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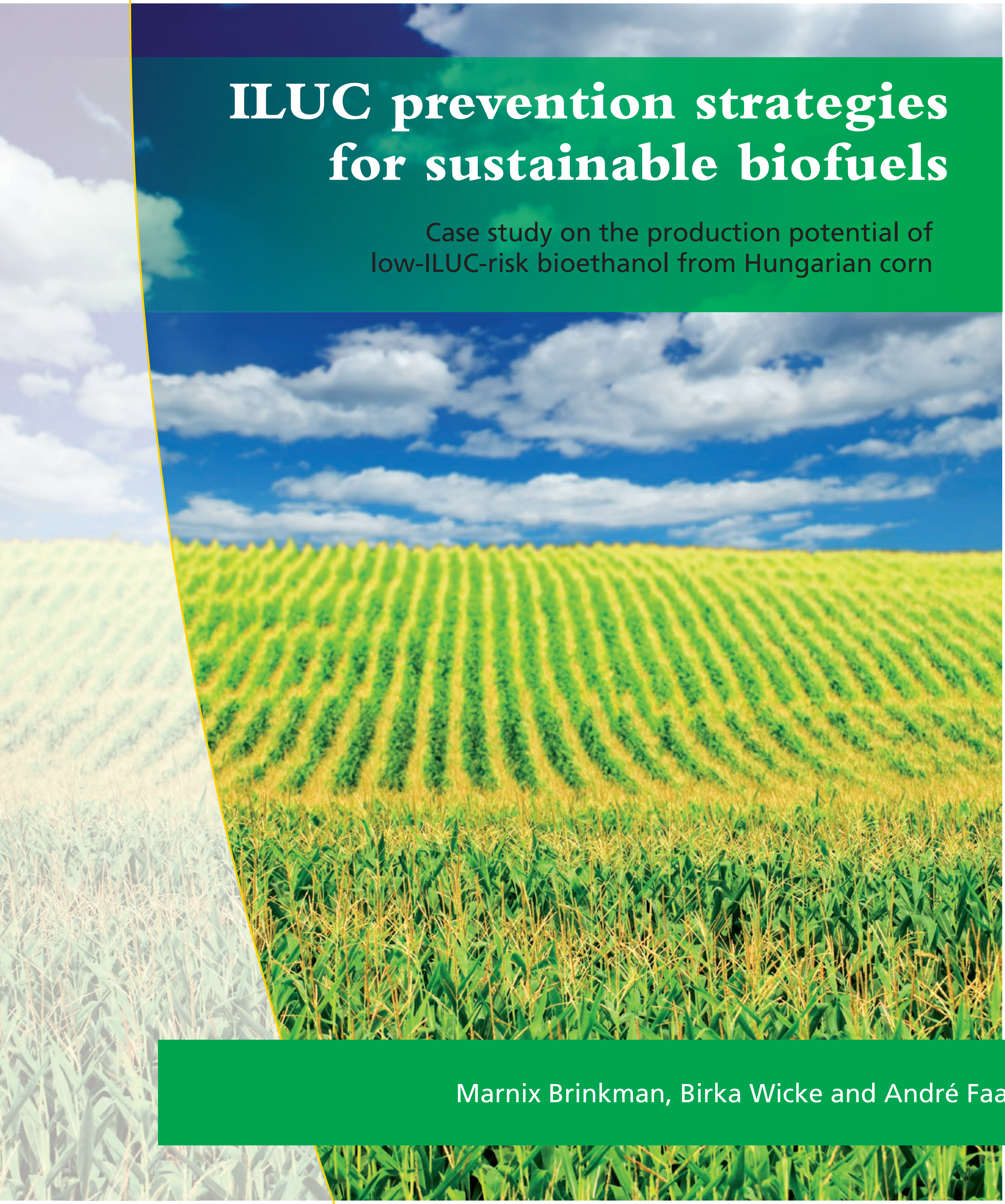

ILUC prevention strategies for sustainable biofuels

Case study on the production potential of low-ILUC-risk bioethanol from Hungarian corn

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Colophon

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Cover photo: Agricultural landscape of corn field on small scale sustainable farm ©Shutterstock-Elena Elisseeva

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ABBREVIATIONS

DDGS	Dried distiller grains with solubles
DGS	Distiller grains
FAO	Food and Agriculture Organisation
GHG	Greenhouse gas
ILUC	Indirect land use change
LCFS	Low carbon fuel standard
LUC	Land use change
LCA	Life cycle assessment
NREAP	National Renewable Energy Action Plan
RED	Renewable Energy Directive
RPR	Residue to product ratio
SRF	sustainable removal fraction
toe	Ton oil equivalent, 42 GJ
WDGS	Wet distiller grains with solubles

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Preface

Potential indirect land use change (ILUC) triggered by increased demand for crops used 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. This methodology focuses on the potential of six measures to reduce the extent of ILUC, control the type of land use change, and limit GHG impacts of biofuels.

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 and illustrate that the relevant weight of the six measures described above can vary widely depending on the context. 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 results of the case study on ethanol production from Hungarian corn conducted under the umbrella of the *ILUC prevention* project. Additional case studies focused on miscanthus production in Lublin Province of Poland, rapeseed production in Eastern Romania and palm oil production in North and East Kalimantan, Indonesia, which are reported separately. In addition, the methodology and a synthesis report (including the policy and governance framework for regional ILUC prevention developed in this project) are published separately.

The *ILUC prevention* project was funded by Netherlands Enterprise Agency (the Dutch acronym is RVO) together with the Dutch Ministry of Infrastructure and the Environment and the 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. The case study on corn presented here was funded by ePure.

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.

Non-technical summary

Potential indirect land use change (ILUC) triggered by increased demand for crops used 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, this case study on ethanol production from Hungarian corn assesses how ILUC risks can be mitigated, how this can be quantified, and how this may be regulated. Underlying the idea of ILUC mitigation or even prevention is the interconnectedness between agriculture and bioenergy. This interconnectedness facilitates ILUC and must therefore also be considered for mitigating and preventing ILUC.

The assessment focuses on six measures to reduce the extent of ILUC, control the type of land use change, and limit GHG impacts of biofuels, with the two key measures 1) above baseline increased agricultural crop yield and livestock production efficiencies; and 2) producing biofuel feedstocks on under-utilised lands. Except for limiting GHG emissions of biofuels, the measures are assessed in terms of their low-ILUC-risk production potential. For each measure, a *low*, *medium* and *high* scenario has been defined in order to i) account for uncertainties in data and level of future efforts and investment to implement the measures and ii) to show the possible effects on the results.

Implementation of the measures can provide 25-109 PJ (1.2-5.2 billion litres) per year of low-ILUC-risk bioethanol from Hungarian corn in 2020 (see Figure S1). Five billion litres equate to roughly 1% of EU transport sector energy projected for 2020, or three quarters of fuel ethanol used in Europe today. The analysis accounts for additional production of food, feed and fibre so that this biofuel potential comes without the need for expansion on high carbon stock lands (or other areas important for biodiversity or ecosystem services) or diversion of production to another location. As a result, this biofuel would result in low or even no ILUC.

Increasing yields above the baseline is the most important measure for realising the potential. Depending on the scenario, 49%-76% of the low-ILUC-risk potential comes from crop yield increases. Although the yield increases applied in this study are high (for corn: 18%-61% growth in comparison to the present), they are feasible given the current high yield gap in Hungary.

Given the importance of yield increases in the low-ILUC-risk potential, the focus of policy and company efforts should be on yield increases. This should not only target corn but all crops as only about 50% of the low-ILUC-risk biofuel potential from yield increases comes from improvements in corn yields. Currently, agricultural management practices in Hungary lag behind those in Western Europe, with lower mechanisation and inefficient fertiliser and pesticide use. Optimized fertiliser use in terms of composition, quantity, timing and frequency of application can improve productivity and thereby decrease GHG emissions per unit of crop. However, at the moment, there is often a lack of capital, knowledge, equipment and incentives to invest in agricultural productivity. Therefore, policies to improve the yield need to stimulate and provide incentives for investment in equipment and knowledge in the agricultural sector. Thereby, performance of the agricultural sector as a whole (not just for feedstocks for biofuels) can be improved, including a reduction in the GHG footprint.

The second most important measure is the use of abandoned agricultural land, which can provide additional low-ILUC-risk corn production for bioethanol ranging from 12% to 30% of the total low-ILUC-risk bioethanol potential. Land use policies stimulating the use of currently under-utilised lands is therefore also important for preventing ILUC. However, there is some uncertainty about the exact location, possible current (extensive) uses and quality of the abandoned lands in Hungary. More insights on these aspects are needed in order to ensure stimulation of only abandoned agricultural land that is under-utilised.

