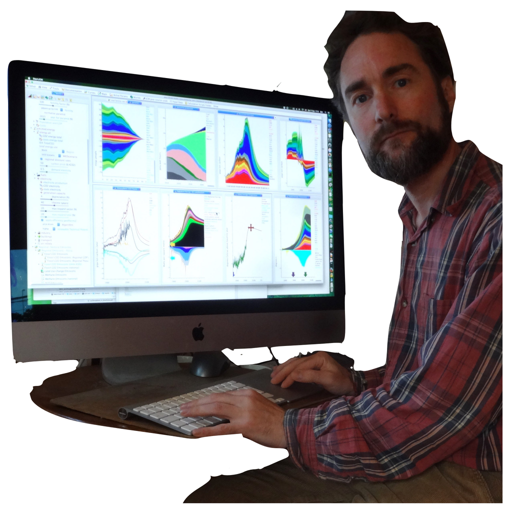
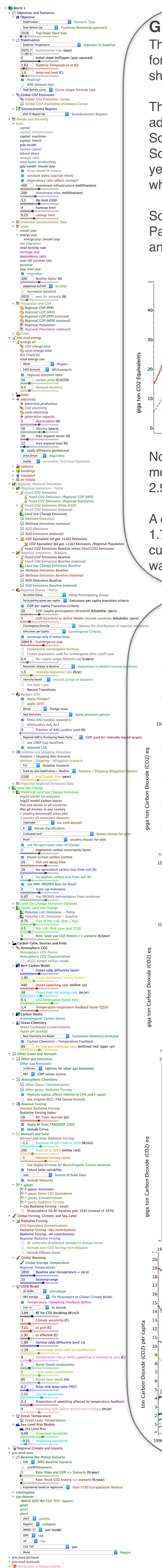
An Interactive Model for Exploring Options and Uncertainties Influencing Pathways towards a 1.5°C goal

Dr Ben J.H. Matthews
ben@benmatthews.eu
+32472987028



Scenarios exploring regional emissions pathways to a 1.5°C goal (or at least, well below 2°C as suggested by the Paris agreement) are analysed using the interactive integrated assessment model JCM. This tool was created to enable stakeholders to explore the sensitivity of climate scenario projections to a diverse range of scientific uncertainties and policy choices. It is not easy to illustrate such a flexible interactive tool with a static poster. However the model structure, designed for rapid response to parameter adjustment, is also efficient for systematic analysis blending hundreds of scenarios, an example of which is illustrated. A similar approach has been applied to 2°C scenarios, indeed JCM made the first probabilistic assessment of 2°C stabilisation, presented in 2003. Since then global emissions have increased (possibly just peaked?), but so has information and concern about projected impacts, hence the more ambitious 1.5°C goal, with which the Paris INDCs are evidently not consistent (as shown below).

JCM has been developed since 2000, working mainly in Belgium, but initially in UK, Denmark, Norway, Switzerland, and recently Brazil. The author has analysed sustainable equitable climate stabilisation pathways for 20 years (first analysis presented at COP2, 1996), following earlier research on air-sea CO2 fluxes. He also tried to apply such calculations to his own lifestyle (e.g. only 3.5 trips by plane in 27 years), a factor explaining his status as an independent scientist.



