Disclaimer: these comments have been overtaken by subsequent model updates.

Workshop on Land Use, Bioenergy and Food Security

DECC – Climate-KIC Global Calculator Project
22-23 April 2014, Imperial College London, UK

Summary notes[1]

1. Overview

The Land/Food/Bioenergy workshop was held on 22-23 April 2014 at Imperial College London. The purpose of this 2-day workshop was to elicit expert feedback on the Land/Food/Bioenergy module of the Global Calculator Project[2] to assist in the calibration and improvement of the effort levels 1-4 for each of the respective levers in the draft model presented, i.e., Calories consumed per person; Type of diet; Crop, Livestock and Bioenergy yields; Bioenergy production; Forest; Land multiuse (integrated land use schemes); and the Utilisation of wastes and residues. These levers allow users to simulate a number of trajectories of land use change and its associated greenhouse gas (GHG) emissions, according to different demands of land-dependent products and services by 2050 and the corresponding effort levels 1-4 should reflect the full range of what experts believe could be possible by 2050.

On Day 1, the workshop focused primarily on the levers related to food production and security, while Day 2 considered bioenergy, forestry and land use (see Appendix 1 for the workshop agenda). On both days, keynote presentations provided a broader policy, economic, science and development perspective of Land/Food/Bioenergy module and helped in framing the subsequent lever discussions, as described below:

- Richard Templer (UK Climate-KIC) "Climate-KIC's support of the Global Calculator";
- NH Ravindranath (IPCC & Indian Institute of Science) "Agriculture, Forestry and Other Land Use (AFOLU) Mitigation – IPCC WG3";
- Adam Brown (IEA) "Bioenergy - Global Status and Challenges";
- Hans Langeveld (Biomass Research) "Insights from: Biofuel cropping systems. Carbon, Land, and Food".

Participants included 44 experts from the private sector, international organisations and academia from 4 continents (see Appendix 2 for the list of participants).

This document provides a brief summary of the workshop's key findings. As Chatham House Rules were followed, any comments recorded here are anonymised and not attributed to any particular participant.

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[2] See more information about the Global Calculator Project at: www.globalcalculator.org

2. Approach

The project team provided a general overview of the Global Calculator project, summarised the key elements of the Land/Food/Bioenergy module and outlined the objectives of the workshop and methodological approach. The workshop was split into four segments, i.e., Calories consumed & Type of diet; Agriculture & Livestock; Bioenergy & Wastes and residues; and Remaining land & Land-use Efficiency. Each segment included an introduction to the respective levers outlining the underlying assumptions and modelling framework, followed by a presentation of the discussion questions (see Appendix 3). Then, participants gathered into their pre-allocated groups (5-7 participants/group, Tables 1-5), discussed the assigned questions with the assistance of a trained facilitator and subsequently reported their findings back to the plenary.

3. Findings

This section includes the detailed summary notes and key findings for each group discussion, as reported by the facilitators and group rapporteurs. These findings informed the subsequent revisions of the Land/Food/Bioenergy module of the Global Calculator.

3.1 Group discussion 1: Calories consumed & Type of diet

3.1.1 Calories consumed

Key issues

- US diet as a benchmark is unrealistic as a global L1 scenario.
- Clarification is needed on what is accounted for in 'Calories consumed'.

Levels	Comments
Level 1 means that global calorie consumption would increase from 2850 kcal/capita/day to the current USA level, i.e., 3700 kcal/capita/day, by 2050. This assumes an extreme situation, in which the whole world would achieve USA levels of calories consumed per capita per day. It represents a high risk of obesity problems, and more land allocation for agricultural purposes.	**Table 1** ▪ Very unrealistic as world will become more poor in case of minimum abatement due to impacts of climate change ▪ Absolutely impossible ▪ Disagreement over the semantics (calories consumed vs calories available) ▪ Broad idea of keeping US as the benchmark for decadence (2850) is ok **Table 2** ▪ Doubt about methodology ▪ Can be reduced by policy, 2500 WHO. ▪ Too extreme, consumption should hit a plateau. **Table 3** ▪ Strong disagreement. ▪ 3700 kcal/day is too high. EU might be more reasonable - 3200 kcal/day? What do high income countries top out at? ▪ Is the USA diet valid as a global average? **Table 4** ▪ Very extreme and is not realistic ▪ Should be based upon American standard and current trends? **Table 5** ▪ The number does not appear to be realistic. Apparently, US average is 2067 kcal. ▪ Waste is not taken into account; there should be leaver for waste. ▪ Extremely pessimistic

