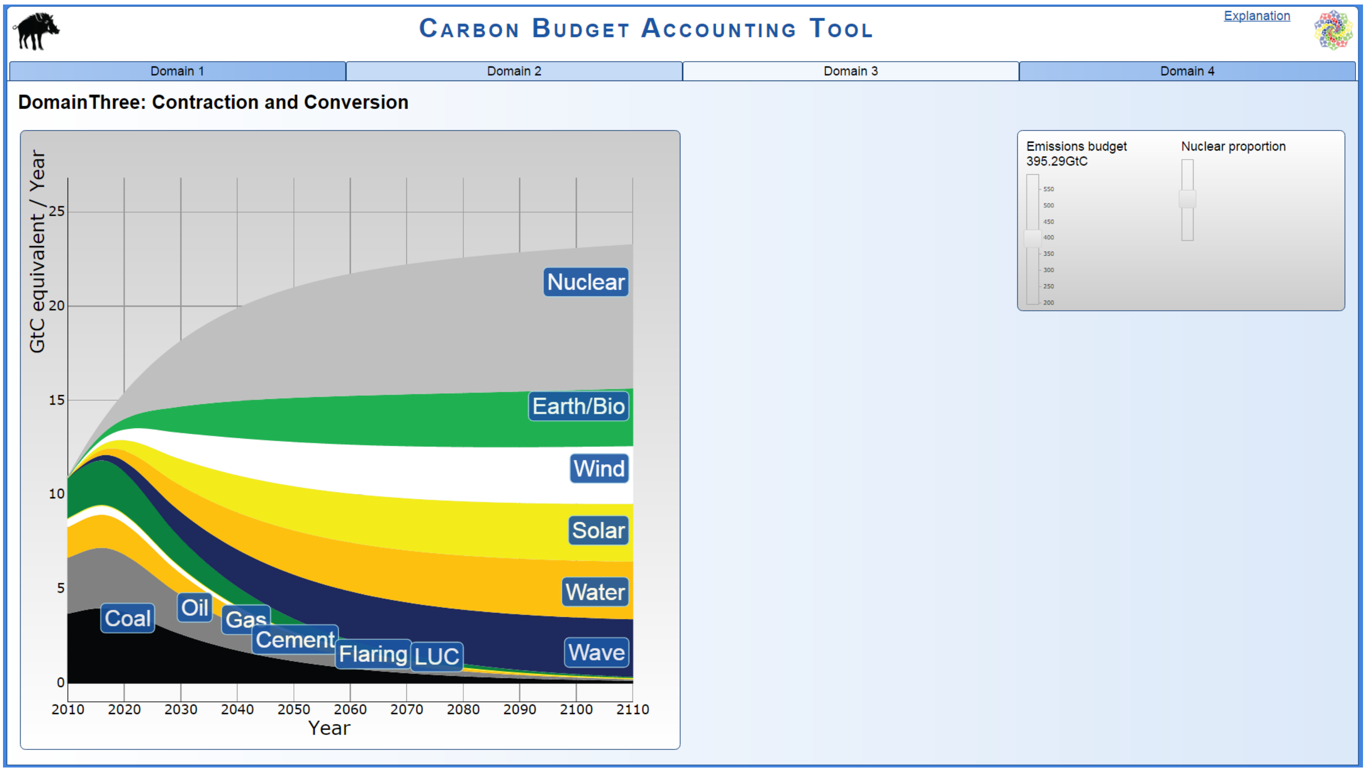
1. Land Use Change
2. Africa
3. Central and South America
4. Rest of Asia

5. India
6. China
7. Eastern Europe
8. Western Europe
9. USA Oceania and Canada

Now use the two blue bars on the left, to set the start and the finish dates for the 'convergence-window'.

Showing both per capita emissions (screen-left top) and gross emissions (screen-left bottom), note how early start and finish dates for convergence assign a greater share of the global emissions budget as 'emissions-entitlements' to developing regions of the world, whereas later start and finish dates do the opposite.