The agricultural sector in Hungary can provide large additional amounts of food, feed, fibre and fuel without the need for expansion on high carbon stock and high conservation value lands or diverting production to other countries. This means that the ILUC risk can be mitigated. The other case studies conducted in this project (Lublin, Poland; Eastern Romania; and North and East Kalimantan, Indonesia) show a similar picture: Low-ILUC-risk biofuel production can be achieved if sufficient efforts and investments are made in the agricultural sector and if land use policies are strengthened and enforced. This shows ILUC is not an irreversible fact, but a risk that can be mitigated. In addition, taking such measures also helps producing other additional agricultural demand for food and feed without unwanted land use change.

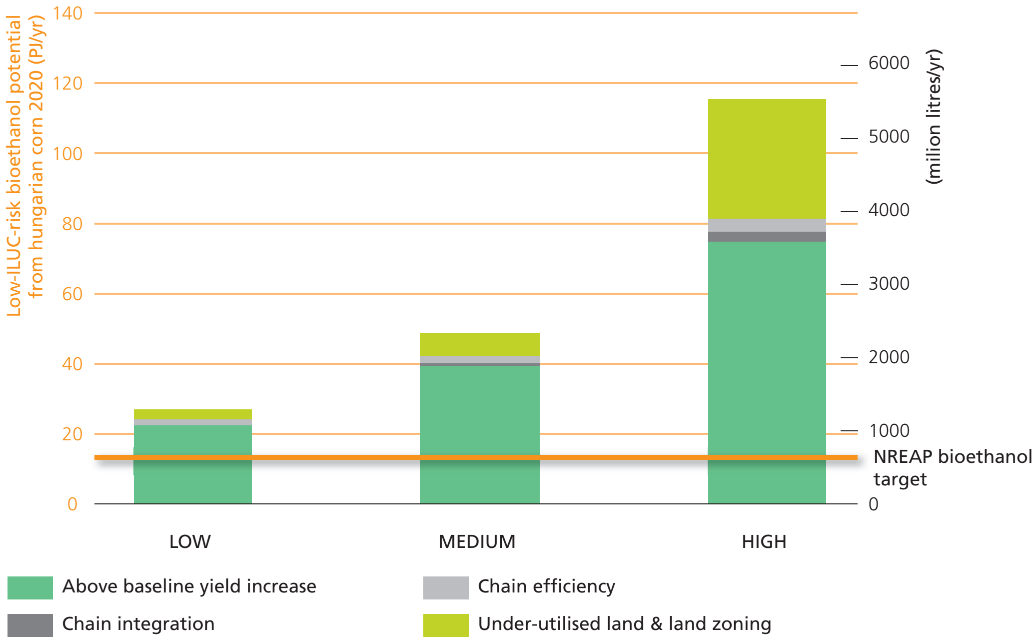

Figure S1 **Low-ILUC-risk bioethanol potential from Hungarian corn in 2020 as a result of the ILUC prevention measures. For reference purposes, the bioethanol target of the Hungarian National Renewable Energy Action Plan (NREAP) of 12.7 PJ/year is also shown.**

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 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 [1] *et al.* in 2008 showed that the climate impact of biofuels could be worse than fossil fuels, as a result of indirect land use change, the topic has been a focus of biofuel research and policy debate. After 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 [2-6]driven initially by oil price hikes and the need for greater energy security. Support measures were established in many countries in recognition of the potential of biofuel development in reducing dependence on fossil fuels, increasing farm revenues, and generating less environmental damage through lower greenhouse gas (GHG 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]. But results vary largely across studies (see Figure 1).

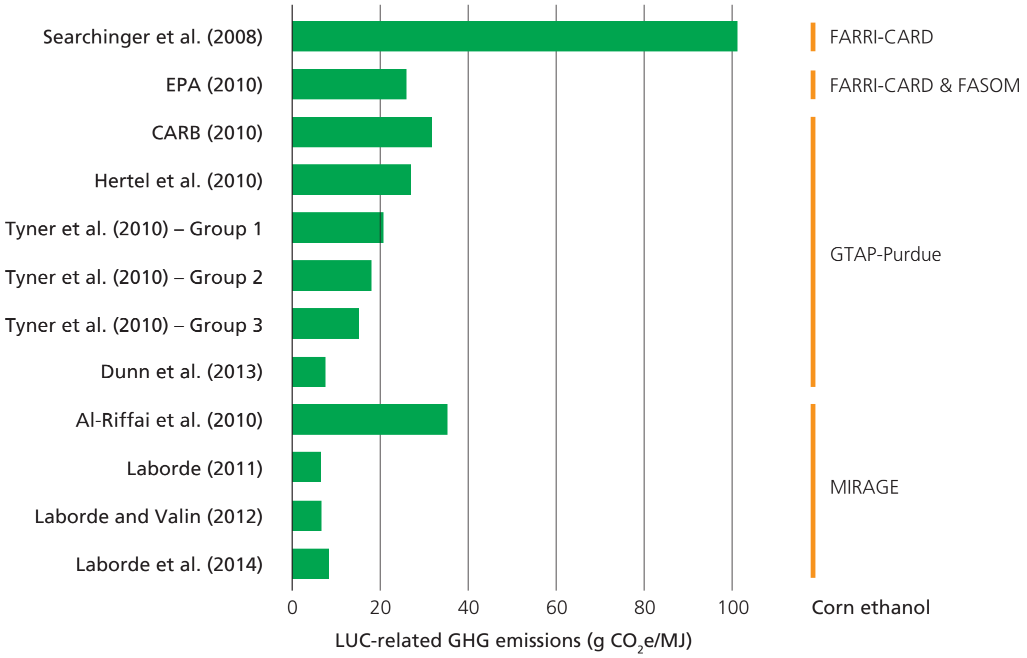

Figure 1 **Overview of GHG emissions from (direct and indirect) land use change of corn ethanol determined in the literature (30 year allocation period) (adapted from Wicke *et al.* 2012 [7]; references up to 2011 can be found now, Dunn *et al.* [8] and Laborde *et al.* [9])**

Wicke *et al.* [7] 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 [7]. A key aspect of the models used for assessing ILUC is that they are based on historical data and so any future changes that deviate from the historical trends (e.g. stricter land use zoning and enforcement to reduce deforestation) are difficult to capture. 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 options 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 [10]. 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 undesirable land use change.

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 does not allow establishing the potential at a higher spatial level. In addition, other ILUC prevention measures exist that have not yet been included, such as increased chain efficiencies or mixed production systems.

Thus, additional work is needed to assess how ILUC can be mitigated or prevented, how this can be quantified 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 studies [11]. This methodology was applied in several case-studies, one of which is the case study on the production of low-ILUC-risk ethanol from Hungarian corn presented here.

The structure of this report is organised as follows: Section 2 describes the choice for this case study and the characteristics of its agricultural sector. Section 3 provides an overview of the general approach and the detailed methodology for assessing and quantifying ILUC prevention measures. Section 4 presents the results per measure and for the analysis integration. Section 5 discusses methodological and data issues of the analysis. Sections 6 and 7 sketches the key policy options for implementing the proposed ILUC prevention measures and describe the parameters for monitoring the possible occurrence of ILUC and ILUC prevention. Section 7 finalises the report with the key conclusions from this case study.

2 Case study region: selection and characteristics

2.1 DEFINITION OF CASE STUDY REGION

The region of analysis in this case study is Hungary. It is traditionally an agricultural country that played an important role in the agricultural production of Central and Eastern Europe. However, since the start of the 1990s, after the end of the communist era, Hungary has seen a large decline in the share of agriculture in GDP [12,13].

Recently, a large corn ethanol plant has been built in the centre of the country, which has a capacity of around 650 k tons of corn [14], and is set to double in 2015. The plant sources its feedstocks from the whole country. Therefore, the country level has been set as the level for the analysis. The advantage of the country level is that data availability is better than on regional or county level, while there is a single agricultural market and the climate and biophysical conditions are more or less comparable.

2.2 AGRICULTURAL SITUATION

For administrative purposes Hungary is divided into 19 counties, plus Budapest. These are further subdivided into 174 sub regions. For statistics they created a higher level of seven regions, these are not in use for policy making. The size of Hungary is 93,028 km^2, of which around 3,000 km^2 is water. 80% of the land is classified as productive land, of which a quarter is covered by forests and 75% is agricultural land [15].

