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Report and testing of improved IAM

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1. Introduction

1.1 Aims and objectives of the deliverable:

Integrated Assessment Models (IAMs) are used as crucial inputs to policy-making on climate change. These models simulate aspect of the economy and climate system to deliver future projections and to explore the impact of mitigation and adaptation policies. The IAMs' climate representation is extremely important as it can have great influence on future political action. However, in general IAMs have very rudimentary representations of the climate system (Glotter et al., 2014; van Vuuren et al., 2011).

Good et al., (2011) have formulated a method of reconstructing general circulation models (GCMs) climate response to emission trajectories through an idealized experiment. This method is called the "step-response approach" after and is based on an idealized abrupt CO2 step experiment results.

The primary objective of this work is to implement this method in the TIAM-UCL Energy System Integrated Assessment Model and to investigate the main consequences of this modification.

1.2 The treatment of climate science in Integrated Assessment Modelling

IAMs contribute in understanding and forecasting the linkage between the climate and the economic systems. IAMs can be classified in different categories, some have a stronger focus on economics, such as multi-sectoral computable general equilibrium models (focussing on cost–benefit analysis) other are more focussed on the physical processes in the natural system (biophysical impact models) or the technological or economic development of society (integrated structural models). The degree of simplification of the climate system depends on the purpose as well as the mathematical development of the model. In IAMs focussing on cost–benefit and optimisation analysis climate system are often strongly simplified. When focussing more on physical processes the representation of climate has more detail using upwelling-diffusion energy balance and a representation of global carbon cycle (e.g. MAGICC). Additionally downscaling techniques can be applied to provide gridded climate parameters. These simplifications in the climate representation are needed in IAMs to allow rapid assessment of projected climate change resulting from a wide number of proposed scenarios and policy options. However, a drawback could arise from this simplified climate representation in term of traceability to the more complex GCM results. How many parameters to include in the simplified version, which processes to parameterise and how to parameterise them? The traceability between response of the IAMs climate model and complex model is vital to address policy relevant questions accurately. Consequently, it makes sense to expect the behaviour of the IAMs climate and carbon cycle modules to be within the range of results of more developed models. Van Vuuren et al., (2011) focused on the climate component of IAM and find a wide spread within IAM in different climate variables. Interestingly, this spread is more pronounced for very low emission scenarios (Van der Linden, 2009). Figure 1 from van Vuuren et al., (2011) represents the spread of IAMs and GCM results for the E1 scenario, an emission scenario used in the ENSEMBLES project that has many features of the RCP2.6. This spread in IAMs performing cost-benefit analysis and assessment of mitigation costs could imply thousands of billion US$ in terms of cumulative abatement costs. There is therefore a clear need of more research in this topic.

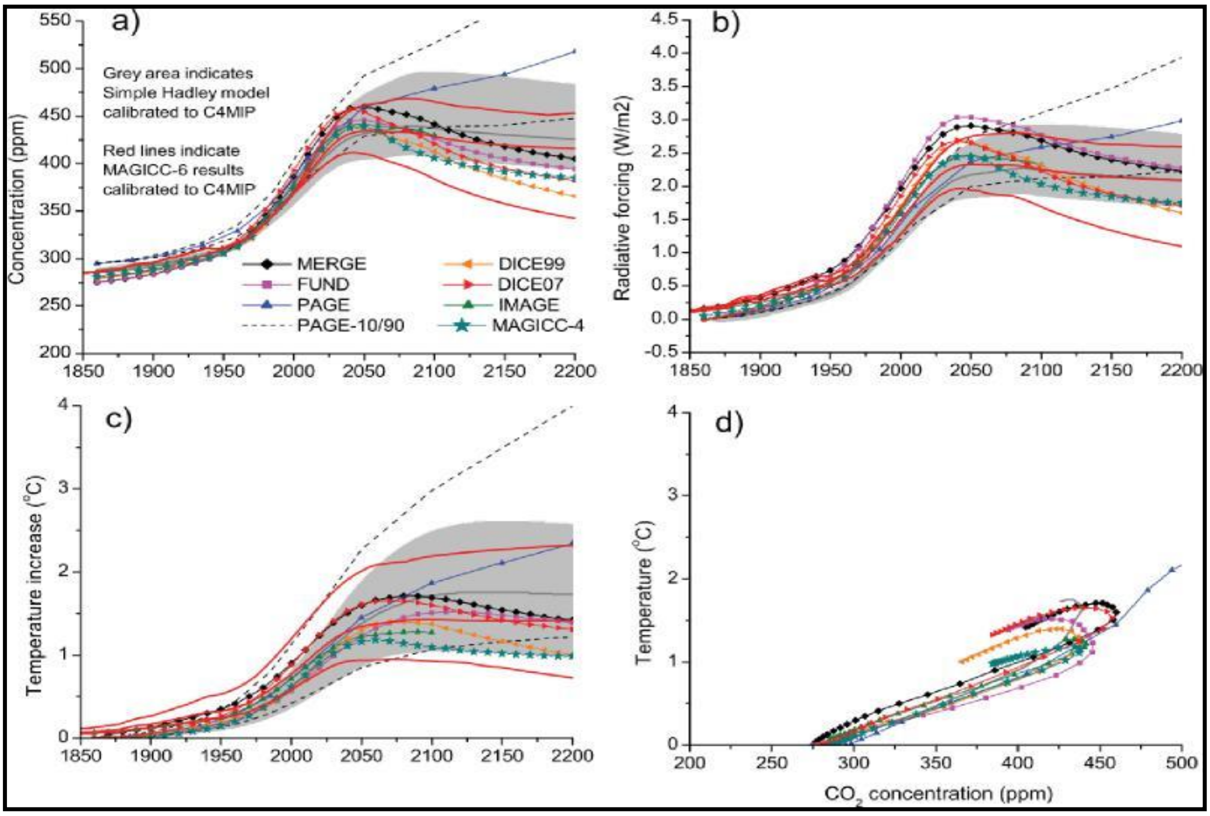

Figure 1: IAM results for a) CO_2 concentration, b) radiative forcing, c) temperature increase, and d) temperature increase versus CO2 concentration. Shaded area indicates results of HadSCCCM1; red lines those of MAGICC-6 (90th percentile and mean) (extracted from van Vuuren et al., 2011)

2. Method:

2.1 The current TIAM_UCL model

TIAM-UCL, which stands for UCL's TIMES Integrated Assessment Model, is an extended version of ETSAP-TIAM, developed to represent a wide spectrum of energy systems, in 16 regions of the globe, including UK (Anandarajah et al. 2011). It is a technology-rich model that belongs to the family of, partial-equilibrium, bottom-up models, next to MARKAL (Strachan et al., 2008), MESSAGE (Strubegger et al., 2004) and POLES (Mima et al, 2015) model. As a bottom-up model, TIAM-UCL uses optimisation functions, to obtain cost-efficient solutions, in meeting an, exogenously, defined set of energy-service demands, given certain technological and environmental constraints over the time horizon of the model (Berglund & Söderholm 2006). Furthermore, it employs linear programming techniques to, initially, calculate total discounted costs, with a global social discount rate of 3.5%, in standard mode, and, finally, maximise social welfare, defined as the sum of producer and consumer surplus, in elastic demand version (Anandarajah et al. 2011).