Levels	Comments
Level 2 increases the world calorie consumption based on the growth rate of past decade, i.e., from 2850 kcal/capita/day in 2011 up to 3200 kcal/capita/day by 2050. Therefore, this pathway is equivalent to approximately the same changes in food consumption observed in the last 10 years, in which some developing countries (e.g., China and India) have substantially increased their food consumptions.	**Table 2** ▪ Most likely scenario **Table 4** ▪ Most suitable, providing it is based on medically informed values **Tables 1, 3 & 5** ▪ No comments
Level 3 means a calorie consumption growth from 2850 kcal/capita/day in 2011 to approximately 3000 kcal/capita/day by 2050. FAO, for example, forecasts 3070 kcal/capita/day by 2050 (Alexandratos & Bruinsma, 2012). In this trajectory, there will be still a significant increase of food consumption globally, but the current trend would be slightly reduced due to, e.g., population and consumption peaks in some countries.	**Table 1** ▪ Problem with FAO data it looks at the global scale and not looks at the different regional differences; developing countries trying to push tourisms; (reference: Prajal Pradhan et al PLos 2013 – very important paper esp. as it shows the sudden drop. **Table 2** ▪ 4 could be level 3. **Table 4** ▪ Levels to aim for should be based on medically influenced levels - this is current ref FAO L3. **Tables 3 & 5** ▪ No comments.
Level 4 keeps the current world calorie consumption stabilised by 2050, i.e., no significant changes in calorie consumption would occur on a global average. However, it would be possible to have some changes in the extreme sides, for example, some developing countries could increase food consumption, e.g., by reducing poverty, whilst some developed countries could reduce the consumption, e.g., by tackling obesity issues.	**Table 1** ▪ Very ambitious should but largely agree, some feel it should be slightly lower; and some suggest that we can recalculate the levers based on the Pradhan et al. 2013 paper; ▪ Current consumption with a contraction and convergence model. **Table 3** ▪ No comments. **Table 2** ▪ Level 4 should be a reduction on current levels since this would be reducing current levels. **Table 4** ▪ Should be based upon a stable, flat line of calorie intake. **Table 5** ▪ It's not the most extreme, there should be another level 5 , based on lower waste and healthy diet.
General discussion	▪ Need to account for differences: some need to increase calorie consumption. What are we assuming for world population at each of these levels? ▪ How is waste considered in the calorie lever- can waste in particular places be distributed. ▪ What is the minimum and maximum consumed across the world and what are the dominant trends that do exist? These should be clearly evident on the calculator. ▪ Regional variation needs to be accounted for. Segregate calories consumed in different regions via weighted averages for example? ▪ A key point is that global averages are simplistic and may impede action. ▪ We could have a global scaling factor that would make the globe more balanced - these need to be taken into account when considering actions at individual country level. ▪ Lifestyles are really important - lifestyle changes and desires will determine calorie demand. ▪ Descriptions should represent diversity and what different regions would need

Levels	Comments
	to do. ▪ Are these calories consumed or produced?

3.1.2 Type of diet

Key issues

- 100% red meat is an unrealistic global L1 scenario.
- Recalibrate splits of red and white meat.
- Consider WHO dietary guidelines for meat consumption.
- Communication: convert kcal of meat to grams.

Levels	Notes
Level 1 represents very high meat consumption. The actual total meat consumption of USA in 2011 is assumed as a global target for 2050. Thus, the world meat consumption, in terms of energy content, would grow from 235 kcal/capita/day to 450 kcal of meat/capita/day by 2050. This is a very risky and complex pathway, given that a significant amount of land would be necessary for supplying such extreme demands for meat. It also assumes a share of 100% red meat (e.g., beef, pork, mutton and goat) and 0% white meat (e.g., poultry) by 2050.	**Table 1** ▪ 100% red meat is not possible and is catastrophic scenario even US has not done it; US as target is OK but the red meat assumptions are not correct; one participant suggested 800 Kcal/ capita/day instead of the 450. ▪ Stick with share of red & white. **Table 2** ▪ Don't strongly disagree, should be less optimistic (level 1) and more optimistic (level 4). ▪ Too extreme, 90%-80% red meat, try to spread a little bit. **Table 3** ▪ The description should specifically state ruminant and non-ruminant. 'White meat' doesn't make sense to us. The convergence to US levels is realistic but the convergence on 100% red meat is not. ▪ Strong disagreement with level 1 the share of red/white meat **Table 4** ▪ L1 is too extreme. Different religious/ethnic groups will continue to choose white meats/other types of meat to the general western standard. 100% red meat is far too extreme. L1 should be only based on American standard currently. ▪ Red:White split: 60:40. **Table 5** ▪ Is it reasonable to assume 100% red meat? Maybe 60% to 40%. ▪ Is that the real situation in the US? What is the proportion of meat per person?
Level 2 means a high consumption of meat, based on a linear extrapolation of meat consumption of the past two decades to 2050. The meat consumption would grow from 235 to 340 kcal of meat/capita/day. It also assumes a share of 75% red meat and 25% white meat by 2050.	**Table 1** ▪ 340 with high red. **Table 2** ▪ More likely. **Table 4** ▪ Red:White split: 50:50. **Tables 3 & 5** ▪ No comments.
Level 3 considers that the current world dietary pattern, i.e., 235 kcal of meat/capita/day, would be stabilised by 2050. In this pathway, there would be no significant changes in calorie consumption, although it presents a gradual increase of the share of white meat, 75% by 2050, and decrease of red meat, 25% by 2050. Thus, the	**Table 1** ▪ 340 kcal with low red. **Table 2** ▪ Most desirable. **Tables 3 & 5** ▪ No comments. **Table 4** ▪ Levels to aim for should be based on medically influenced levels - this is current ref FAO L3. ▪ Red:White split: 40:60.