After the collapse of the Soviet Union, the demand for agricultural products has declined. This has been reflected in rapid decrease in agricultural production in the first years of the 1990s. The production of crops has since recovered and is back at the level of the mid-1980s [15]. The FAOSTAT database [16] gives an overview of the current production of various crops. The most important crops are corn and wheat at an average production (2008-2012) of 7.2 M ton and 4.3 M ton. In Table 25, in Appendix A, the agricultural production in Hungary in the period 2005 to 2012 is presented of the ten most important crops. These crops cover half of the production of the country in the five-year period 2008-2012. Also a regional division is presented in Figure 8 (page 64, Appendix A); the most prominent regions for corn production are Southern Transdanubia and the Northern and Southern Great Plain. The area covered by these crops is reported in Table 28.

The production of animal products is, although again rising, still far below old production levels. Deceasing demand from Russia has e.g. led to a reduction in the amount of pigs from around nine million to the current three million. This is seen as a problem by the national government and the official goal is to increase the number back to six million. Overall, animal production is nowadays only half of the maximum levels of the mid-1980s [15]. The current production of meat, milk and other animal products is presented in Table 26. Table 27 presents the amount of living animals in Hungary in 2011 and

2012, based on FAO and national statistics. Current (in 2011) area occupied by meadows and pastures is 750,000 ha [16].

The crop yields of the ten most important crops in Hungary are presented in Table 29 (Appendix B). Here it appears the yield varies significantly between years. This has mostly to do with the weather and especially the amount of rain during summer. Yields can therefore even double or triple between two years. There are also differences between regions. The average corn yield (2005-2009) in the regions with the highest yield was 6.96 t/ha and the lowest 5.47 t/ha; for wheat this was 4.86 and 3.82 respectively [17].

Databases from the World Bank suggest fertiliser use and mechanisation in Hungary are low compared to other European countries. Per 100 square kilometres arable land there are only 260 tractors, compared to over a thousand for many other European countries (2005). At less than 80kg/ha the fertiliser use is also lower than the 150 that is the lower value for Western European countries, although the applied amount per hectare is rising [12,15]. Nevertheless, the knowledge how to apply the fertilisers is often lacking. Top agricultural export products from Hungary were on average (2005-2009) corn (3,356 kton), wheat (1,980 kton), sunflower seed (512 kton) and rape and mustard seed (444 kton).

As a result of the privatisation of agricultural land there are many smallholders in Hungary. In 2010 there were 577,000 agricultural holdings in Hungary at an average size of 6.5 hectare [17]. 96% of the agricultural holdings can be considered smallholders at a size below 20 hectares. The number is however rapidly declining. These farms still occupy one sixth of the arable land. The 4,000 largest, with a size of over 150 hectare (on average 533 ha), occupy 58% of the arable land area in Hungary [17].

Research from 2001 indicated that, although land-ownership is quite scattered, the actual management is concentrated in larger farms. Farms smaller than ten hectares are in general only part-time farms [18]. This is also illustrated by the fact that a large part of these farms consumes at least half of their production [17].

It can be expected that these have smaller yields, due to lower investment capacity in equipment and chemicals, which is also seen in other settings.

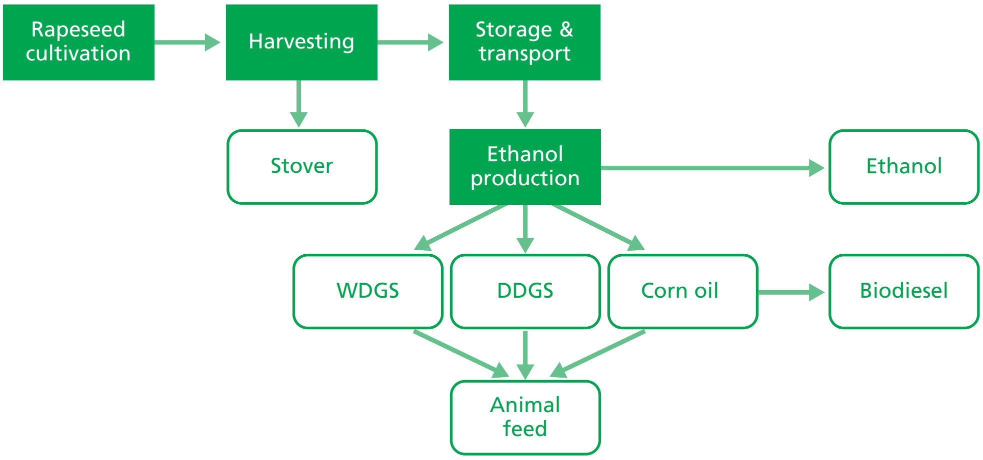

Figure 2 **Schematic representation of the bioethanol production chain. The final products are bioethanol and distillers grains with solubles (DDGS). Not included is the CO_2 from fermentation.**

2.3 BIOFUEL CHAIN

In Figure 2 the production chain of corn ethanol is presented. Corn and stover, an agricultural residue, are produces in equal quantities [19]. However, raising yields lowers the residue to product ratio (RPR), but at the typical yields in Hungary the ratio remains close to 1 [20]. The amount that can be sustainable removed, without negative effects for the soil quality is lower than this.

After harvest the corn is stored, after which it is transported to the production facility. After the corn is milled the starch is saccharified and then fermented into alcohol. The whole stillage that remains after distillation of the alcohol is processed into Dried Distiller Grains with Solubles (DDGS) and Wet Distiller Grains with Solubles (WDGS). The DDGS can be considered as the primary co-product of the mill. Due to its moisture content WDGS, can only be stored for a limited period and transport becomes less attractive. Both the wet and dried grains are used as animal feed. Corn oil is also separated from the stillage described above. This corn oil can be used as cooking oil, as animal feed or to produce biodiesel. The efficiencies of plants vary, but typically these produce equal parts bio-ethanol, animal feed and CO_2. In the present study, we use an ethanol yield of 0.335 $kg_{ethanol}/kg_{corn}$ or 0.424 $litre_{ethanol}/kg$ corn based on the process data of Mueller [21].

3 Methods & materials

3.1 GENERAL APPROACH

The approach applied here was developed Brinkman *et al.* (2015) [11] and 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 an applicable regional biofuel target. The approach is based on a combination of a top-down and bottom-up approach, and distinguishes three main steps (Figure 3):

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 3, 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 feedstock for biofuels needed to meet the biofuels mandate. The difference between the target and baseline (Figure 3) 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 modernisation of the agricultural sector and proper land zoning can

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[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.

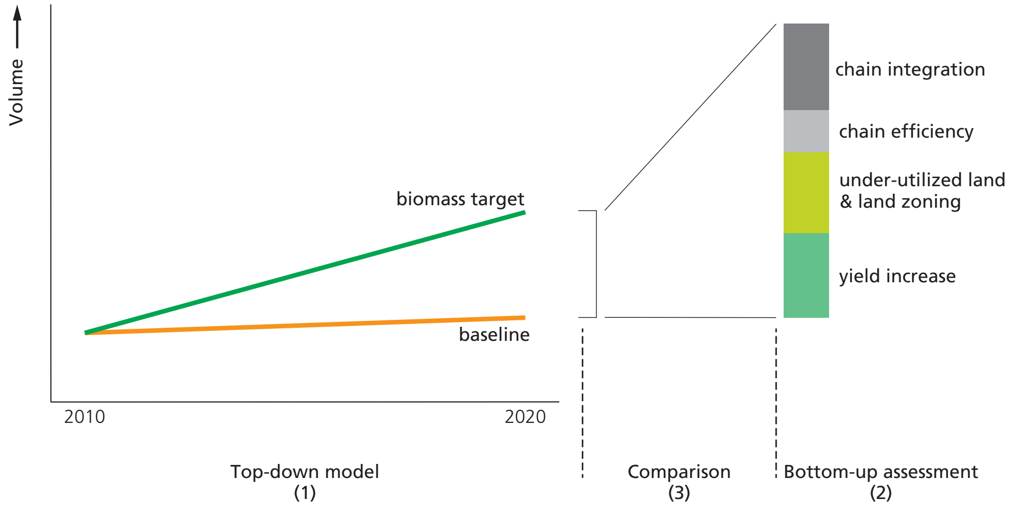

Figure 3 **General approach to analyse and quantify biomass production potential with low-ILUC-risks. The approach consists of three steps: 1) top-down establishment of additional biomass production in the target scenario in 2020 compared to the baseline scenario, 2) bottom-up assessment of potential 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 undesired[4] LUC (Section 3.4). 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 3) 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, MIRAGE[5] is used to project land use change until 2020 as a result of the European Union Renewable Energy Directive (RED), based on the National Renewable Energy Action Plans (NREAP) [3]. 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

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[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 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) [3]. 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. Each section first provides the method used in all case studies and then explains in a sub-section the application and input data used in the case of ethanol production from Hungarian corn.

