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Methodology for assessing and quantifying ILUC prevention options

ILUC Prevention Project – Methodology report



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Colophon

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Preface

Potential indirect land use change (ILUC) triggered by increased production of crops for biofuels became a critical point of discussion with respect to the sustainability of biofuels in recent years. Various studies have shown a wide variability in potential ILUC impacts of different crops and in different settings; and results remain uncertain. In addition, a key limitation of existing studies is that they exclude the impact of possible mitigation options and policies. Therefore, the *ILUC prevention* project aimed at providing insights into how ILUC risks can be mitigated, how this can be quantified and how this may be regulated. This project applied a regional approach that presumes that ILUC can be prevented if increased regional production (as a result of a biofuel mandate) is made possible without 1) diverting other crop production or 2) expanding on high carbon stock land. To do so this approach accounts for the various uses of land for food, feed, fibre and fuels production and thereby takes an integral perspective of agriculture and bioenergy.

Within the *ILUC prevention* project, first a general methodology to quantify ILUC prevention measures was developed. Thereafter, four regional case studies were conducted to demonstrate, test and refine this methodology, as well as to assess the availability and reliability of data that are required for the analysis. The case studies also investigated policy and governance options that are relevant in the specific settings. The results were subsequently used to translate the key parameters and pre-conditions into a methodological framework and monitoring and policy options. The case-specific governance options were then used in the development of a general policy framework for governing ILUC mitigation.

The present report describes the methodology used in the case studies to quantify ILUC prevention measures. Additional publications from the project include the reports from the four case studies (miscanthus ethanol production in the Lublin province of Poland, corn ethanol production in Hungary, rapeseed biodiesel production in Eastern Romania and palm oil biodiesel production in North and East Kalimantan, Indonesia) a synthesis report (including the policy and governance framework for regional ILUC prevention developed in this project), and a two-page summary.

The *ILUC prevention* project was funded by the Netherlands Enterprise Agency (the Dutch acronym is RVO) together with the Dutch Ministry of Infrastructure and the Environment, Dutch Sustainable Biomass Commission, and the Rotterdam Climate Initiative together with the Port of Rotterdam. The case studies were funded by industry partners that helped select the case study region based on recent and/or expected increases in production of the selected feedstocks.

Research for the *ILUC prevention* project was conducted by Utrecht University (Copernicus Institute of Sustainable Development) and followed the Netherlands code of conduct for scientific practice. The views expressed in this report are those of the authors and do not necessarily reflect those of the funding agencies.

1 Introduction

Increased production of biofuels in the last decade, greatly driven by stimulation policies in the United States and European Union, has led to questions around their sustainability. A major issue in policy debates is land use change (LUC) induced by bioenergy production. Particularly debated is the indirect land use change (ILUC), which is caused when agricultural production is diverted to another location in order to accommodate biofuel expansion and which can lead to increased GHG emissions. Since the scientific article by Searchinger *et al.* (2008) showed that the climate impact of biofuels could be worse than fossil fuels, as a result of indirect land use change [1], the topic has been a focus of biofuel research and policy debate. Since 2008 various other studies have been conducted to explore the size of the problem. As ILUC cannot be observed directly, models are used in order to establish the amount of ILUC caused by biofuel policies. Most of these models are complex, non-transparent economic models that consider the effects of an increased biofuel demand on (parts of) the economy. These modelling studies [2–5] have confirmed that increased biofuel demand leads to expansion of agricultural lands and a rise in GHG emissions. However, they found this to occur at a much lower extent than originally postulated by Searchinger *et al.* [1] although it varies largely across studies (see example of corn ethanol in Textbox 1).

Wicke *et al.* (2012) explored the uncertainties in the modelling efforts of ILUC. They found key uncertainties related to the underlying datasets, the amount, location and type of projected LUC, by-/co-products allocation, future production and trade patterns of bioenergy, technological change over time and dynamic nature of LUC [2]. Furthermore shortcomings include a focus on first generation biofuels and insufficient inclusion of the effects of sustainability criteria and land use policies [6]. Until now, little work has been done on how ILUC can be mitigated or even prevented. For example, Bauen *et al.* [7] divided potential policy option into two categories, an ILUC factor approach and an action based approach. The former is a ‘penalty’ added to biofuels GHG emission performance, to stimulate biofuels with a lower ILUC impact. Msangi *et al.* (2012) tested this, by including an ILUC factor policy in an economic model on the LUC emissions. They found LUC emissions reduced significantly as a result of it [3]. However, the penalty approach focuses on biofuels alone, while it is clear that ILUC of biofuels is the direct LUC of another activity. Therefore, also these other activities need to be addressed in order to really tackle LUC.

An example of the second approach, the action-based approach, has been developed by the Roundtable for Sustainable Biomaterials (RSB) and Ecofys. They have jointly come up with a methodology for a certification programme for low indirect impact biomass (LIIB) [8]. The methodology presents a quantification that crop producers can use to establish the amount of biomass they have produced with a low risk of causing ILUC. Actions that are included are e.g. increasing yields, integrating crop and livestock production and using unused lands. The methodology is only applicable on farm level and is not applicable to establish the potential at a higher level. In addition, other ILUC prevention measures exist that have not yet been included, such as increased chain efficiencies or mixed production systems.

BOX 1: VARIATION IN LUC-RELATED GHG EMISSIONS FROM CORN ETHANOL

Land use change emissions (including ILUC) have been studied for key first generation biofuel supply chains. Corn ethanol is the feedstock conversion route that has received most attention in these studies (Figure T1). The following is an excerpt from Wicke et al (2012) describing how the results of different studies vary and what explanations for these differences are.