Domain 3



Carbon Emissions Budgets – Contraction and Conversion

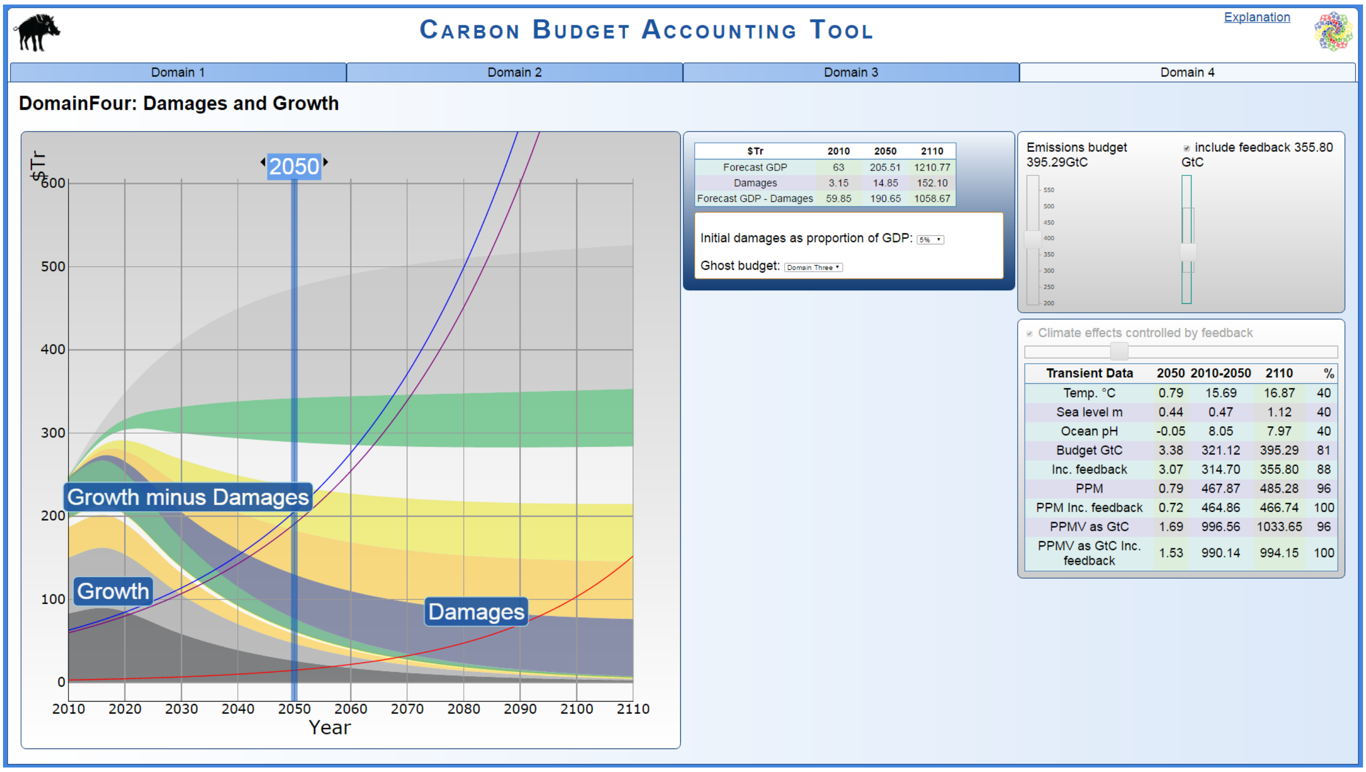
The budgets in Domain 3 also correspond with the budgets in Domain 1. Resetting the Budget in any of the four Domains, resets it in all four Domains.

Note how an enlarged carbon budget requires only a slower implementation of low carbon sources of energy but with a higher level of climate risk.

Note how a more reduced carbon budget requires a more rapid implementation of low carbon sources of energy, but with much lower levels of climate risk.

Now move the slider to vary the 'nuclear proportion' of the energy mix, and see the corresponding consequences on demand for the other forms of low carbon energy.

Domain 4



Carbon Emissions Budgets – Damages and Growth minus Damages

In the screen-middle box, set initial damages as a percentage of global GDP in 2010, in a range of 1% to 10%. Choose whether to use Domain 2 or 3 as the backdrop.