Levels	Notes
global meat consumption overall in 2011 is kept constant until 2050.	
Level 4 represents diets without any conventional meat, but instead high in plant-based foods, including vegetarian diets and meat alternatives (e.g., soy meat substitutes, yeast-based meat and potential stem cell-based technologies). This pathway was estimated through a linearisation from the 2011 meat consumption, i.e., 235 kcal/capita/day, until reaching zero meat consumption by 2050. This is a very extreme situation and assumes an unprecedented change in dietary preferences worldwide. It also assumes a gradual shift of meat types towards 0% red meat and 100% white meat before a decrease in total meat consumption to zero by 2050.	**Table 1** ▪ Participants feel it's completely unrealistic to have zero meat consumption, some suggest 25% of meat looks sensible. ▪ Indian level of consumption 250 kcal, considering Indian consumption structure. **Table 2** ▪ It's an extreme scenario, impossible and not recommended. **Table 3** ▪ Most participants think the figure is too extreme. One person thinks it's not extreme enough considering the threat we face which would justify rapid and drastic action. ▪ Do level four scenarios assume the existence of democratic societies? ▪ Strong disagreement. **Table 4** ▪ L4 is too extreme, no meat or 100% is possible. ▪ Red:White split: 25:75. **Table 5** ▪ Low amount of meat, but not 0% meat. ▪ There will be a gradual shift into lesser meat.
General comments	▪ What we need is a global policy calculator. ▪ Should have one of the levels representing the Harvard recommended diet 90g ANIMAL PRODUCT/day - page 38 of the IPCC WG3 Chapter 11. ▪ In the demonstration, when the type of diet was set to 4, pasture land was set to zero but we assume there is still milk consumption so where is that coming from, and 50% of meat consumption comes from dairy cows. ▪ Meat to be represented as weight or ruminant not calories. ▪ Trade-offs between levers. ▪ Missing the half/half assumption. ▪ Methodological points: description should be in grams to make it easier for users to visualise.

3.2 Group discussion 2: Agriculture & Livestock

3.2.2 Crop yields

Key issues

- Strong disagreement on L1 CAGR, lower bound should be 0 or negative, accounting for adverse climate change impacts under low mitigation scenarios.
- Some disagreement on L2-4 growth trajectories.

Levels	Notes
Level 1 represents a low productivity increase, 20% overall by 2050, or approximately 0.5% a year. This is much lower than the world yield growth presented in the past decades	**Table 1** ▪ Is this only tonnes/ha or calories/ha? ▪ We are approaching the limits; its linear growth and must plateau somewhere, we feel this scenario in not justified and that lower bound should be zero. ▪ We suggest that we shift the level by 1 i.e. level 3 becomes level 4 with level 1 replaced by zero.

and may include some potential negative impacts of climate change on agriculture or availability of natural resources, e.g. water and fertilisers.	▪ Don't strongly disagree, should be less optimistic (level 1) and more optimistic (level 4). **Table 2** ▪ Could be a bit more aggressive, projections say that yield could be even negative. Maybe consider 0%. **Table 3** ▪ Strong consensus and agreement! **Table 4** ▪ Wastage of food should be included in L1. ▪ L1 is more than business as usual and is very extreme. ▪ Should be more flat and include less growth – Developed world. ▪ Also consider L1 to include radical climate change and no adaption methods. ▪ Realistically pessimistic. **Table 5** ▪ The assumed growth (0.5%) should be lower. Group consensus was that it should be small negative (-0.1 to -0.5%)
Level 2 assumes a moderate yield growth, 50% overall by 2050, or approximately 1.0% a year, which is a similar to FAO forecasts. It presumes that the current growth rates of productivity would be slightly reduced by 2050.	**Tables 1, 2, 4 & 5** ▪ No comments. **Table 3** ▪ OK, but possibly not ambitious enough. Should not be any lower.
Level 3 represents that the global yield growth would increase 80% by 2050, or approximately 1.5% a year. This increase would be slightly higher than a linear trend from the past two decades. This level assumes a significant contribution from biotechnology, better farm management and technology transfer in order to reduce the yield gap, as well as capacity development programmes, and low climate change impacts on agriculture.	**Tables 1 & 2** ▪ No comments. **Table 3** ▪ Strong consensus and agreement. **Table 4** ▪ L3 should be more stretching. **Table 5** ▪ Crop yield should increase to average 2% per year with reduced post-harvest waste, etc.
Level 4 presents extreme yield growth, 120% by 2050, or approximately 2.0% a year. This aggressive level of effort assumes a substantial use of genetically modified organisms (GMOs), a high increase in photosynthetic efficiencies, technology transfer, mechanisation, and potentially positive climate change impacts (e.g., CO_2 fertilisation) on crop productivity, on average terms. Such an extreme growth rate has been observed in a regional context of some countries, and even higher rates (e.g., the production of grains in Brazil has increased about 5% a year in the past two decades, as demonstrated by Strapasson et al. (2010, p. 52)), yet such rates would be unlikely to occur as	**Table 1** ▪ Some participants feel that even 1.5% is too high even and a 1.2% may be more realistic. **Table 2** ▪ Don't strongly disagree, should be less optimistic (level 1) and more optimistic (level 4). ▪ More comfortable to be optimistic in that case since technology can do a lot. It could be even doubled. Policy here would be the issue. **Table 3** ▪ Consensus agreement, but see caveat on climate impact. ▪ Description for level 4 to be changed – no need to emphasise GMOs. **Table 4** ▪ L4 should be more stretching. ▪ CO_2 fertilisation should be removed as the effects it can make are minimal. **Table 5** ▪ Caveat: Energy inputs must be considered and increase to support increasing output. If that is considered, given potential to minimize post-harvest wastes and improve yields, we think "extreme" case is 5% (see Foley group climate bin research and other studies of potential increases if money is not the limiting factor).

a global average for all crops by 2050.	
General comments	▪ Glossary of the terms with units. ▪ There is no link between carbon emissions and yields in the calculator and its feedback. ▪ Feedback of climate change impacts is not considered on the yields ▪ Waste reduction accounted? ▪ Water is key constraint to increases. Assumptions about water use efficiency and irrigation are important. ▪ Premises related to water use and irrigation - availability in agriculture? ▪ Methodology question: is it considered if the values will be able to feed the population now or in 2050 based on population growth? ▪ Don't strongly disagree, should be less optimistic (level 1) and more optimistic (level 4). ▪ Regional variations again important: different regions with different yield scenarios will have different levels of effort required. ▪ Assumption of net negative impact switches to assumption of net positive impact for the crop yield lever.