“With respect to corn ethanol production, the initial LUC effect of US corn ethanol was given as 104 g CO₂-equivalent (CO₂e) per megajoule (MJ) (for reference purposes, the emission factor of gasoline is 92 g CO₂e/MJ) [3]. However, the development and improvements of the Global Trade Analysis Project (GTAP) bioenergy model from Purdue University have resulted in a large reduction in the estimates of LUC-related GHG emissions (first to 32 g CO₂e/MJ used in California’s Low Carbon Fuel Standard [13] and more recently to 15 g CO₂e/MJ [14,15]. If California’s Low Carbon Fuel Standard LUC emission factor of corn ethanol was to be adjusted accordingly, most corn ethanol production would be able to meet the required emission reduction percentage of 10% compared with fossil fuels by 2020 while this is not the case with the current factor of 32 g CO₂e/MJ [13]. The main improvements in the modeling relate to increased spatial resolution, updates in the global economic database used in GTAP (from 2001 to 2006), including pastureland as an option for conversion to bioenergy production, treatment of animal feed co-products, crop yields (both for agricultural crops and bioenergy crops) on existing agricultural land and newly converted land, and the fraction of carbon that is stored for a longer period in wood products [15]. Several of these improvements are related to strategies for mitigating (I)LUC and its effects, such as the type of land being allowed to be converted to bioenergy feedstock production and increasing crop yields and help explain the reduction in LUC-related GHG emissions. Also Al-Riffai *et al.* [16] and, most recently, Laborde [17] have found significantly lower values for corn ethanol than originally proposed. Laborde [17] indicates even lower LUC-related emissions than calculated from the GTAP model, namely 7 g CO₂e/MJ. The model improvements and the changes in results emphasize how sensitive the market equilibrium models are to underlying assumptions and datasets” (Wicke et al. 2012). A key aspect of all models used for assessing ILUC is that they are based on historical data and so any future changes that deviate from the historical data (e.g. stricter land use zoning and enforcement to reduce deforestation) are difficult to capture.

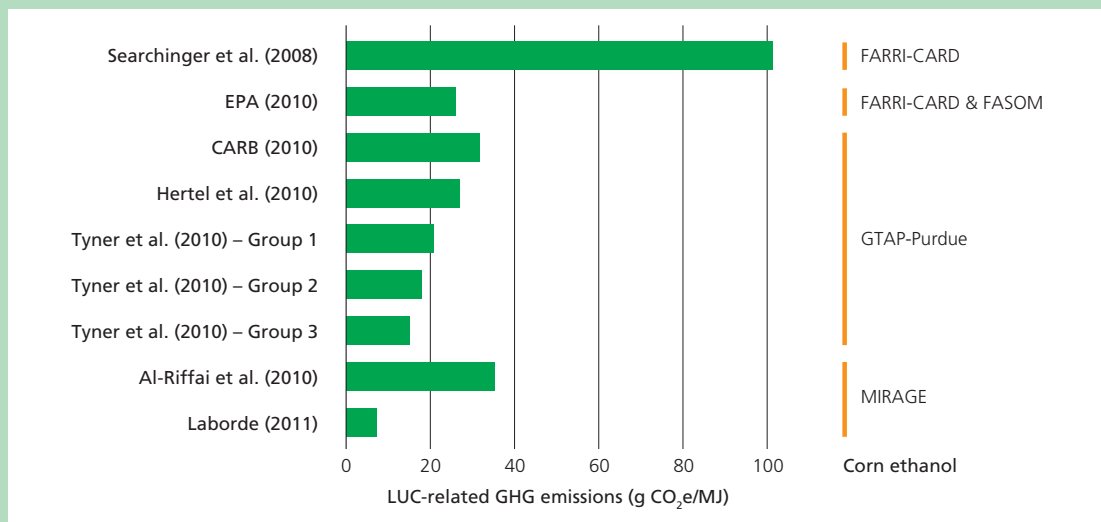


Figure T1 Overview of (direct and indirect) land use change -related greenhouse gas emissions of first generation biofuels determined in the literature (30 year allocation period) (adapted from Wicke et al. 2012)

References used in excerpt and figure: [3] Searchinger T, Heimlich R, Houghton RA et al. Use of US croplands for biofuels increases greenhouse gases through emissions from land use change. *Science* 319(5867), 1238 – 1240 (2008). [13] CARB. Low carbon fuel standard. California Air Resources Board, Sacramento, CA, USA (2010). [14] Hertel TW, Golub AA, Jones AD, O’Hare M, Plevin RJ, Kammen DM. Effects of US maize ethanol on global land use and greenhouse gas emissions: estimating market-mediated responses. *BioScience* 60(3), 223 – 231 (2010). [15] Tyner WE, Taheripour F, Zhuang Q, Birur DK, Baldos U. Land use changes and consequent CO₂ emissions due to US corn ethanol production: a comprehensive analysis. Center for Global Trade Analysis, Purdue University, West Lafayette, IN, USA (2010). [16] Al-Riffai P, Dimaranan B, Laborde D. Global trade and environmental impact study of the EU biofuels mandate. International Food Policy Research Institute, Washington, DC, USA (2010). [17] Laborde D. Assessing the land use change consequences of European biofuels policies. International Food Policy Research Institute, Washington, DC, USA (2011). [18] EPA. Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. United States Environmental Protection Agency, Washington, DC, USA (2010).

Thus, additional work is needed to better assess how ILUC can be mitigated or prevented and how it may be regulated. This is the aim of the *ILUC prevention* project. Under this project, a methodology was developed to assess different ILUC prevention measures in regional case study. This methodology is explained in detail here.

The approach for analysing ILUC prevention measures consists of five components, as described in the following sections:

1. General approach (Section 2)
2. Definition of biofuel target for the region (Section 3);
3. Selection of agricultural products and definition of their projected production volume (Section 4);
4. Analysis of the ILUC mitigation measures in terms of low-ILUC-risk potential (Section 5);
5. Integrated analysis of the measures (Section 6).

2 General approach

The approach developed here aims at analysing and quantifying ILUC prevention measures by assessing i) how much additional biofuel feedstock can be produced with these measures (herein after also called low-ILUC-risk potential) in a specific region in the future, and ii) how this production potential compares to the biofuel feedstock target of that region. The approach is based on a combination of a top-down and bottom-up approach, and distinguishes three main steps (Figure 1):

1. From the economic models used to analyse ILUC factors (top-down approach), a biomass production baseline (without additional biofuels)¹ and target (with a biofuel mandate)² for each region is established. The difference between target and baseline is the amount of feedstock production induced by a biofuel mandate, which in the models is the cause of LUC (including ILUC)³.
2. A bottom-up approach is used to assess the biomass production potential from key ILUC mitigation measures. Three scenarios *-low, medium and high-* are applied in order to indicate the variability and uncertainty in the data and test its effect on the low-ILUC-risk potential.
3. This low-ILUC-risk potential is then compared to the difference between target and baseline bioenergy production from the economic model (see step 1). If the potential is equal to or larger than the induced feedstock production, the measures help prevent ILUC. If the potential is lower than the induced feedstock demand, ILUC cannot entirely be prevented by the measures included in this study alone and additional action needs to be taken in order to prevent ILUC.