Technologies and processes are treated, explicitly, in a separate module for each region, while modules interconnection is allowed via the commodity trading network, called Reference Energy System (RES). Regional activities, described by TIAM-UCL, comprise all stages of an energy system, covering from primary commodities supply, through conversion, transportation and distribution of energy carriers, to end-uses energy demand (Anandarajah et al. 2011). There is, also, a built-in module for new technologies, becoming later available in the model, based on costs, capacity factors and sector-specific hurdle rates. The emission's trading market is modelled, explicitly, as well. Lastly, the climate module accounts for energy and non-energy related CO_2 emissions, in combination with non-CO_2 gases emission (CH_4 and N_2O), integrating them up to periodical atmospheric concentrations. Arithmetic formulas are, then, used by the model to infer radiative forcing, of each substance and, finally, compute an average change in global air temperature. The Climate Equations used to perform these calculations are adapted from Nordhaus and Boyer (1999), who proposed linear recursive equations for calculating concentrations and temperature changes. The choice of the Nordhaus and Boyer's climate equations is motivated by the simplicity of the approach. The multi-module structure of TIAM-UCL is shown by the diagram of figure 2 (Anandarajah et al. 2013).

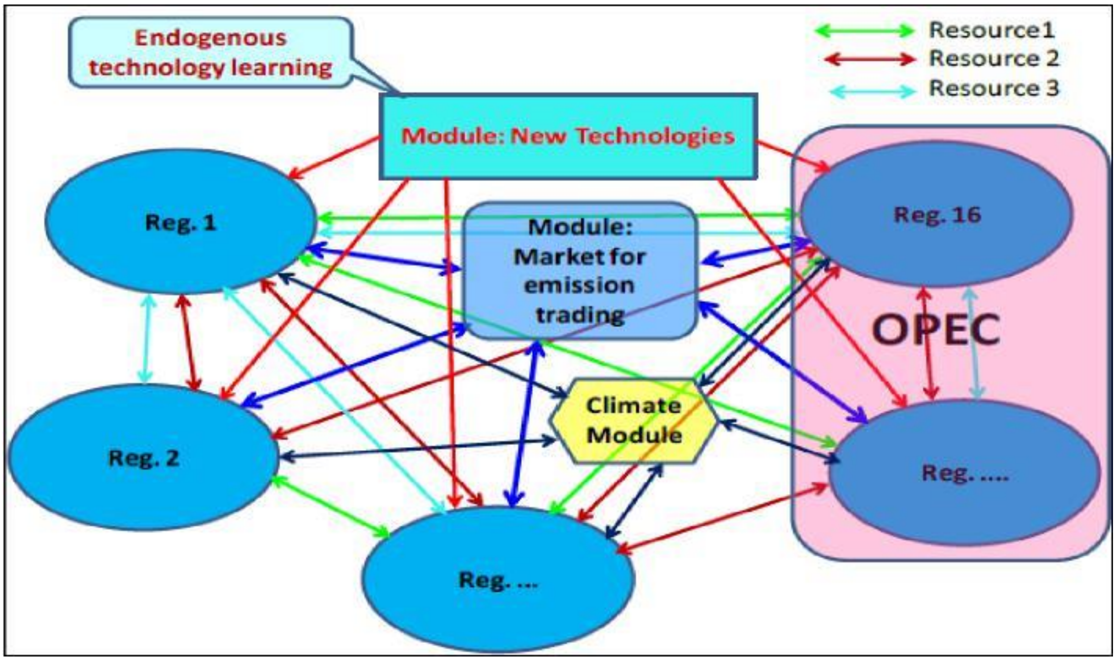

Figure 2: The structure of TIAM-UCL model in the form of independent modules.

The base year of TIAM-UCL is 2005. Data, used in the model, are calibrated to IEA data sets of Extended Energy Balances, in OECD and non-OCD countries. Base-year templates are maintained, describing processes and resources in regional residential, commercial, agriculture, transport, upstream and industry sectors (Anandarajah et al. 2011). Primary and final energy consumption values are, also, calibrated to 2005 IEA's databases data, in each region. Finally, regional demand for energy-services in end-use sectors is set, exogenously, to the model, and it is driven by socio-economic factors, like number of households, Gross Domestic Product (GDP) and progress in a sector. Overall, TIAM-UCL's output depends, at a great extent, on dynamic properties pertaining to parts of the model, such as the progressive development of technologies and supply, rise of energy- services' demand, the various targets and constraints implemented by policies and assumptions made in alternative scenarios, over the time horizon of the model. The results are extended to a time-period between 2005 and 2100.

The original climate module in TIAM-UCL contains equations that model the concentrations of three different greenhouse gases with strong global warming potential: CO_2 CH_4 and N_2O. The model then tracks the accumulation of anthropogenic emissions in the atmosphere and calculates the resulting change in radiative forcing. On a global scale a succession of equations calculates the realised temperature change consequential to the change in radiative forcing. The temperature calculation involves the slow transfer of heat from the atmosphere to the ocean. These relatively simple equations need to represent and capture a complex system such as the earth climate. To justify this approximation we need to keep the results of these simplified equations as close as possible to the results obtained by more complex climate models. In order to calibrate the climate module the choice has been to use the results of the well-known climate model MAGICC in its latest version (Meinshausen et al., 2011). The calibration of the module is made offline by comparing the responses of the TIAM-UCL climate module to specific GHG emissions (following the RCPs scenarios) to the corresponding results from MAGICC6. The calibration has been conducted for each mathematical equations used for the three steps (calculation of atmospheric concentrations, radiative forcing change and temperature change) of the climate module. The reader can find the full list and description of the equations used within the TIAM-UCL climate module in a special report (Anandarajah et al., 2011); only the equations for temperature change will be reproduced within this report.

The representation of the temperature change to a certain radiative forcing in the climate module of TIAM uses a two reservoir model for balancing the achieved temperature. One reservoir represent the faster processes, such as the surface response and the atmosphere and a second reservoir represents slower processes, and in particular the deep oceans. In these equations the achieved atmospheric temperature changes are calculated using the equilibrium climate sensitivity applied on the radiative forcing and fluxes of heat between the two reservoirs that are fixed by three coefficients predetermined.

$$\Delta T_S(y) = \Delta T_S(y-1)+\sigma 1\{\Delta F(y)-\lambda \Delta T_S(y-1)-\sigma 2[\Delta T_S(y-1)-\Delta T_L(y-1)]\}$$

$$\Delta T_L(y)= \Delta T_L(y-1)+\sigma 3[\Delta T_S(y-1)-\Delta T_L(y-1)]$$

Where: ΔT_S is the globally averaged surface temperature increase above pre-industrial level

ΔT_L is the deep-ocean temperature increase above pre-industrial level,

$\sigma 1$ is the speed of adjustment parameter for atmospheric temperature (or lag parameter),

$\sigma 2$ is the coefficient of heat loss from atmosphere to deep oceans,

$\sigma 3$ is the coefficient of heat gain by deep oceans,

λ is the feedback parameter and

ΔF is the radiative forcing.

y is the year in the simulation (and y -1 the previous one).