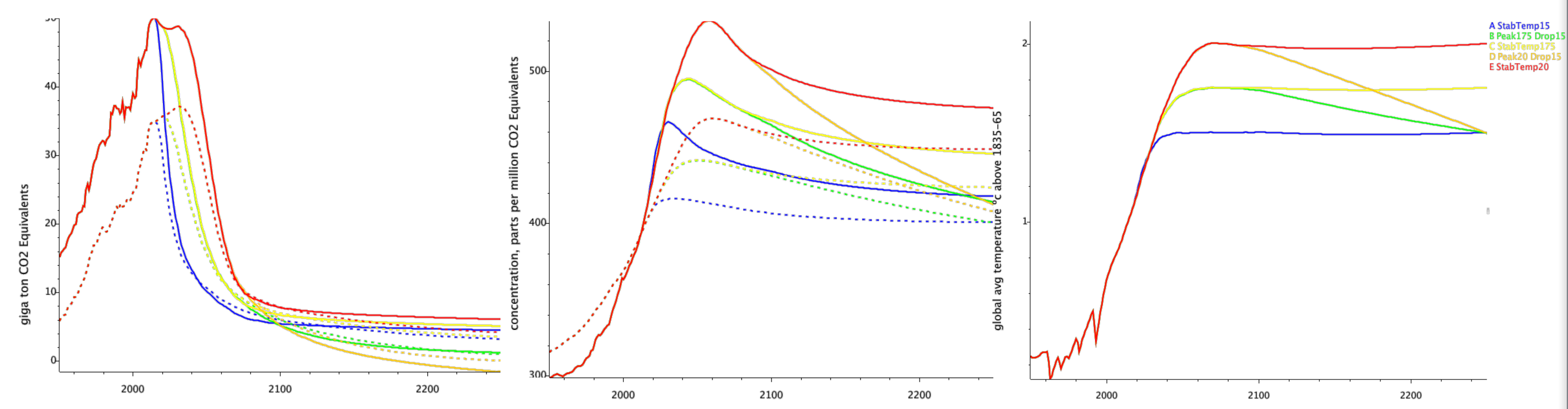
This model-control tree illustrates some of the user-adjustable parameters and plots available in the interactive model. They are organised by module, some still under development. More parameters appear, depend on visible plots and options chosen. When a parameter changes, only modules affected and needed (for plots) recalculate, controlled by a dynamic model interactions system (illustrated bottom left). This keeps JCM fast, both for interactive exploration and probabilistic analysis.

Global Scenario Definitions

The plots illustrate CO2eq emissions (all GHGases+ Sectors), CO2eq concentration (derived from radiative forcing, including aerosols and ozone) and Global Temperature rise, for **5 global scenarios**. The dashed lines show energy (no LUC) CO2 emissions, and CO2 (only) concentration, respectively.

These scenarios are calculated using an **inverse** method, defining a temperature pathway and **iteratively** adjusting the pathway of emissions (all gases and sectors) to meet it.
Scenario A (blue) which stabilises directly at 1.5C is very challenging, requiring immediate deep reductions.
Scenario B (green) which peaks at 1.75C in 2075 then slowly returns to 1.5C by 2250 may be more achievable, yet still help to avoid longer-term impacts such as sea-level rise. For comparison, a scenario D peaking at 2°C which returns to 1.5C (orange), and non-peaking scenarios C and E stabilising at 1.75 and 2C are also shown.

Scenario A diverges from trends immediately (2016), B & C diverge in 2021 (after CA pledges) and D & E after Paris INDCs in 2031. CO2eq emissions (Gt) in 2020 are 39.3 (A) and 48.8 (BCDE), in 2030 19.8 (A), 39.8 (B,C) and 48.8 (D,E), in 2050 10.1 (A), 17.1 (B), 17.2 (C), 32.2 (D), 32.3 (E). (*Integral data also available - ask*).

