Assessment of global land availability: land supply for agriculture

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FOOD AND NUTRITION SECURITY

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Abstract

We developed a new assessment method of the land supply for agriculture, on a grid scale basis and per region, which takes into account both biophysical, institutional and socio-economic parameters of land availability and suitability for conversion into agricultural production. In many world regions most of the available and suitable land has already been included in agricultural production. Our assessment focuses on the issue of remaining (i.e. potentially available and suitable) agricultural land per region. We first estimated the total available and biophysically suitable land by excluding areas with certain biophysical restrictions (i.e. marginally productive areas, permafrost, steep slopes, wetlands, built-up area). Secondly, we applied institutional parameters of land suitability to exclude protected areas and – in some regions – also intact forests. Thirdly, we used a suitability index to define the potentially available land that is also suitable for conversion to agricultural production from a socio-economic perspective. Subsequently, we subtracted the current agricultural land from the total available and suitable land to derive the remaining (i.e. potentially available and suitable) land per region. As well, we provided the information on the quality and suitability of the available land, based on classes of crop productivity. We also discuss the distribution of global grasslands, in both intensive and extensive agricultural systems, and the effects of this distribution on potentially available land per region.

Our results are applicable for global change analysis and modelling. Accurate estimation of agricultural land currently in use influences the possible impact on regional land use change and associated land use emissions from implementation of land-based mitigation schemes, such as REDD, or other policies (e.g. RED).

Keywords: global land reserve, agricultural area, biophysical and institutional availability parameters

JEL codes: Q24, Q15, O13

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This paper is work in progress; comments are welcome. The authors only are responsible for any omissions or deficiencies.

1. Introduction

The quality and availability of land and water resources, together with important socio-economic and institutional factors, is essential for food security (FAO/IIASA 2012). Increase in global population and GDP drives a growing demand for food, feed and fiber (Bruinsma 2011; Alexandratos and Bruinsma 2012). The extra production needs will be achieved either through land expansion or intensification of existing agricultural land, and will largely depend on the amount of land that is available and suitable for cultivation (Lotze-Campen et al. 2010; Wirsenius et al. 2010; Lambin and Meyfroidt 2011; Alexandratos and Bruinsma 2012; Lambin 2012; Prieler et al. 2013; Eitelberg et al. 2014). At the same time, the perception of approaching the limit in available productive land is growing, highlighting the need for improved information on land availability (Campbell et al. 2008; Lambin et al. 2013; Eitelberg et al. 2014).

In the recent literature on global land availability different definitions of available and suitable agricultural land are found. Lambin et al. (2013) define potentially available cropland (PAC) (sometimes referred to as land reserve, underutilized, or spare land) as the moderately to highly productive land that could be used in the coming years for rainfed farming, with low to moderate capital investments, and that is neither under intensive use, legally protected, nor under intact mature forest cover. This definition excludes areas that could only be put into cultivation with major investments – e.g. irrigation or costly soil reclamation – and for which the ecological cost of conversion in terms of biodiversity and carbon storage is known to be very high – i.e. protected areas and intact or little disturbed forests. Among other criteria found in the literature, (e.g. Van Asselen en Verburg (2013)), which define areas to be excluded from potential agricultural use, are: (i) 'very severe constraints' regarding salt excess, nutrient retention capacity, oxygen availability, rooting conditions or toxicities; (ii) a median slope greater than 45 degrees, (iii) a length of growing period less than 45 days on lands lacking irrigation (irrigation area less than 1%, (from Siebert et al., 2006)); and (iv) classified as urban land system.

Estimates on land availability in the literature are highly variable and debated, given the various constraints beyond biophysical suitability (Fritz et al. 2012). Besides biophysical parameters, social, political (administrative) and economic factors largely define whether land is potentially suitable for the agricultural use. One can think here of security and land tenure issues, institutional arrangements, transaction costs for land conversion, land accessibility, etc. (Lambin et al. 2013).

Current agricultural land plus the potentially available cropland are often referred to as agricultural land supply. Some of the uncertainty in assessing land availability arise from the uncertainty in land cover products, and due to different assumption used. Data quality issues further complicate an accurate analysis of land availability: i.e. in many existing global land cover datasets one grid cell represents one land cover type, whereas in reality, cells often represent mosaics of different land cover/land use types. Ignoring the heterogeneity of the land cover may lead to an under-or overestimation of the actual coverage of specific land covers (Verburg et al. 2011; van Asselen and Verburg 2012). This issue is especially relevant for the agricultural land, which is characterized by a large heterogeneity of different elements: hedgerows, roads, and other infrastructural elements; grassland and cropland of different intensity levels; wetlands. Letourneau et al. (2012) showed that heterogeneity of agricultural landscapes, including marginal land cover/land use types, often neglected in global impact assessments, is an important factor of land use to be considered in land-use change modelling.

The global availability and quality of land resources can be reflected by the land's suitability and productivity for the cultivation of major agricultural crops (Fischer et al. 2011). Recently the most complete global assessment of potentially available and suitable agricultural land has been performed by IIASA/FAO (2012). The results comprise spatially detailed, quantified potentials for individual crops and quality of land resources. The assessments account for population density, land requirements and feasibility of land conversion for agricultural production and market access. It excludes land from conversion if it is protected for the following reasons: environmental, biodiversity and nature value.