3.2.3 Livestock yields

Key issues

- Definition of livestock yields unclear. Clarifications needed on sub-levers, i.e., 'pasture intensification', 'feed conversion ratios' and 'intensification of animals'.
- Some disagreement on CAGR, i.e., on par with crop yields vs higher/lower.

Levels	Notes
Level 1 means a low increase of livestock yields, 20% overall by 2050, or about 0.5% a year, particularly pasture yields. Such low yield growth could be caused by potential negative impacts from climate change in the livestock sector, e.g. low pasture yields, as well as scarcity of natural resources, diseases and international market disruptions. This lever also includes a low increase in the intensification of animals, concentration of animals in grass-fed systems and feed conversion ratios.	**Table 1** ▪ Given that crop yield will grow at lower rate very high livestock yield growths doesn't look feasible. Actually the fact is that we failed to understand this lever. ▪ Currently only the feedback from the pastures is factored into the livestock yield projections. In this case the growth rates are reasonable. However we feel that the crop yields should also be factored in to this and connected to livestock production. In this case the growth rates may change. **Tables 2, 3 & 4** ▪ No comments. **Table 5** ▪ Units of Livestock Yield – it's number of animal per hectare converted into percentage increase. We need standardized units. ▪ Assume parallel assumptions to crop yields; e.g., small decrease.
Level 2 represents a moderate growth of 50% overall by 2050, or approximately 1% a year (pasture improvements). This increase is often observed in developing countries, where potential yield gains are common, due to past low performances. It also assumes a moderate increase in the intensification of animals, concentration of animals in	**Tables 1 -5** ▪ No comments.

Levels	Notes
grass-fed systems and feed conversion ratios.	
Level 3 considers a high increase in global meat yields, 120% by 2050 or about 2% a year (pasture improvements). This means a high use of conventional animal genetic improvements, pasture rotation management, technology transfer to developing countries and capacity development programmes. This lever also includes a high increase of confined systems, concentration of animals in grass-fed systems and feed conversion ratio.	**Tables 1 - 4** No comments. **Table 5** ▪ Similar to crop yield should increase to 2%.
Level 4 means an extreme yield growth, 220% overall by 2050 or approximately 3% a year (pasture improvements). This assumes extensive use of biotechnology, including genetically modified animals, and strong technology transfer from developed to developing countries in order to leap-frog the learning curves for higher productivities. It further assumes an extreme increase in the intensification of animals, concentration of animals and feed conversion ratios.	**Table1** ▪ No comments. **Table 2** ▪ Why is it much bigger than the crops levels (220% vs. 120%)? **Table 3** ▪ Not credible on a worldwide basis. **Table 4** ▪ Too optimistic. **Table 5** ▪ Assume higher rate as extreme case (to match crop yield; up by 5% as well).
General comments	▪ All levels seem to be ok if compared to the 1.4%-0.9% FAO numbers exposed in the paper. ▪ Definition of livestock yield is not clear to us (Table 1). ▪ Need to be more closely bounded by the data from literature. ▪ Low knowledge about the theme to judge (Table 2). ▪ How to deal with trade-off related to intensification: climate change vs. welfare? ▪ Can be more optimistic about livestock growth than crop yield growth due to the science of breeding. Rapid technological transfer is key. Larger potential to increase livestock than crops due to fewer problems in this expansion. ▪ Assume parallel assumptions to crop yields. ▪ Mixing too many levers into one is a bad idea. ▪ Fish should be included as a livestock as this is a major stable food for many parts of the world. ▪ Could be more optimistic with higher levels as the demand for meat and the science of breeding is likely to lead to a L3 type scenario. ▪ Do we model the fact we need significantly more energy to produce 1 kcal of beef, compared to 1 kcal of crops?

3.3 Group discussion 3: Bioenergy & Wastes and Residues

3.3.2 Bioenergy yields

Key issues

- L1 & 4 should be recalibrated.
- Consider biophysical constraints in yield projections.

Levels	Notes
Level 1 means a low yield increase of energy production per area, 50% overall by 2050, or approximately 1% a year. This is based on the current crop yield growth rate and includes the use of crops with low energy balance (e.g., corn-based ethanol, and oilseed-rape-based biodiesel).	**Table 1** ▪ Participants feel that the context here is about change or increase in NPP not as much about crop yield. Since this scenario is the most pessimistic scenario a per annum growth rate of 0% seems OK for level 1 (all participants agree). ▪ Since this scenario is the most pessimistic a per annum growth rate of 0% seems OK for level 1 (all participants agree). Also we do not know the amount of area. Small areas can be massively productive. Scale issue is not considered in this analysis or levers. **Table 2** ▪ Between 0-0.5% so it is consistent with food crop growth. No minimum effort should imply in no change on crop mix. Split yield per crop, crop mix. **Table 3** ▪ General consensus, but conservative for a lower bound. **Table 4** ▪ No comments. **Table 5** ▪ The figure of 1% is high and too optimistic. The proposed figure is between 0% to -0.5%.
Level 2 assumes a moderate increase in yields, 80% overall by 2050, or approximately 1.5% a year. It represents the global trend of using more efficient energy crops and technologies for bioenergy. It also requires better farm management and industrial integration with the production systems.	**Table 1** ▪ L2: 33% and L3: 66% growth rate of energy yield seems possible; to be bounded by NPP and its biophysical dynamics under different circumstances. **Tables 2 & 4** ▪ No comments. **Table 3** ▪ Set Levels 2 and 3 in between e.g. In L2 assume 1.5% p.a. yield increase and no crop switching, and in L3 1.5% pa yield increase but full crop switching. **Table 5** ▪ Could be the figure quoted in Level 1 (1%).
Level 3 considers a high yield increase, 120% overall by 2050, or about 2% a year by 2050. This yield growth is expected through an expansion of some new biofuels technologies, e.g., lignocellulosic bioethanol and Fischer-Tropsch biodiesel, which may affect further investments on agricultural yields for energy crops. In this level, crops with high energy performance would increase their share in the global market.	**Table 1** ▪ L2: 33% and L3: 66% growth rate of energy yield seems possible; to be bounded by NPP and its biophysical dynamics under different circumstances. **Table 2** ▪ More likely only depending on business opportunity perceived by farmers. **Tables 3 & 4** ▪ No comments. **Table 5** ▪ Calibrate the level 3 with the IEA estimates or some other reference.
Level 4 represents an extreme increase of bioenergy yields, 280% overall by 2050, or 3.5% a year. This is based on advanced fuel technologies,	**Table 1** ▪ We need to see if this kind of growth 3.5% or 280% is bio-physically possible. We feel a doubling (100%) of bioenergy crop yields is possible given that technological interventions and irrigation etc. takes place. ▪ We think this discussion is not as much about crop yields, but it has to be