For the calculation the three radiative forcing values from the three greenhouse gases included in the TIAM-UCL module (CO_2, CH_4 and N_2O) are added together and complemented with external values of radiative forcing representing the other greenhouse gases (CFCs ozone for example), aerosols and clouds impacts. This external forcing is independent of the TIAM-UCL simulation and is supplied by the user pre-calculated for the possible scenario. As mentioned above the global surface temperature as calculated in TIAM-UCL depends only on the radiative forcing values with no distinction which greenhouse gas or climate factor is involved. This characteristic makes the model perfectly adapted to the possible use of the step-function that will be introduced later.

2.2 The step-response approach

The step-response is a simple climate model recently developed by a group at the UK Met Office and is an alternate method of estimating the climate response to an emission trajectory directly from global climate model step simulations. This SCM is fully described in Good et al. (2011) and Good et al. (2012). The main advantage of this approach (apart from the low computational cost it entails) is that its results are traceable to the GCM involved and closely connected to well-known methods of analysing GCMs with the step-experiments.

The model assumes linearity in the response to a step change in forcing. This is, the response to a sequence of changes in radiative forcing is assumed to be identical to the sum of the responses to each individual case and the response to each step is assumed to be linearly proportional to the magnitude of the change in forcing (this is referred as the SR linearity assumption). The Step-response SCM results are directly obtained from idealised GCM step-experiments (specifically in this case, from a 4xCO2 experiment in HadGEM2-ES GCM (Bellouin et al., 2011; Collins et al., 2008, 2011) where CO_2 is abruptly quadrupled and kept constant afterwards for 150 years). Then, the response to this idealised experiment can be used to replicate the GCM response to any time-dependent change in emissions scenario. Assuming the SR linearity, the response of a given magnitude at a given year (i) to any change in forcing is the summation of the responses of the previous years:

$$y_i = \sum_{j=0}^{i} x_j * \frac{\Delta f_{i-j}}{\Delta f_s}$$

Where: x_j is the response of the same variable in the year j

Δf_{i-j} is the change in radiative forcing in the year ($i-j$)

Δf_s is the change in forcing in the idealised step experiment.

Good et al., (2013) demonstrate that feedback estimates and physical understanding from CO_2 step-experiments can be transferred to understanding of more realistic experiments with time-dependent forcing. Nevertheless, from Good et al., (2011) step-model validations it can be found that the assumed SR linearity may be violated under certain conditions for some climate variables. The increase, decrease or stabilisation of CO_2 appears to play a very important role in SR linearity: for scenarios of increasing CO_2, SCM reconstructions of GCM temperature are excellent and heat uptake reconstructions are satisfactory in every considered scenario (Good et al., 2011). However, non -linearities arise from temperature and specially precipitation when CO_2 concentration is stabilised or decreased (for a step-response based on a HadCM3 step-experiment) but Good et al., (2011) argue that these non-linearity details may be strongly GCM-dependent. The approach was used in the IPCC 5th assessment to interpolate between scenarios in the climate projection chapters.

2.3 The HADGEM2-ES data

Available data consist on the results of an abrupt 4xCO_2 experiment, a control run, a historical run and runs for the four RCPs (2.6, 4.5, 6.0 and 8.5) performed by HadGEM2-ES model. These results are expressed in terms of temperature (in K) and flux at the top of the atmosphere (in W/m^2), hence, we aim to calculate radiative forcing and temperature rise from these variables. For this purpose, we will make use of an adapted "Forster and Taylor method" (Forster & Taylor, 2006; Long & Collins, 2013; Good et al., 2013)

Starting from the standard formula (Gregory et al., 2004):

$$N = \alpha T + F$$

Where: N is the net top of the atmosphere (TOA) flux (in W/m^2),

F is the radiative forcing (in W/m^2),

α is the climate feedback parameter which is characteristic of the GCM,

T represents the temperature change from the 4xCO_2 experiment expressed as an anomaly with respect to the control GCM run.

For experiments involving a step increase in radiative forcing, such as our 4xCO_2 HADGEM2-ES run, the characteristic feedback parameter (α) and radiative forcing (F_S) (Good et al., 2013) can be calculated by regressing ΔT variations against ΔN variations (Figure 3) the following way (Gregory et al., 2004):

$$\Delta N = \alpha \Delta T + F_s$$

Both variations in respect to the HadGEM2-ES preindustrial control run in order to eliminate climate drift and delete the effects of any preindustrial energy imbalance.

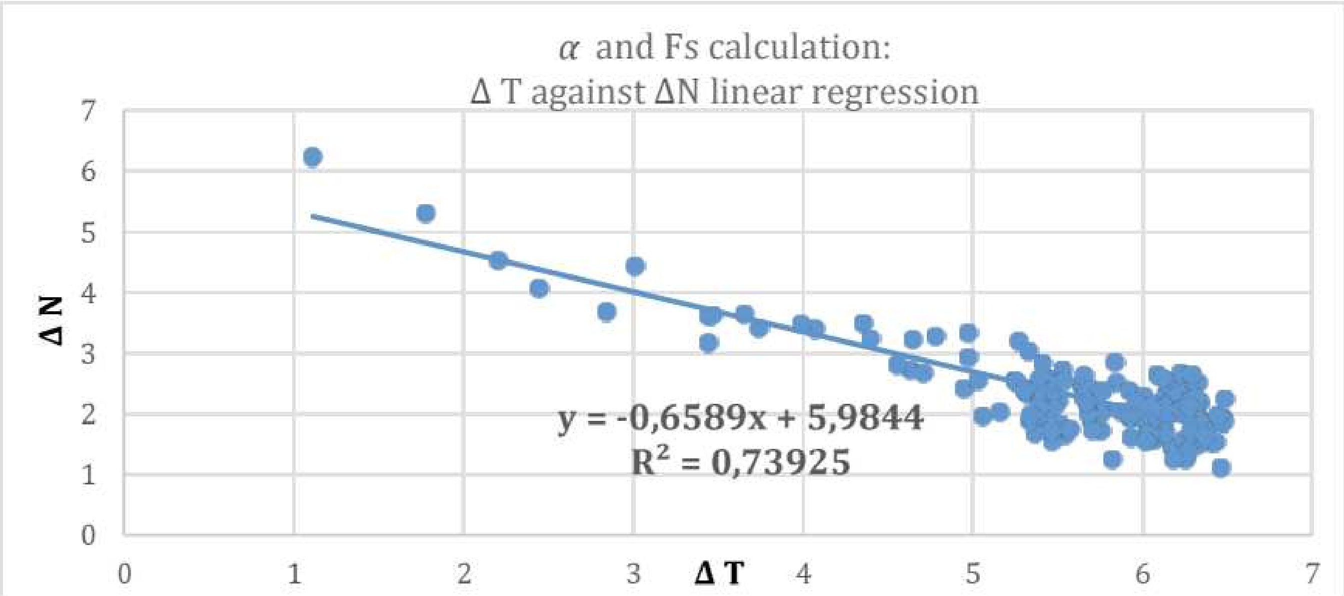

Figure 3: Plot showing the calculation of the feedback parameter (α = − 0, 6 5 8 9) and the radiative forcing change in the 4xCO2 step experiment (F_S = 5,9844 W/m[2]) .