The global land availability assessment requires accurate estimation of agricultural land already in use and the remaining potentially available area for agricultural production. The aim of this research is to assess land supply for agriculture, which takes into account biophysical, institutional and socio-economic parameters of land suitability and the quality and suitability of agricultural land already in use (current agricultural land). Past estimates of PAC have adopted one of the two approaches (Lambin et al. 2013): ‘‘residual approach’’– i.e. estimating the total area that is agro-ecologically suitable and then excluding cultivated areas and, in some cases, intact forests, protected areas and densely populated areas (Ramankutty et al. 2002; IIASA/FAO 2012); and ‘‘categorical approach’’ – i.e. identifying specific categories of land use/cover that could be converted to croplands (Campbell et al. 2008; Cai et al. 2010). In this study we aim at estimation of total and potentially available area for agriculture by a “residual” approach.

We developed a new assessment of the land supply for agriculture, on a grid scale basis and per region. We built a database of map-products (i.e. thematic layers), which are combined in this assessment by partially excluding grid cells with certain characteristics.

Our results are applicable for global change analysis and modelling. Compared to the recent most complete assessment of land suitability by (IIASA/FAO 2012) the proposed method has the following novelty aspect. Here we provide the results on how much of the available land has already been in use for agricultural production and whether the current agricultural area fully comply with the criteria used to define the potentially available cropland. We assess land availability and suitability for agricultural production with emphasis on crop productivity versus other biophysical, institutional and socio-economic parameters. We also discuss the distribution of global grasslands in both intensive and extensive agricultural systems, and the effects of this distribution on potentially available land per region.

Similarly to the assessment of IIASA/FAO (2012) we produced ready-to-use maps and land use statistics for global change analysis and modelling at global and regional levels.

2. Method

2.1 General

This study follows the residual approach to estimate global land reserve. We first estimated the total available and biophysically suitable land by excluding areas with certain biophysical restrictions (i.e. marginally productive areas, permafrost, steep slopes, wetlands, built-up area). Secondly, we applied institutional parameters of land suitability to exclude protected areas and –in some regions– also intact forests. Thirdly, we used a suitability index to define the potentially available land that is also suitable for conversion to agricultural production from the socio-economic perspective. Subsequently, we subtracted the current agricultural land from the total available and suitable land to derive the remaining (i.e. potentially available) land per region (see Figure 1 for an illustration).

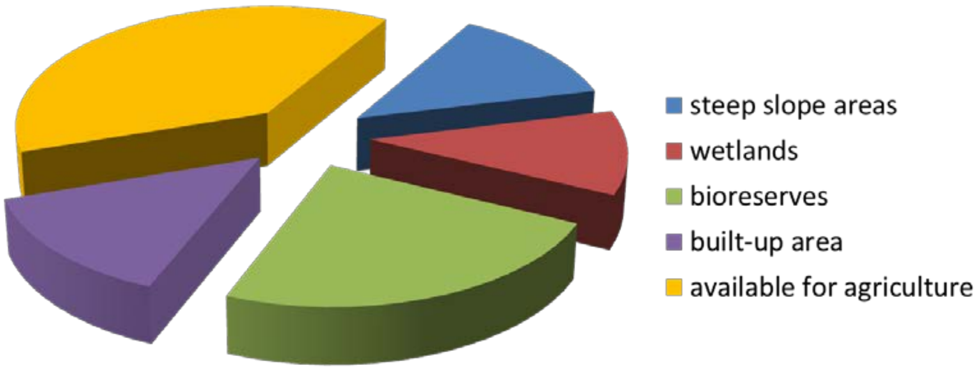

Figure 1 – Schematic representation of fractions within a grid cell according to the datasets used in the assessment.
Please note that overlap between the various categories is possible.

2.2 Datasets

The analysis is done on a grid basis and uses information from several global datasets (Table 1):

Table 1 – Datasets used in the study

Dataset	Source	Reference	Resolution	Unit
land area	IMAGE 3.0	Stehfest et al. (2014)	5 arcmin	Km^2
slopes	GAEZ	IIASA/FAO (2012)	30 arcsec	percentage classes
wetlands	GLWD	Lehner and Döll (2004)	30 arcsec	Category (1-12)
permafrost	GAEZ	IIASA/FAO (2012)	5 arcmin	Km^2
built-up area	HYDE 3.1	Klein Goldewijk et al. (2011)	5 arcmin	Km^2
bioreserves[1]	WDPA	UNEP-WCMC (2005)	5 arcmin	Km^2
cropland and grassland	HYDE 3.1	Klein Goldewijk et al. (2011)	5 arcmin	Km^2
potential (rainfed) crop yield	IMAGE 3.0	Stehfest et al. (2014)	5 arcmin	Index (0-1)

[1]for regions Japan and Korea forest is included in bioreserves

2.3 Total available and suitable land

To estimate total available and suitable land we first excluded areas with certain biophysical restrictions for agricultural production: marginally productive areas (1); permafrost (2); steep slopes (3); wetlands (4); built-up area (5). We also excluded bioreserves (protected areas) (6), where no agricultural activities are allowed under a special status of the areas. Due to the different types of data sources, either entire grid cells with certain institutional or biophysical restrictions (case of permafrost and marginally productive areas) or parts of a grid cell (slopes, wetlands, bioreserves, built-up area) are excluded. For slopes and wetlands we first calculated fractions per grid cell at 5 arcmin since these data were originally available at a finer resolution (30 arcsec).

1) Marginally productive areas

Marginally productive areas have been estimated based on the index of relative potential rainfed crop productivity, which relates the crop productivity in a grid cell to the global average crop productivity. The index varies between 0 and 1, and is available for eight IMAGE crop groups. We calculated an average index value from the three most productive crops per grid cell. We excluded grid cells with the index value below a threshold of 0.1. Crop productivity is a very uncertain parameter in the availability and suitability assessment, as there is not always a direct link between this parameter and the distribution of current agricultural land. We chose 0.1 for the standard assessment, as e.g. with a 0.3 suitability threshold, 40% of Chinese agricultural land would have to be excluded from the land supply.