Levels	Notes
biotechnology, state-of-the-art farm management, and further use of irrigation and fertilisers. This level assumes highly efficient energy crops (e.g., sugarcane, oil palm, switchgrass), would dominate the market and consequently also increase the average yield of bioenergy crops.	bounded by NPP and its biophysical dynamics under different circumstances. **Table 2** ▪ In line with blue map; most of members comfortable with number bearing in mind it is pretty ambitious. Questions about where the expansion might be. ▪ Disagreement on level 4 is due to pragmatism related to land use in Africa. **Table 3** ▪ Contentious calculation, with much local variation, we may even be able to go beyond 3.5%. ▪ To work out level 4, remove all low yielding bioenergy crops and give high percentage increases e.g. 3% for high-yielding crops. Convert this into an overall %. ▪ Many unknowns: water availability, crop mix, conversion technologies and their development. Calculate this by assuming that all land uses the most efficient crops, and that their yields increase by 3% p.a. **Table 4** ▪ Realistic. L4 is perfectly feasible and simply rely upon the implementation of existing technology and policy to new crops and new areas of the world e.g. existing agronomy knowledge, plant breeding and largely ignored major species in developing countries, compared to maize, wheat and canola. ▪ If there is political will, the levels could be much more ambitious. **Table 5** ▪ The figure can be increased further to 5% by increasing the growing of efficient energy crops. ▪ If we are choosing level 4 (or any increased level) there should be an increase in energy input.
General comments	▪ We have concerns on mixing of traditional vs. modern bioenergy and also we have concerns about the scale issues. ▪ The title for this lever is confusing. Bioenergy yields should not be called 'yields'. You could say 'GJ/ha'? Or Bioenergy production. Make it clear it includes crop switching as well as crop yield to avoid erroneous comparisons with the levels of food crop yield increase. ▪ Baseline scenarios are very important - crop types differ and what mix are you considering? ▪ The upper bound for level four for the bioenergy crop yields again depends on increased irrigation which may not be feasible. Water to be factored in. ▪ For the bioenergy lever is it 'to' or 'by' 2050? ▪ The upper limit is also contingent on conversion technologies, their efficiency and their development. It is not clear how these are accounted for in the model. There is no level that controls the efficiency of crop conversion to liquid biofuels. ▪ The description for the bioenergy yields lever seems to assume the continuation of particular forms of intensive monoculture production which are problematic. ▪ What about decreases as a result of climatic factors etc.? ▪ Need a clearer definition between woody and other biomass in the model. Possibly lower estimate of possible growth. Efficiency of conversion between biomass and energy needs to be added into the model - this is technology dependant. ▪ All levels are fairly credible.

3.3.3 Wastes and residues

Key issues

- Clarification needed on waste and residues definitions and how production and collection thereof are accounted for in the calculator.

Levels	Notes
Level 1 assumes a low increase in the collection of total wastes/residues, from 5% (2011) to 10% (2050), and that the production of food and meat wastes/residues (post-farm) would remain stabilised in 40% by 2050. It includes collection of on-farm residues from 5% (2011) to 10% by 2050.	**Table 1** ▪ L1-L4: The global average waste as presented in the calculator is disputed. Globally it is likely to be 25% (WRI, 2013). ▪ Let's take even lower increase in collection of total waste/residue 5% at farm and 0% (residue) **Table 2** ▪ Collecting on farm seems to reach 10% easily. Ok with 40%. Post farm collection stay on 5%. **Table 3** ▪ Get a baseline number for Level 1. **Table 4** ▪ Collection in L1 should be set to a higher level. **Table 5** ▪ It remains at the current levels of 5 % with or without any intervention.
Level 2 represents a moderate increase in the collection of total wastes/residues, from 5% (2011) to 20% (2050). This also assumes that the production of post-farm wastes would be slightly reduced, from the current 40% to 30% by 2050, approximately. It also includes collection of on-farm residues from 5% (2011) to 20% by 2050.	**Tables 1, 3, 4 & 5** ▪ No comments. **Table 2** ▪ More likely.
Level 3 means a high increase in the collection of wastes/residues, from 5% in 2011 to 30% by 2050, and that post-farm wastes/residue production would be reduced from 40% to 10% by 2050. Significant conversion of agricultural residues into co-products or by-products. Public policy support would be fundamental. It also includes collection of on-farm residues from 5% (2011) to 30% by 2050.	**Tables 1, 3, 4 & 5** ▪ No comments **Table 2** ▪ Okay.
Level 4 means a massive increase in the collection of post-farm wastes/residues, from the current 5% to 40% by 2050, and an extreme reduction of waste/residue production from 40% to 5%. Farm and agro-industrial residues, for example, would be not only reduced but also converted into co-products of the production chain. Strong public policy support required. It also includes collection of on-farm residues from 5% (2011) to 50% by 2050, which represents an extreme collection increase.	**Table 1** ▪ 40% on farm collection of residues. Globally looking at 2/3rd reduction of waste, but that will be over the real waste number i.e. 25%. **Table 2** ▪ Increased infrastructure to reach that. Technically possible to reduce waste to 5%. 5-to-40% is doable with BAT. Could do more though. But 50% is doable (for on-farm collection). Could be more ambitious on farm residues (60%?). Most desirable. **Tables 3 & 4** ▪ No comments. **Table 5** ▪ The reduction of waste residue figures is acceptable, but it should be described better, so that the users can easily understand.