In Figure 1, the baseline indicates the production of biomass for food, feed and fibre applications in the absence of a biofuels mandate (i.e., assuming current biofuel production to remain constant, see footnote 2). The target refers to the total biomass production when a biofuels mandate is implemented (see also footnote 3). Thus, it includes food, feed and fibre demand as well as the extra feedstocks for biofuels needed to meet the biofuels mandate. The difference between the target and baseline (Figure 1) is the extra production due to the biofuel requirements (whether directly caused by increased demand for meeting the mandate or induced by increased crop prices due to the mandate). In the economic models, this amount is projected to cause LUC. In our approach, we assess how different measures related to sustainable intensification and modernization of the agricultural sector and proper land zoning can

1 The biomass production baseline refers to the developments as a result of projected energy prices and economic growth. The baseline assumes biofuel production to remain approximately constant at current levels - although small variations may occur due to price developments in the baseline.

2 The target projection applies the same developments in energy prices and economic growth as in the baseline but adds a specific biofuel mandate.

3 Economic models assessing the indirect effects from biofuels do not distinguish indirect from direct LUC, so that total LUC induced by a biofuel mandate is modeled.

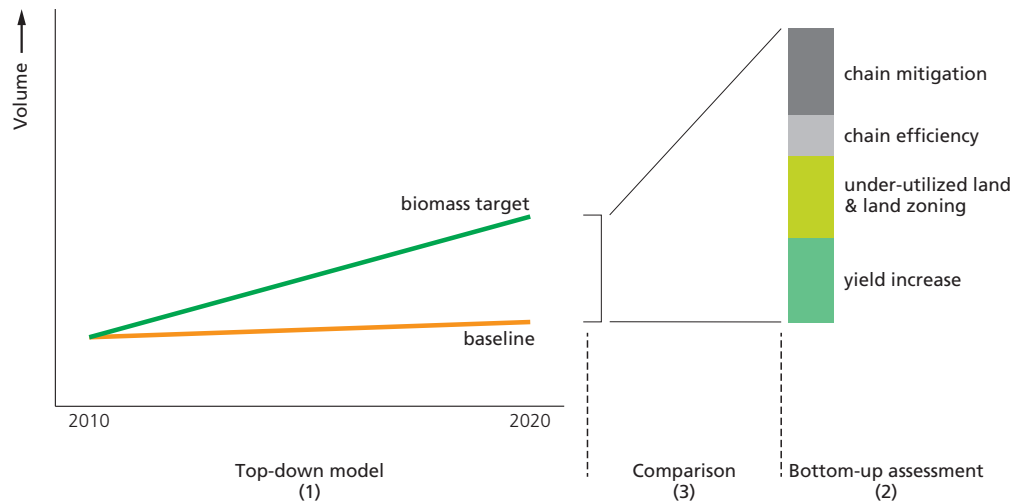


Figure 1 General approach to analyse and quantify biomass production potential with low ILUC risks. The approach consists of three steps: 1) top-down establishment of additional biomass production in the target scenario in 2020 compared to the baseline scenario, 2) bottom-up assessment of potential biomass production in 2020 from ILUC mitigation measures and 3) comparison of the required additional biomass production in the target scenario with the biomass production potential with low ILUC risk. The share of each measure in bridging this gap presented here is only for illustration purposes. The applicability of measures and their share in bridging the gap will differ per region and per scenario.

contribute to producing this amount of biomass without undesired⁴ LUC (Section 5). We thus take an integrated view on all land uses for food, feed, fibre and fuel production and look for synergies between agriculture, forestry and bioenergy.

Although we are primarily interested in how ILUC from biofuels can be mitigated, ILUC from biofuels is the direct LUC of another product and therefore all LUC actually needs to be addressed in order to mitigate ILUC from biofuels. Consequently, the integrated view of land use for all uses introduced above suggests that we compare the final results from the bottom-up assessment with the model projections of all demand increases (not just for biofuels). To do so, this study compares the total land area needed for food, feed, fibre and fuel production (i.e., the difference between projected target production in 2020 and current (2010) production in Figure 1) to surplus land from ILUC prevention measures in order to assess to what extent all additional land requirements can be met by the measures. This comparison is done in terms of land area to be able to account for all crops (as the summation of the production volumes of different crops is not logical).

In this study, biomass production in both baseline and target projections are based on outputs generated by the computable general equilibrium model MIRAGE (Modelling International Relationships in Applied General Equilibrium). In a study for DG Trade of the European Commission, MIRAGE⁵ is used to project land use change until 2020 as a result of the European Union Renewable Energy Directive (EU RED), based on the National Renewable Energy Action Plans [4]. Three scenarios are implemented: one reference scenario (here also referred to as baseline), which assumes no additional biofuel demand; and two scenarios for implementing the biofuels mandate, which are defined by the

4 We specifically refer to undesired LUC here because not all LUC is undesirable. For example, using degraded land for woody and grassy bioenergy feedstock production can result in the re-vegetation and restoration of that land and can have positive impacts on e.g. carbon stocks, water quality and availability (Wicke et al. 2012).
 5 The model version MIRAGE-Biof is applied in this study. For clarity reasons, MIRAGE-Biof is referred to as MIRAGE in the remaining report.

future trade policy (trade policy status quo vs. free trade policy) [4]. In the present study, the scenario based on trade policy status quo (leaving all currently existing import tariffs on biofuels unchanged in 2020) is used for establishing the biomass target.

Having defined the case study region and reviewing the current agricultural situation, the methodology for the case studies consists of the following steps:

1. Definition of the biofuel target for the region;
2. Selection of agricultural products and their projected production volumes;
3. Analysis of ILUC prevention measures;
4. Integrated analysis of all measures.

Each step is described in more detail in the following sections.

3 Definition of the biofuel target

To establish the baseline and target production of the biofuel crop for the given region, results from MIRAGE are used. Given that the MIRAGE model outputs are only available on an aggregate level higher than the selected case studies (see Table 1 in the appendix), the baseline and target production of the world region, in which the case study is located, must be disaggregated to the case study region. The disaggregation is based here on the current share of the case study biofuel feedstock production in the total production of this crop in the corresponding MIRAGE world region (Equation 1). Two key assumptions in this method are that i) the production share of the case study in the world region will not change, and ii) that crops that are important now will remain so in the near future and vice versa. Although this may not hold true for the long term, for the timeframe considered in this study (2020) these assumptions are likely to hold.