2) Permafrost

All grid cells located in areas with continuous permafrost are have been excluded from the available area, as they are considered unsuitable to sustain agriculture.

3) Steep slope areas

Per grid cell we excluded the areas with slopes larger than 45%. Comparing current agricultural area and slope maps shows that most current agricultural land is in areas with slopes less than 45%. In developed countries areas with slopes larger than 30% were also excluded as they are considered unsuitable for industrialized agriculture.

4) Wetlands

We made different assumptions on availability of grid cells with wetlands for (potential) agricultural use based on the type of wetland. If a large part of a grid cell is wetland, then the entire cell is regarded unavailable, as it is probably not worthwhile developing agriculture in such an area (infrastructure investment etc.). Therefore we excluded grid cells with fractions of wetlands 0.5-1.0. For grid cells with 0.25-0.50 fraction wetlands, the mean of the class (0.38) is assumed to be wetland. Consequently this grid cell fraction was extracted from the available area of a grid cell. For the grid cells within wetland category “lakes” we applied a fractional threshold of less than 0.1 and an extra criterion of more than two lakes per grid cell for a grid cell to be entirely excluded from the globally available land for agriculture. Fractions of “bogs and fens” were also excluded from the grid cells under wetlands.

5) Built-up area

We excluded fractions of built-up area per cell potentially available for agriculture.

6) Bioreserves

Finally, we excluded grid cell fractions of protected areas with highly protected status. In case of bioreserves we applied an institutional rather than a biophysical constraint, since most of the protected areas are biophysically suitable for crop production. We treat bioreserves with highly protected status as not available for agriculture. In regions Japan and Korea all forest has a protected status and is therefore excluded from the land reserve.

As a result of our analysis we obtained fractions of grid cells representing areas with neither biophysical nor institutional restrictions to crop production, referred to as total available land per grid cell. We summed those fractions per grid cell within the region for those cells where rest fraction was larger than zero. Thus we implicitly overestimate the total available land.

Subsequently, we applied a 15% reduction in area to the estimates of total available land per grid cell to account for cell fractions that cannot be used for crop cultivation. Studies have shown that cropland estimates based on raster cells often overestimate the true amount of cropland because they do not account for infrastructure, settlements, and other areas that are unsuitable for crops at the subpixel level (Young 1999; Fritz et al. 2012; Eitelberg et al. 2014).

We used the following land productivity classes in our assessment to represent the quality of the total available land: low (0.1-0.2); medium (0.2-0.3); high (0.3-0.4); very high (>0.4). The classes are based on the index value that refers to the potential rainfed crop yield per grid cell (see also Table 1).

2.4 Socio-economic determinants of available and suitable land

The estimated total available land as calculated in section 2.3 is based on biophysical and institutional parameters exclusively. However, land might not always be attractive or feasible for conversion from a socio-economic perspective, due to, for example, an additional cost when the areas are situated remotely from the current agricultural area (Lambin et al. 2013). Doelman and Stehfest (in preparation, see section 4.2.3 in Stehfest et al. 2014) developed a suitability index that captures four different determinants for allocation of potential future agricultural land use on a grid cell level:

1. potential yield which covers effects of climate and soil (IMAGE model);
2. terrain slope index (IIASA and FAO, 2012) based on SRTM elevation data (Shuttle Radar Topography Mission) from NASA;
3. population density (Klein Goldewijk et al. 2010);
4. accessibility index from JRC (Nelson 2008), which is defined as minutes travel time to major cities (>50,000 inhabitants)

These four independent variables were used in multiple linear regression analysis to investigate the relationship between these land-use determinants and the current land use per region (fractions of crop and grassland in 2005 from (Klein Goldewijk et al. 2011). Based on the logarithmic relationship found for all independent variables except for potential crop yield, where the relation was linear, the suitability index was calculated.

We used the suitability index to define whether estimated potentially available and suitable land would be also suitable for conversion to agricultural production from a socio-economic perspective. We assumed that the current agricultural area is situated on the suitable land, as defined by the suitability index. We selected areas within total available land per region, with the value of suitability index, where 90% of current agricultural land in the region belongs to. It is implied here that the area that has not yet been converted into agricultural production should have comparable suitability index values as to the current agricultural land in the region, thus indicating its likelihood and socio-economic attractiveness for the conversion. By using the suitability index we improved the accuracy for estimation of potentially available and suitable land for agricultural production.

2.5 Current agricultural land

Following the residual approach, the estimated total available and suitable land includes the agricultural land already in use and the remaining potentially available area for agricultural production. Therefore, an accurate estimation of the current agricultural area is an important methodological step necessary to assess how much of the total available land has not yet been converted for agricultural production.

The current agricultural area in our assessment was represented by a grid-cell specific allocation of crop and grass harvested area from the HYDE 3.1 dataset (Klein Goldewijk et al. 2011). We assumed that the grid fractions with either HYDE crops or grass comprise the current agricultural area. We applied an additional constraint for grassland, namely a productivity threshold, assuming that all marginally productive grassland areas with productivity below 0.1 value index of potential crop productivity should be excluded from current agricultural area. We subtracted grid fractions representing cropland and grassland from the fractions of total available land to estimate the remaining potentially available land.