3.2 DEFINITION OF THE BIOFUELS 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 30 in Appendix B), 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. Although this may not hold true for the long term, but for the timeframe considered in this study (2020) these assumptions are likely to hold.

Equation 1

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

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 five years We use 2008-2012 in this 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) are determined.

In previous years (2009-2011), Hungary produced around 4% of European ethanol [22,23]. The projected bioethanol production in the EU27 in 2020 is 159 million GJ [3]; so for Hungary this is 6.6 million GJ.

3.3 SELECTION OF AGRICULTURAL PRODUCTS AND THEIR PROJECTED PRODUCTION VOLUME

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 3.2).

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 31 in Appendix B). Translation of 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

Table 1 Selected crops for assessment of the ILUC prevention measures in Hungary, production and area data based on FAOSTAT database [16].

Crop	Area (kha)	% of total arable land area 2010[a]	% of total agricultural land area 2010[b]	Production (kilo tonne) 2010[c]
Corn	1,174	25%	21%	7,229
Wheat	1,064	23%	19%	4,328
Sunflower seed	556	12%	10%	1,277
Barley	293	6%	5%	1,092
Sugar beet	14	>1%	>1%	751
Potatoes	22	>1%	>1%	559
Rapeseed	233	5%	4%	541
Oats	54	1%	1%	136
Rye	38	1%	1%	83
Soybeans	36	1%	1%	79
Total Crops	**3,485**	**75%**	**63%**	**16,075**
Permanent pastures and meadows	859		16%	
Total	4,344		79%	

[a] total arable land area is 4,659 k ha (average 2008-2012) [16]

[b] total agricultural area is 5,518 k ha (average 2008-2012) [16].

[c] average production in the period 2008-2012.

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. Table 1 presents an overview of the crops that will be considered in the calculations for this case study. Crops that, on average in the period 2008-2012, cover less than 20,000 hectare (less than 0.5% of the arable land) or have a production lower than 100,000 ton are not expected to make a large impact on the total land use. The ten selected crops cover three quarters of the arable lands in Hungary. Over 80% of the annual agricultural production[6] is covered by these crops. Table 2 presents the agricultural production in the baseline and target scenario in Hungary for 2020.

Table 2 **Crop-specific production target in Hungary for 2020, according to the MIRAGE model including the effects of the exclusion of the co-products.**

	Current production (k ton)	2020 Production baseline (k ton)	2020 land use baseline (k ha)	2020 Production target (k ton)	2020 land use target (k ha)
Corn	7,229	8200	1301	8124	1285
Wheat	4,328	5007	1212	4977	1202
Sunflower seed	1,277	1573	604	1672	636
Barley	1,092	694	182	692	180
Sugar beet	751	805	14	934	15
Potatoes	559	356	14	354	14
Rapeseed	541	736	292	839	327
Oats	136	87	34	86	33
Rye	83	53	23	53	23
Soybeans	79	103	44	103	44
Total	**16,075**	**17,614**	**3,721**	**17,833**	**3,760**

3.4 POTENTIAL BIOMASS PRODUCTION PER ILUC MITIGATION MEASURE

Six 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 fertiliser application, mechanisation 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

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[6] Based on the average production in the period 2008-2012 according to FAO data.

example, reduction of losses in storage and transport, and improvement of conversion and processing efficiencies.
- **Biofuel feedstock production on under-utilised lands:** under-utilised lands include set-aside land, abandoned land, degraded land, marginal lands and other land that does not currently provide services, i.e., “unused lands” [24]. 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-utilised land in order to define what is under-utilised 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 fertiliser 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 scenario. The scenarios per measures are described in detail in the sections below.

For each measure the surplus agricultural area is used to calculate the amount of low-ILUC-risk corn that can grow on these lands. This amount of corn can be converted to bio-ethanol, it is assumed for each ton of corn 0.335 ton of ethanol is produced [21], which has an energy content of 27 MJ/kg. This is the lower heating value, taken from the European Renewable Energy Directive [25].

3.4.1 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.

3.4.1.1 Crops

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

Equation 2

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

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

Equation 3

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

Where $Pot_{\text{low-ILUC-risk}}$-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;
$Y_{\text{biofuel feedstock}}$-projected biofuel feedstock yield (tonne/ha).

Agriculture in Hungary can be characterised by comparatively low yields. Reducing land use in production by increasing the yields can free-up land that can facilitate biofuel production. Fertiliser use and mechanisation are low [12], and it is expected the many smallholders are also less productive. Increasing the production intensity by applying better chemicals (e.g. fertilisers, pesticides), irrigation and stimulating mechanisation and other aspects of precision farming can improve production. Also the use of better seeds, double cropping and livestock intensification leads to higher production in the same area. For some of these measures better education is required. Farmers in Hungary are considered conservative and not all are aware of the technical possibilities that are available.

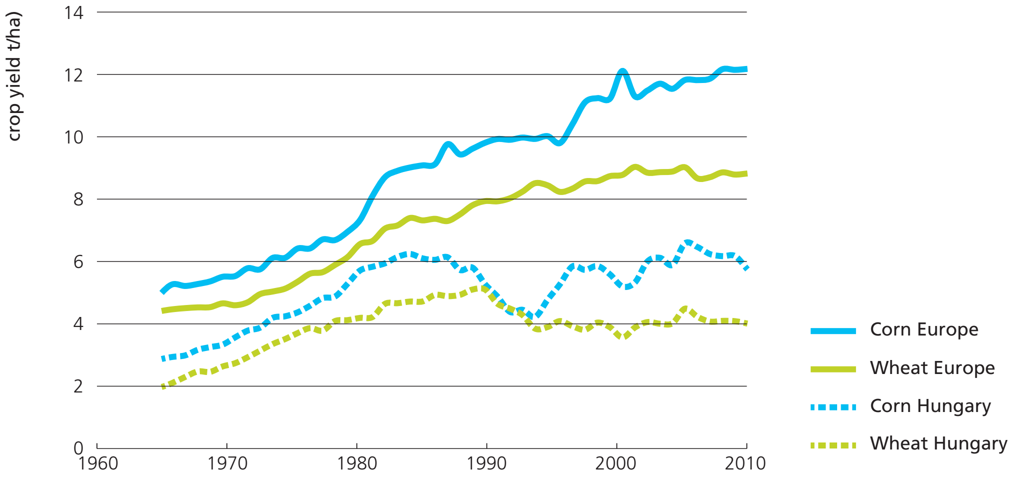

Figure 4 **Comparison of the five year average best corn and wheat yield in Europe and the Hungarian yield. The 1960s and 1970s showed Hungarian yields rose faster than the best in Europe, but after 1990, the yields decreased and are only for corn back to the level pre-1990. This shows a lot can improve in Hungary.**

In the past, Hungarian yields were relatively higher; in the 1970s and 1980s Hungarian corn and wheat yields were in the top half of Europe, at 60% to 80% of the best European yield. In recent years, Hungary is in the bottom half or even bottom quarter and obtains yields around 30% to 55% of the European best. Although Hungarian yields have risen, Hungary lagged behind other countries in this respect.

As the yields in Hungary were among the top in Europe, it is expected the decline has less to do with biophysical factors, such as soil and climate and more with sub-optimal management practices. Improving these practices can therefore lead to an increase in agricultural yields. The size of the yield gains depends on an intricate combination of factors that are hard to quantify separately. Therefore a scenario approach was taken. In order to provide a range of potential yield increases, we investigated past yield trends in Hungary and neighbouring countries, current yields in regions with comparable biophysical condition, yield projections in the literature and the maximum attainable yield (see Appendix C). Based on this a low, middle and high yield development scenario have been formulated. The various assumptions for the future yield scenarios are provided in Table 3.

The yields from the scenarios will be compared to a baseline yield. The baseline yield is determined based on the projections of the MIRAGE model. The MIRAGE model projects yields for various crops in 2020. However, these projections are aggregated on the level of the EU27. The yields in Europe differ significantly between various countries. To avoid assuming a too high baseline on low yielding countries or a too low baseline on high yielding countries the yields are disaggregated to country level. The disaggregation is based on the ratio between the current yield in Hungary and the average EU27 yield, in the period 2008-2012. This ratio is calculated for each crop and multiplied by the projected yield in the MIRAGE model.

Projected yields for 2020 based on the scenarios are illustrated for corn and wheat, the two most important crops by production volume, in Table 4. These are increases from 6.2 and 4.1 ton per hectare for corn and wheat respectively.

