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# Briefing Paper on Land, Food and Bioenergy of the Global Calculator Project[1]

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## 1. Overview

The Global Calculator Project enables users to explore the options for reducing global greenhouse gas (GHG) emissions associated with land, food and energy systems in the period to 2050. It builds on the success that a number of countries have had in developing their own country-level 2050 Calculators but it extends the approach by illustrating the detrimental impacts of climate change associated with global-level choices. The project is led by the UK Department of Energy and Climate Change (DECC)[5], and co-funded by Climate-KIC[6].

The Global Calculator presents a novel methodological approach for modelling both carbon and land use dynamics at a global scale for the following sectors: Transport; Manufacturing; Electricity; Land, Food and Bioenergy ("Land/Food/Bioenergy"); and Buildings. It also considers climate change impacts, different rates of population growth and urbanisation, and scenarios for the inclusion of speculative Greenhouse Gas Removals (GGR) technologies. All sectors and variables are interconnected in a dynamic model, which allows users to generate a large number of GHG emission reduction trajectories online. The Global Calculator can be used by decision-makers in the public and private sectors to inform management strategies for GHG mitigation, land use change, food and biomass production.

Imperial College is leading the Land/Food/Bioenergy and GGR areas of this project in collaboration with PIK-Potsdam, Rothamsted Research, the University of Reading and the University of Oxford. Similarly, the World Resources Institute (Washington, USA) is managing Transport, Climact (Brussels, Belgium) Manufacturing, Ernst & Young (Delhi, India) Electricity, and Energy Research and Development International (Beijing, China) Buildings, respectively. Climate Media Factory at PIK-Potsdam is developing the visuals and online version of the Global Calculator, whereas the London School of Economics and Political Science (LSE) is managing the climate science contribution.[7]

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[1] This paper was originally prepared for the Global Calculator's Workshop on Land Use, Bioenergy and Food Security hosted by Imperial College London on 23-24 April 2014, as described in the workshop notes. The current version presents a summarised document, given that further explanations are already available in the respective levers' pagers of the Global Calculator web tool, as well as in its spreadsheet, especially in the Worksheet G.60(data) and G.60. Additional discussions can also be found in Strapasson (2014).

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[6] See more at: www.climate-kic.org

[7] For more information, access: www.globalcalculator.org

## 2. The Land/Food/Bioenergy Model of the Global Calculator

The convergence of rising energy and food demand and limits to the availability and distribution of natural resources to meet these, require the need for more sustainable pathways. The approach employed in the Land/Food/Bioenergy model of the Global Calculator applies a mathematical methodology for balancing the necessary expansion in the production of food crops, livestock, biofuels and other bio-based products with resources conservation. It allows users to simulate a number of trajectories of land use change and its associated greenhouse gas emissions, according to different demands for land-dependent products and services by 2050. Users can then develop their preferred pathways to 2050 by varying the weight of a selected set of parameters ("Levers") according to their GHG mitigation objectives ("Levels" 1-4, with several intermediate levels, at increasing levels of ambition). These include:

- Calories consumed per person;
- Meat consumed (quantity and type of meat);
- Crop yields;
- Livestock yields, which includes changes in feed conversion ratio, the share of feedlot systems, and animal density in pasture systems;
- Bioenergy yields;
- Bioenergy – solid or liquid;
- Surplus land (forest & bioenergy);
- Land use efficiency;
- Wastes and residues.

The model also considers several additional variables for the calculations, including the use of fertilisers, agricultural losses, GHG emissions factors, feed conversion ratios, the proportion of animals raised in intensive production systems (feedlots) vs. animals in grass-fed systems (pasture), a potential higher concentration of animals in grazing systems (i.e., more animals per hectare of pasture), limiting factors for land distribution, etc.

The accuracy of each trajectory is limited by the availability of and uncertainty associated with data for global scale estimates and the restricted number of input parameters in the calculator, given the high complexity and uncertainty of all these levers. The model draws on several data sources, primarily FAO, IEA and IPCC statistics, and representative international references on land use modelling, with the purpose of obtaining not only a robust and credible methodology, but also a simple and user-friendly calculator for the lay user. Furthermore, the inputs for Levels 1-4 were carefully calibrated through expert review.

## 3. Description of the Land/Food/Bioenergy methodology

The Global Calculator is presented as a web tool, which was built on a database generated by Ruby (C language programme) from a comprehensive model in MS Excel format. The model has several input parameters and variables, which are used for estimating future land use distributions, as well as the associated $CO_2$, $N_2O$ and $CH_4$ emissions. Land use change is determined by a hierarchy of land use types[8], i.e., priority is given to food production (crop and pasture lands), and the remaining land area is allocated to forestation and/or increase in energy crops worldwide. Figure 1 presents a flow diagram of the Land/Food/Bioenergy methodology.