The amount of land currently used to satisfy the demand for land-based resources has increased to occupy much of the most productive lands as well as many areas where agricultural production would normally be restricted by biophysical, institutional or socio-economic factors. As a result, current agricultural land is also situated in the areas beyond the availability and suitability parameters, described in sections 2.3 and 2.4. An example is agricultural land on very steep slopes in China (>45%). Next to this, HYDE 3.1 dataset did not account for fractions of wetlands or bioreserves when allocating (sub-) national FAO crop area statistics to grid cells.

3. Results

The results of the analysis are provided in Tables 2 and 3 and Figures 2 - 4.
We estimate the total of 53.093.114 km^2 (5309 Mha) to be available for agricultural production globally (Table 2). This includes land currently used for crop production and land that is potentially available for crop production if converted from its current state. The largest available and suitable land is found in Western Africa, USA, Southern Africa,

Brazil, Rest South America, and China (Table 2). In terms of the quality of the total available land, defined by the potential crop productivity, the largest reserves of best suited lands for crop production (very high productivity class) are based in the USA and Russia. In many regions (e.g. Middle East Asia, Oceania, Northern Africa, Brazil) a substantial part of the total available land - between 30 and 65% - is represented by land with a low crop productivity, which impedes efficient agricultural production (Figure 2). The regions with a high share of very productive lands are Ukraine, Central Asia (Asia-Stan region), Russia, USA and Canada (Figure 3).

Estimated total available and suitable land has already been included in agricultural production to a different extent, per region (Figure 4 and Table 3). In Northern Africa, Central Asia (Asia-Stan region) and Japan (almost) all available land is already in use for agricultural production, whereas in Indonesia, South-East Asia, Western Africa, Brazil, Rest South America, Canada and Russia there is still a large land reserve. The share of current agricultural land situated in the area beyond our availability and suitability parameters is around 10% in all regions (column 2 in Table 3). In regions Japan and Canada this share is more substantial (i.e. exceeds 20% of current agricultural land in the region), due to steep slopes (case of Japan) and wetlands (case of Canada).

Combining the results on total available and suitable land and on areas already included in agricultural production, we can conclude that expansion of agricultural area can still potentially occur on a large scale in South-East Asia, Indonesia, Western Africa, Canada and Russia. The majority of land in those regions is not yet converted into agricultural production and belongs to the moderate and high productive classes. In Brazil the available area is of low and moderate productivity, which can potentially impede the land expansion in the region. In other world regions the future increase in agricultural production can be expected mostly through intensification, since major part of the available and suitable land has already been converted into agricultural land.

Table 2 – Total available land per class of crop productivity (in km^2 and as a percentage of total available and suitable land)

Regions	Total available land – Classes of crop productivity: low		moderate		high		very high		Total
	0.1-0.2	%	0.2-0.3	%	0.3-0.4	%	> 0.4	%	
Canada	21.853	2	267.914	23	427.708	37	444.255	38	1.161.729
USA	218.978	4	649.847	13	1.474.822	30	2.615.059	53	4.958.705
Mexico	139.823	12	259.401	22	525.171	45	254.020	22	1.178.415
Rest Central America	1.586	0	45.712	10	296.768	62	136.171	28	480.237
Brazil	1.374.582	32	2.087.484	49	774.834	18	61.698	1	4.298.598
Rest South America	461.102	11	1.760.227	40	1.303.849	30	863.468	20	4.388.646
Northern Africa	231.739	34	247.456	36	182.640	27	25.759	4	687.594
Western Africa	1.089.246	20	3.138.743	57	1.185.285	21	110.587	2	5.523.861
Eastern Africa	568.518	17	1.640.183	50	757.782	23	333.805	10	3.300.289
Southern Africa	595.771	13	2.370.587	52	1.188.569	26	366.579	8	4.521.506
OECD Europe	91.958	4	629.801	31	963.182	47	363.986	18	2.048.928
Eastern Europe	33.202	3	119.507	12	549.461	55	296.880	30	999.051
Turkey	146.359	24	156.106	26	196.454	32	112.910	18	611.829
Ukraine region	496	0	7.478	1	96.071	14	567.170	84	671.215
Asia-Stan	272.974	21	161.027	13	196.888	15	639.622	50	1.270.511
Russia region	129.150	4	395.845	11	1.258.225	36	1.743.593	49	3.526.813
Middle East Asia	370.832	67	143.917	26	32.659	6	5.318	1	552.726
India region	214.482	8	465.854	17	1.443.305	53	601.751	22	2.725.392
Korea	10.426	14	24.772	33	22.344	30	17.088	23	74.630
China region	874.360	21	1.334.793	32	1.822.161	43	188.561	4	4.219.875
South East Asia	51.110	3	725.477	47	760.260	49	7.930	1	1.544.777
Indonesia region	132.291	9	688.872	49	556.206	39	42.100	3	1.419.469
Japan	7.212	14	14.086	28	25.384	50	3.788	8	50.469
Oceania	1.108.938	39	1.013.541	35	507.920	18	247.449	9	2.877.848
Total	8.146.987	15	18.348.632	35	16.547.947	31	10.049.548	19	53.093.114