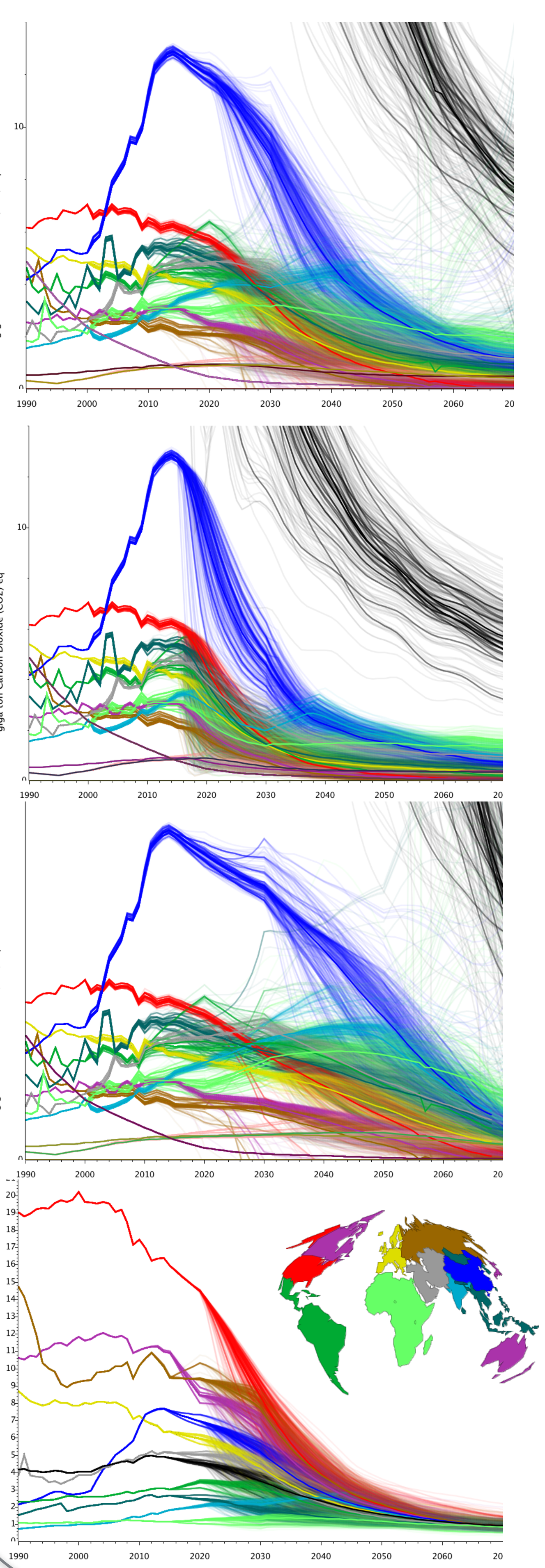


Note that even when temperature is flat, radiative forcing (~ COeq concn) must be falling slightly, but this is mostly achieved by reducing forcing from the shorter lived gases. The radiative forcing of IPCC-RCP 2.6 (peak 2.9) lies between scenarios A and B.

A concept behind such peaking scenarios, is that reducing the temperature back towards 1.5°C after a peak (e.g. 1.75°) would help to reduce long-term impacts such as sea-level rise, which depend to a first approximation on the cumulative temperature rise. As the science of ice-melt has evolved significantly since JCM's sea-level module was developed, this is not shown, pending an update.

Inverse regional analysis - varying many factors

In each plot below, all emissions curves lead to one temperature pathway (spec above), showing a range of emissions consistent with this goal, depending on diverse scientific uncertainties and sharing criteria.



Note: This top-down inverse approach approach differs from that of well known 2°C analyses of published bottom-up scenarios, filtered according to probability of passing 2°C, but with variable temperature pathways.

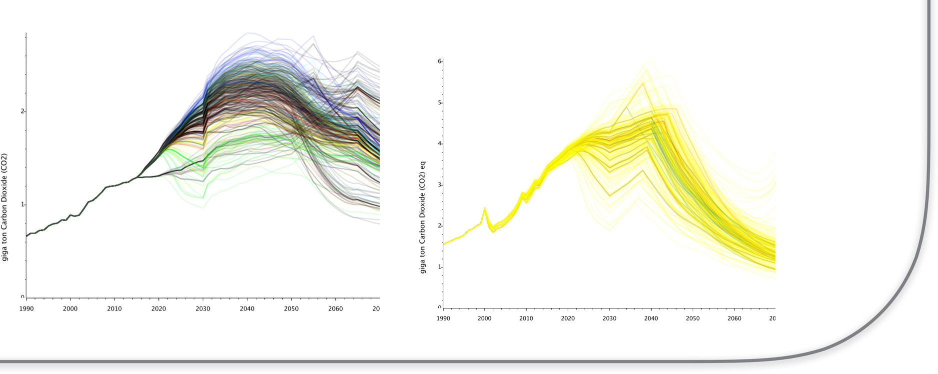
Factors varied include:

- **climate model** (multi-parameter fit to GCMs),
- **carbon cycle** (ocean mixing, fertilisation & temperature feedbacks),
- **baseline scenarios** -various incl SSPs 1,2,4 (multiple IAMs) & SRES. These influence, inter alia, the relative reduction of other gases and LUC compared to fossil CO2.
- potential **land-use** sink
- **INDC / pledge** level (conditional or not)
- post-INDC **sharing algorithms** - e.g. developing countries pass a (variable) GDP threshold before descending, meanwhile emissions intensity is constrained
- **convergence** per capita or per gdp, and timing

These combine to 1200000 variants, filtered to retain sets where only a few parameters deviate from central cases, giving **457 curves** shown here. The plots show, for scenarios B A and D, CO2eq (all gases/sectors - F-gases separate) for 10 regions (map below), and international transport (10 regions are for plotting - JCM calculates individual countries). Black shows global total. Note how **peaking** is later, and **uncertainty** is greater, for **developing** countries, as expected. Energy (fossil) CO2 per capita is also shown for scenario B.

In (extreme) Scenario A (1.5° flat) the combination of bottom-up INDCs with a top-down inverse temperature stabilisation curve, leads to some strange curves - India falls to 2030 (due to low share of scaled-down INDCs) and rises again thereafter. Emissions in some variants fall impossibly steeply, but filtering these out could be misleading - it is a **challenging** temperature pathway (for mitigation - others are more challenging for adaptation).

Recolouring the curves according to specific parameter sets helps **explain the factors** behind divergences. For example a plot below (left) shows how the CO2eq for Africa (Scenario B) is influenced by **carbon-cycle uncertainty** - green curves have lower biosphere fertilisation and soil respiration feedback (which offset, but on different timescales), blue curves faster ocean mixing, etc.
Such longterm factors don't explain the early divergence, which (as examination of other plots shows) is related more to **uncertainty in baseline** scenarios. The next plot illustrates the effect of different **sharing algorithms** for India (CO2Eq, ScenB).