Levels	Notes
General comments	▪ L1-L4: The residues and energy yields are related which may not be captured in the current framing. ▪ The global average waste as presented in the calculator is disputed. Globally it is likely to be 25% (WRI, 2013). While the developed world is 40%. ▪ Wastes and residues to be distinguished from each other, and types of waste are quite distinct. These seem confused and conflated between levels. ▪ Much local variation, no idea of baseline. ▪ Regional variation very important: in parts of Africa some waste simply burnt on field, in the UK, significant percentage used for other purposes and then moved back onto the land. ▪ The lever needs to distinguish between waste and residue - lots of what is harvested is 'wasted'; how are residues defined? ▪ Woody waste, agriculture, crop and other waste should be separated as they can't be considered the same in their economic outputs. When wastes become valuable, the investment is dropped because the costs change dramatically. ▪ Public policy should be recommended for all levers and not only this lever. ▪ Confusing and misleading definition to the user. It's not easily interpretable and is inconsistent. ▪ Propose a diagram to visually describe the resources of waste and residues. ▪ Residues and energy yields are related which may not be captured in the current framing and you may want to refer to it. ▪ The waste scenario is largely speculative but achievable. ▪ Many technologies already exist to convert major crop waste streams in developing countries. This is reliant upon the transfer of machinery, technology, knowledge and a market being present. ▪ When the waste is considered a valuable resource, the estimates of its use would completely change in comparison to the estimates we make here. This influences all levels. ▪ Need to clarify what this lever is. One suggestion was to include a diagram showing where in the system wastes and residues were produced and collected.

3.4 Group discussion 4: Remaining land & Land-use Efficiency

3.4.2 Remaining Land (Forest & Bioenergy)

Key issues

- In addition to forestation and bioenergy, natural revegetation should be an option.
- Carbon stocks need to be accounted for.
- Account for additional demands on land and associated land use changes, e.g., settlements and infrastructure, desertification.

Levels	Notes
Level 1 means that if more land becomes available by 2050 due to a potential reduction of crop/pasture lands, such land will not be used for any other purpose and remain unallocated, i.e., it will not be used for forestation and/or energy crop production.	**Table 1** ▪ Do not fully understand the intention behind just leaving this. However we would like to flag that if the land is left devoid of human intervention (crop/pasture) then natural regeneration will take place and forest will crop up automatically. So we don't agree with this assumption. For example the case in EU can be cited. **Table 2** ▪ Agree, but can't assume zero carbon stock. **Table 4** ▪ Minimum should be re-vegetation (grass/forest) land not left unused

Levels	Notes
	Table 5 ▪ Agree with the description of the level.
Level 2 assumes that the remaining land would be allocated for additional forest, based on extreme forest rate expansion in global scale (0.2% a year). If there is still remaining land by 2050 after such extreme forest expansion, then this area would be allocated to energy crops (up to 5% a year of bioenergy expansion rate). If there is still an available land after such forest and energy-crop expansions, then it will remain as unallocated.	**Tables 1, 2 & 3** ▪ No comments. **Table 4** ▪ Unlikely to end up with more forest than crops in a realistic world. **Table 5** ▪ What is the basis on the maximum figure?
Level 3 means that the remaining land would be allocated for additional forest and energy crops, balanced as 50/50, based on extreme rates of expansion for both forest (up to 0.2% a year) and energy crops (up to 5% a year). If there is still unallocated land by 2050 after such extreme balanced expansions, then the remaining area would stay as unallocated land.	**Tables 1 - 3** ▪ No comments. **Table 4** ▪ Reasonable but market dependant. **Table 5** ▪ Agree with the description of the level.
Level 4 assumes that the remaining land would be allocated to additional energy crop first, based on extreme bioenergy rate expansion in global scale (up to 5% a year). If there is still unallocated land by 2050 after such extreme bioenergy expansion, then the remaining area would be allocated to additional forest (re-composition, up to 0.2% a year). If there is still remaining after these extreme energy crop and forest expansions, the remaining land would be kept as unallocated.	**Table 1** ▪ Quiet demanding but seems achievable. **Table 2** ▪ 0.2% is a net deforestation rate, not representative of afforestation technical potentials. 5 million ha planted each (~ 0.125%) year. Overall, afforestation rates could be a lot higher. Suggestion: use absolute numbers, not percentages. Consider scale-up Brazil. On the 5% bioenergy growth: it depends from where we start from – could be 50% if a tiny area. The principle of level 4 being energy crop focused is correct, it produces the most energy. **Tables 3** ▪ No comments. **Table 4** ▪ Feasible and our preferred pathway. **Table 5** ▪ Agree with the description of the level.
General comments	▪ Assumptions about land availability are opaque - land loss due to urbanisation, for example, needs to be factored in. This interaction to be explained to the user. ▪ What are the carbon implications of leaving land unused, turning it to forestry or turning it to energy production? i.e. does the unused land accumulate carbon? What carbon factors are assumed for forest and bioenergy, and will you consult on these? ▪ How is soil carbon and above-ground carbon accounted for? ▪ Drivers for land-allocation? ▪ How do they account for soil carbon and the above-ground carbon? ▪ What are the drivers for leaving land alone or allocating use? i.e. it needs to be explicit to the user that if they leave land alone, the land owner will have to be given an incentive to do so. Same with forestry and bioenergy.