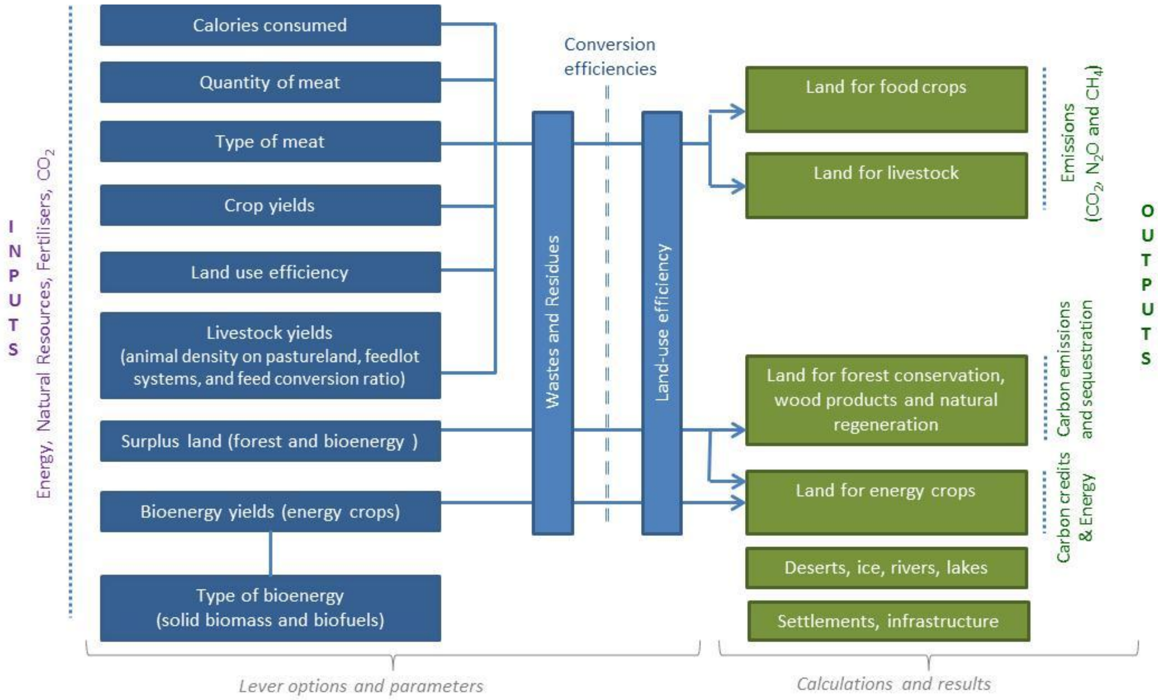


**Figure 1: Land/Food/Bioenergy Diagram of the Global Calculator**

The following sections provide a brief description of the key "Levers" and definition of "Levels" adopted in the Land/Food/Bioenergy module of the Global Calculator tool for modelling land use change and the supply and demand for food, forestry and bioenergy. These are further refined through several underlying sub-levers and fixed parameters which are used to improve the accuracy of this module and its integration with other sectors.

### *3.1. Calories consumed*

The consumption of food is a major driver for land use change. This lever models the land demand for food production, along with the 'Quantity of meat' and 'Type of meat' levers and respective efficiency parameters. Actual time series from FAO (2014) on calorie consumption were used for estimating future trajectories according to assumptions adopted in the calculator. Figure 2 shows the global and regional per capita food consumption (including food losses) in 2005/2007 and projections to 2050.

[8] For more information on land use types, please access the paper on *Descriptions of Land Classifications*, which is available in the Global Calculator.

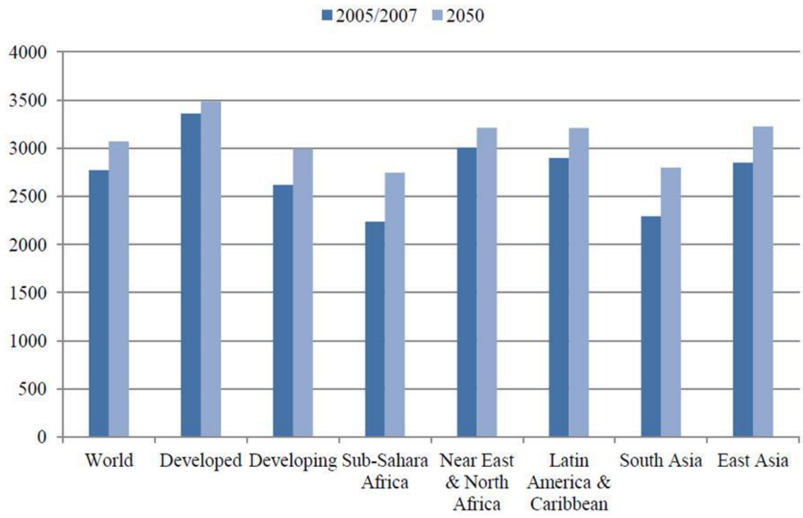


**Figure 2. Per capita food consumption (kcal/person/day), including losses (Alexandratos & Bruinsma, 2012)**

To estimate the effective food intake per person, it is necessary to exclude food losses (farm residues, post-farm and consumers' wastes), which are assumed to account for approximately 24% of the food supply in terms of energy content[9]. Thus, in 2011, the global average calorie consumption was 2180 kcal/person/day (excluding food losses), with extremes of obesity and undernourishment worldwide in terms of dietary energy intakes. This value is above the Minimum Dietary Energy Requirement (MDER), which changes according to region, age and sex, but it is important to note that presently, approximately 500 million people obtain less than 2000 kcal/day. FAO consolidates the food consumption data based on National Balance Sheets, rather than from actual consumption surveys, and therefore the effective consumptions here estimated are approximated values.

### *3.2. Quantity of meat*

This lever is aimed at obtaining input values for the future demand for meat to estimate the necessary land area (direct and indirect) for livestock production. Figure 3 shows the relationship between meat consumption and per capita income by country (based on purchasing power parity) and Figure 4 illustrates the amount of meat consumed as a proportion of total calories intake by country. This lever also includes the consumption of milk and eggs, but fish consumption is considered in the calculations of 'Calories consumed' and is not modelled in this lever. Global average meat consumption (excluding losses) amounted to 187 kcal/person/day in 2011 (FAOSTAT, 2014). In its healthy diet guidelines, the WHO recommends a daily intake of 90 g of meat/person/day (approximately 152 kcal/person/day).

[9] WRI and UNEP (Lipiski et al., 2013) estimated that 32% (on weight) of all food produced in the world was lost or wasted in 2009. This is equivalent to 24% when converted into calories.