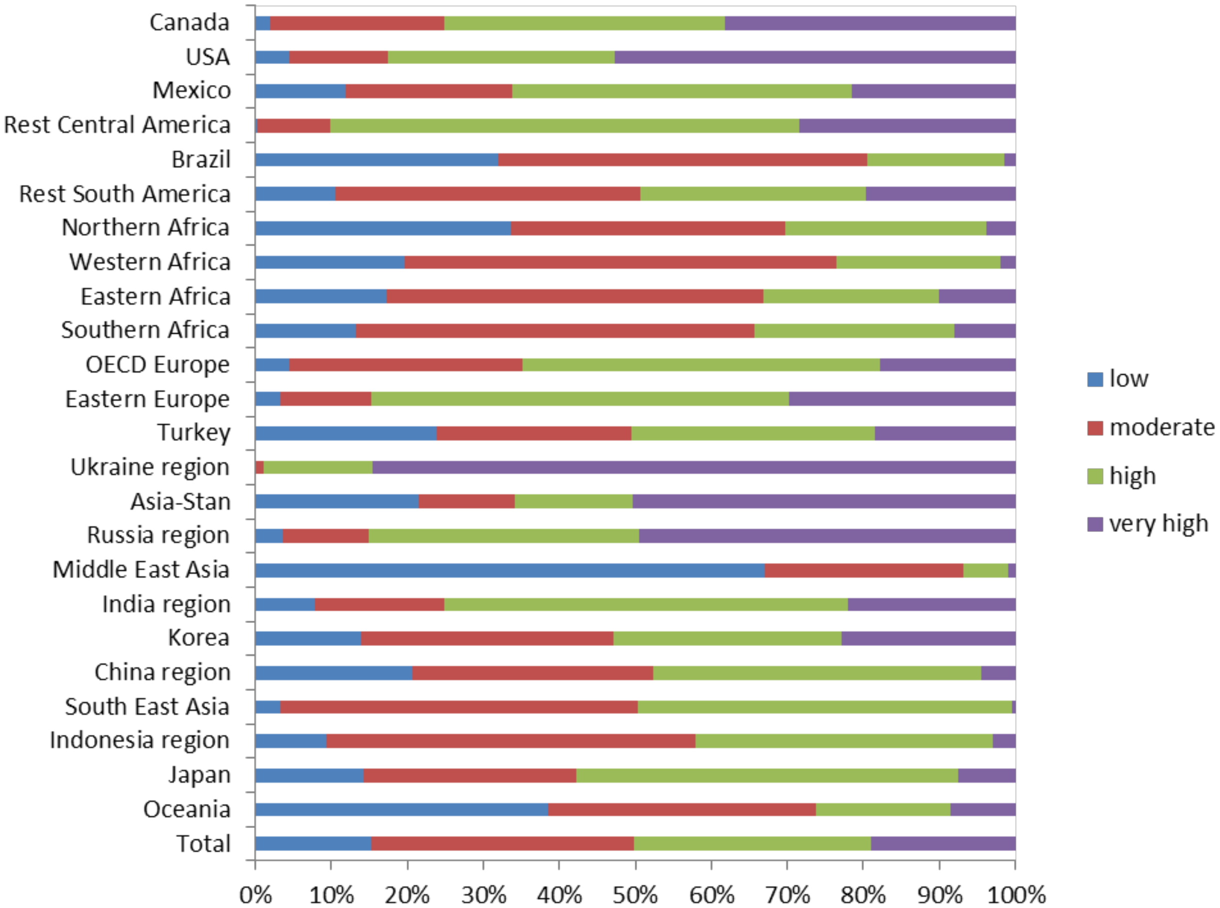

Figure 2 - Total available land per class of crop productivity (as a percentage of total available land