Table 3 **Low, middle and high yield development scenarios and their key characteristics.**

Scenario		Description
Low	Yield trend	Extrapolating the crop-specific linear yield trend in Hungary of the period 1961-2010 to 2020. Yield data is taken from the FAOSTAT database [16].
Middle	Best counties	For each crop the yield of the best county is extrapolated to the whole country. Data are taken from Eurostat [17] and Hungarian National Statistics Office [15]. For those crops where no regional data is available best national average yield in the period 2008-2012 is assumed.
High	Austria	Ratio of the maximum attainable yield and actual yield currently achieved in Austria applied to the maximum attainable yield in Hungary [a]. Austria is a neighbouring country, but with an agricultural sector that is much further developed using more fertilisers, pesticides and machinery [12,16,17]. The Eastern part of the country is also on the Pannonian plain.

[a] for description see Appendix C.

Table 4 **Crop yields in 2020 for corn and wheat in the three scenarios.**

Scenario	Corn yield (t/ha)	Wheat yield (t/ha)
Current [a]	6.2	4.1
MIRAGE [b]	6.3	4.1
Low	7.3	5.0
Middle	7.7	5.0
High	10.0	4.7

[a] average 2008-2012 [16].
[b] disaggregated from the EU27 level to Hungary based on the ratio of the current yield to the EU27 average.

3.4.1.2 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 beef produced per animal (tonne beef[7] 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);

$C_{\mathrm{producing,ABS}}$-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

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

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

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

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

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

$R_{\mathrm{slaughtered\text{-}total\ non\ dairy}}$-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

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

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

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

$A_{\mathrm{ABS\text{-}}}$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;

$C_{\mathrm{total,baseline}}$-total number of cattle (# heads) required for the projected future production of beef and milk in the

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[7] Beef production also includes the production of veal.

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.

The productivity per dairy cow in Hungary is 5,499 kg milk per cow per year; this is below the European average of 6,140 kg/cow/year. The largest increase was between 1974 and 1988 [16]. In these fifteen years the average milk production per cow doubled from 2500 kg milk per cow per year to 5000 kg per year. For beef cattle the weight per carcass is 257 kg, similar to the start of the 1960s, at the middle of the 1970s the average yield per cow was the highest at around 300 kg.

These data are low compared to Western European countries such as the Netherlands where the average dairy cows produces around 7300 kg of milk per year or even the US where cows produce on average 9600 kg milk per year. The meat production per cow is a bit lower than in Austria (327 kg) and Luxemburg (354 kg).

In the period since Hungary joined the EU, productivity per cow, expressed as milk production per cow and carcass weight have remained almost stable at a very limited decrease. Therefore no change compared to the current situation will be assumed for the baseline. For the density (0.9 heads/hectare) also a stable situation is assumed[8].

To provide a range in the yield increases historical trends in Hungary and developments in other European countries and constructed three potential scenarios for the yield increase. These are presented in Table 5.

Table 5 **Potential productivity increase in the livestock sector.**

Scenario		Description
Low	Current productivity Slovakia	Slovakia neighbours Hungary and was also under communist rule until the start of the 1990s. The country boasts a somewhat higher productivity per unit of livestock [16], although the cattle density (heads/hectare) is comparable to Hungary.
Middle	Highest historical productivity	From the FAOSTAT database [16] the maximum productivity per cow in the period 1961-2012 will be considered as a productivity that can be achieved again.
High	Current productivity East Germany	East Germany was, like Hungary, also under communist rule before 1990, but joined the European Community (and thus the common agricultural policy) immediately after the reunification, fourteen years prior to other countries from Central and Eastern Europe. Eastern Germany is therefore expected to be a frontrunner and that similar yields are a viable option. Milk production data are from Eurostat, meat production data for the East German Bundesländer are taken from the National Statistics Office [26]. Land use data are from Eurostat [17]. For the production data averages in the period 2008-2012 are used.

3.4.2 Improved chain integration

In the supply chain of biofuels various co-products (e.g. DGS), oilseed meal, glycerine, and straw or stover). Following the principles of consequential LCA (see Textbox 1) 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 crop production and from biofuel production. Co-products from crop production are the crop

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[8] Between 2004 and 2009 the density varied around 0.7 and jumped to 0.9 in 2010. This had to do with a large re-categorisation of meadow and pasture land in the category other land in the FAOSTAT statistics.

BOX 1: CONSEQUENTIAL LCA

Life Cycle Assessment (LCA) is a technique used to gain insight into 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 [29-34].

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.

Table 6 **Above baseline productivity in cattle farming. The current productivity is 5517 litre per cow per year and a slaughter weight of 257 kg.**

	Milk (l/cow/year)	Meat (kg/carcass)	Density (heads/hectare)
Current	5,517	257	0.83
Low	5,869	252	0.81
Middle	6,173	311	1.10
High	8,449	302	0.97

residues[9]; for example, wheat straw, corn stover or sugarcane leaves and thrash. For crop residues, 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) [27,28] The amount of residues generated is calculated with Equation 7.

Equation 7

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

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

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[9] The analysis focuses here on crop residues from 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.

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 2). 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

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

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, animal feed or electricity. When the crop residue is suitable for the production of second generation biofuels, an estimate of the low-ILUC-risk biofuel potential from crop residues is made in

BOX 2: INCLUSION OF BIOFUEL CO-PRODUCTS IN MIRAGE AND CORRECTION OF CROP PRODUCTION VOLUMES FOR THE PRESENT STUDY

The use of 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. [35]). At the same time, an analysis of the co-product factor used in MIRAGE and other literature [1,4,5] 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 3.2 and 3.4) and then analysed with a bottom-up approach (Section 3.4).

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 8 (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 9 in main text). The calculation is then repeated for the production of wheat DDGS, corn 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 corn, 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 corn, 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, corn and soy meal (as defined in Section 3.2 and 3.3), as if no co-products would be used.

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 7) 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

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

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 8;
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

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

Where $SA_{\text{chain integration}}$-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 9;
$Y_{\text{feed crops}}$-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.

For the calculations for this case study we limit the analysis of the co-products of corn ethanol production to the production of DDGS. Following the reasoning from Bauen (2010) the potential impact of the co-products from crop production, such as the stover, are assumed to be limited in comparison to the production of DDGS and meal. These are therefore not further included in the calculations of this analysis [36]. In addition in plant breeding a bias towards higher grain production and lower straw production can be expected[10], which leads to decreasing availability of straw products per ton of corn. The production of DDGS, the industrial co-product of bioethanol production, is around one third of the corn input for ethanol production; data varies from 28% [21], 31% [37]its role among other biofeedstock alternatives to petroleum-based energy sources has to be balanced with its predominant purpose for food and feed, economics, land use, and environmental stewardship. We model land usage attributed to corn ethanol production in the US to evaluate the effects of anticipated technological change in corn grain production, ethanol processing, and livestock feeding through a multi-disciplinary approach. Seven scenarios are evaluated: four considering the impact of technological advances on corn grain production, two focused on improved efficiencies in ethanol processing, and one reflecting greater use of ethanol

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[10] Scarlat *et al.* already showed a negative relation between increasing yields and the crop-residue ratio [20]. As plants have a limited amount of energy available for growth, plant breeding will focus on increasing the corn yield rather than stover yield.

co-products (that is, distillers dried grains with solubles to 36% [38]. The MIRAGE model assumes a co-production factor of 49%. This is significantly higher than what is seen in practice.

An overview of the co- and by-products from the corn ethanol production and their production quantities is presented in Table 7.

Table 7 **Overview of the co/by products of corn ethanol production and the production stage where these are produced.**

Co-/by-product	Origin	(Potential) use/function	Rate of production	Reference
Stover	Field	Nutrients for soil, stall bedding, animal feed, second generation ethanol	1t/t corn [a]	[19,20]
Corn oil	Separation from DGS	Animal feed, food, biodiesel production.	0.1 t/tcorn	[21]
DDGS/WDGS	Fermentation	Animal feed	0.32 [b] t/tcorn	[21]

[a] This does not include the sustainable removal rate, which would lower this number significantly.

[b] Sum for wet and dried distiller grains. The two are produced in varying combinations based on the local market context

The calculations for this measure will focus on the production and use of DDGS. DDGS is most widely used; large-scale deployment of second generation ethanol production from stover is not expected for the next few years and other aspects are more experimental or not linked to land use. The quantity of DDGS that is produced is derived from the results of the MIRAGE model. On average in the EU27 6.2% of the corn production will be used for ethanol production. This percentage is also applied to Hungary. This means 505 k ton corn will be used for bioethanol production, which means 141 k ton of DDGS is projected to be produced.

For the substitution of agricultural crops by the DDGS three scenarios have been made, which are presented in Table 8. These are based on a worst case scenarios, where all land use savings will be achieved outside of Hungary and a best case scenario, where all land use savings are achieved in Hungary itself thereby creating the largest surplus area in the case study area.