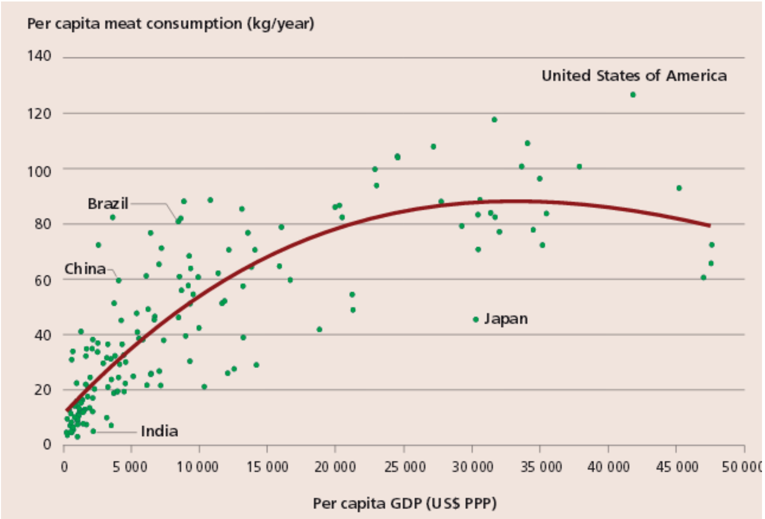


**Figure 3. Per capita GDP and meat consumption by country (2005) (FAO, 2009)**


**Figure 4. Meat consumption vs. total food calories consumed, in kcal/person/day, excluding losses, per country**

**Source:** Strapasson (2014), adapted from FAO (2014, 2011 base year), excluding 24% of food wastes, 19% of meat wastes, both in energy terms (Lipinski, 2013), and health assumptions adapted from FAO (2012) and WHO (2008).

### *3.3. Type of meat*

As the GHG and land use impacts of different types of meat differ significantly, this lever considers the proportion of meat calories consumed of ruminant (cows and other bovines, sheep and goats) vs. non-ruminants (pigs and poultry). Table 1 summarises world livestock production by type of meat.

**Table 1. World livestock production by livestock sector (Alexandratos & Bruinsma, 2012)**

| | 1961/ 1963 | 2005/ 2007 | 2050 | 1961 -2007 | 1987 -2007 | 1997 -2007 | 2005/ 2007 -2050 |
|---|---|---|---|---|---|---|---|
| **World** | **million tonnes** | | | **annual growth (% p.a.)** | | | |
| Total meat | 72 | 258 | 455 | 2.9 | 2.5 | 2.2 | 1.3 |
| Beef | 30 | 64 | 106 | 1.6 | 0.9 | 1.2 | 1.2 |
| Mutton | 6 | 13 | 25 | 1.7 | 1.8 | 2.1 | 1.5 |
| Pigmeat | 26 | 100 | 143 | 3.1 | 2.3 | 1.7 | 0.8 |
| Poultry | 9 | 82 | 181 | 5.2 | 4.7 | 3.9 | 1.8 |
| Milk | 344 | 664 | 1077 | 1.4 | 1.3 | 2.2 | 1.1 |
| Eggs | 14 | 62 | 102 | 3.5 | 3.3 | 2.3 | 1.1 |

In the Global Calculator the share of meat types by 2050 also varies according to the level selection. The meat consumed is converted to the effective meat intake, i.e. excluding losses (wastes and residues) along the supply chain, which account to approximately 19% (Lipiski *et al.*, 2013) in terms of energy content. In 2011, the global average split between ruminant vs. non-ruminant meat was about 22% vs. 78%, respectively.

### *3.4. Crop yields*

This lever controls the need for land resources for producing food. The higher crop yields, i.e., the greater the productivity, the smaller the area of arable land required for the production of a certain amount of food, e.g., grains, fruits and vegetables. It is challenging to predict crop yield potentials, particularly because the complexity regarding biotechnology potentials, future use of water and fertilisers, and positive and negative impacts of climate change on agriculture. Positive impacts assume $CO_2$ fertilisation effects and temperature increases, whilst negative effects include severe changes in precipitation, particularly a potential increase in drought seasons in some regions, which may affect the global agricultural productivity.

The main references used for estimating crop yields in each level of effort were the FAO Statistics, which predicts, for example, that these may increase by approximately 1.3% a year until 2030 and then 0.8% a year by 2050 globally (Alexandratos & Bruinsma, 2012). Table 2 and Figure 4 show average global crop production growth rates and world cereal yields and harvested areas, respectively. The current situation shows that crop yields tend to substantially increase yet, particularly in most of the developing countries where there is a significant productivity gap (Table 2, Figure 5, Figure 6).

**Table 2. Annual crop production growth (%) (Alexandratos & Bruinsma, 2012)**

| | 1961-2007 | 1987-2007 | 1997-2007 | 2005/ 2007-2030 | 2030-2050 |
|---|---|---|---|---|---|
| World | 2.2 | 2.3 | 2.3 | 1.3 | 0.7 |
| Developing countries | 3.0 | 3.1 | 3.0 | 1.4 | 0.8 |
| idem, excl. China and India | 2.8 | 2.8 | 3.2 | 1.7 | 1.0 |
| Sub-Saharan Africa | 2.6 | 3.3 | 3.0 | 2.4 | 1.9 |
| Latin America and the Caribbean | 2.7 | 2.9 | 3.7 | 1.7 | 0.7 |
| Near East / North Africa | 2.9 | 2.5 | 2.4 | 1.4 | 0.9 |
| South Asia | 2.6 | 2.4 | 2.1 | 1.5 | 0.9 |
| East Asia | 3.4 | 3.6 | 3.2 | 1.1 | 0.3 |
| Developed countries | 0.8 | 0.4 | 0.5 | 0.8 | 0.3 |