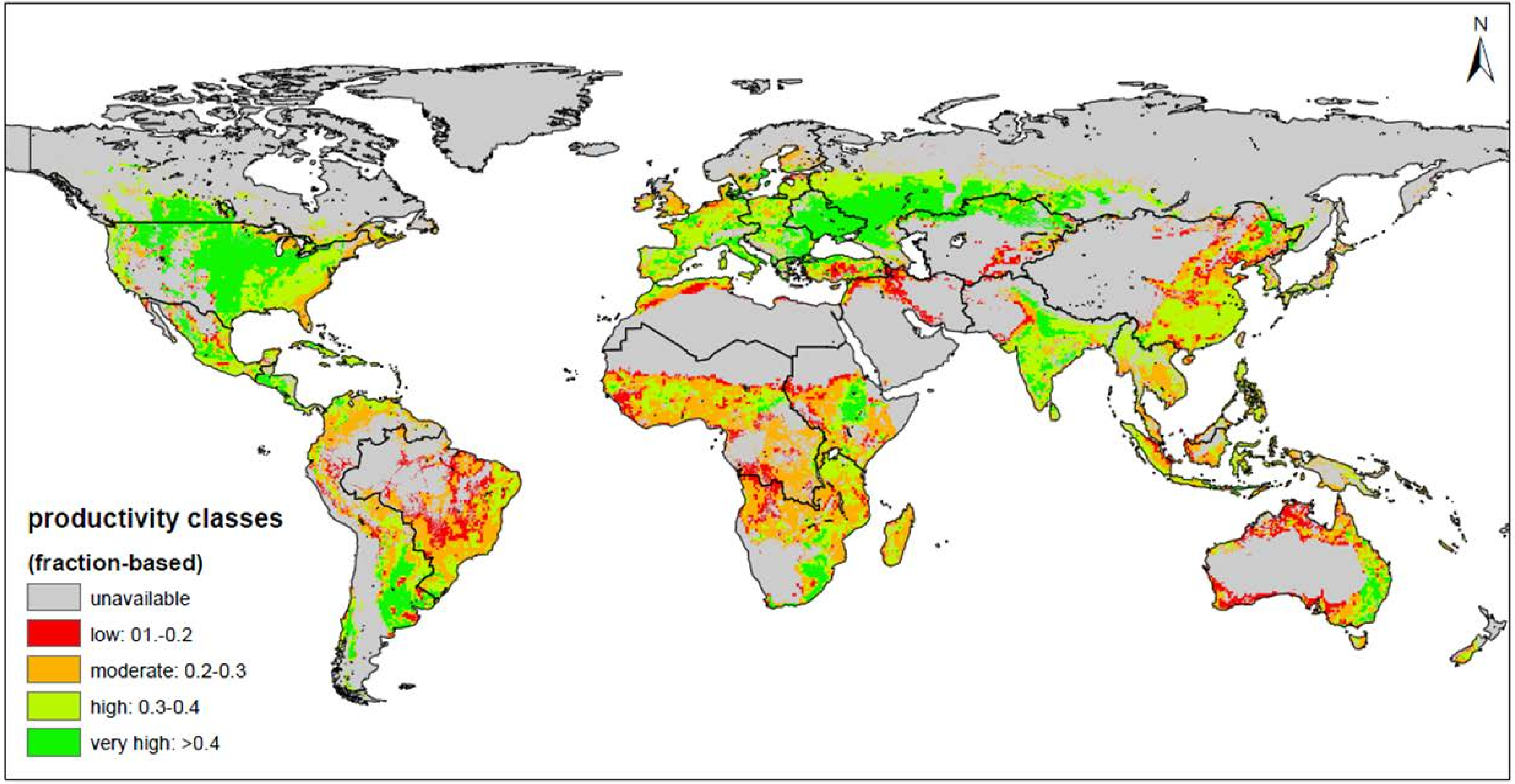

Figure 3 – Productivity classes of total available land. The classes are defined by the index value that refers to the potential rainfed crop yield per grid cell

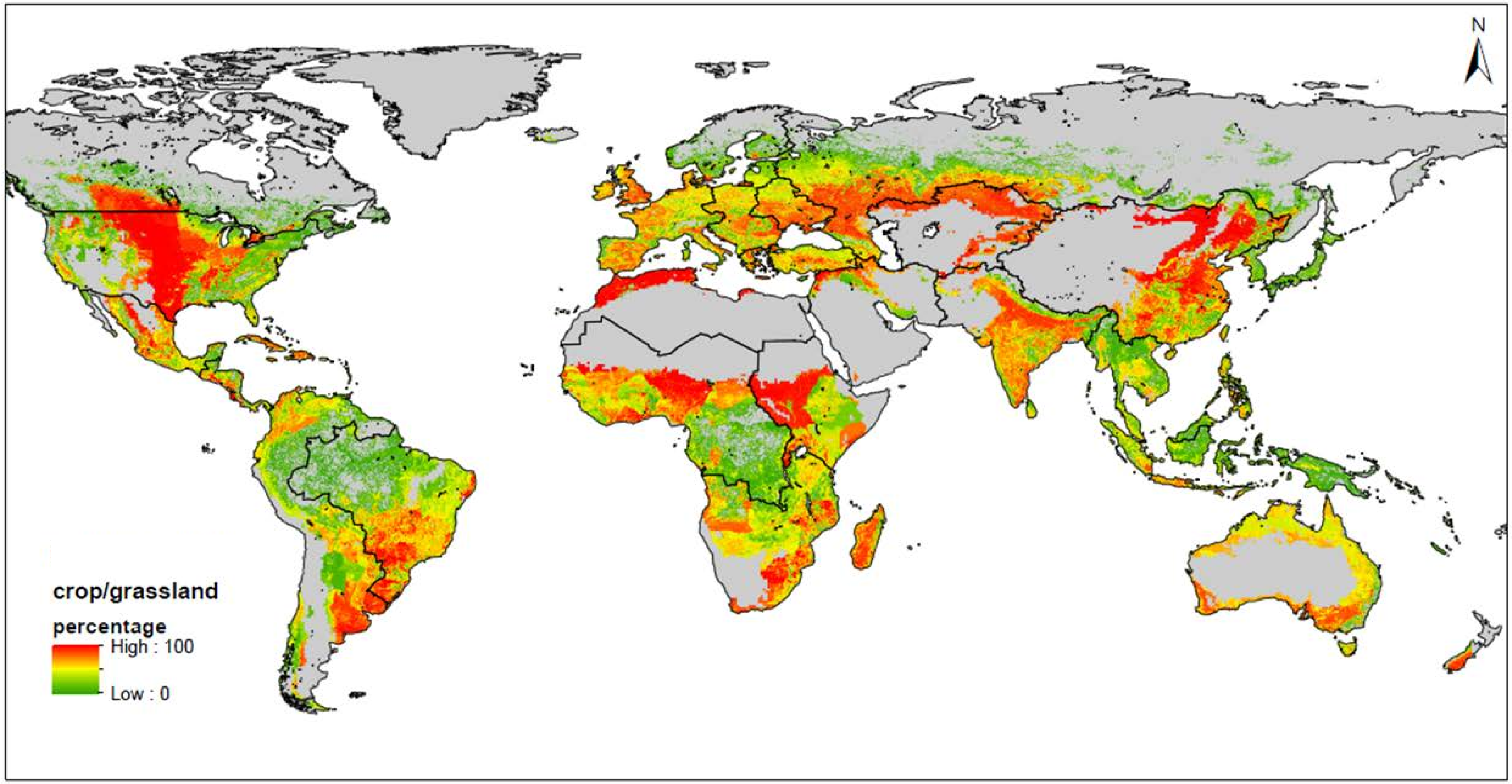

Figure 4 – Fractions of crops and grassland per grid cell (current agricultural land; HYDE 3.1)

Table 3 – Percentage of total available and suitable land already in use, total current agricultural land, and percentage of current agricultural land situated in areas which are estimated as not being available or suitable