To calculate the land use savings for crops that grow in Hungary the projected Hungarian yields are used. For the replaced soymeal, that is imported from abroad, a weighted average of the trade from Brazil and Argentina in a ratio 3:1 is taken. These two countries are the predominant exporters to the Netherlands and Germany, which are in turn the most important exporters to Hungary [45]. The projected soy yields in 2020 for these countries are also taken from the MIRAGE model.

Table 8 **Low, medium and high scenario for the substitution of agricultural crops as a result if corn DDGS use.**

Scenario		Division	Substitution
Low	Protein content of DDGS	Following the methodologies of [34,39] and [40] it is assumed the marginal protein source (imported soy) will be replaced by the increased use of corn DDGS. The protein content of soymeal is 44%, for corn DDGS this is 27% [41].	
Middle	Hungarian feed tests and US division.	Based on the current practice in the US (taken from Hoffman & Baker [42]). [a]	The study by the University of Pannonia [43] presents the substitution factor based on feeding tests in Hungary (see Table 35).
High	Energy content of DDGS	Following the methodology of [34,39] it is assumed the marginal energy source (barley) will be replaced by the increased use of corn DDGS. The energy content of barley is 8.68 MJ/kg, for corn DDGS this is 10 MJ/kg [44].	

[a] Although beef is the most important sector in the US, but the feed tests form the University of Pannonia did not include beef cattle, therefore this share has been attributed to the dairy sector.

3.4.3 Increased production chain efficiency

Food losses and food waste are often thought to be around half of the food produced [46]. 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 [47,48]. 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 industrialised 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 12).

Equation 11

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

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) (%);

$L_{\text{i,reduced-}}$share of biomass lost in the food chain in 2020 after efficiency improvements (%).

Equation 12

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

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 3.4.1). For the case study, first the current losses have to be estimated. The only estimate of crop-specific losses in the production chain is published in the FAOSTAT database [16]. Kim and Dale [19] used the FAOSTAT data to estimate the potential biofuel production from reduced losses. The data reflects the losses of the commodity during storage, distribution and processing and explicitly excludes the losses in agriculture and households [16]. The FAO states the level of waste is hard to estimate and relies partly on the assessment of local experts and in some cases on generic loss percentages. These estimates are therefore largely uncertain. However, as Kim and Dale stated, these are the best available estimates [19]. Other assessments (e.g. [47,49,50]) on the quantities of losses in Europe are not country or crop specific and also rely on samples or expert judgement.

The data from FAOSTAT are used to calculate the share of crops lost in Hungary. The losses for each crop (average 2007-2011[11]) are expressed as a share of the total supply; which is the sum of the production, imports and stock withdrawals. If no country specific estimates are available for a crop the

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[11] The most recent data in FAOSTAT are from 2011. A five year average has been used as the share tents to very a lot between years (e.g. for corn in Hungary between 0.3% and 2.7% in the period 2002-2011). This could be caused by the uncertainty in the data.

average for the CEE EU countries will be taken. If no crop-specific data is available, the average loss for all other crops will be used as a proxy.

Table 9 presents three scenarios for the reduction of losses in the supply chain, these scenarios are based on the European policy and current best case scenarios in Europe.

Table 9 three scenarios for the reduction in supply chain losses in Hungary.

Name		Description
Low	50% reduction	The European Commission has set a target to decrease food waste by 50% in 2020 [51].
Middle	Best CEE	For each crop the current lowest loss in Central and Eastern European EU countries will be taken.
High	Best EU	For each crop the current lowest loss in the EU will be taken as the lowest loss that can be achieved in Hungary.

Table 10 presents the current losses for corn and wheat and illustrates reduction in the scenarios for corn and wheat production. Table 40 in Appendix E presents the overview for all crops.

Table 10 Current losses in the chain and three scenarios illustrated for corn and wheat, the most important crops in the region. The current losses amount to 152 k ton corn and 80 k ton wheat per year.

Scenario	Corn	Wheat
Current	2.1%	1.8%
Low	1.3%	1.1%
Medium	1.2%	0.6%
High	0.1%	0.3%

3.4.4 Biofuel feedstock production on under-utilised lands

Under-utilised 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" [24]-can be used for the production of biomass with low risk of ILUC. To define the amount of under-utilised 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-utilised 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

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

Where $Pot_{\text{low-ILUC-risk, UUL}}$-additional production potential of biofuel feedstock with low-ILUC-risk on under-utilised land (tonne/year);
A_{UUL}-area of under-utilised land available and suitable for biofuel production (ha);
$Y_{\text{biofuel feedstock}}$-projected biofuel feedstock yield (tonne/ha);
MYF-marginal yield factor (%) for adjustment of the yield due to the lower productivity expected on under-utilised 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 3.4.6).

Hungary has seen a decline in the amount of agricultural land in use since 1990 by 1.1 million hectares [16]. A key reason for agricultural land decline in the early 1990s was decreased demand for the agricultural products from Russia after the collapse of the Soviet Union (see section 2.2). No direct statistics on the amount of under-utilised land exist for Hungary. Therefore an estimate of the available lands is made. Two possible approaches are outlined in Table 11. They focus on the use of abandoned lands and not specifically at degraded lands or marginal lands. In the short term, these are the most promising lands for low-ILUC-risk biofuels. As parts of these areas may already be used for other purposes and functions (including e.g. natural afforestation), not all abandoned land areas may actually be available. This is described in Section 3.4.5 and summarized in Table 11.

Table 11 **Three alternative methods to establish the amount and availability of abandoned land in Hungary.**

	Method	Description
Low	Amount of land that is not in use for CAP	Under the European common agricultural policy (CAP) farmers can be paid to leave a portion of the land unattended. This land can be taken back into production easily and thereby help to increase production. The estimate is based on data from the Agricultural Research Institute of the Hungarian Academy of Sciences that keeps these records [52].
High	Reduction in agricultural land 2002-2012	The amount of abandoned land is estimated by the difference in agricultural land between 2002 and 2012[a]. However, the country has also seen an increase in forest area, which can come in the place of the agricultural land and should not be used for biomass production. Therefore, the estimate of abandoned land will therefore be reduced by the increase in forest area in the same period. No expansion of the built-up environment is assumed, as the national population decreased since 1990 [15]. Land use data are taken from FAOSTAT [16].

[a] This period is chosen based on the most recent data available being for 2012, while a ten-year period is applied in order to account for carbon stocks that increase significantly after ten years of abandonment [53] (see Section 3.4.5). Thus, land abandonment in the 1990s is not included.

The estimates for the availability of land from Table 11 are used in combination with estimates on the productivity of these lands in the three scenarios to calculate the potential low-ILUC-risk corn production in Hungary. These three scenarios are presented in Table 12.

3.4.5 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

Table 12 Three scenarios for the availability of abandoned lands and the productivity of corn on these lands.

	Availability	Productivity
Low	It is assumed that only half of the area in the low estimate of Table 11 will be available for corn production. Some of the areas will be too small or yields will be too low to be profitable.	It is assumed the abandoned lands have a lower productivity and therefore have a yield of only 75% of the projected yield in 2020. This is the standard assumed in Laborde's uncertainty analysis [3].
Medium	All lands in the low estimate of Table 11 will be available for corn production.	It is assumed the abandoned lands have a lower productivity and therefore have a yield of only 75% of the projected yield in 2020. This is the standard assumed in Laborde's uncertainty analysis [3].
High	All lands in the high estimate of Table 11 are considered available.	Laborde's uncertainty analysis sets the upper boundary of the yield on under-utilised lands at 99% of the average [3].

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-utilised land, as it can limit the amount of under-utilised land that could be available for biofuels production. In this case study, this measure is combined with the under-utilised lands measure. The under-utilised lands with a high carbon stock value should not be used for agricultural production. Two of the approaches in Table 11 only focus on the use of agricultural lands that are taken out of production temporarily. These lands are agricultural lands and can therefore be expected to not lead to large carbon emissions when used for the cultivation of corn.

The high estimate of available lands includes the observation of Schierhorn *et al.* (2013) that carbon stocks in abandoned lands start to increase rapidly after ten years [53]. This means that when sites were abandoned more than ten years ago, and if natural afforestation occurs, they are not suitable for conversion anymore due to potentially high carbon stock losses. Therefore, this study excludes areas abandoned longer than ten years ago from the estimate of the available lands. This is clearly a simplification of reality. For identifying specific abandoned sites that may be converted, field checks (incl. assessment of carbon stocks) are needed.

3.4.6 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
- fertiliser management in the crop cultivation (type and amount of fertiliser)
- 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 refuelling 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 fertiliser 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.