Equation 1

$$P_{\text{case study, future}} = \frac{P_{\text{case study, current}}}{P_{\text{world region, current}}} \times P_{\text{world region, future}}$$

Where P refers to the production of the biofuel feedstock (in tons) at different times (currently or in the future) and for different regions (case study or the MIRAGE-world region where the case study is located).

Equation 1 is applied for the disaggregation of the production volume in both the baseline and the target scenarios from MIRAGE. In order to avoid bias due to annual variation in production and yield, the current production is based on the average production over a period of three to five years depending on the case study.

Although the focus of this case study is on one biofuel supply chain, the case study also accounts for the additional demand of other biofuel crops. The MIRAGE model includes the production of all first generation biofuels. This means that biomass production in the target scenario takes into account the feedstock demand for all first generation biofuels projected to be produced in the case study region. The following section explains how the projected production volumes of all crops (including the demand for other first generation biofuel feedstock) is determined.

4 Selection of agricultural products and their projected production volumes

The impact of some ILUC prevention measures depends on (changes in) agricultural production and yield levels that are crop-specific. Therefore, also crop-specific production and yield data are required for the calculations. Although in each case study a large number of different crops are produced, for most crops the production is very small and would have little effect on the overall results. Therefore, for each case study, an overview of the most important crops in terms of areal extent and their share in total agricultural land in the region is made. Based on this overview, those crops are selected that together cover at least 75% of the total arable land, depending on the case study.

For each of these crops, the projected production in the case study in 2020 is determined in the same way as for the biofuel feedstock; that is, disaggregating the projected production in the world region (from MIRAGE) to the case study region is based on the current share of crop production in the case study compared to the world region (Section 3).

In addition to a regional disaggregation, for some crops also a disaggregation of crop groups is needed because only the most important (biofuel) crops are modelled in MIRAGE, while others are aggregated to larger categories (see Table 2 in the appendix). Translating the production target for the crop category to the specific crop is based on the share of the current production of that crop within the category. With regard to livestock production, the importance of the livestock sector in the case study region is assessed by parameters such as the area of land under pasture and meadow, livestock population, and current production of milk and beef. Poultry and pigs are not grazing animals and are mainly fed with processed feed. The land use (change) related to this feed is already taken into account by assessing agricultural crops. Cattle production is closely related to the use of meadows and pastures. Thus, the area of meadows and pastures that can become available for bioenergy production mainly depends on changes in cattle production.

If cattle production makes up a significant share of land, also the projected production in 2020 needs to be assessed. However, the production for beef and milk in 2020 cannot be derived from the MIRAGE model. Therefore, the projected production is derived from extrapolating the historical trend line.

5 Analysis of ILUC mitigation measures

Six key measures for preventing ILUC and mitigating effects of biofuel production are investigated. These are:

- **Above baseline yield development:** increases in agricultural crop yield and livestock production efficiencies above the baseline projection result in a reduction of agricultural land required for crop and livestock production (assuming the production volume remains constant). On the resulting surplus land area, biomass can be produced with low ILUC risk. Yield increases can be achieved by, for example, improved fertilizer application, mechanization and intensification of animal farming.
- **Improved chain integration:** integration of the biofuel chain in food and feed production. Examples of integration are multi-functional land use practices like agroforestry and the use of biofuel by-/co-products as animal feed. Such approaches increase the total output per hectare and reduce the demand for land.
- **Increased chain efficiencies:** Improving the efficiency of agricultural and bioenergy supply chains increases the productivity per hectare. Efficiencies can be improved through, for example, reduction of losses in storage and transport, and improvement of conversion and processing efficiencies.
- **Biofuel feedstock production on under-utilized lands:** under-utilized lands include set-aside land, abandoned land, degraded land, marginal lands and other land that does not currently provide services, i.e., “unused lands” [5]. This, often low-productive, land can be used to cultivate extra biomass for bioenergy.
- **Land zoning:** land zoning helps avoid the use of land with high carbon stocks, biodiversity or other ecosystem services for biofuel feedstock production. Land zoning is often combined with the measure on under-utilized land in order to define what is under-utilized and when is it available for conversion.
- **Lower GHG emissions in the biofuel supply chain:** improve the sustainability of the biofuel production system through, for example, better fertilizer application or measures to increase soil carbon sequestration.

The last two measures in this list, i.e. lower GHG emissions in the production chain and land zoning, are not directly related to preventing ILUC, but contribute to mitigating the effects of land-use change and the biofuel chain, and thereby improve the GHG emission performance of biofuels.

In the following subsections, we describe how each measure is assessed. In the analysis of the measures, we apply three scenarios (*low, medium, high*) in order to indicate the variability and uncertainty in the data and test its effect on the results. In order to prevent ILUC from biofuel production, the performance of each measure needs to be better than in the baseline developments (e.g. baseline projections of MIRAGE or extrapolation of historical trends). The scenarios *low, medium and high*, therefore, refer to low, medium, high developments above this baseline, respectively. The *low* scenario is thus still an improvement

compared to the current situation and baseline scenario⁶.

5.1 ABOVE BASELINE YIELD INCREASE

Increases in agricultural crop yield and livestock production efficiencies above the baseline projection result in a reduction of agricultural land required for crop and livestock production (assuming the production volume remains constant). On the resulting surplus land area, biomass can be produced with low ILUC risk. Increasing yields depends on various aspects that are specific per case. In the following, the general method for assessing low-ILUC-risk biomass potentials from yield increases is described. In the case studies, the potential yield increases per scenario are defined based on a detailed investigation of past yield trends in the case study and neighbouring regions/countries, current yields in regions with comparable biophysical conditions, yield projections in the literature and the maximum attainable yield.

5.1.1 Crops

In order to calculate the potential surplus agricultural area generated from above baseline yield increases, the following formula is used:

Equation 2

$$SA_{ABY,crops} = A_{baseline} - A_{ABY} = \sum_{i=1}^n \frac{P_i}{Y_{baseline,i}} - \sum_{i=1}^n \frac{P_i}{Y_{ABY,i}}$$

Where

$SA_{ABY,crop}$ – surplus area (ha) that becomes available from above-baseline yield increases (ABY) for crops;

$A_{baseline}$ – area (ha) needed for projected baseline crop production, applying the baseline yield growth rate;

A_{ABY} – area (ha) needed for projected baseline crop production, applying an improved yield growth rate;

$Y_{baseline,i}$ – projected baseline yield for crop i (tonne/ha/yr);

$Y_{ABY,i}$ – projected above-baseline yield for crop i (tonne/ha/yr);

P – projected baseline production (tonne) for crop i , as derived from the MIRAGE baseline scenario.