The budgets in Domain 4 also correspond with the budgets in Domain 1.
Resetting the Budget in any of the four Domains, resets it in all four Domains.

Now, using the box in the top right hand corner, set the emissions budget and the level of feedback effects. If the size of the global carbon budget increases due to any delay in decarbonization, the potential for damage rates to rise exponentially increase as well, leading to the growing collapse of the curves that are calculations of 'growth minus damages.' This is Mark Carney's *"Climate Horizon"* and is what is meant by the phrase used at the IEA in January 2016 by Sir David King who said, *"Unless we become very pro-active, what we face is a looming catastrophe for mankind."*

6. CBAT definitions and terms back to 'contents'

'Carbon budget' is expressed in Gigatonnes of Carbon (Gt C). Divide by 3.67 to convert CO_2 to C. The CBAT range of ~200 to 600 GtC, is ~730 to 2200 Gt CO_2. The default setting for CBAT is 395 GtC (the global budget in the UK Climate Change Act 2008). This is ~1500 Gt CO_2, 50% in excess of the 1000 Gt CO_2, (272.7 Gt C) which IPCC AR5 proposes as offering a 66% chance of staying under 2° Celsius.

PPM is used to denote parts per million (by volume) of CO_2 molecules in the air, and is generally regarded as the critical determinant of future warming. IPCC AR4, for example, argues that PPM has to stabilize at 450 to avoid exceeding the 2 degrees Celsius temperature target. Many, including the respected climatologist, Dr. James Hansen, believe 350 PPM is the safe level. As of August 2016, the level is 404 PPM.

The **Constant Airborne Fraction ('CAF')** of carbon emissions is the percentage of those emissions remaining in the atmosphere after absorption by carbon sinks.
In recent history average CAF is estimated to be between 45 and 50% of emissions.

'Feedback effects' may be positive (accelerating change i.e. 'bad') or negative (decelerating change i.e. 'good'). Positive effects increase emissions and reduces sink efficiency. Increased emissions reduce the capacity of oceans to absorb CO_2 as they acidify. Warmer oceans tend to outgas. Climate induced forest fires reduce sinks and increase emissions. Warmer air holds more water vapour (a GHG). Melting ice and permafrost, reduce albedo (reflectivity) and release CH_4 & CO_2. Negative effects include increasing plant growth in response to increasing concentrations of atmospheric carbon. As a simplifying device, CBAT resolves all feedback effects back into trend-path arrays of atmospheric carbon concentrations. Summed this way reflects that increasing concentrations of atmospheric carbon lead to an increasing probability that positive feedback effects will outweigh the negative, though estimating these trends across future time is fraught with uncertainty and risk.

'Climate sensitivity' or λ is defined as the temperature response to a doubling of the concentration of atmospheric CO_2. With a base of 230 PPM, the pre-industrial average for 100,000s years prior to 1800, the λ range in CBAT is 1.5° to 7.8° C.

'Climate Effects' (not to be confused with 'feedback effects') defines the sensitivity / responsiveness of not only Temperature to increasing Atmospheric Concentrations, but also of Sea-Level Rise and Ocean Acidification.

7. Hypothetical case study [back to 'contents']

Determining national emission reductions

Following the Paris Agreement, the government of Country A plans to implement a Climate Change Act legislating for set levels of emission reduction over time. The government's intentions are to:

i) Ensure national UNFCCC compliance;

ii) Encourage others to follow its lead; and

iii) Provide the policy certainty that will encourage investment in low carbon forms of energy production.

The head of the policy team responsible for the legislation wants to understand the global carbon budget for keeping warming below 2 degrees Celsius. She is aware of the IPCC AR5 assessment that a budget of 1000 Gt CO2, as from 2010, gives a 66% probability of keeping within that budget, but does not consider that gives her sufficient insight to frame national policy of profound, long-term national significance.

By using CBAT she gets a sense of the critical relationships between global emissions, feedback effects, climate sensitivity, future warming and is able to interrogate her scientific adviser on the uncertainties. She also sees the relationship between carbon budgets, future energy demands and economic growth.