Once α is calculated, we can calculate the radiative forcing for every year in any RCP or any experiment by just applying the following relation:

$$F = N - \alpha T$$

The temperature rise in any different case is simply calculated by subtracting the average of temperature in the control run to every year's temperature.

Figure 4 shows the results for radiative forcing and global mean temperature change for the Abrupt4xCO_2 step experiment and the four Representative Concentration Pathways (RCP) runs in the HadGEM2-ES model. It is clear that radiative forcing in the RCP runs do not reach the theoretical values by 2100 (8.5, 6.0, 4.5 and 2.6 w/m^2). Good et al., (2013) argue that major GCM differences in RCP projections may be split in two parts (i) the model dependence in the time-resolved response to forcing (quantified in the abrupt 4xco2 experiment) and (ii) model dependence in the forcing (quantified by a modified Forster and Taylor method; Forster & Taylor, 2006).

(i): The simple climate model reconstruction is made using the GCM's response in the Abrupt4xCO_2 experiment. Differences in simple model projections arise solely from the GCM responses in the Abrupt4xCO_2 experiment. Good et al,2012 reports of small errors, including a slight over-estimate for global-mean temperature that could arise from non-linear behaviour (Good et al. 2011), however the errors are small compared to the mean change and to the model spread.

(ii): The approach is extended to work with non-CO_2 forcings. In this case, the assumption is that the effects of these constituents can be described by a single climate feedback parameter for all kinds of forcing, and a global-mean radiative forcing from all agents together. This commonly used assumption neglects any differences in response for different forcing agents, which could arise for instance in the case of more regionally-specific forcings such as aerosol. Validation in Good et al., 2012 suggests this is a minor issue for global-mean surface temperature in CMIP5 RCP projections.

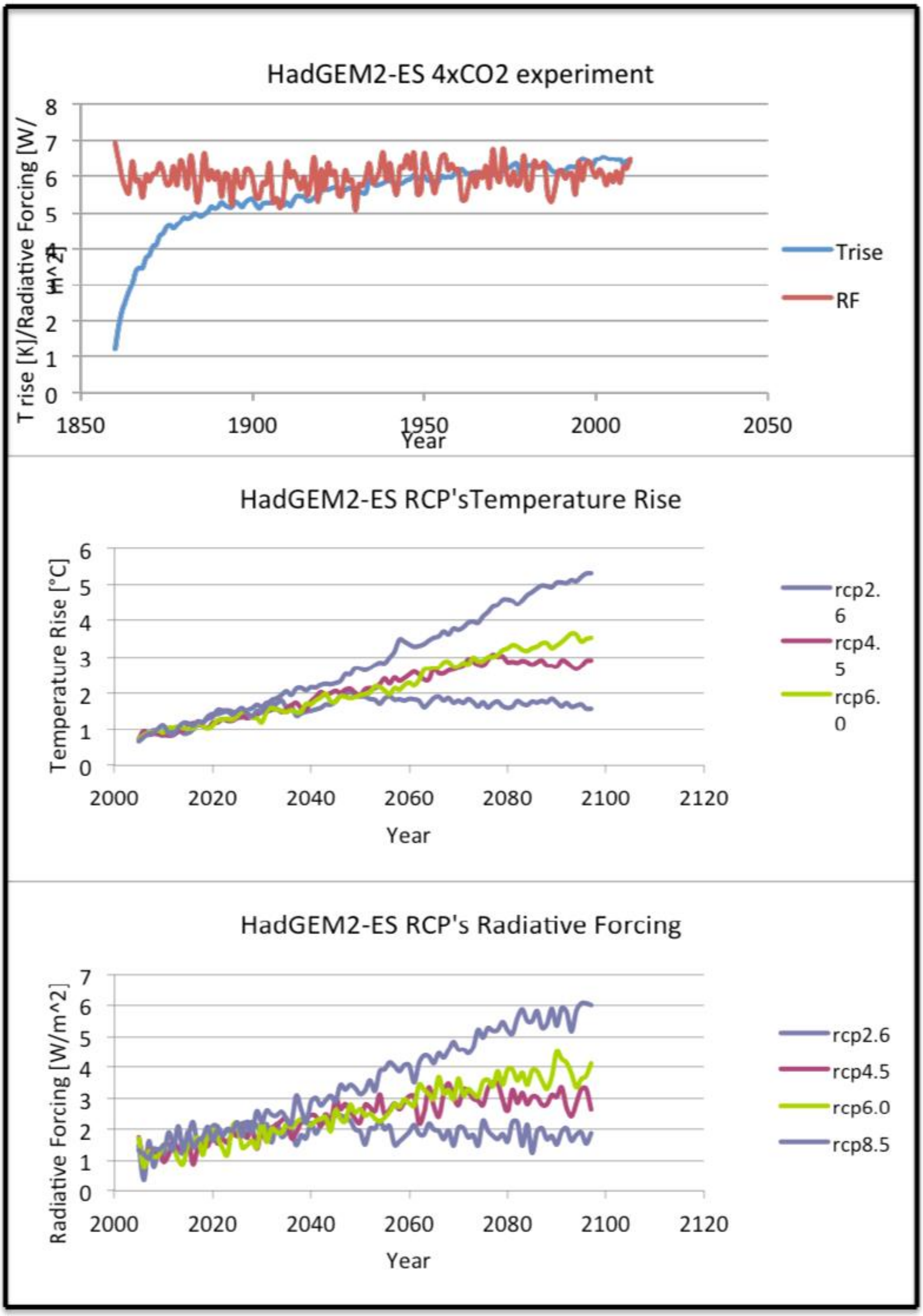

Figure 4 Radiative forcing and temperature rise for the 4xCO2 step experiment and the four RCPs runs in the HadGEM2-ES model.

2.4 The Scaling Factor for the radiative forcing

The total radiative forcing for TIAM-UCL and HadGEM2-ES reflect variations in the individual forcing between the two models. There is a clear overestimation of radiative forcing in the TIAM-UCL model when compared to HadGEM2- ES. The scaling factor (SF) between the two models' results is needed for the reconciliation of the radiative forcing calculations from GHG concentrations.