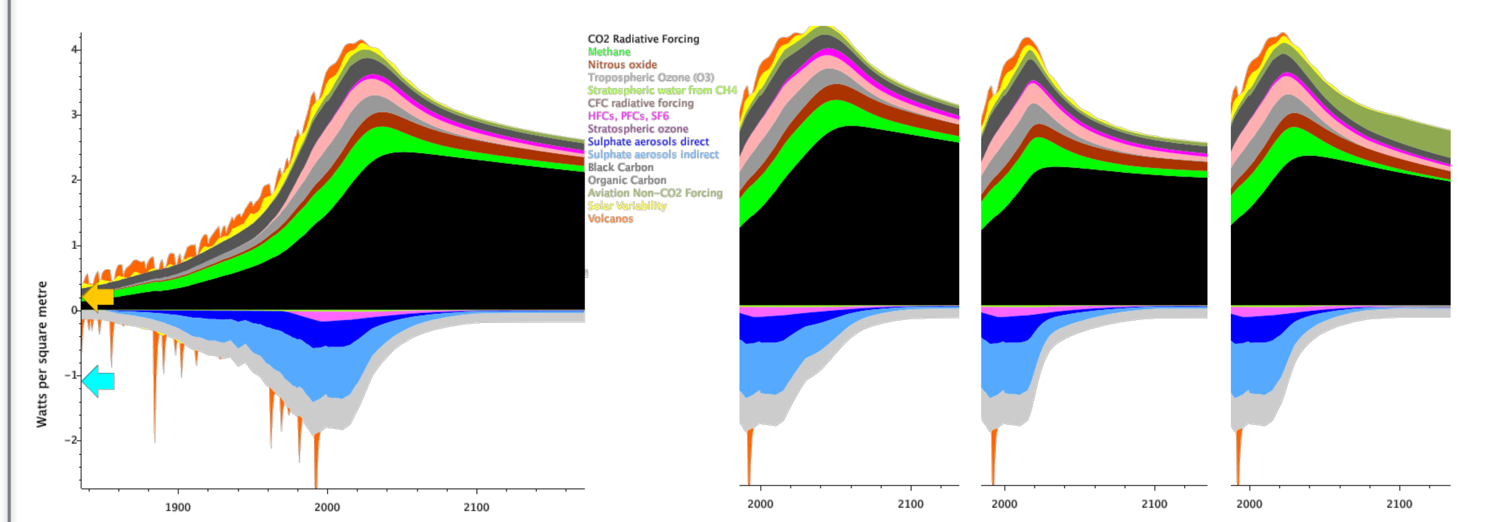


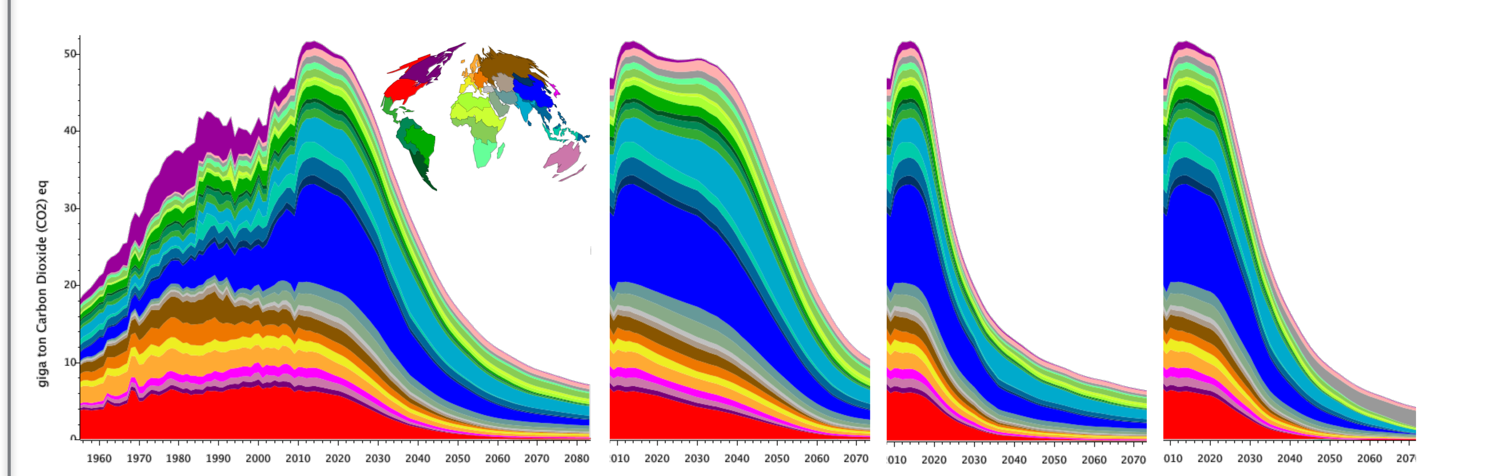
Observations -regional pathways

Plots of regional emissions (CO2eq, all gases+sectors) for scenarios B,D,A, all show a rapid drop, faster than historical growth. The plots of radiative forcing also show the importance of reducing emissions of shorter-lived CH4, ozone precursors and BC aerosols, whose forcing drops much faster than that of CO2 (and N2O), although this drop is offset by inevitable reductions in sulphate aerosols.