Regions	Current agricultural land		
	Current agricultural land located at unavailable or unsuitable areas [%]	Current agricultural land area, [km^2]	share of current agricultural land in total available and suitable land [%]
Canada	21	673.961	58
USA	15	3.634.462	73
Mexico	10	787.589	67
Rest Central America	11	325.809	68
Brazil	7	2.533.921	59
Rest South America	9	2.502.389	57
Northern Africa	19	650.487	95
Western Africa	8	3.134.424	57
Eastern Africa	12	2.536.328	77
Southern Africa	10	2.711.564	60
OECD Europe	9	1.388.428	68
Eastern Europe	8	667.212	67
Turkey	7	407.127	67
Ukraine region	9	526.495	78
Asia-Stan	12	1.179.747	93
Russia region	7	2.141.801	61
Middle East Asia	10	399.069	72
India region	9	2.128.998	78
Korea	10	46.845	63
China region	15	3.351.039	79
South East Asia	5	648.378	42
Indonesia region	5	491.592	35
Japan	43	50.469	100
Oceania	12	1.986.389	69
TOTAL	16	34.904.526	66

4.Discussion

In this paper we assess total area available and suitable for agricultural use, and estimate the area still available for agricultural expansion. In this assessment, we subsequently addressed the following issues:

1. Estimation of total available and suitable land for agricultural production, based on three sets of availability and suitability parameters:
    a) Biophysical
    b) Institutional
    c) Socio-economic
2. Estimation of current agricultural land, including land beyond availability and suitability parameters

3. Estimation of rest suitable and available land, potentially available for conversion into agricultural production

In each of the steps we had to deal with uncertainties arising from the assumptions made in the method and - in some cases - with inconsistencies of the data sources.

Total available and suitable land

We compared our results on total available land for agriculture with the suitable areas as provided in the assessment of FAO-GAEZ (2012). Land supply estimates from FAO-GAEZ (2012) have been used for global integrated assessment modelling, including those performed by the modelling framework of GLOBIOM (e.g. Havlik et al. 2011). Since GAEZ land suitability statistics are either available per individual crop or per management level, the comparison could not have been performed in absolute terms. We chose winter wheat (intermediate input level, rain-fed) to have a first impression of how close our results are to the estimates from FAO-GAEZ. Naturally, those comparisons are only relevant for the regions, where areal of winter wheat strongly corresponds to the total suitable area. For regions Asia-Stan, Eastern Europe and USA our estimations are 2 to 5 % less area than those of FAO-GAEZ. For OECD Europe we exceed the FAO-GAEZ estimations of suitable land by 10%. The only large deviation is in Canada, where we estimate 82% less area available for agricultural production based on suitability for winter wheat cultivation. The land supply assessment method of FAO-GAEZ (2012) largely depends on where you put a threshold on the management level, especially for marginally suitable lands. It is therefore almost impossible to make an absolute estimation of potentially available land per region, given a large uncertainty on the requirements and definition of a management level threshold.

According to the range of results on potentially available cropland reported in a recent review paper of Eitelberg et al. (2014), we produced the highest estimates of total available land for agriculture (exceeding the previous highest reported result of Havlik et al. (2011) by 3%). Since Havlik at al. (2011) focused on potentially available land for cultivation of short rotation tree plantations (biofuels), they used the thresholds of tree growth for estimation of area potentials for biomass plantations and therefore underestimated potentially available land for crop production.

Studies that estimated global land reserve according to the categorical approach (Campbell et al. 2008; Cai et al. 2010), focused on particular land use and land cover categories, i.e. forest and grassland, without checking where the forest or grassland is located. In this research, we added the availability and suitability parameters –

biophysical, socio-economic and institutional – and therefore we produced more accurate estimates of the total land reserve.

Current agricultural land

Our results on current agricultural land already in use are sensitive to the assumption to exclude marginal grassland areas from the land reserve. If we had included marginal grasslands as part of current agricultural area, we would have obtained a larger land reserve in some regions, e.g. China (see Appendix 1). This, in turn, would also influence the land supply as provided by the IMAGE model to MAGNET model (Figure 5).