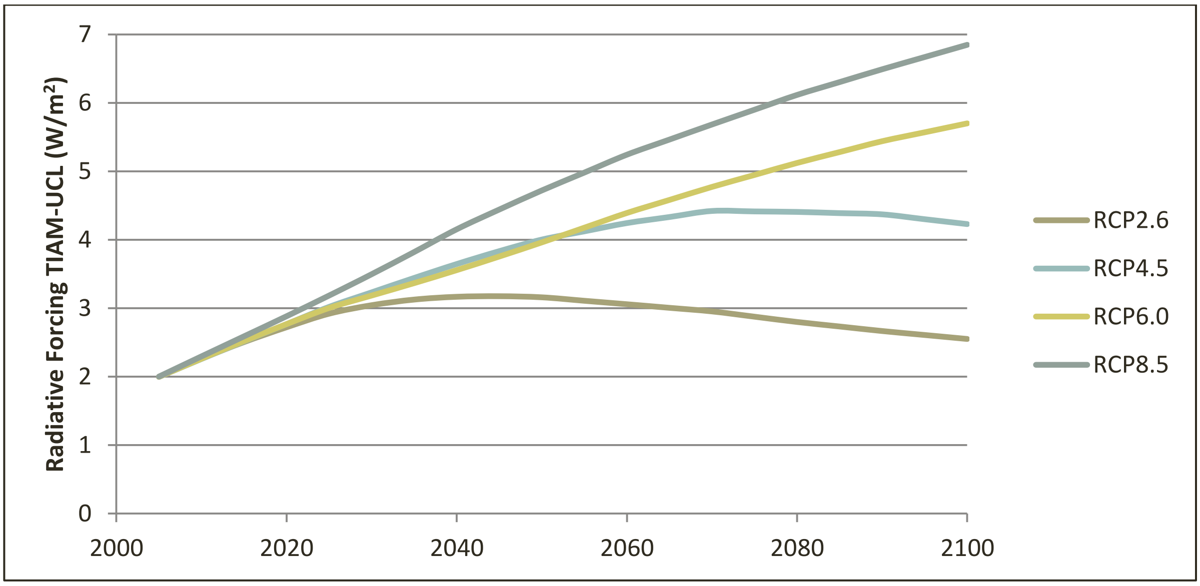

Figure 5 Radiative forcing rise for the four RCPs runs in the TIAM-UCL climate module.

The step function to keep within the linearity range will be applied to a deviation from an existing forcing. The calculation for the step function will use an RCP as reference (in our case RCP4.5) and the difference between this specific RCP and the scenario to be represented is presented in figure 5(for RCP 2.6-4.5, 6.0-4.5 an 8.5-4.5). The difference between RCP4.5 and a second RCP will be calculated (RCP8.5 for example). Then, the projection for global-mean temperature changes is given by:

(RCP4.5 –piControl)*from GCM* = (RCP8.5 – piControl)*from GCM* + (RCP4.5 – RCP8.5)*from Step Function*

(piControl = constant-forcing control experiment representative pre-industrial conditions to remove climate drift).

In this case, the simple model is forced by the difference in forcing between RCP4.5 and RCP8.5. This approach has the advantage to minimises reliance on the simple model by asking to simulate only response to a smaller difference in forcing. Figure6 illustrates the method we will use to estimate the scaling factor. The two plots represent the radiative forcing (RF) vs time for the four RCP runs in both models. The whole time period (2005-2100) will be divided into five shorter time intervals (only two of these time intervals are represented in figure 6 for simplicity) and a RF mean value will be calculated for the four RCP runs in both models for the five time periods. Next, the difference of these radiative forcing mean values respect to the RCP 4.5 means values (this makes RCP 4.5 our basis RCP) will be calculated.

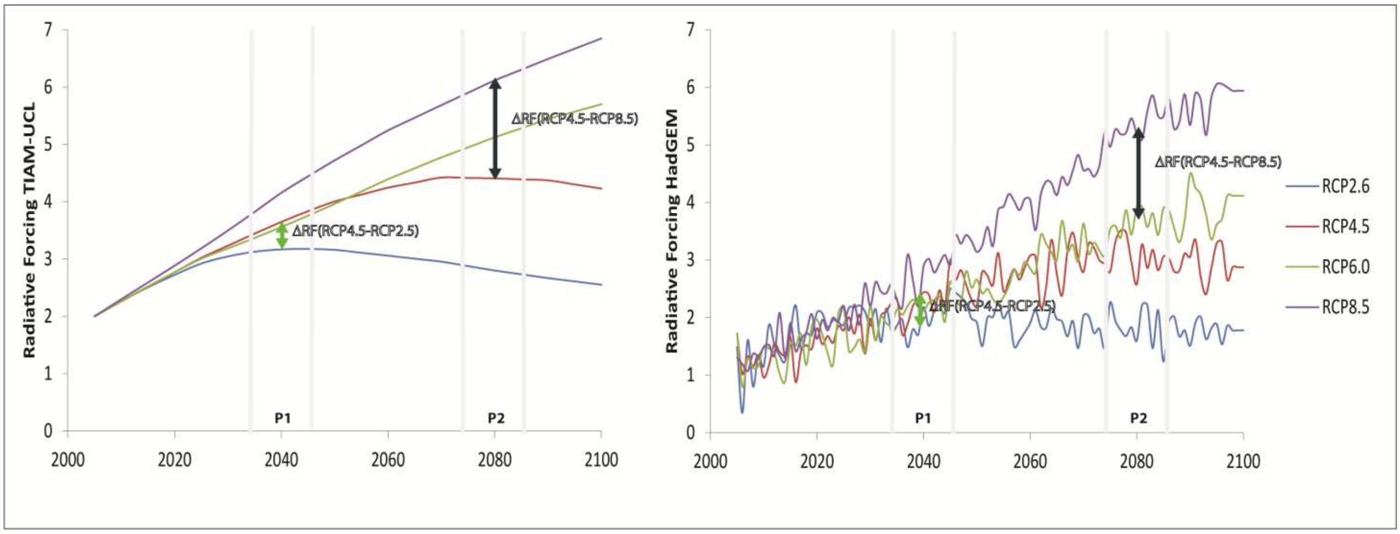

Figure 6: Method to determine the scaling factor between the two models using RCP4.5 as reference radiative forcing.

The scaling factors between the RCPs with respect to the RCP 4.5 basis (RCP 8.5, RCP 6.0 and RCP 2.6 with respect to RCP 4.5) for the 5 periods are given by the slope of the linear regression as shown in figure 7. Each point in the plot represents the mean value for one of the RCP differences at one of the five time periods. The scaling factor calculated will be the mean of the three different slopes (0.82, 0.76 and 0.72) of the linear regression:

SF = 0.74 and in our case , $RF_{HadGEM}=SF*RF_{TIAM}$.