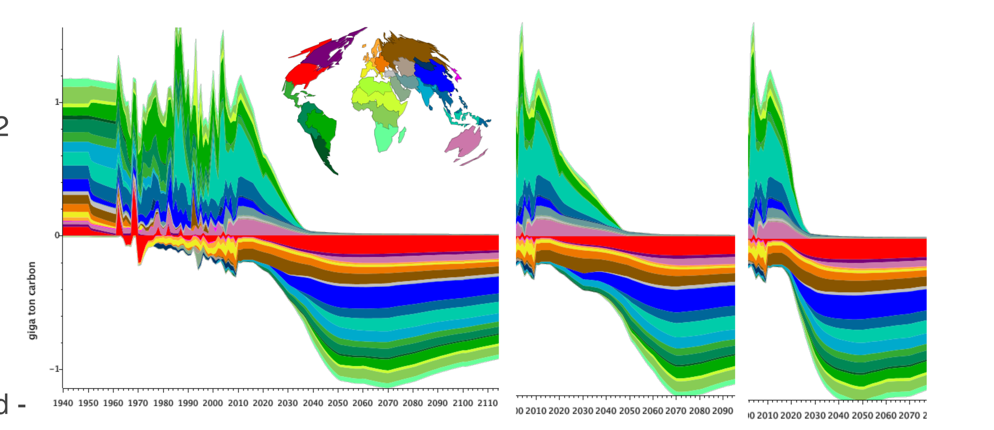
Emissions are reduced **below the INDCs** from 2016 (now) in scenario A, from 2020 in scenario B, C and from 2030 (after INDCs) in scenario D,E. It is evident that the 2030 INDCs (as they are now) imply too much delay to be compatible with 1.5°C scenarios A,B,C. However, close inspection suggests that many INDCs assume inflated baseline growth assumptions, real emissions may be lower. So for all analyses here, even if the INDCs are applied until 2030, any surplus above a modest baseline is removed (this applies mainly to China Russia and Ukraine). It is thus assumed, projecting recent economic trends, that **China has peaked** in 2015.

In the CO2eq plots contributions from CFCs (purple, mostly history), HFCs (pink), and **international aviation and shipping** (grey) are also shown. The latter is scaled down from a modest baseline (Fa1), in proportion to the total, i.e. assuming strong policy applied to these sectors. The last column (B+AS) illustrates what happens if there is no such policy - the additional forcing from aviation cirrus, plus the extra CO2, uses up so much of the budget that other emissions (in LUC) are virtually zero by 2075. Thus, the jet-set **lifestyle** of most UNFCCC delegates is far from consistent with 1.5°C scenarios.



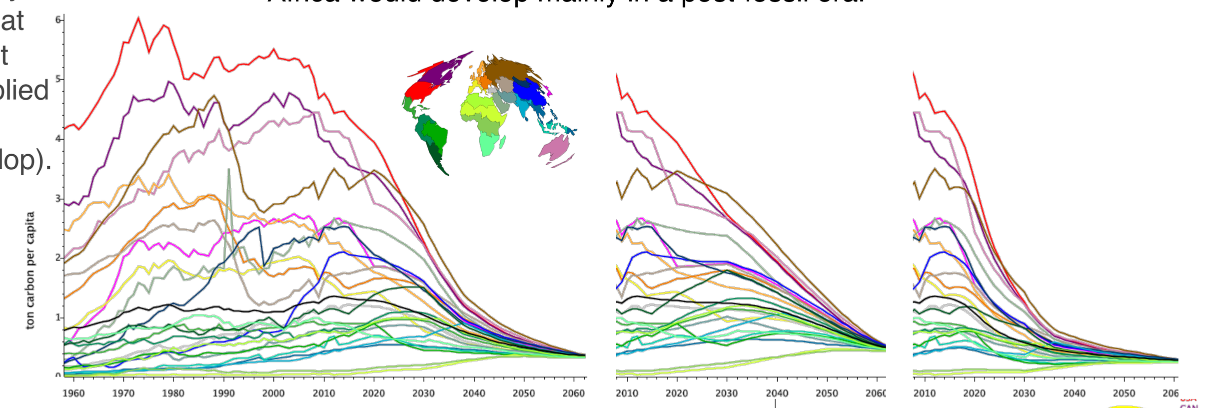


As the global emissions curve is fixed, **LUC and other gases** are scaled down relative to baselines (evolving from trends, towards SSP2 Ref from IMAGE), in proportion to energy CO2, above a potential LUC sink (it's complex…). Plots (right) show that **LUC emissions become rapidly negative.**