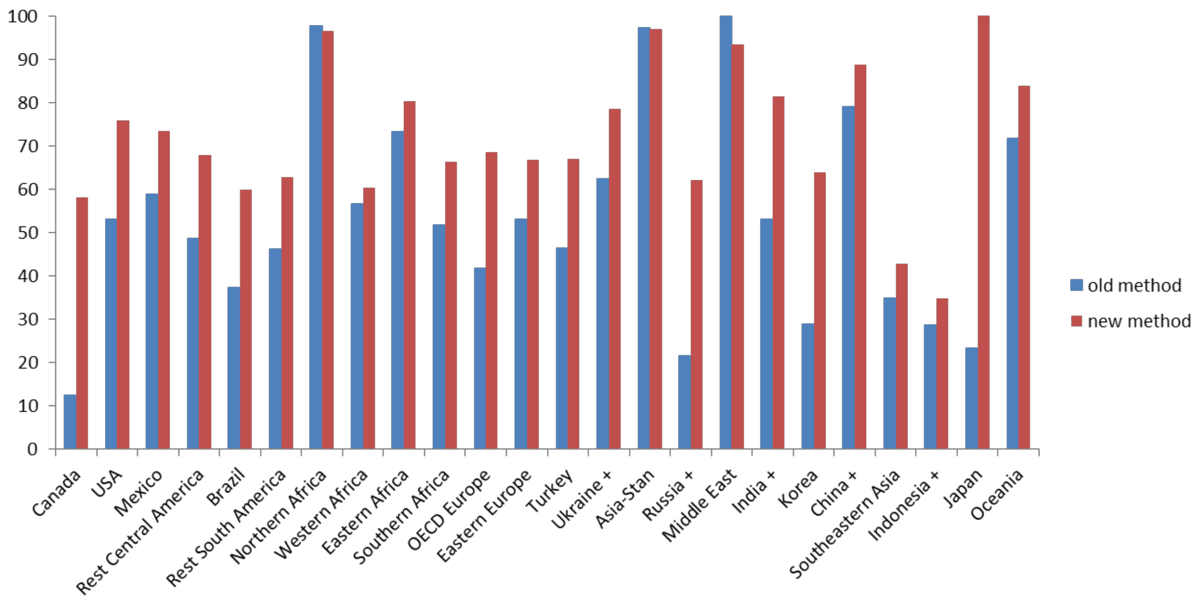

Figure 5 – Revised estimates of the share of land supply already in use

Note: Share of land supply already in use according to the method applied in IMAGE 2.4 (Bouwman et al. 2006), and the new method presented here, for IMAGE 3.0 (Stehfest et al. 2014). Mostly as a result of the improved estimation of total available and suitable agricultural area (the land supply), the percentage of the land supply already in use has changed.

Until 2013 the land supply as provided by the IMAGE model (IMAGE 2.4, Bouwman et al. 2006) generally resulted in underestimation of available land for agricultural production in several regions, especially in Canada and Russia (Figure 5). In Japan and Korea, in contrast, the institutional aspect of protected forests had not been taken into account previously. Therefore, almost 70% of land in those regions had been treated as available for agricultural production. In the new method we show that there is no land reserve in Japan and only 35% available for conversion to agricultural land in Korea.

Due to a certain overlap between land use classes in different datasets we may have situations when certain grid cell fractions belong to different land use classes at the same time. For example, there are overlaps between wetlands and protected areas. Currently, HYDE 3.1 dataset is being revised and the new version of HYDE will include areas of wetlands and steep slope areas per grid cell, thus in many cases certain grid fractions will not be double counted when using wetlands dataset from a different source than that of crops and grassland areas.

Rest suitable and available area and implications for global food security

In general, expansion of agricultural area can still potentially occur on a large scale in South-East Asia, Indonesia, Western Africa, Canada and Russia. The majority of land in those regions is not yet converted into agricultural production and belongs to the moderate and high productive classes. In Brazil the available area is of low and moderate productivity, which can potentially impede the land expansion in the region. In other world regions the future increase in agricultural production can be expected mostly through intensification, since major part of the available and suitable land has already been converted into agricultural land.

Some studies report that agricultural land area is expected to stabilize by 2050 at roughly 10 percent above the 2010 level: growth in agricultural output mainly relies on technological progress and capital accumulation (Lanz et al. 2014).

According to Alexandratos and Bruinsma (2012) it is often not very relevant to speak of global numbers concerning abundance or scarcity of land resources. Countries that face land scarcities and would need to expand food supplies will not necessarily have access to the productive potential of these lands. This constraint can lead to increased trade or, as recent experience has shown, to investments in land where this is abundant or eventually to migration. These are not very promising prospects for poor and food-insecure countries with high demographic growth and scarcity of own land and water resources. Thus, local resource scarcities will likely continue to be a major constraint in the quest for achieving food security for all.

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APPENDIX

Appendix 1 – Current agricultural land (km^2) and percentages in use – an approach including marginal grasslands in land reserve

Regions	Current agricultural land		
	already in use (% of total available land)	area, km^2	beyond availability parameters, %
Canada	58	675,120	21
USA	76	4,149,349	23
Mexico	73	1,073,290	27
Rest Central America	68	325,857	11
Brazil	60	2,637,290	10
Rest South America	63	3,164,069	20
Northern Africa	96	1,007,789	47
Western Africa	60	3,628,645	16
Eastern Africa	80	3,094,154	25
Southern Africa	66	3,544,796	24
OECD Europe	68	1,430,973	11
Eastern Europe	67	667,212	8
Turkey	67	413,644	8
Ukraine region	78	526,495	9
Asia-Stan	97	2,834,548	62
Russia region	62	2,257,156	10
Middle East Asia	93	2,165,187	79
India region	81	2,613,372	23
Korea	64	49,225	13
China region	89	6,878,955	53
South East Asia	43	669,101	6
Indonesia region	35	491,743	5
Japan	100	51,200	43
Oceania	84	4,634,756	54

FOODSECURE
FOR POLICIES THAT MATTER

The FOODSECURE project in a nutshell

Title	FOODSECURE – Exploring the future of global food and nutrition security
Funding scheme	7th framework program, theme Socioeconomic sciences and the humanities
Type of project	Large-scale collaborative research project
Project Coordinator	Hans van Meijl (LEI Wageningen UR)
Scientific Coordinator	Joachim von Braun (ZEF, Center for Development Research, University of Bonn)
Duration	2012 - 2017 (60 months)
Short description	In the future, excessively high food prices may frequently reoccur, with severe impact on the poor and vulnerable. Given the long lead time of the social and technological solutions for a more stable food system, a long-term policy framework on global food and nutrition security is urgently needed. The general objective of the FOODSECURE project is to design effective and sustainable strategies for assessing and addressing the challenges of food and nutrition security. FOODSECURE provides a set of analytical instruments to experiment, analyse, and coordinate the effects of short and long term policies related to achieving food security. FOODSECURE impact lies in the knowledge base to support EU policy makers and other stakeholders in the design of consistent, coherent, long-term policy strategies for improving food and nutrition security.
EU Contribution	€ 8 million
Research team	19 partners from 13 countries

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