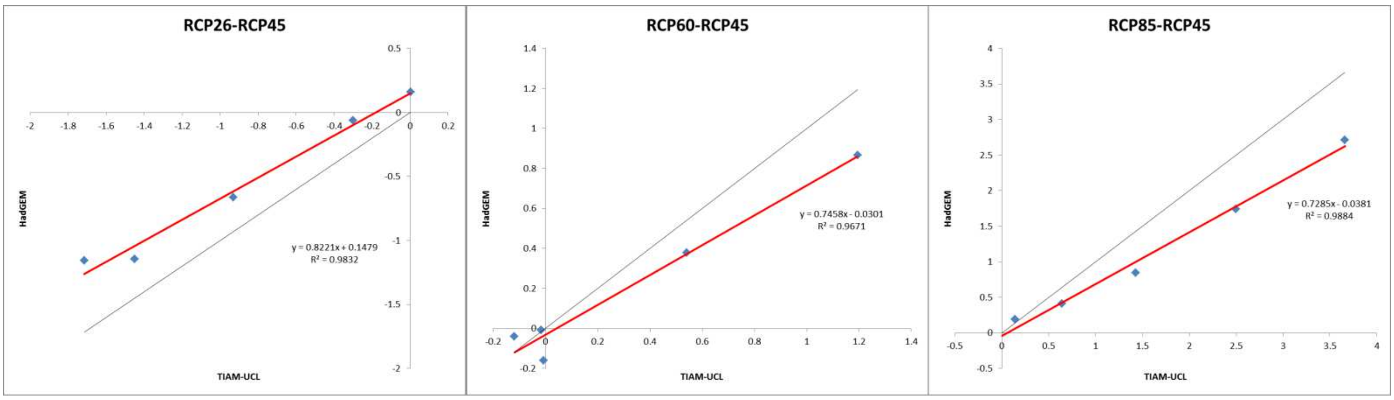

Figure 7: RCP radiative forcing difference using the RCP4.5 as reference in HadGEM2-ES and TIAM-UCL for the scaling factor estimation. The Blue Dimond markers are the radiative forcing difference data from the two models for different periods (as decribed in figure 6) , the red line is the Linear Fit for the data to extract the scaling factor.

3. **Step-function results in the UCL IAM:**

3.1 The Step-function

The step-function for a variable y_i is expressed as:

$$y_i = \sum_{j=0}^{i} x_j * \frac{\Delta f_{i-j}}{\Delta f_s}$$

Where: x_j is the response of the same variable in the year j,

Δf_{i-j} is the change in radiative forcing in the year (i-j) and

Δf_s is the change in forcing in the idealised step experiment; calculated in the previous section Δf_s=5.9844

Figure 8 illustrates howthe step function for temperature will be written for any given radiative forcing trajectory. We will first calculate the radiative forcing variation with respect to the RCP4.5 baseline for every year (Δf_i) as shown in figure 8 a). The temperature increase at any given year, will be:

$$\Delta T = \Delta T_{RCP4.5} + \frac{\Delta f_i}{f_s} * AVG(\Delta T_{4xCO2})$$

Where $AVG(\Delta T_{4xCO2})$ is the average change in temperature in the HadGEM2-ES step experiment ($4xCO_2$) and equals 5,583°C.

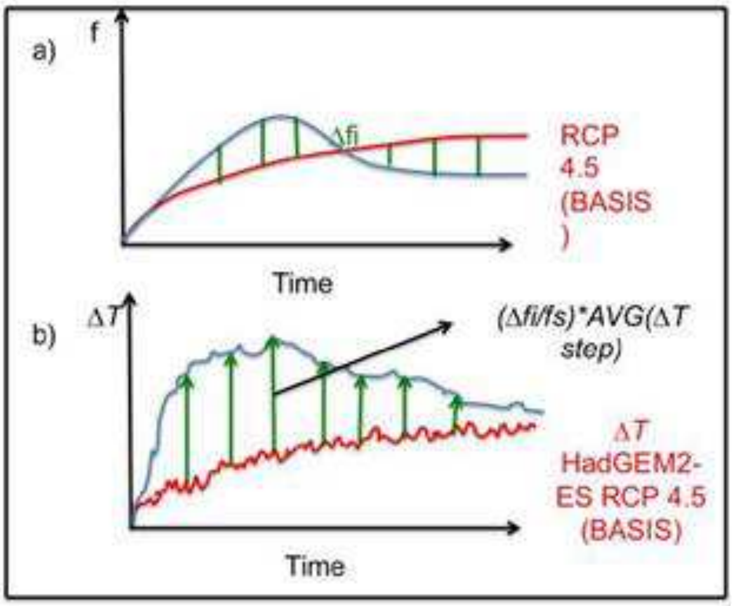

Figure 8: Schematic of the step-response implementation method in TIAM-UCL; the step-response is applied to deviation in forcing from a reference scenario (in this example RCP4.5).

The main advantage of this integration method is that it reduces the reliance of the projections on the simple climate model as it simulates the response to a smaller difference in forcing (RCP4.5-other RCPs) (Good et al., 2013).However the internannual variability of HadGEM2-ES in the data supplied cause some unintended problems with TIAM-UCL model as variables (including the climate variables) are only for specific years (every 5 years from 2005 to 2050 and every 10 years only until 2100). This means that when using the step function with all its inherent variability, we take the risk of taking one of the temperature extremes as an estimate for the energy system model climate module. To overcome this issue the results of the step-function are averaged over a moving period of 9 years (figure 9) in order to smooth the radiative forcing and temperature curves used in the step function in the TIAM-UCL model.