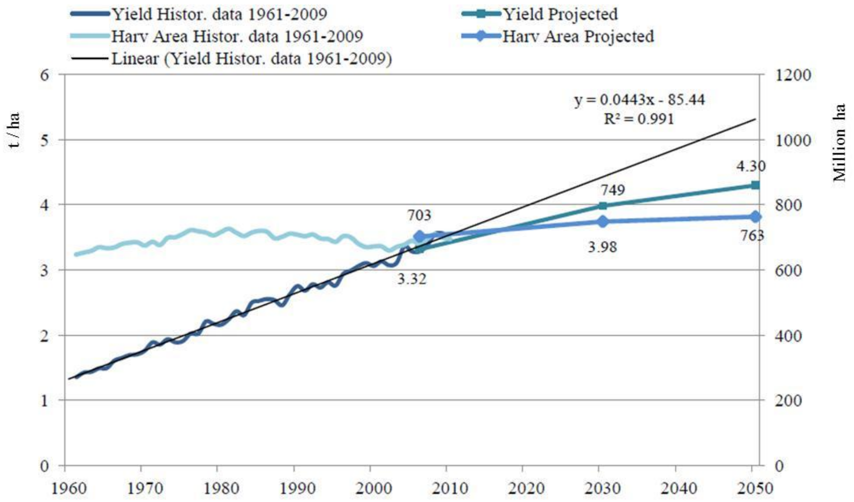


**Figure 5. World cereals, average yield and harvested area (1960-2050) (Alexandratos & Bruinsma, 2012)**

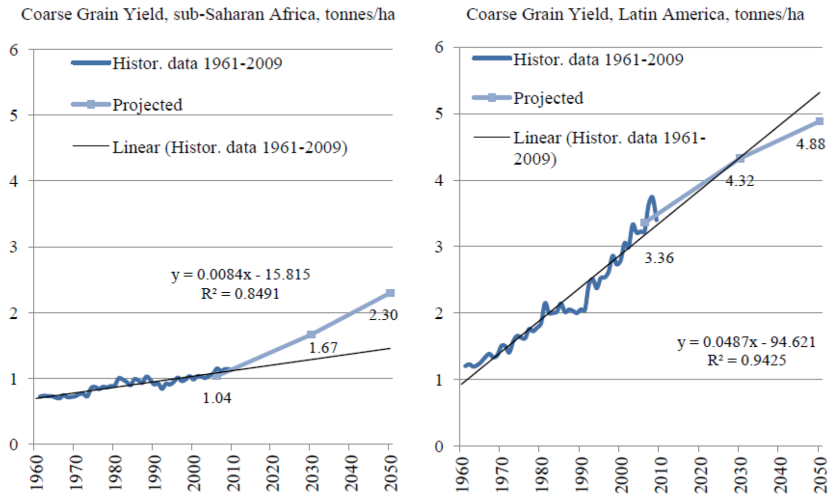


**Figure 6. Grain yields, Sub-Saharan Africa and Latin America (Alexandratos & Bruinsma, 2012)**

### *3.5. Livestock (grains / residues fed)*

The production of meat to meet future demand poses a major challenge for land use change. The land necessary for meat production is estimated based on the dietary preferences, which provides the amount of meat needed for the projected consumption, and the livestock yield growth. In the Global Calculator, different yield factors are applied to livestock reared in feedlots (grains / residues fed) and those raised on pasture land (pasture fed, see Section 4.3).

Livestock yield increases in confined systems can be primarily achieved through improvements in the animals' genetic stock, enhancements in feed conversion ratios (FCR)[10], and

[10] The Feed Conversion Ratio (FCR) represents the conversion efficiency of meat, i.e., the amount of feed intake (e.g., grain, grass) that is effectively converted into edible meat. FCRs vary according to the type of animal, age, life time, region, genetics and feed quality. Approximate FCRs were estimated as 5% for cows and other bovines, sheep and goats (average), 24% for chickens and other poultry, 27% for pigs, 13% for eggs, 8% for milk and 15% as a mean for other types of meat, with potential increases by 2050, depending on the selected level of effort. These numbers were estimated based on several references (FAO, 2006, Galloway et al., 2007; Best, 2011; Wirsenius, 2000). However, there is no comprehensive database available for FCR in global scale per type of animal to date.

improvements in management practices. Figure 7 shows the historic, comparative production growth rates for selected animal products and feed requirements in developed countries.

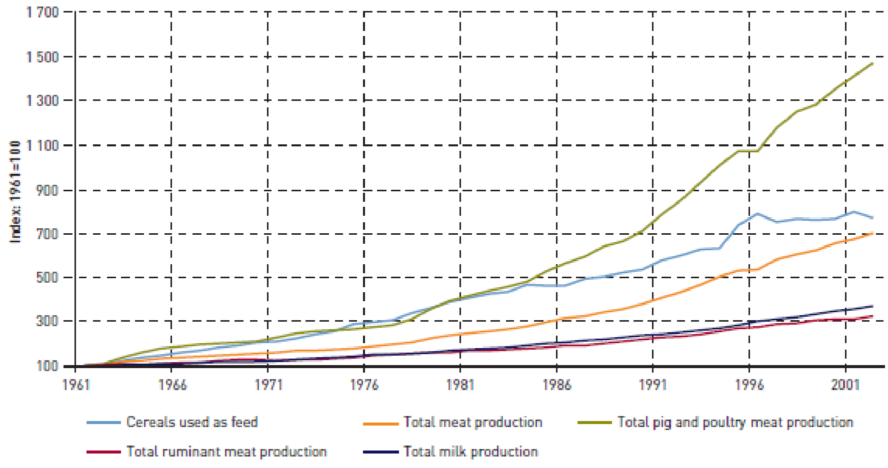


**Figure 7. Comparative growth rates for production of selected animal products and feed grain use in developed countries (1961-2001) (Alexandratos & Bruinsma, 2012)**

This lever allows users to choose the proportion of livestock reared in confined systems vs. those raised on pasture lands. In 2011, approximately 6% of all beef cattle were raised in confined systems globally, and 1% of the sheep and goats. These values were estimated from FAO (2006). FCRs are also considered in the modelling of this lever but are not subject to user choice. Although confined and semi-confined systems often present higher efficiencies, they also require substantial land use for producing feed, i.e., an external area (in the same farm or elsewhere) for cultivating animal feed products, such as maize, soybean, oats, sorghum, barley and hay (FAO, 2006).

### *3.6. Livestock (pasture fed)*

This lever allows users to select the concentration of animals (animal density) on pasture on pasture lands. Generally, higher stocking densities result in higher livestock yields (amount of meat produced per unit of land). Substantial livestock yield increases would result in less land area used for livestock production and more area would be available for other purposes, e.g., the production of grains, forest or bioenergy crops. There is a trend for a gradual annual increase in livestock yields worldwide, particularly due to a significant yield gap in developing countries and the prevalence of extensive production systems. Currently, the global average stocking density for cattle is <1 cow/ha and about 3 sheep/ha, respectively (FAOSTAT, 2014). Similarly to 'Livestock (grains/residues, see Section 3.5), FCRs factor into the calculations (at lower rates than in confined systems) and are indirectly subject to user choice.