She does not take CBAT projections as scientific certainty, but interprets them in light of input from her scientific and actuarial risk advisers.

On the basis of these discussions she feels confident in recommending to her Minister, that for the purposes of the national legislation,

- The sizing of a global emissions budget consistent with limiting warming to 1.5 or 'well below' 2 degrees Celsius is defined by a full global carbon-contraction event of 'X' Gt C;
- Limiting the international sharing of this to a carbon-convergence process of 'Y';
- Linked to a technological low-carbon conversion rate 'Z' that is coupled with the rate of 'X/Y';
- Aimed at avoiding the looming catastrophe of climate-damages 'CD' that ensues if the rates of 'X Y Z' are too slow.

Determining a national adaptation plan

Country A is at high risk from climate change: it has extensive coastal settlements that are vulnerable to sea-level rise, and a large proportion of its population depends on subsistence farming, the viability of which is threatened by increasing drought. The department of health is concerned about the spread of mosquito borne viruses (including zika) resulting from increasing domestic storage of still water, and rising temperatures.

The government of Country A must develop a cross-departmental adaptation plan, led from the Office of the President.

The policy lead concludes that an adaptation plan must depend on accurate projections of temperature and sea-level rise for the different regions of the country, at different points in time (that are subject to constant revision as reality unfolds). A crucial input are the projections for average global warming.

While welcoming the Paris Agreement commitment to limit warming to 1.5 or well below 2 degrees Celsius, she is aware of the gap between actions and goal. The commitment cannot provide the basis for an adaptation plan that addresses the risks for the citizens of country A. Nor is she prepared simply to defer such a crucial policy question to her scientific advisors.

She uses CBAT to structure the discussion with her advisers, and as a result concludes that by 2030 the country must be prepared for warming of *a* degrees Celsius, and sea-level rises of *b* meters; and by 2050 of *c* degrees Celsius and sea-level rises of *d* meters.

Country A's adaptation plan proceeds on this basis.

8. CBAT testimonials back to 'contents'

"It is important to deal with worst-case scenarios, and clearly this includes feed-back effects. At this point however, they are difficult to quantify or even estimate, however important. Converting this into impacts is what the 'Carbon Budget Accounting Tool' (CBAT) programme deals with and CBAT is obviously a great piece of work."

Sir David King, UK Government Special Representative for Climate Change

"By separating out the effects of human-induced and feedback-related emissions, the GCI's brilliant CBAT visualization tool sidesteps the wishful thinking and provides a sharp dose of reality. I urge all who wish to view a true picture of how climate change will transform our world as the century progresses to use it and promote it."

Bill McGuire, Professor of Geophysical & Climate Hazards, UCL

"CBAT is an extremely useful tool, and shows what needs to be done to reduce our emissions on a range of scenarios … It should be a go-to resource for all our governments. Because of the level of detail and scenarios it considers and the quantitative figures, someone needs to share this with the Australian government. Along with all national governments, they would benefit greatly from understanding how our future will or will not change due to the choices we make now and in the near future. It's a testament to CBAT that the U.K. are already employing it. I will keep this tool on file and refer to it when necessary."

Dr. Sarah Perkins, Climate Research Centre University of New South Wales

"The unknowable has just become knowable. Politicians, economists and policy-makers are faced with making decisions today on scientific details and projections they know embarrassingly little about. The Carbon Budget Analysis Tool (CBAT) will give them what they need. CBAT is a seriously powerful dynamic tool for understanding the consequences of climate change, GHG emissions, the all-important climate feedbacks, and of course, political and economic choices."

Dr. Tom Barker, Head of Education Centre for Alternative Technology

"We recognize GCI has made a unique breakthrough in creating a user-interactive, non-directive dashboard with potential to simulate such an inclusive range of the system dynamics of the natural/human interaction! Separating the contribution to CO2 concentrations driven by anthropogenic emissions from the contribution coming from the feedback system is brilliant at a conceptual level."

David Wasdell, Chairman of the Apollo Gaia Group