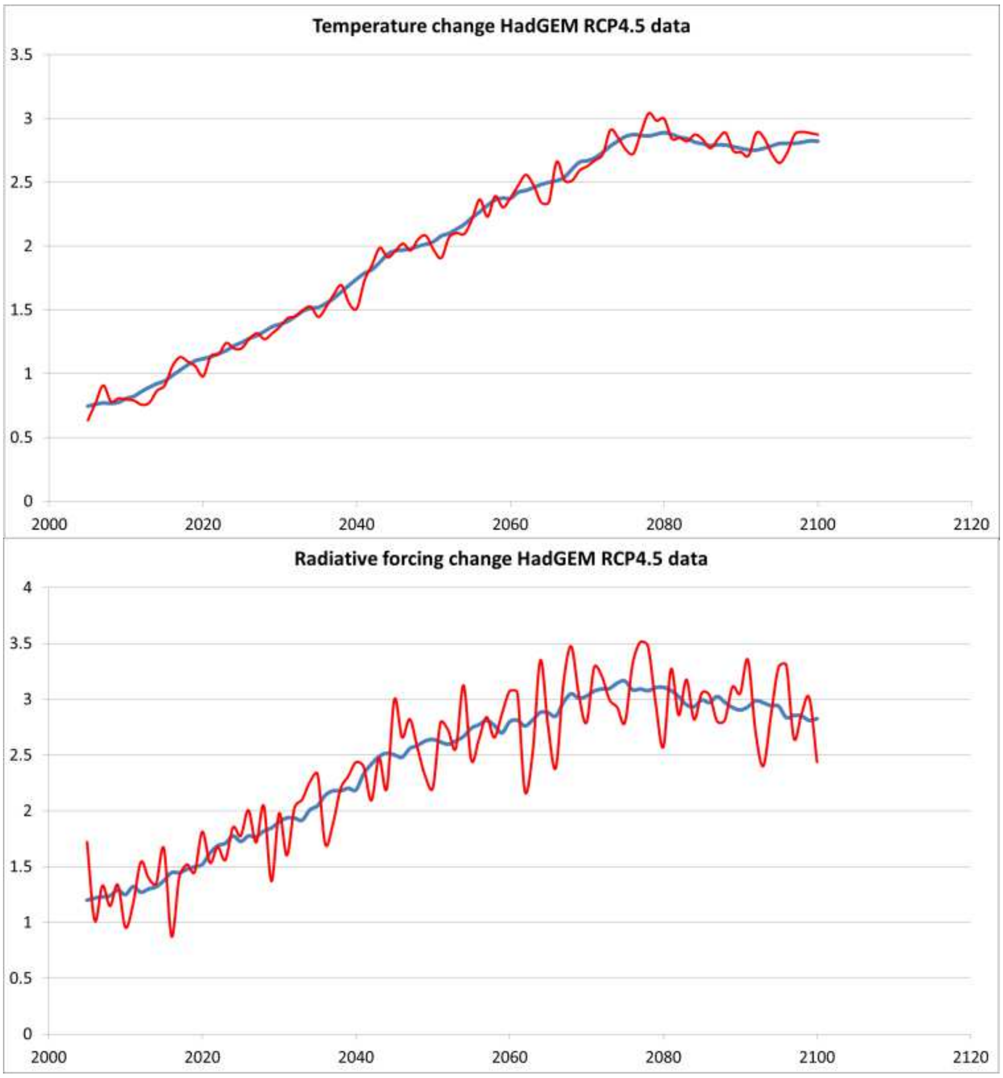

Figure 9: Nine years moving average (blue line) for Temperature and Radiative Forcing for the RCP4.5 reference data from HadGEM (red line) used in TIAM-UCL.

The step function is introduced in TIAM-UCL as an alternate climate module. This means that radiative forcing is calculated by TIAM-UCL from emissions and policies and the step function will calculate a new equilibrium global temperature for each output year of TIAM-UCL. This new estimate of equilibrium temperature will influence the model's GHGs emissions feedback calculations resulting in new emissions, concentrations and radiative forcing under temperature constraint. Impacts will be calculated by TIAM-UCL in term of energy system and energy mix development under the new temperature change calculation.

3.2 Results with TIAM-UCL

After having validated the SCM against HadGEM2-ES, we can introduce it in TIAM-UCL and analyse some of the features to see how they have changed as a consequence of the inclusion of the step model in the IAM's climate module.

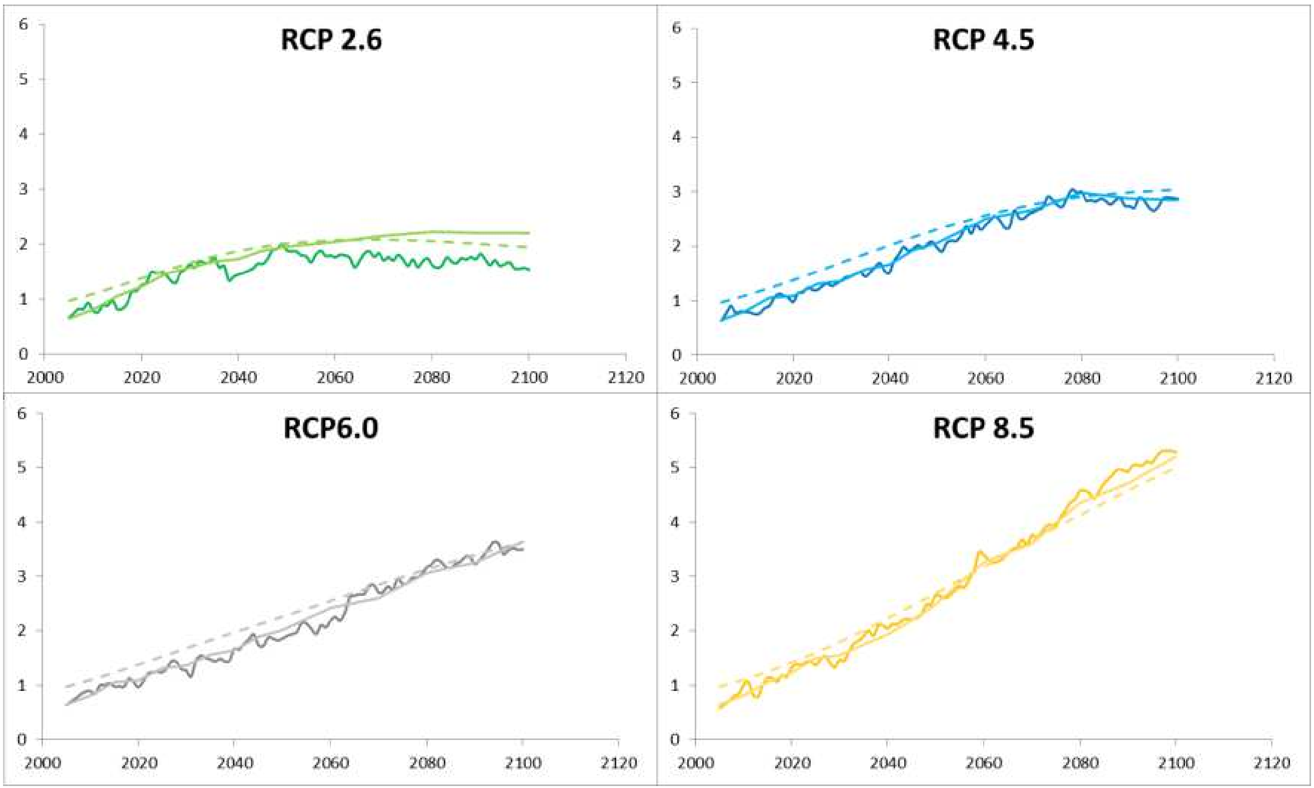

Figure 9: temperature results for the four RCP scenarios calculated by TIAM-UCL (original climate module: dotted line and step function: plain line) and HadGEM (darker colour) until 2100.

Results from the RCP scenarios provide very satisfactory results for RCP8.5, RCP6.0 and RCP4.5 for the step function compare to the original TIAM-UCL climate module (figure 9). However, a far less good performance of the step function is observed for RCP2.6 particularly for the second part of the century (period from 2050 to 2100). This could be due to the change in the sign of the radiative forcing slope in this RCP (RF increases to its maximum around 2050 and then slightly decreases until 2100 - Moss et al., 2010) this is also increased by having at the end of the RCP2.5 scenario negative GHG emissions driven by biomass-carbon-capture-sequestration technologies introduced in the RCP to prevent the global temperature to peak above the 2°C target. In their description of the step model, Good et al., (2011) explain that the SR linearity assumption on which the model is based (the assumption that the response to a sequence of changes in radiative forcing is assumed to be identical to the sum of the responses to each individual case and the response to each step is assumed to be linearly proportional to the magnitude of the change in forcing), may be violated for temperature in radiative forcing stabilisation and ramp-down circumstances, which would justify why the step model validation is not as satisfactory for RCP2.6 as for RCP 8.5 and 6.0 in which radiative forcing is increasing during the whole time period. As HELIX research focused on higher temperature warming levels the good response to RCP4.5 and above is more important than the response for RCP2.6. However, it may be possible to improve the RCP2.6 response by choose to drive the model with a CO2 doubling step rather than the four times CO2 step used here.