### *3.7. Bioenergy yields*

Bioenergy yields are affected by (a) crop yield (b) energy content of the crops, and (c) technological advances. Yields of food crops used as bioenergy feedstocks (e.g., wheat, maize, sugarcane, oilseed rape, etc.) were assumed to be approximately the same as in the 'Crop yields' lever. However, it is expected that by 2050, a significant shift toward energy crops with high energy efficiency (e.g., switchgrass, elephant grass, sugarcane, miscanthus, eucalyptus, oil palm) will occur, particularly with the potential progress in the large-scale deployment of new commercial technologies, such as, lignocellulosic ethanol, and Fischer-Tropsch diesel (biomass-to-liquids).

Energy crops are also usually more subject to intensification schemes and agronomic supervision, on a global average. Finally, technological advances in crop breeding (e.g., genetic improvements for higher yields of celluloses and hemicelluloses) and industrial conversion efficiencies for producing biofuels could be expected. Therefore, the resulting global average for bioenergy yields is assumed to be slightly higher overall than that of (food) 'Crop yields' in the Global Calculator, in terms of net primary production of energy per unit of area. Algae-based fuels were not considered in this lever as they may not significantly affect land use change agricultural lands, even if the technology becomes feasible in large scale by 2050 in a global context. Table 3 summarises the historic and projected global demand for crops for biofuels, Figure 8 shows the international demand for biofuels and associated land requirements. Current global average biocrop yields are 6.5 odt/ha (solid biomass) and 2,720 L/ha (liquid biofuels as a weighted average of oil and sugar crops), which were estimated using IEA (2013), Woods *et al.* (2014) and FAOSTAT (2014).

**Table 3. World use of crops for biofuels (Alexandratos & Bruinsma, 2012)**

| | | 2005/ | 2030 | 2050 |
|---|---|---|---|---|
| Cereals | million tonnes | 65 | 182 | 182 |
| Cereals | percent of total use | 3.2 | 6.7 | 6.1 |
| Veg. oils | million tonnes | 7 | 29 | 29 |
| Veg. oils | percent of total use | 4.8 | 12.6 | 10.3 |
| Sugar (equiv. of sugar cane) | million tonnes | 28 | 81 | 81 |
| Sugar | percent of total use | 15.1 | 27.4 | 24.3 |
| Cassava (fresh) | million tonnes | 1 | 8 | 8 |
| Cassava | percent of total use | 0.4 | 2.3 | 1.8 |

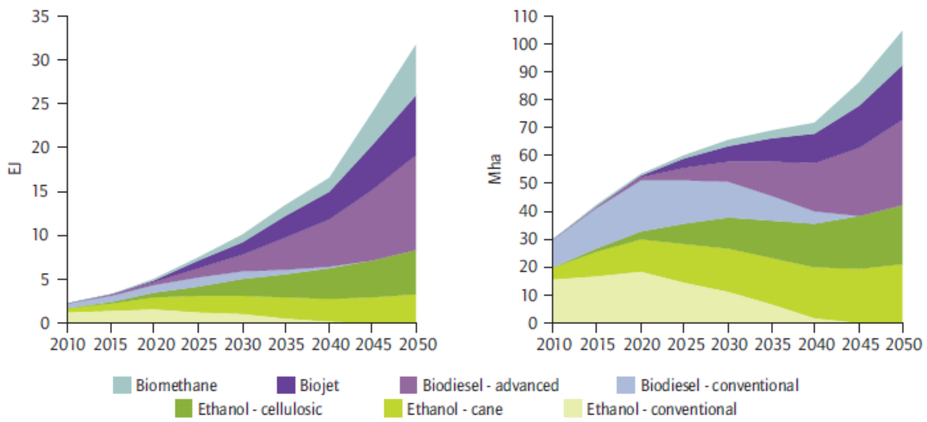


**Figure 8. International demand of biofuels, in terms of energy (left) and land use (right) (IEA, 2011)**

### *3.8. Bioenergy – solid or liquid*

This lever allows users to select the proportion of modern bioenergy used in solid vs. liquid form. Currently, approximately 40% of global bioenergy is used as liquid biofuels, while 60% is consumed in solid form, such as wood pellets and chips, excluding traditional biomass. Technological changes, such as the electrification of the transport system, may result a reduction of liquid-biofuel share. On the other hand, high levels of liquid biofuel penetration (including in the shipping and aviation sectors) would require technological advances and increases in the competitiveness of advanced biofuels (e.g., lignocellulosic ethanol and biomass-to-liquid (Fischer-Tropsch).

### 3.9. Surplus land (forest & bioenergy)

The land use dynamics in the calculator and potential increase in land use types (e.g., agriculture, pasture, forestry, energy crops, and other lands) are restricted to the total land available on Earth, and therefore, it is necessary to have a zero-sum equation to match all land uses. It was assumed that food security should be a priority over other uses, which are then adjusted in the calculator to fill the remaining lands.

Therefore, depending on the agricultural and pasture dynamics worldwide by 2050 there may (or may not) be a remaining land (i.e., freed up land) for additional forest and energy crop expansions. Current data (FAO, 2014) indicate that deforestation tends to continue in the coming years worldwide, not only due to livestock and agricultural expansion, but also because of timber extraction and land tenure issues. If new land becomes available in the future, e.g., because of a reduced need for crop/pasture area, forestry and bioenergy could also be expanded; or, alternatively, the share of remaining land for natural regeneration may increase instead. Figure 9 shows the historic (1980 -2000) and Figure 10 the projected change in global forest cover (2010-2050).