Table 13 **Inputs for the BioGrace GHG emission calculation tool in the reference case and a high savings scenario. Where available, case specific data is used. The reference is the current situation or baseline. In column on the right, data from the high production scenario are used as this will give the highest savings.**

	Reference	High savings
Corn yield (t/ha)	6.3	10.0
Energy consumption diesel (MJ/ha/yr)	3.6 [a, h]	3.6 [a, h]
N-fertiliser (kg/ha/yr)	63.0 [b]	59.0 [b,g]
CaO-fertiliser (kg CaO/ha/yr)	1600 [a]	1600 [a]
K_2O fertiliser (kg/ha/yr)	12.2 [c]	21.6 [c,g]
P_2O_5 fertiliser (kg/ha/yr)	10.9 [d]	16.4 [d,g]
Pesticides (kg/ha/yr)	2.72 [e]	3.30 [e,g]
Field N_2O emissions (kg/ha/yr)	0.82 [a]	0.82 [a]
Transport loss [f]	2.1%	0.1%
Transport distance (km)	50 [a]	50 [a]
Ethanol yield LHV ($MJ_{ethanol}/MJ_{corn}$)	0.62	0.62
DDGS production (ton per ton ethanol) [i]	0.95	0.95

[a] default value from BioGrace [54]

[b] FAOSTAT average of nitrogen fertilisers, measured in kg of N-nutrient per hectare of arable and permanent crops in the period 2008-2012 [16].

[c] FAOSTAT average of potash fertilisers, measured in kg of K_20-nutrient per hectare of arable and permanent crops in the period 2008-2012 [16].

[d] FAOSTAT average of phosphate fertilisers, measured in kg of P_2O_5-nutrient per hectare of arable and permanent crops in the period 2008-2012 [16].

[e] FAOSTAT average of total pesticides use, measured in kg of fungicides & bactericides, herbicides, insecticides and other pesticides per hectare of arable and permanent crop land in the period 2007-2011 [16].

[f] we use the losses in the chain here (see 3.4.3)

[g] data from Austria.

[h] As there is no country specific data available, the default value is used. It can however be argued that in Hungary less fuel is used at the moment as mechanisation lags behind that of Austria. Due to a lack of data, this is not included in the calculations.

[i] ratio between the ethanol yield in this research (0.33 t/t_{corn}) and DDGS yield (0.32t/t_{corn}).

To calculate the greenhouse gas savings in the production chain, the BioGrace Greenhouse Gas calculation tool is used [54]. This tool complies to the specifications defined in the EU Renewable Energy Directive (RED) [25]. Table 13 defines the inputs for the calculations in order to come to the GHG savings. Where applicable case-specific information is used for the calculations. If no other information is available, default values have been used. For the *high* scenario the agricultural practices from Austria are taken as a starting point. The use of fertilisers and pesticides are based on the management practices in Austria, because we also assumed these for the yield (see Section 3.4.1.1). With regards to land use change, a GHG emission credit can be awarded for use of degraded lands for biomass production that restore soil organic carbon, however we do not include this here, as the use of degraded lands is not expected (see Section 3.4.5). The BioGrace methodology, like the RED, does not include a penalty to account for the foregone sequestration for abandoned lands that may have developed towards forest [25,54].

3.5 ANALYSIS INTEGRATION

Having evaluated the individual measures, the total potential biomass production with a low-ILUC-risk is analysed (Figure 5). 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 how much land is saved.
- 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-utilised land. For the assessment of the potential on under-utilised land a potentially lower yield on under-utilised 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-utilised 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 lands. 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 3.3). If higher than the

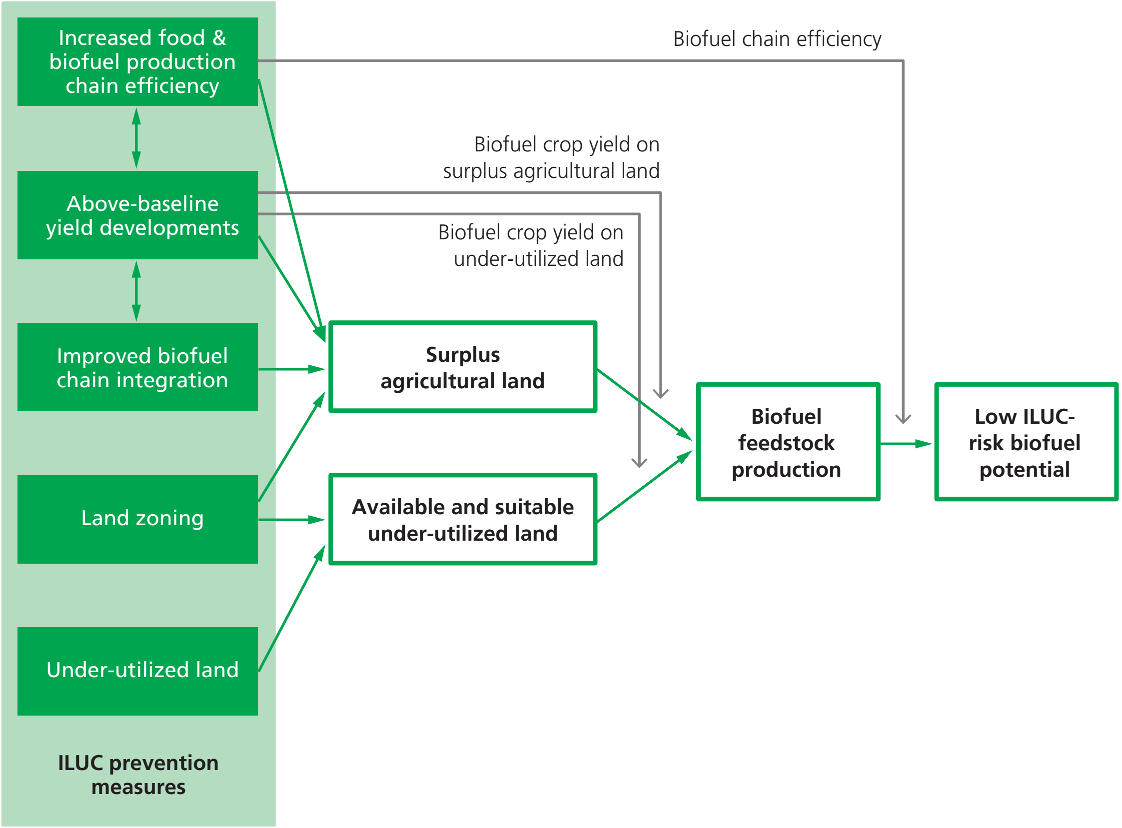

Figure 5 Schematic illustration of integrated analysis

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.

Table 14 presents an overview of the low, medium and high scenarios that are used for each measure to assess the low-ILUC-risk potential (as defined in Sections 3.4.1 to 3.4.5). In the integration phase, the calculations of the separate measures will be combined into a single comprehensive result for each of the scenarios.

Table 14 Overview of the scenarios for the various measures.

	Above baseline yield increase (crops)	Above baseline yield increase (livestock)	Increased chain integration	Increased chain efficiencies	Land zoning and biofuel feedstock production on underutilised lands
Baseline	Crop specific projections from MIRAGE for the EU27 disaggregated to Hungary based on the current yield in Hungary as a share of the current EU27 average.	No change in the productivity per cow or hectare.	None	No change in the losses	Underutilised lands will remain non-productive.
Low	Yields keep increasing at the average linear rate of the period 1961-2011.	The current productivity in Slovakia.	Replacement on basis of protein content (i.e. imported soy).	Meet the EU target of 50% food loss reduction throughout the whole chain.	Half of the lowest estimate will be taken into production at 75% of the average productivity.
Medium	The average yield in Hungary reaches the yield level in the current (2008-2012) best county.	The best historical productivity in Hungary.	Replacement based on feed tests in Hungary and division data to the livestock sectors from the US.	Gain the same level of chain losses (per crop) as the current best CEE country	All the lands in the lowest estimate will be used, at 75% of the average yield.
High	The ratio between the maximum attainable yield and currently achieved yield in Austria is applied to the maximum attainable yield in Hungary.	The current productivity in East Germany.	Replacement based on energy content (i.e. barley)	Gain the same level of chain losses (per crop) as the current best EU country	All lands in the highest estimate can be taken into production at a productivity of 99% of the future average yield.