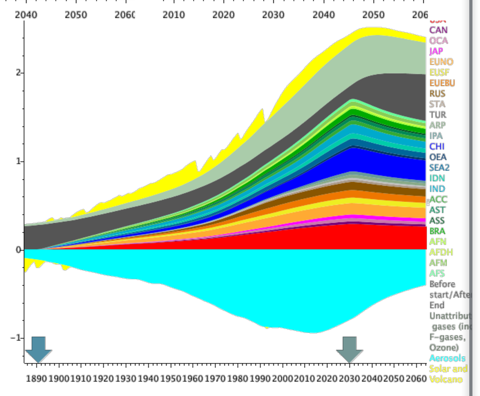


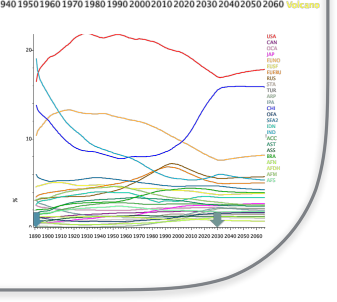
On the other hand, negative energy emissions (BECCS) are not included - it is assumed that reforestation, combined with renewable energy, would be a better way than energy crops to achieve a net sink, especially for biodiversity. As a large land area is reforested, while population is still growing, significantly reduced consumption of meat and other inefficient food sources is implied (quantifying this in JCM is still to develop).

The evolution of energy **CO2 emissions per capita** are also shown (below). Beyond the INDCs, a sharing formula is assumed, in which per-capita emissions eventually converge, but later-developing countries with GDP/capita below 20k$ may peak above the world average. **India's peak** is 2038 (35)(41) in scenario B (A)(D), but this peak (absolute) is below half that of China's. In 1.(7)5°C scenarios, Africa would develop mainly in a post-fossil era.