When it is assumed that the entire surplus area generated by improved yields will be used to produce the biofuel feedstock investigated in the case study, the low-ILUC-risk feedstock production potential from this measure can be calculated by Equation 3. This is foremost a theoretical concept to show the potential for low-ILUC-risk biomass/biofuel production. In practice, the surplus area will be intertwined with other areas/uses and thus will not be used for one crop only. Also from a biodiversity and prevention of monocultures perspective, the complete conversion to one crop would not be desirable. In some cases, already only a fraction of the surplus land area is used in the calculation of the potential in order to account for the biofuel crop being part of a crop rotation (so that only a fraction of the land is used each year; e.g. rapeseed is produced only every three to four years, while other crops are produced in the years in between).

Equation 3

$$Pot_{low\ ILUC\ risk} = SA \times Y_{biofuel\ feedstock}$$

Where

$Pot_{low\ ILUC\ risk}$ – additional production potential of biofuel feedstocks with low ILUC risk (tonne/yr);

SA – surplus area generated from IULC prevention measures (ha), e.g. Equation 2;

$Y_{biofuel\ feedstock}$ – projected biofuel feedstock yield (tonne/ha).

⁶ An exception is made for the *low* scenario in the above-baseline yield developments measure when MIRAGE already projects high yields in the baseline, as is the case for palm oil in South-East Asia (see case study on North-Kalimantan). In this case, no surplus land can be generated in the *low* scenario from this measure.

5.1.2 Livestock

Generating surplus land through cattle production improvements can be achieved by increased cattle density on meadow and pasture land and growth in cattle product yields (higher meat or milk production per animal per year). To calculate the potential surplus area, different scenarios regarding the improvement of cattle density and milk and beef productivity are defined. Then, the number of animals slaughtered or the number of animals producing milk is calculated from the projected production and the productivity as defined in the specific scenario (Equation 4).

Equation 4

$$C_{producing,ABS} = \frac{P}{Y_{ABS}}$$

Where

Y_{ABS} – annual amount of milk or beef⁷ produced per animal (tonne beef or litres milk per animal per year) in the above-baseline scenario (ABS);

P – total projected annual beef or milk production in the case study area (tonne beef or litres milk per year);

$C_{producing,ABS}$ – total number of cows (heads) that is slaughtered for beef production or number of dairy cows producing milk in the case study area.

Only a part of the non-dairy animals is slaughtered each year for beef production (animals not slaughtered are, for example, used for reproduction or have not reached the age for slaughter yet). Therefore, the total number of animals related to meadow and pasture use is higher than the amount of animals slaughtered and producing milk. The total number of animals is calculated by Equation 5.

Equation 5

$$C_{total,ABS} = C_{milk,ABS} + C_{total\ non-dairy,ABS} = C_{milk,ABS} + \frac{C_{beef,ABS}}{R_{slaughtered-total\ non\ dairy}}$$

Where

$C_{total,ABS}$ – total number of cattle (# heads) required for the projected future production in the above-baseline scenario (ABS);

$C_{milk,ABS}$ – number of dairy cows (head) producing milk in scenario S ;

$C_{total\ non-dairy,ABS}$ – total number of non-dairy cows (head) in scenario S ;

$C_{beef,ABS}$ – total number of beef cows (head) slaughtered in scenario S ;

$R_{slaughtered-total\ non\ dairy}$ – ratio of animals slaughtered for beef production to the total amount of non-dairy animals. In each scenario, the ratio for 2020 is set equal to the average ratio as found for recent years in the case study area.

In order to calculate the potential surplus land area as a result of an increase in total cattle density (including both dairy and beef cows), Equation 6 is applied. The biofuel feedstock production from this surplus land area can then be calculated by using Equation 3.

Equation 6

$$SA_{ABS,livestock} = A_{baseline} - A_{ABS} = \frac{C_{total,baseline}}{D_{baseline}} - \frac{C_{total,ABS}}{D_{ABS}}$$

Where

$SA_{ABS,livestock}$ – surplus area (ha) that becomes available from applying an above-baseline scenario for cattle density and/or productivity;

$A_{baseline}$ – total meadow and pasture area (ha) that is required to produce the projected amount of beef or milk in the baseline scenario;

⁷ Beef production also includes the production of veal.

A_{ABS} – total meadow and pasture area (ha) that is required to produce the same amount of milk or beef as in the baseline applying an above-baseline scenario for cattle density and/or productivity;

$C_{total,baseline}$ – total number of cattle (# heads) required for the projected future production of beef and milk in the region under the assumption of no improved productivity (calculation similar to Equation 5);

$C_{total,ABS}$ – total number of cattle (# heads) required for the projected future production in the above-baseline scenario (Equation 5);

$D_{baseline}$ – cattle density (# heads per ha of meadow and pasture land) in 2020 for the baseline density scenario;

$D_{above\ baseline\ scenario}$ – cattle density (# heads per ha of meadow and pasture land) in 2020 for the above baseline density scenario.

5.2 IMPROVED CHAIN INTEGRATION

The production of biofuels generates various co-products (e.g. distiller grains solubles (DGS), oilseed meal, glycerine, and straw or stover). Following the principles of consequential LCA (see Textbox 2), these co-products can be argued to reduce land demand and thereby help prevent ILUC.

A first step in the analysis is an inventory of the co-products produced in the biofuel supply chain, the amount generated and the current usage. In the assessment, a distinction is made between co-products from the crop production and from the biofuel production. Co-products from the crop production are the crop residues: for example, wheat straw, corn stover or sugarcane leaves and thrash. For crop residues⁸, the assessment of the amounts generated and the share available for removal must be conducted specific to each crop given their different residue-to-product ratio (RPR) and sustainable removal fraction (SRF) [6], [7] The amount of residues generated is calculated with Equation 7.