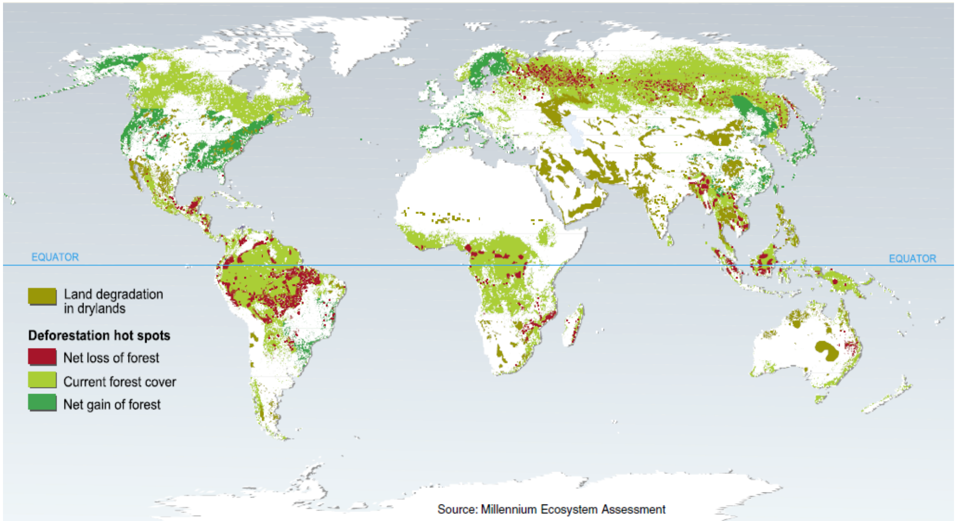


**Figure 9. Forest cover change (1980-2000) (MEA, 2005)**

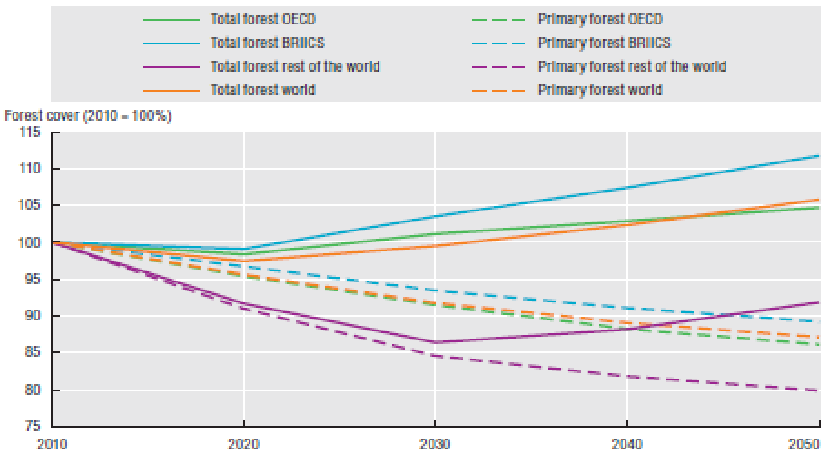


**Figure 10. Projected change in global forest cover (2010-2050) (OECD, 2012)**

Bioenergy currently accounts for about 55 EJ of the world energy mix, which include both traditional and modern biomass, representing a significant renewable energy source for several countries. Countries like Brazil, for example, increased the sugarcane area with peaks of 12% a year in some past-decade years and simultaneously reducing the production costs of both the biomass feedstock and the biofuel (MAPA, 2009; Pacini & Strapasson, 2012). However, this occurred under specific regional circumstances, and such extreme growing rates would be unlikely, and very extreme, see for example the SRREN Report (IPCC, 2011), Slade *et al.* (2011a, 2011b), Shah *et al*. (2013), van Vuuren *et al*. (2009). The current global bioenergy area is about 100 Mha (including for solid and liquid bioenergy), and therefore an analogous expansion of 12 Mha a year would be even more extreme on a global scale, i.e., a kind of theoretical upper limit. Extremes scenarios for bioenergy in the global calculator are in line with the numbers presented by IPCC (Figure 11)

| | Low | High |
|---|---|---|
| Dedicated crops | 25 | 675 |
| Forest & agricultural residues | 40 | 125 |
| Optimal forest harvesting | 25 | 75 |
| Industrial organic residues | 10 | 15 |
| Reduced demand for traditional biomass | 10 | 20 |
| Total | 110 | 910 |

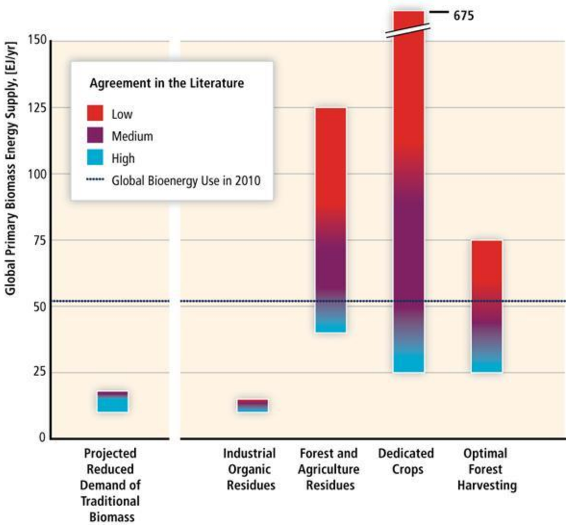


**Figure 11. Range of global estimates of bioenergy potentials (EJ) (IPCC, 2014)**

In contrast, deforestation rates (as net forest loss) in past decades were 0.2% a year maximum (FAO, 2014[11]), which includes massive deforestations observed in Amazon forest, savannah regions and some temperate forests worldwide, although this rate has recently slowed. Therefore, afforestation/reforestation in rates higher than 0.2% a year (i.e., in order to reverse the deforestation rate in the same proportion) would be unrealistic to occur by 2050. However, surplus land may be subject to natural regeneration too. OECD (2012) suggests that the deforestation is likely to continue until 2020, when an expansion in forest cover is forecasted by 2050 (representing 106% of 2010 baseline), due to regeneration, restoration, reforestation and afforestation, including plantations. Similarly, MEA (2005) estimated several scenarios of forest loss and recovery by 2050.

On the other hand, if an extreme increase in global crop/pasture land is necessary to meet potentially high calories and/or meat demands, there may not be any land available by 2050, either for additional forest area or energy crops. Under such circumstances, even further deforestation may occur to meet the food security assumptions set in the calculator.

[11] FAOSTAT includes commercial forest as part of 'forest area'.