Levels	Notes
	▪ The bioenergy vs. forest choice is not clear-cut, as implied by this lever - see IPCC for example, where Chapter 11 states that the choice between forest and bioenergy on a GHG basis is highly location specific, and that a generalisation can't be made. ▪ Some of the agronomic practices listed in the levels are not necessarily designed to improve yields but to stabilise and increase resilience, with an explicit understanding that there might be a small and acceptable trade-off. ▪ Recommendation - Don't assume all land that is currently classified under current definitions, be different and add in the 500bn hectares of land currently underutilised. Add a new lever where the user can add/subtract from that unused land. ▪ Create a class for unallocated land from the beginning. ▪ There is a need to clarify the definition of 'unallocated land' and also it should be made clear 'what forestation actually means' – naturally or anthropogenic. ▪ Forestry: is it for products, carbon sequestration or energy? ▪ Remaining land levels: are they a choice? A-D instead of 1-4. ▪ The choice between forestry and bioenergy is complex and location-specific, determined also by social needs. ▪ We should express the maximum possible growth in forest (or bioenergy) area as hectares rather than % change.

3.4.3 Land-use efficiency

Key issues

- Lever needs to be defined more clearly.
- Explore interactions with crop, livestock and bioenergy yields levers.

Levels	Notes
Level 1 reflects mismanaged land use, which can cause soil degradation or desertification process, e.g. through erosion, water scarcity or soil salinisation. This level assumes that 5% more agricultural land would be necessary to meet the selected food/livestock/bioenergy production levels.	**Table 1** ▪ Mismanaged system itself is chaotic and a drop of 5% looks pretty managed; it looks very optimistic, and we feel that the lower bound should be between 5-10%. **Table 2** ▪ OK. **Table 3** ▪ Where does the percentage come from? **Table 4** ▪ L1 happens all over the world currently. ▪ Acceptable as this currently occurs and the 5% is consistent with the FAO. **Table 5** ▪ 10% more agricultural land will be needed in consistent with level 3 OR 25% more agricultural land will be needed in consistent with level 4.
Level 2 assumes that the current world pattern of agricultural system stabilises until 2050. This means that either no further benefit or damage would be expected from land multiuse by 2050, i.e., no impact.	**Tables 1 & 3** ▪ No comments. **Table 2** ▪ Needs to be more clear that the 3 other levers stay the same. **Table 4** ▪ Acceptable and realistic. **Table 5** ▪ Agree with the description of the level.

Levels	Notes
Level 3 represents an increase in agro-forestry-pasture synergies and best farming practices, e.g., crop rotation, dual cropping, co-cropping, no tillage technologies. In this level of effort, 10% less agricultural land would be necessary to meet the selected food/livestock/bioenergy production levels. In this context, Langeveld et al. (2013), for example, suggested ranges of Multiple Cropping Index (MCI) that vary between 0.53 in South Africa and 1.45 in China, and around 0.8 in Brazil, the USA, and the EU.	**Tables 1 & 3** ▪ No comments. **Table 2** ▪ OK. **Table 4** ▪ 10% is acceptable. **Table 5** ▪ Agree with the description of the level.
Level 4 means climate-smart agriculture and high levels of integrated agricultural land use management (e.g., dual/triple cropping). It assumes a substantial increase in agro-forestry-pasture synergies, best farming practices. As a result, 25% less agricultural land would be necessary to meet the selected food/livestock/bioenergy production levels.	**Table 1** ▪ What the selected production level does mean? Do you take demographics into account? We feel that the upper bound of 25% less agricultural land is an OK assumption and is broadly consistent with the other sectors such as crop yields, livestock yield. **Table 2** ▪ Based on the L4 of crop yields being ambitious and focused on dedicated energy crops, hard to see how you can increase another 25% (yield). **Table 3** ▪ Not clear what the impact of the MCI is, or whether it's possible. **Table 4** ▪ L4 is very desirable and ambitious but is consistent with IPCC chapter 11 30% reduction (1.6-->1.2bn ha). **Table 5** ▪ Agree with the description of the level.
General comments	▪ It is not clear whether these %s are reasonable - need references to show whether these percentage losses/gains are possible. ▪ Dual and triple cropping is not only technological concern but also imply other pre-requisites such as water etc. It is important that L4 is strongly backed up from the literature. ▪ It has to be made clear to the user that this lever is combined with the crop yield lever. ▪ Do we need this lever? It's a top-up on at least 3 other levers. ▪ Assumptions about land availability are opaque - land loss due to urbanisation, for example, needs to be factored in. ▪ Clarify that this lever impacts on food crops, livestock and bioenergy crops. ▪ We should be clear what we're assuming forestry is used for, i.e., products, bioenergy or carbon sequestration. ▪ Some concern that co-cropping may not work for L4 food crop and L4 biocrop assumptions because these crops (e.g. perennial energy crops) are not suited to co-cropping.