BOX 2: CONSEQUENTIAL LCA

Life Cycle Assessment (LCA) is a technique used to gain insight in the environmental performance of a product or service over its complete life cycle, from cradle to grave. In a consequential LCA also the consequences that are outside the direct production chain are considered, as opposed to an attributional LCA that only considers the direct impacts in the production chain. One of the differences between attributional and consequential LCA is how they handle co-products. In an attributional LCA, a portion of the environmental impacts are assigned to the co-products, based on their energy or economic value. In a consequential LCA, the effect on the whole system is considered, by expanding the area of analysis from the specific production chain to include the savings of not producing other products. That means, it can be used to determine the environmental benefits of reduced production of other products. Consequential LCA is especially relevant when the effects of a change are considered [11] – [16].

The principles of consequential LCA are relevant for this study when dealing with the use of co-products outside the biofuel production chain. Co-products such as DGS and oil seed meal can replace other forms of animal feed, thereby reducing the amount of feed crops that has to be produced and thus the land use associated with it. Although these benefits do not occur directly in the production chain of the biofuel, they are a positive consequence of the biofuel production and should therefore be included as positive indirect effect. Applying principles of consequential LCA, the surplus land area created by replacing other feed types are attributed to biofuel production.

⁸ The analysis focuses here on crop residues from the biofuel feedstock. But residues from other crops for food production could also provide a significant, additional low-ILUC-risk biomass production potential. Existing uses must be excluded in order to avoid displacement and potential indirect effects.

Equation 7

$$P_{\text{crop-residues}} = Y \times RPR \times SRF \times A_{\text{biofuel crop}}$$

Where

$P_{\text{crop residues}}$ – amount of crop residues for the biofuel crop (tonne);

Y – crop yields (tonne/ha);

RPR – residue-to-crop ratio (tonne residue/tonne product);

SRF – sustainable removal fraction (%);

A – area under crop cultivation for biofuel production (ha).

Co-products from crop processing and biofuel production are, for example, DGS, glycerine and oilseed meal. MIRAGE already accounts for DGS and oilseed meal in its analysis. In order to provide a comprehensive assessment of co-products' effects on ILUC prevention, the effect of including co-products in MIRAGE is removed from the projected crop production volumes (see Textbox 3). Then, a detailed assessment of all co-products and their low-ILUC-risk potential is determined. This is done by first assessing the amount of co-products from biofuel production as described in Equation 8.

Equation 8

$$P_{\text{co-products}} = \frac{P_{\text{biofuel}}}{CE} \times CPF$$

Where

$P_{\text{co-products}}$ – amount of co-products generated from biofuel production (tonne);

P_{biofuels} – biofuel production volume in the region (tonne);

CE – feedstock-to-biofuel conversion efficiency (tonne biofuel per tonne feedstock);

CPF – the co-product factor is the amount of co-products produced per tonne feedstock (tonne co-product per tonne feedstock).

The second step is to assess the potential use of the co-products and the rates at which they can replace other products. Potential uses for agricultural crop residues are the production of second generation biofuels or electricity. When the crop residue is suitable for the production second generation biofuels, an estimate of the low-ILUC-risk biofuel potential from crop residues is made in order to assess how residues compare to other ILUC prevention measures assessed in this study. This is done by converting the amount of crop residues (as determined with Equation 9) to biofuels by applying the expected residue-to-biofuel conversion efficiency from the literature.

For co-products that can be used for livestock feed, an analysis of the nutritional and energetic value of the co-product and possible replacement of other feed type needs to be conducted per co-product and livestock type. The amount of land that is freed-up from using co-products of biofuels production also depends on the origin of the crop that is substituted. Surplus land generated from this measure can therefore be either in the same region or outside of it. Assuming trade balances will not shift, the import ratio from current trade statistics can be used to establish the original source of the biomass (e.g. a region that heavily imports soymeal from Argentina and increases its own production of rapeseed meal could reduce the need for import and thereby theoretically reduce production in Argentina).

The land freed for biofuels production is then calculated as follows (illustrated here for feed):

Equation 9

$$FS = P_{\text{co-products}} \times SR$$

Where

FS – amount of feed crops saved by substituting them with biofuel co-products (tonne);

$P_{\text{co-products}}$ – amount of co-products generated from biofuel production (tonne), Equation 10;

SR – substitution ratio (tonne feed crop substituted per tonne co-product), which depends on the type of co-product and what it replaces.

Equation 10

$$SA_{chain\ integration} = \frac{FS}{Y_{feed\ crops}}$$

Where

$SA_{chain\ integration}$ – surplus area generated by using co-products from the biofuel production;

FS – amount of feed crops saved by substituting them with biofuel co-products (tonne), Equation 11;

$Y_{feed\ crops}$ – yield of feed crops that are displaced by co-products depends on the area where the replaced feed would have come from (see text above).

Given this amount of surplus land and assuming this is available for biofuel production, we then determine how much extra biomass for biofuels can be produced according to Equation 3.

BOX 3: INCLUSION OF BIOFUEL CO-PRODUCTS IN MIRAGE AND CORRECTION OF CROP PRODUCTION VOLUMES FOR THE PRESENT STUDY

The use of dried distiller grains with solubles (DDGS) and oilseed meal as animal feed is already incorporated in MIRAGE. In the model, the production target for some crops is reduced as a result of the production of these co-products. Although substitution by co-products for feed is better than in other models, MIRAGE still does not account for the complexity of feed requirements in defining the substitution mechanism (for a short review, see e.g. [17]). At the same time, an analysis of the co-product factor used in MIRAGE and other literature [1], [18], [19] indicates that MIRAGE applies values much higher than the literature for some biofuels and lower values for others while other co-products (such as palm kernel oil or glycerine) are not considered. A better understanding of these factors and the effect on the ILUC prevention potential is needed. Therefore, the effect of the inclusion of co-products in MIRAGE is removed from the projected target production volumes (Sections 3 and 4) and then analysed with a bottom-up approach (Section 5.2).

Removing the effect of including co-products projected by MIRAGE is done in two steps

1. *Assessing the amount of feed that is saved according to the model:* The amount of co-products that is projected in MIRAGE is calculated by using Equation 10 (in main text) using input data on co-product production from MIRAGE. This amount of co-products is multiplied by the co-product-specific substitution factor from MIRAGE to calculate the replacement of feed (Equation 11 in main text). The calculation is then repeated for the production of wheat DDGS, maize DDGS, sunflower meal and rapeseed meal. A complicating factor is that the extra production of DDGS or oil seed meal not only reduces the demand for maize, wheat and soy, but also for other types of DDGS and oil seed meal. This means that an assumed reduction in DDGS or meal production of one biofuel chain increases the demand for other types of DDGS and meal. For reasons of simplicity, we assume this to be covered by higher production of maize, wheat and soymeal as these three crops are produced for feed, while DDGS and meal are merely co-products.
2. *Adding the amount of feed saved by using co-products to the production projections* of wheat, maize and soy meal (as defined in Section 3 and 4), as if no co-products would be used.