### 3.10. Land-use efficiency

This lever presents a novel concept to characterise different land use interactions in the Global Calculator. It was introduced to capture potential land use efficiency gains associated with agro-livestock-forestry schemes (and any combinations of them), dual-cropping (e.g., a summer crop followed by a winter crop in a same year), triple-cropping (e.g., starting with a summer crop, then a second summer crop of short cycle, followed by a winter crop), the use of climate-smart technologies (e.g., no-tillage systems), among other similar positive interactions from land multiuse. Conversely, an overexploitation of land resources due to inappropriate integrations and mismanagement, can lead to land degradation. Generally, land use integration is associated with benefits to the farmers.

Ideally, these integrated management practices would be represented by a larger number of levers to more accurately reflect the complexity of land use change. However, given the underlying structure of the model, the inclusion of additional levers was not feasible, and the lack of comprehensive datasets may not have allowed users to obtain sufficiently robust results. Thus, to simplify this complexity, yet to account for effects of land use integration, this lever presents four levels of land use abatement potentials, i.e., less or more land would be necessary than calculated based on the food (calories & meat consumed, crop & livestock yields) and bioenergy yields alone. In other words, it acts as a deflating factor, like a land bonus (or penalty), depending on the level of effort in agriculture maximisation selected. The descriptions and values listed below were calibrated by experts involved in the global calculator project and literature (FAO, 2013; Langeveld et al., 2013; Byerlee & Deininger, 2013; Cox et al., 2009; Okario, 2006). Table 4 and Table 5 show the magnitude of cropping intensity in selected regions and countries.

**Table 4. Sources of growth in crop production (%) (Alexandratos & Bruinsma, 2012)**

| | Arable land expansion | | Increases in cropping intensity | | Yield increases | |
|---|---|---|---|---|---|---|
| | 1961-2007 | 2005/2007-2050 | 1961-2007 | 2005/2007-2050 | 1961-2007 | 2005/2007-2050 |
| All developing countries | 23 | 21 | 8 | 6 | 70 | 73 |
| Sub-Saharan Africa | 31 | 20 | 31 | 6 | 38 | 74 |
| Near East/North Africa | 17 | 0 | 22 | 20 | 62 | 80 |
| Latin America and the Caribbean | 40 | 40 | 7 | 7 | 53 | 53 |
| South Asia | 6 | 6 | 12 | 2 | 82 | 92 |
| East Asia | 28 | 0 | -6 | 15 | 77 | 85 |
| World | 14 | 10 | 9 | 10 | 77 | 80 |
| *memo items* | | | | | | |
| Developing countries with less than 20 percent of their potentially arable land in use in 2005/2007* | | 35 | | 6 | | 59 |
| Developing countries with over 60 percent of their potentially arable land in use in 2005/2007** | | 4 | | 6 | | 90 |

* 24 countries with a gross land balance exceeding 80 percent of total suitable land in 2005/2007.
** 19 countries with a gross land balance less than 40 percent of total suitable land in 2005/2007.
Source historical estimates: Bruinsma (2011).

**Table 5. Land cover, land use, and multiple cropping indexes (Langeveld et al, 2013)**

| Region | Land area | Forest | Agricultural area | Permanent grassland | Arable area | Multiple Cropping Index (-) |
|---|---|---|---|---|---|---|
| Brazil | 846 | 520 | 273 | 196 | 50 | 0.86 |
| USA | 914 | 304 | 411 | 249 | 160 | 0.82 |
| EU | 418 | 157 | 187 | 68 | 107 | 0.84 |
| Indonesia and Malaysia | 214 | 115 | 62 | 11 | 25 | 1.21 |
| China | 933 | 207 | 519 | 393 | 111 | 1.45 |
| Mozambique | 88 | 39 | 49 | 44 | 5 | 1.08 |
| South Africa | 121 | 9 | 97 | 84 | 13 | 0.53 |

## *3.11. Wastes and residues*

This lever involves three sub-levers: one for the amount of food wasted from production to consumer (post-farm wastes and residues), a second for on-farm residues, and a third for the percentage of waste and residues collected. Each of them has four levels of effort, which were subsequently combined into a single lever, 'Waste and residues'. In addition, two supporting parameters were included: waste from animals, e.g., manure, animal slurry, and tallow, which gives the potential energy production from animal waste; and waste per person, which presents the energy potential from waste treatment, e.g., sewage or landfills. Figure 12 summarises the dynamics of wastes, residues and bioenergy in the Global Calculator.

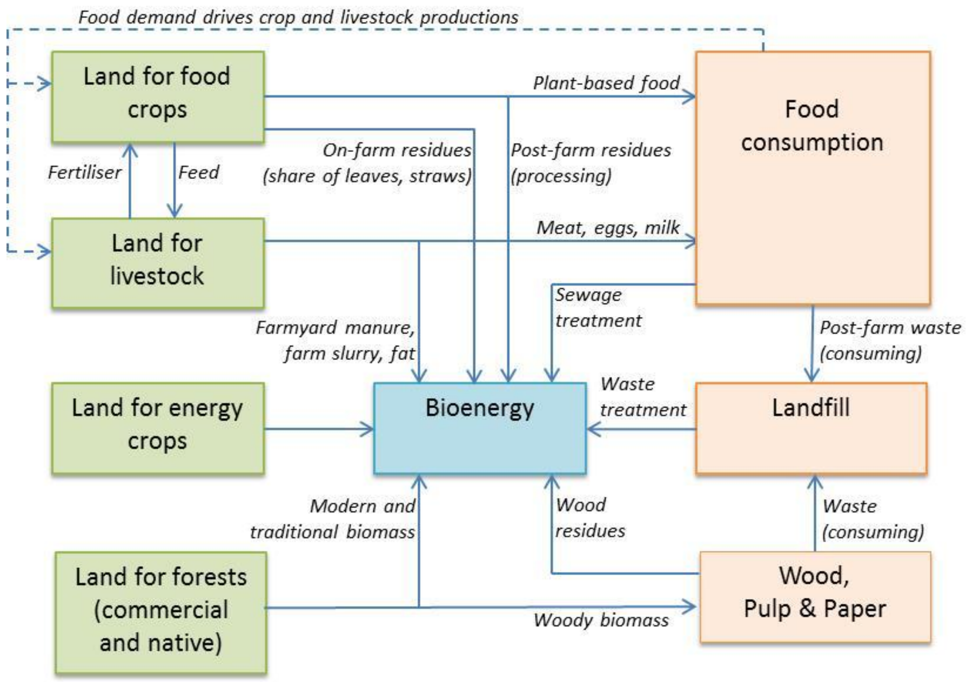


**Figure 12: Balances of bioenergy, wastes and residues in the Global Calculator**

Currently, there is a substantial production of wastes and residues worldwide, but collection rates remain still low worldwide. The post-farm waste production ranges around 30-40% out of the total food production, eventually reaching landfill/dump sites (Modak, 2011; Partiff et. al., 2010; Foresight, 2011; Themelis, 2014). Figure 13 and Figure 14 show the quantities and composition of municipal solid waste (MSW) generated by country and GDP, respectively.