Appendix 1- Agenda

Day 1: Food and Agriculture	
8:30 - 9:00	***Welcome coffee***
9:00 - 9:15	**Introduction to the Land Use, Bioenergy and Food Security workshop** Chairman Jem Woods (Imperial College)
9:15 - 9:45	**Keynote presentation** Richard Templer (UK Climate-KIC)
9:45 - 10:45	**Global Calculator – Project overview** Project Leader Sophie Hartfield (UK Department of Energy and Climate Change)
10:45 -11:15	***Coffee break***
11:15-11:45	**The Land/Bio/Food approach in the Global Calculator** Area Leader Alexandre Strapasson (Imperial College)
11:45 -12:30	**Group discussion 1: Calories consumed & Type of diet** Nicole Kalas (Imperial College)
12:30 - 13:00	**Feedback to plenary**
13:00 - 14:00	***Lunch***
14:00 - 15:00	**Group discussion 2: Agriculture & Livestock** Alexandre Strapasson (Imperial College)
15:00 - 15:30	**Feedback to plenary**
15:30 - 16:00	***Coffee break***
16:00 - 16:20	**Agriculture, Forestry and Other Land Use (AFOLU) Mitigation – IPCC WG3** NH Ravindranath (Indian Institute of Science / IPCC)
16:20 - 16:45	**Wrap up Day 1** Jem Woods, Alexandre Strapasson, Nicole Kalas (Imperial College London)
19.00 - 22.00	***Group dinner***
	Pizzeria Da Mario, 15 Gloucester Road, London SW7 4PP http://www.damario.co.uk/

Day 2: Bioenergy, Forestry and Land Use	
9:00 - 9:30	***Welcome coffee***
9:30 - 10:10	**Keynote presentations** • Adam Brown, IEA • Hans Langeveld, Wageningen University, Biomass Research
10:10 - 11:00	**Review of Day 1 and Introduction to Day 2** Nicole Kalas, Alexandre Strapasson, Jem Woods (Imperial College London)
11:00 - 11:30	***Coffee break***
11:30 -12:30	**Group discussion 3: Bioenergy & Wastes and residues** Alexandre Strapasson (Imperial College)
12:30 - 13:00	**Feedback to plenary**
13:00 – 14:00	***Lunch***
14:00 -15:00	**Group discussion 4: Remaining land & Land-use Efficiency** Nicole Kalas (Imperial College)
15:00 - 15:30	**Feedback to plenary**
15:30 - 16:00	***Coffee break***
16:00 - 16:30	**Wrap up Day 2 and close** Sophie Hartfield (UK DECC) Jem Woods, Alexandre Strapasson, Nicole Kalas (Imperial College)

Appendix 2 – List of participants

	Name (alphabetical by surname)	Affiliation
1	Zareen Bharucha	Essex University
2	Phil Briscoe	Rezatec
3	Adam Brown	IEA
4	Grahame Buss	Shell
5	Carlos Eduardo Cerri	University of Sao Paulo
6	Rajiv Kumar Chaturvedi	Indian Institute of Science
7	Annie Chimphango	Stellenbosch University
8	Lionel Clarke	Shell
9	Paul Colonna	INRA
10	S Dasappa	Indian Institute of Science
11	Duncan Eggar	BBSRC
12	Mosad Elmissiry	NEPAD
13	Tom Fullick	NFU
14	Zsolt Gemesi	Climate-KIC
15	Sophie Hartfield	DECC
16	Siyuan He	University of Cambridge
17	Jo Howes	BP Biofuels
18	Nicole Kalas	Imperial College London
19	Emma Keller	Unilever
20	Keith L Kline	ORNL
21	Ana Kojakovic	FAO
22	Juergen Kropp	PIK
23	Tim Kruger	Oxford University
24	David Laborde	IFPRI
25	Hans Langeveld	Wageningen University, Biomass Research
26	Sally Mills	RSPB
27	Ben Muok	African Centre for Technology Studies (ACTS)
28	Richard J Murphy	University of Surrey
29	David Norse	UCL
30	Catherine Oriel	Climate-KIC

	Name (alphabetical by surname)	Affiliation
31	Tim Oxley	Imperial College London
32	NH Ravindranath	Indian Institute of Science / IPCC
33	Sean Richmond	DECC
34	Goetz Richter	Rothamsted Research
35	Jansle Vieira Rocha	UNICAMP
36	Frank Rosillo-Calle	Imperial College London
37	Bill Rutherford	Imperial College London
38	Jonathan Scurlock	NFU
39	Raphael Slade	Imperial College London
40	Clifford Spencer	Global Biotechnology Transfer Foundation
41	Anna Stephenson	DECC
42	Alexandre Strapasson	Imperial College London
43	Richard Taylor	e4tech
44	Richard Templer	Climate-KIC
45	Tim Vallings	Rezatec
46	George Watson	Tesco
47	Helen Watson	University of KwaZulu-Natal
48	Jeremy Woods	Imperial College London

Appendix 3 – Discussion questions

- Level 1: Is this an accurate reflection of a minimum abatement effort?
    - Why? Why not?
    - Should alternative scenarios be considered?
- Level 2: Is this level ambitious, yet achievable?
    - Why? Why not?
    - Should alternative scenarios be considered?
- Level 3: Is this level very ambitious, yet achievable?
    - Why? Why not?
    - Should alternative scenarios be considered?
- Level 4: While extraordinarily ambitious and extreme, is this still a credible scenario?
    - Why? Why not?
    - Should alternative scenarios be considered?
- What are the group's main concerns with regard to this lever?
    - Data
        - robustness / uncertainty
        - additional sources of data
- As a group, can you agree on one level, i.e., a representative pathway?
    - What were the main points of contention?