5.3 INCREASED PRODUCTION CHAIN EFFICIENCY

Food losses and food waste are often thought to be around half of the food produced [8]. Food losses, the term used to indicate the pre-consumer losses, are mostly associated with developing countries and there is large room for improvement. Food waste, the term used for post-consumer losses, is the largest cause of supply chain inefficiencies in industrialised countries [9], [10]. Although the gains of limiting food waste could be very large, it would involve behavioural changes by consumers. This falls outside the scope of this project. However, in the agricultural supply chain in industrialized countries, there is also still potential for improvement. Therefore, this ILUC mitigation measure on increasing chain efficiency addresses the reduction of losses in transport, storage, (un)loading, etc. Reducing the losses in the chain between production and consumption will help to fulfil food demand with less land. Thereby, surplus land is generated that could be used for biofuel production (as described in Equation 11 and Equation 1124).

Equation 11

$$P_{\text{saved},i} = \sum_{i=1}^n P_i \times (L_{i,\text{baseline}} - L_{i,\text{reduced}})$$

Where

- $P_{\text{saved},i}$ – amount of crop i prevented from being lost due to efficiency improvements in the food chain (tonne);
- P_i – production of crop i in MIRAGE baseline (tonne);
- $L_{i,\text{baseline}}$ – share of biomass lost in the food chain in the baseline (without efficiency improvements) (%);
- $L_{i,\text{reduced}}$ – share of biomass lost in the food chain in 2020 after efficiency improvements (%).

Equation 12

$$SA_{\text{efficiency}} = \sum_{i=1}^n \frac{P_{\text{saved},i}}{Y_i}$$

Where

- $SA_{\text{efficiency}}$ – surplus area generated from chain efficiency improvements (tonne);
- $P_{\text{saved},i}$ – amount of crop i prevented from being lost due to efficiency improvements in the food chain (tonne);
- Y_i – projected yield of crop i (tonne/ha).

The potential production of the biofuel feedstock on the surplus land area is calculated by Equation 3. The calculations for cattle are similar to crops; in this case the beef and milk productivity and cattle density are equal to the baseline scenario applied for the measure *above baseline yield increase* (Section 5.1).

5.4 BIOFUEL FEEDSTOCK PRODUCTION ON UNDER-UTILIZED LANDS

Under-utilized land includes set-aside land, abandoned land, marginal lands or degraded land. The share of this land type that does not provide other services (e.g. agriculture, biodiversity, high carbon stocks or other ecosystem services) – i.e., “unused lands” [5] – can be used for the production of biomass with low risk of ILUC. To define the amount of under-utilized land available in the case study area, information about location and extent of these types of land, its current uses and functions, and its suitability for the biofuel feedstock investigated in the case study is needed. Partially, this information may be found in statistics and existing literature, but in some cases spatially explicit analysis is used.

For determining the amount of extra biofuel feedstock production from using this type of land, also its productivity needs to be assessed. In most cases, this is expected to be lower than average. Therefore, a marginal yield factor is applied (Equation 13). However, not in all cases yields on under-utilized land are

actually lower than on agricultural land as it depends on the soil and climate conditions. For example, abandoned land in Eastern Europe does not necessarily have lower yields than agricultural land in use because abandonment was related to the structural changes due to the collapse of the Soviet Union. Another example is the *Imperata* grasslands in Indonesia, which are often considered degraded land because the grass *alang-alang* is hard to remove. However, the soil is not necessary of lower fertility and yields in those cases are therefore not lower than elsewhere. The marginal yield factor will be determined based on literature for the case study region and crop. Given the uncertainties in the yield, the scenarios *low*, *medium* and *high* apply different marginal yield factors.

Equation 13

$$Pot_{low\ ILUC\ risk, UUL} = A_{UUL} \times Y_{biofuel\ feedstock} \times MYF$$

Where

$Pot_{low\ ILUC\ risk, UUL}$ – additional production potential of biofuel feedstocks with low ILUC risk on under-utilized land (tonne/yr);

A_{UUL} – area of under-utilized land available and suitable for biofuel production (ha);

$Y_{biofuel\ feedstock}$ – projected biofuel feedstock yield (tonne/ha);

MYF – marginal yield factor (%) for adjustment of the yield due to the lower productivity expected on under-utilized land.

In some cases of degraded lands, the re-vegetation of the land (particularly if by cultivation of perennial crops) can lead to net storage of carbon in the soil, thereby increasing the GHG emission performance of the biofuel (see also Section 5.6).

5.5 LAND ZONING

Land zoning is a measure that helps reduce impacts of LUC, specifically the associated GHG emissions (unlike the previously described measures that attempt to prevent ILUC). This study includes land zoning in order to prevent the conversion of (primary and secondary) forest, other high carbon stock land, important biodiversity areas or land with other ecosystem services for biofuel feedstock production. Land zoning criteria do not include specific conditions on maximum carbon stocks to allow land use conversion. However, the analysis excludes all areas that are prohibited by the RED to be used for biomass production because of high carbon stocks (i.e. wetlands, forested areas, and peat land). Also existing nature conservation regulations and plans for the expansion of protected areas in the case study region are taken into account.

This measure is closely linked to the previous measure, i.e. biofuel feedstock production on under-utilized land, as it can limit the amount of under-utilized land that could be available for biofuels production. Therefore, in some case studies, the analyses of these two measures are linked.

5.6 LOWER GHG EMISSIONS IN THE BIOFUEL PRODUCTION CHAIN

Lower GHG emissions in the biofuel value chain help to increase the GHG emission reduction potential of biofuels compared to fossil fuels. To assess possibilities for GHG mitigation, first GHG emission data for the production chain is collected from literature. Key data to be included are:

- direct land use change, including soil organic carbon changes due to cultivation
- fertilizer management in the crop cultivation (type and amount of fertilizer)
- consumption of fossil energy during crop production (e.g. due to use of machinery)
- transportation method(s) and distances
- GHG emissions from feedstock conversion and credits from co-products

- biofuel end-use (e.g. transport to fuelling station)

Then, the data are combined into a low and high GHG balance. Based on these two balances, potential GHG mitigation strategies in different parts of the value chain are identified and discussed. These could, for example, include better fertilizer use, best practice with regard to tillage, improved yields, and reduction or capture of methane emissions. Finally, the GHG balances are compared to the GHG emissions of fossil fuels.