Figure 13. Per capita municipal solid waste by country (UNEP, 2011)

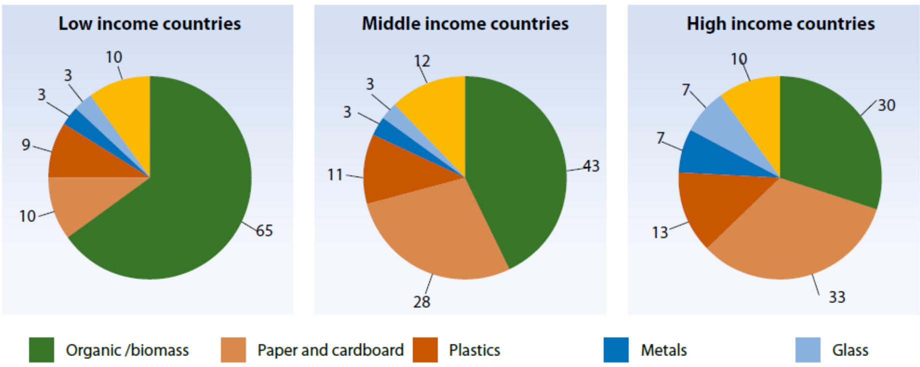


Figure 14. Composition of Municipal Solid Waste by national income (UNEP, 2011)

In contrast, on-farm residues equate approximately 100% of the total food amount produced, i.e., on average for each tonne of food that leaves the farm, another tonne remains within the farm as straws, leaves, roots etc. Rosillo-Calle et al. (2007), for example, listed a number of production efficiencies (t/t), moisture and energy contents regarding agricultural residues from several crops (Table 6). In the calculator, a part of the collected wastes is allocated for feeding the livestock under different levels of effort and per type of animal, as well as bioenergy. The collection of wastes and residues also includes a partial collection of sewage and animal slurry for energy purposes (biogas), as a sub-lever of this lever, but under different proportions and magnitudes.

Table 6. Crop residues production coefficients (Rosillo-Calle *et al.*, 2007)

| Crop | Production coefficients | | Energy content | |
|---|---|---|---|---|
| | t/t | Moisture | GJ/t | Moisture |
| Cereals | **1.3** | Air dry | 12 | Air dry |
| Vegetables and melons | **1.0** | Air dry | 6 | Air dry |
| Roots and tubers | **0.4** | Air dry | 6 | Air dry |
| Sugar beet | **0.3** | Air dry | 6 | Air dry |
| Sugar cane | **0.6** | 50% | 16 | Air dry |

## 4. Final comments

Energy calculations are based on data from energy consumption and production from food, livestock and bioenergy, energy conversion efficiencies, the land use distributions and also consider wastes/residues. The emissions are estimated based on the respective emission factors from food, meat and bioenergy production, and the associated land use allocations, by type of greenhouse gas, based on FAO (2014) and IPCC AR4 WGIII (Barker et al., 2007) data. Thus, it is possible to estimate the emissions by type of land and greenhouse gas. The gases considered in the calculations are $CO_2$, $N_2O$ and $CH_4$, which represent the main gases related to land use, land use change and forestry (LULUCF). As for forests, deforestation results in $CO_2$ emissions, whilst afforestation/reforestation means net $CO_2$ sequestration from the atmosphere through photosynthesis, particularly during the forest establishment stage. Mature forests act as carbon sinks. Temporal variations were considered in the forest recovery, as well as for soil carbon dynamics from land use change (see more in Strapasson, 2014).

With regard to bioenergy emissions, IPCC accounts for bioenergy emissions indirectly. Thus, bioenergy is considered relatively carbon neutral as a renewable source, given the growing biomass captures equivalent levels of $CO_2$, which are released back to the atmosphere upon combustion. However, there are several emissions associated with the production of biofuels, which are indirectly accounted for in the global GHG assessments (e.g., transport, industrial sectors). Therefore, despite some fossil fuel inputs usually required in the bioenergy production, distribution and consumption chain, these are accounted for elsewhere. The same approach has been applied in the Global Calculator through the strong interconnection of levers across all sectors. Thus, e.g., the emissions from the bioenergy combustion are measured by different end use sectors in the Global Calculator. Therefore, the calculator generates a $CO_2$ credit from bioenergy, which are then consumed by different sectors, e.g., transport (liquid fuels), heating and power (buildings, manufacturing and electricity sectors). Part of the bioenergy can be also allocated for GGR, for example, for Bioenergy with Carbon Capture and Storage (BECCS). Substantial afforestation/reforestation is also considered in the GGR calculations, along with some speculative technologies, e.g., biochar, ocean fertilisation, enhanced weathering (terrestrial and oceanic) and direct air capture.

The calculator also presents a methodology for costs, which is focused on the energy systems involved in the estimates. Thus, the fuel costs and the CAPEX/OPEX regarding bioenergy were estimated based on the Imperial College report "Halving Global $CO_2$ Emissions by 2050: Technologies and Costs" (Shah *et al.*, 2012) and the UCL TIAM model. Furthermore, the calculator also offers a range of cost estimates according to the user's choices, with ranges of high, low and midpoints, which can be useful for discussing the feasibility of different carbon reduction strategies.

Finally, the global calculator is a work in process and, therefore, the methodology here discussed and the calibration of all lever's levels are subject to further updates and improvements, whenever necessary, in order to keep the model as much accurate as possible, in a simple and user-friendly manner.

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