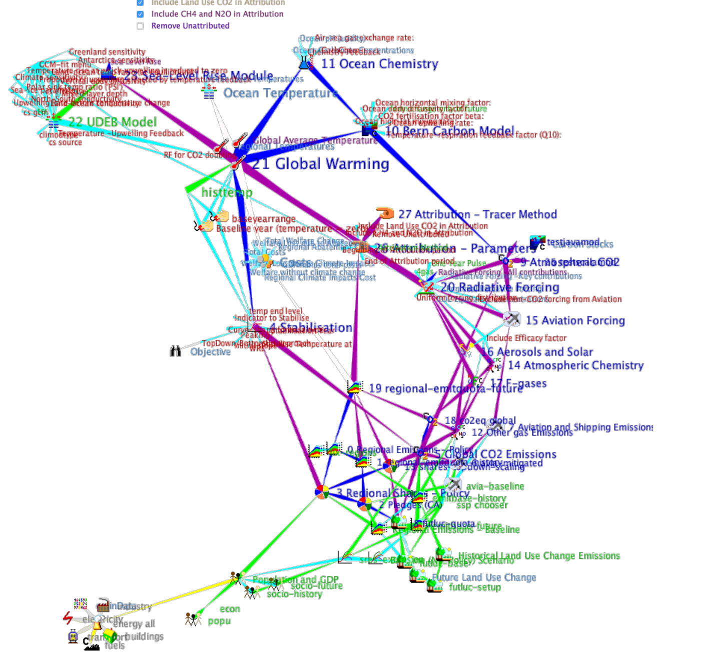


In such rapidly falling scenarios it is inevitable that earlier-developed countries retain a much greater share of **historical responsibility** for climate change. JCM can calculate, using methods developed for inter-comparison projects, the relative national contributions to global warming, shown in the last plot. Considering emissions from 1890 to 2030, after applying the INDCs, **contributions** would be USA 17.0%, China 15.5%, Europe (inc Ukraine) 15.3%, India 6.0%, Russia 5.6% (reducing the INDCs - scenario B- changes these only 0.1%). This may be relevant to **funding** for adaptation and **loss&damage** for the more vulnerable tropical countries, most of which contributed little to the problem, and also for helping them with equitable access to (very low emission) sustainable development.



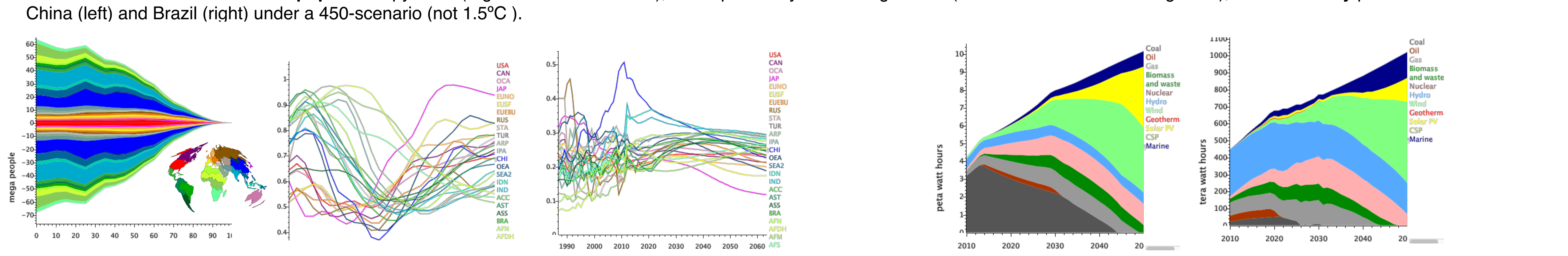


It should be stressed that these plots just apply 'best-guess' carbon / climate parameters, i.e. they do ***not*** *seek a* ***likely*** *chance to stay below a level (as is commonly the case for 2°C scenario analyses). It is too late to seek a high probability to stay below 1.5°C, but avoiding 2°C with a likely chance, may be considered similar to aiming (with best-guess) for a little above 1.5°C.*



JCM Current / Future Development

To explore practical steps (energy, lifestyles, land-use etc.) needed to achieve these pathways, and to reduce dependence on imported scenarios, further development in JCM is underway. Detailed modules for **demographics, economy and energy** already exist but lack inter-connections (e.g. sectoral energy demand). An **investment**-based approach is taken, to distinguish energy demand for infrastructure (capital) and "sustainable" development, from that for current consumption. Together with future land-use/food and **lifestyle** options, these will enable exploration of sensitivity to driver assumptions, which may be compared and calibrated with new IPCC-**SSPs** using a built-in visualiser. Plots below illustrate a **population** pyramid (region colours as above), the dependency and savings ratios (which influence economic growth), and **electricity** production for China (left) and Brazil (right) under a 450-scenario (not 1.5°C).



To balance this, much further development is needed at the **impacts** end of the chain, including updated sea-level rise, and regional impacts. A particular interest is to study potential climate-related **migration**, which links both ends of this chain. JCM's structure is optimised for studying whole system **feedbacks** *(note interactions illustration left).*

New code will be developed in **Scala**, a modern multi-paradigm efficient coding language, which compiles together with existing java, and offers potential export to JS for a web interface.

JCM was designed to be available from in any web browser, but recent changes in client-side java made this more difficult. A new web interface is considered. JCM has a website jcm.climatemodel.info , however this needs updating, Meanwhile please write to me for a copy of the latest version.