6 Analysis integration

Having evaluated the individual measures, the total potential biomass production with a low ILUC risk is analysed (Figure 2). This is an integrated assessment that accounts for the interactions and feedback between different measures. Key interactions and feedback between measures are:

- Reducing food losses decreases the food production volume required for supplying the same amount of food. As a result, above baseline yield developments result in lower surplus area.
- Using co-products from the biofuel supply chain more optimally reduces the production of crops that are substituted by the biofuel co-product. The crop yield determines the reduction in land demand.
- Above baseline yield developments in existing food, feed and biofuel production result in surplus agricultural area when projected demand is met. The biofuel crop yield is then used to assess how much low-ILUC-risk biofuels can be produced on the surplus agricultural land and under-utilized land. For the assessment of the potential on under-utilized land a potentially lower yield on under-utilized land compared to surplus agricultural land is considered.
- The improvements in the chain efficiency for food and biofuel production result in making surplus land area available for biofuel feedstock production. The biofuel chain efficiency is also used in the conversion of feedstock to biofuel low-ILUC-risk potential.
- Land zoning affects the availability of under-utilized land by excluding certain land areas (e.g. primary and secondary forest, other high carbon stock land, high conservation value areas, protected areas or other land not legally available for the production of biomass) and land biophysically unsuitable for the specific crop assessed in the case study.
- Land zoning also affects the availability of surplus agricultural. Although one might consider all surplus agricultural land to be available for biofuel feedstock since it is already in agricultural use, this is not necessarily the case. This is because sometimes land is legally available for food crop production but not for second generation energy crop production (see e.g. case study on miscanthus in Poland).

The main result of the integration is the comparison of the low-ILUC-risk potential with the increase in production projected by the economic model in the target scenario (Section 2). If higher than the target, the case study region can provide biomass for biofuels without causing ILUC. If the potential is lower than the projected increase in production, the region cannot provide the required biomass without undesired (direct or indirect) LUC. This can happen either as a result of diversion of baseline production or deforestation and conversion of other natural land. In these cases, additional action needs to be taken in order to prevent or mitigate ILUC.

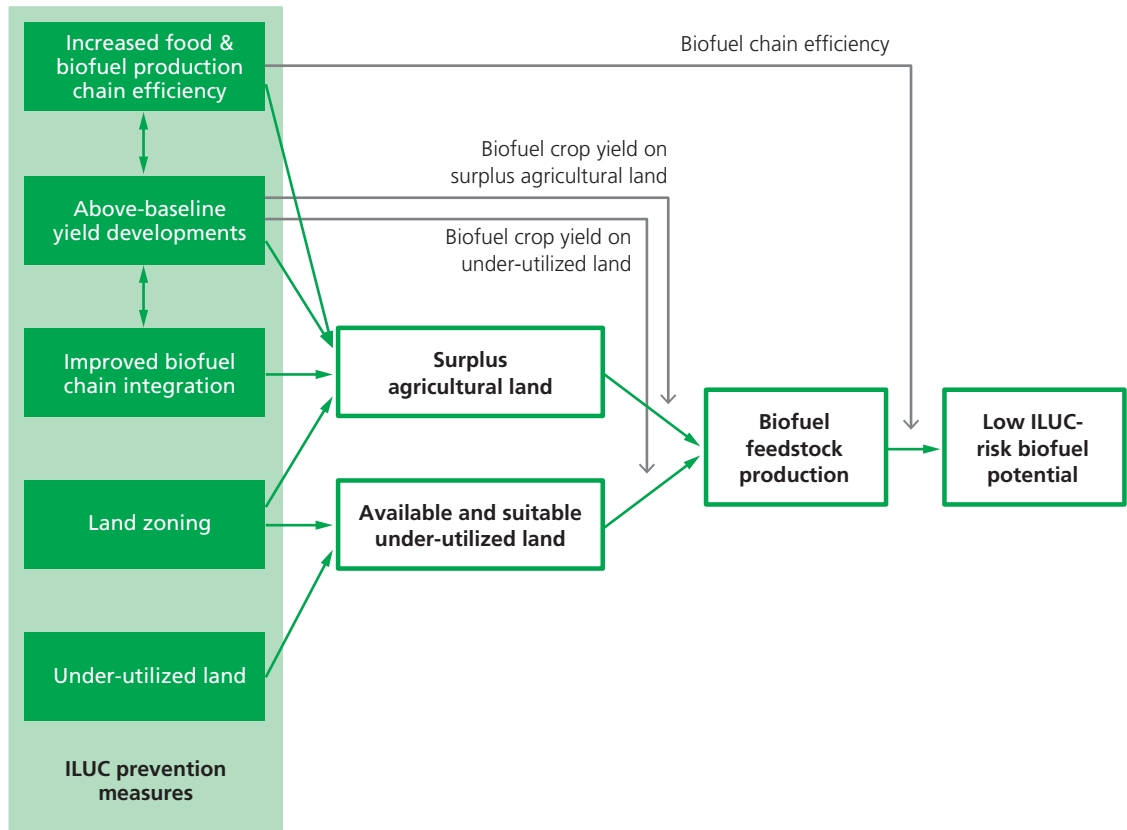


Figure 2 Schematic illustration of integrated analysis

Appendix

Region and crop aggregation in MIRAGE

Table 1 Regional aggregation in MIRAGE

Abbreviation	Description of region
Brazil	Brazil
CAMCarib	Central America and Caribbean
China	China
CIS	Commonwealth of Independent States, former Soviet Union
EU27	European Union with 27 member states
IndoMalay	Indonesia, Malaysia
LAC	Latin American Countries without Brazil
RoOECD	rest of the OECD
RoW	rest of the world
SSA	Sub-Saharan Africa
USA	USA

Table 2 Crop aggregation in MIRAGE

Crop aggregation
Wheat
Maize
Sugar_cb (sugarcane and sugarbeet)
Soybeans
Sunflower
Rapeseed
Palmfruit
Rice
OthCrop (other crops)
OthOilSds (other oil seeds)
VegFruits (vegetables and fruits)

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