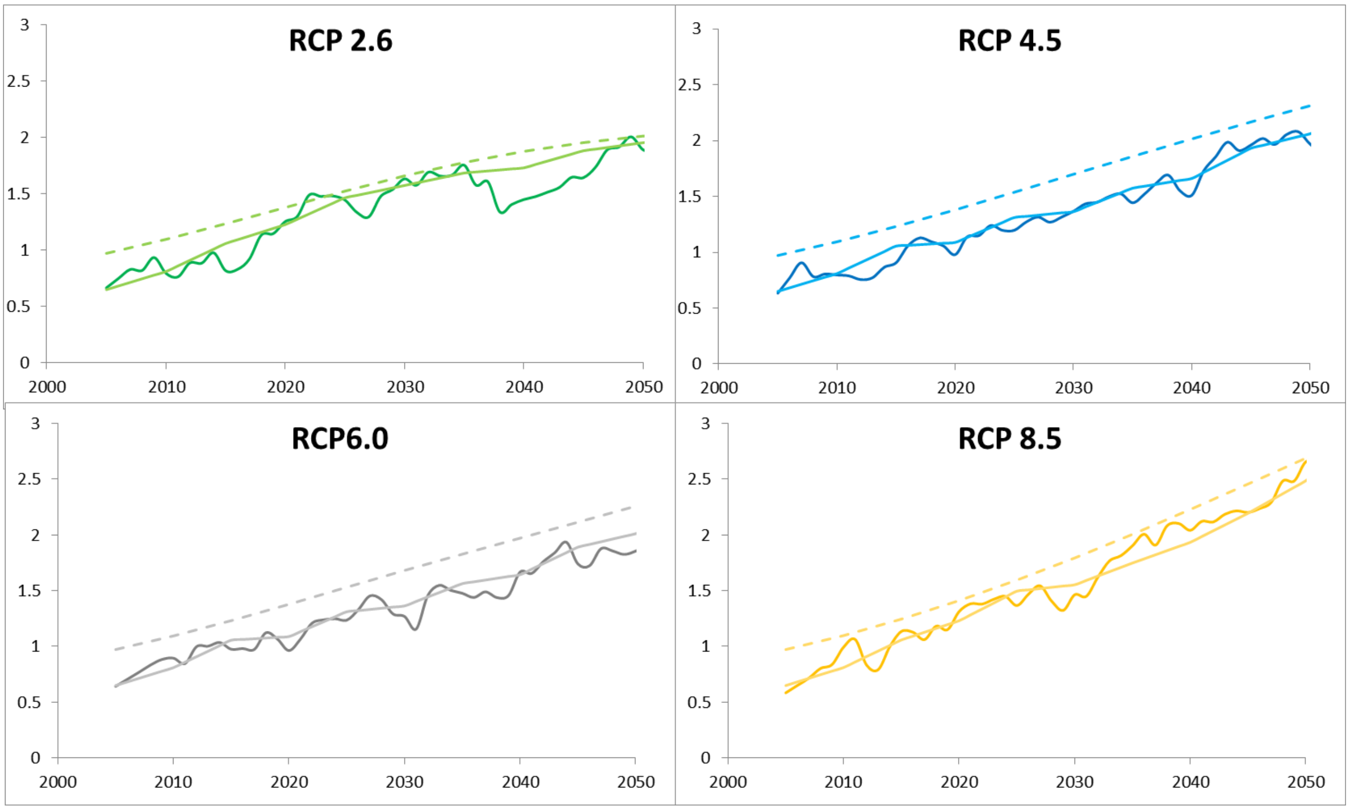

Figure 10: same as Figure 9 but from 2005 to 2050 only.

More importantly the TIAM-UCL model being a energy system technology rich bottom-up cost-optimisation model the technology projections results are usually for policy decisions limited from the present period to 2050 (ie 35 years of storyline). The second part of the scenarios (until the end of the century) is indeed extremely uncertain in terms of technology development and costs evolution. Focussing on the first part of the RCP simulation (2005-2050) in figure 10, the temperatures show an improvement of the results, moving them towards the HadGEM-2ES general circulation model results in all the scenarios. This is especially relevant when using the TIAM-UCL model, where large weight is given to climate predictions by assigning costs of mitigation policies and possibly basing future and actions on them.

TIAM-UCL climate module is responding to the step-function with lower climate sensitivity than the default original climate representation with the two different boxes for temperature (atmosphere and ocean). The differences in global mean temperature change between both models are: -0,28°C in RCP8.5, -0,3°C in RCP6.0, -0,3°C n RCP4.5 and -0,1°C in RCP2.6 respect to original TIAM-UCL by the year 2050 (figure 10).

4. Conclusion:

The step-function has been successfully implemented for global mean temperature in TIAM-UCL climate module and validated against the GCM RCP runs. These validations deliver successful results for RCP8.5, RCP6.0 and RCP4.5. A more careful conclusion arises from the end of the RCP2.5 validation; in this case the he step-function SR linearity has been revealed less effective. In this case of radiative forcing stabilisation and ramp-down circumstances this limitation was predicted by Good et al., (2012, 2011). This fact needs further investigation through validation against GCM runs.

The effectiveness of the step-function to calculate the temperature changes due to the radiative forcing values from the first part of the simulations (period before 2050) for all the RCPs is very encouraging as this period is the main focus of results analysis for integrated bottom-up technology rich assessment models such as TIAM-UCL.

TIAM-UCL climate module is responding to the step-function with lower climate sensitivity than the default original TIAM-UCL. Comparison with other GCMs from CMIP5 presenting different climate sensitivity and the creation of a simulations ensemble will be of great interest.

It is important to emphasize that, the step-function implementation results in some of the IAM's climate estimates "responsibility" being transferred to the GCM as the results of the temperature change calculation are directly interconnected to the GCM results.

As a final conclusion, it can be said that the step-response approach has great potential in improving TiAM-UCL climate projections but further efforts are needed in order to fully exploit this potential, i.e. introducing new variables (precipitation; cooling heating days) and regional results. This could be relatively easy to solve through a "pattern scaling approach" developed in HELIX for the climate variable that have been tested in WP2 (temperature or precipitation). However development of "regional step function" will be needed in the case of non-tested variable. Applied regionally the step function may also have some advantages over pattern-scaling where there are local deviations in the response times. Performing regional change projections would allow the model to successfully calculate climate change costs and impacts estimates on the energy sector, which are TIAM-UCL's key output for policy advice. A first step will be to critically assess the importance of such variables onto the TIAM-UCL model results to focus upon the most significant.

The current version of TIAM-UCL including the step function applied to the global temperature change will be used in the second stage of the HELIX project within WP2 (development of GHG emission scenarios coherent with specific warming level pathways) and WP5 (study of global socio-economic impacts of climate change with focus on energy-system).

5. References:

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