4 Results

For the measures presented in the previous section, the amount of surplus land they may make available in Hungary and the quantity of low-ILUC-risk corn that can be grown on these lands are presented in this chapter (Section 4.1 to 4.4). In order to put these results in context, this includes a comparison of the results with the amount of bioethanol defined in the national renewable energy action plan (NREAP) for Hungary in 2020 (304 ktoe or 13 PJ, [55]) and the projections for the EU road transport energy use in 2020 (12 EJ, [56]). Section 4.5 presents the GHG emissions of the corn ethanol supply chain, while Section 4.6 shows the results of integrating the different measures (also compared to the NREAP and the EU road transport energy use for 2020).

4.1 ABOVE BASELINE YIELD INCREASE

The surplus land and potential extra production as a result of the crop yield increases are presented in Table 15. The potential additional production of Hungarian corn for bioethanol with a low risk of causing ILUC from increases in crop yields is in all scenarios enough to meet the NREAP. In order to realize this potential, particularly in the high scenario, large yield increases are assumed. These are based on the ratio of actual yields to maximum attainable yields in Austria (for corn 96%, for the other crops 42-74%, see Appendix C). Although yield increases are high, the absolute yield would still be lower than in Western Europe (see also the discussion in section 5.1.1 on the feasibility of these yield increases).

Table 15 **Surplus land in 2020 as a result of the yield improvements scenarios, divided to the effects on corn, wheat and other crops. The columns on the right present the potential extra corn and ethanol production.**

Scenario	Surplus land (k ha)			Extra corn production (k ton) [a]	Extra ethanol production (TJ)[b]	%NREAP bio-ethanol [c]	% EU road transport energy 2020 [d]
	corn	wheat	Other crops				
Low	169	201	-27[e]	2,498	21,582	170%	0.18%
Medium	232	197	36	3,598	31,089	244%	0.26%
High	468	136	55	6,556	56,645	445%	0.47%

[a] The corn production on the land is calculated based on the projected corn yield in 2020 in the three different scenarios (Section 3.4.1.1).

[b] At an ethanol yield of 0.335 $kg_{ethanol}/kg_{corn}$ and an energy content of 27 $MJ/kg_{ethanol}$

[c] The national Renewable Energy Action Plan (NREAP) projects Hungary will produce 304 ktoe (12,728 TJ) of bioethanol in 2020. The amount that can be produced with low-ILUC-risk is expressed as a percentage of this NREAP target.

[d] The Joint Research Centre projects a road transport energy use in 2020 of 288 Mtoe (12057 PJ) [56]. The amount that can be produced with low-ILUC-risk is expressed as a percentage of this amount.

e The negative value for the surplus land in the low scenario for other crops means the projected yield for those crops increases faster in MIRAGE than the average for the period 1961-2011 in Hungary. The share of the other crops in Hungary is relatively small and is therefore compensated by the increases in corn and wheat.

Table 16 Surplus land in 2020 as a result of the yield improvements in cattle farming. The columns on the right present the potential extra low-ILUC-risk corn and ethanol production.

Scenario	Surplus land (k ha)	Potential extra corn production (k t) [a]	Extra ethanol production (TJ)[b]	As percentage NREAP bio-ethanol [c]	% EU road transport energy 2020 [d]
Low	16	102	879	7%	0.01%
Medium	126	798	6,897	54%	0.06%
High	209	1,324	11,436	90%	0.09%

[a] The corn production on the land is calculated based on the projected corn yield in 2020 in the MIRAGE model (Section (Section 3.4.1.1)).

[b] At an ethanol yield of 0.335 $kg_{ethanol}/kg_{corn}$ and an energy content of 27 $MJ/kg_{ethanol}$

[c] The national Renewable Energy Action Plan (NREAP) projects Hungary will produce 304 ktoe (12,728 TJ) of bioethanol in 2020. The amount that can be produced with low-ILUC-risk is expressed as a percentage of this NREAP target.

[d] The Joint Research Centre projects a road transport energy use in 2020 of 288 Mtoe (12057 PJ) [56]. The amount that can be produced with low-ILUC-risk is expressed as a percentage of this amount.

Table 15 indicates that a large share of the potential comes from yield increases in only two crops (corn and wheat). This might make it easier to achieve the assumed yield gains, as improvement options can be focussed on these two crops. However, this does not mean there should be a one-sided focus on these two crops. If the other crops do not show a yield increase the ILUC risk increases again since the region still has to provide all agricultural products without diverting production to other regions. Furthermore, investing in all crops allows reaping benefits for all farmers. In addition to crop yield increases, also yield improvements in the livestock sector can significantly contribute to low-ILUC-risk production of corn (Table 16).

The surplus lands as a result from intensification in the livestock sector are lower than the gains in the crop sector, but still very substantial. The *medium* scenario, based on the highest intensity from the past in Hungary (1968) shows the corn produced on the surplus lands in Hungary can provide up to half of the NREAP bioethanol target.

4.2 IMPROVED CHAIN INTEGRATION

Surplus lands resulting from replacement of animal feed in Hungary due to the use of DDGS is presented in Table 17. This shows both the domestic savings as well as the savings abroad resulting from the replacement of imported soymeal. The additional production of corn is calculated for the domestic surplus lands only. In the *low* scenario there are no domestic land use savings as all DDGS is assumed to replace imported soy. However, this scenario has an additional benefit of land use savings abroad. Only in the *high* scenario all feed replacement is assumed to take place in Hungary, which leads to no savings abroad. The extra benefits of reduced land demand abroad could be more important in a strict carbon accounting sense as the expansion areas are more likely to be on high carbon stock areas and also to have low productivity.

In addition to DDGS, other residues and co-products are produced (see Section 2.3). These are not included in this study because large scale deployment in the short term is unlikely. Instead, we provide here only an approximation[12] of the low-ILUC-risk ethanol potential from corn stover in order to show

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[12] For each ton of maize a ton of straw is available (see section 2.3). Scarlat *et al.* [20] estimated 50% of the residues of maize production would be available. Applying this to the Hungarian situation gives a sustainable removal rate of 3 t_{corn}/ha. Data of DuPont's corn stover ethanol plant that will come online in 2015 in Iowa suggests an ethanol yield of 0.24 ton ethanol / ton stover [64]. This is similar to the assessment by Gerssen-Gondelach *et al.* (2014) that presented a conversion efficiency of 0.25 t ethanol /ton stover [67].

Table 17 Domestic and foreign surplus lands as a result of the use of corn DDGS as an animal feed in different scenarios. The potential corn production is based on the projected yields.

Scenario	Surplus lands (k ha)			Extra corn production (k ton)	Extra bioethanol production (TJ) [a]	% NREAP [b]	% EU road transport energy 2020 [c]
	total	domestic	abroad				
Low	33	0	33	0	-	0%	0.00%
Medium	35	22	13	138	1,188	9%	0.01%
High	42	42	0	268	2,318	18%	0.02%

[a] The corn production on the land is calculated based on the projected corn yield in 2020 in the MIRAGE model (Section 3.4.1.1).

[b] The NREAP is the National Renewable Energy Action Plan; the column presents the share of the NREAP bioethanol production in 2020 that can be achieved by using the surplus lands.

[c] The Joint Research Centre projects a road transport energy use in 2020 of 288 Mtoe (12057 PJ) [56]. The amount that can be produced with low-ILUC-risk is expressed as a percentage of this amount.

the order of magnitude. Thus, if also the stover from only the corn used for ethanol production will be utilised for second generation ethanol production, an additional 1,600 TJ low-ILUC-risk ethanol can be produced. We limit it to the use of the stover only from additional corn production for ethanol in order to avoid competition for this resource with current uses

4.3 INCREASED PRODUCTION CHAIN EFFICIENCY

Surplus land and production potential from reducing losses in the chain (from after harvest to before the household) is presented in Table 18. The largest savings can be achieved in the corn and wheat sector, as these are the two most important crops in Hungary. Reducing the losses to the level of the best Central or Eastern European country (*medium* scenario) can reduce demand for land by 32 thousand hectares that can be used to produce 201 kton of corn.

Table 18 reduction of losses in the agricultural supply chain and the potential extra low-ILUC-risk corn and ethanol production that can be achieved on that land.

Scenario	Loss reduction (k ton)			Surplus land available (k ha)	Potential extra corn production (k ton) [a]	Amount of ethanol (TJ/yr)	% NREAP [b]	% EU road transport energy 2020 [c]
	corn	wheat	other crops					
Low	69	37	23	24	155	1,336	10%	0.01%
Medium	76	59	35	32	201	1,735	14%	0.01%
High	163	76	47	54	340	2,933	23%	0.02%

[a] The corn production on the land is calculated based on the projected corn yield in 2020 in the MIRAGE model (Section 3.4.1.1).

[b] The NREAP is the National Renewable Energy Action Plan; the column presents the share of the NREAP bioethanol production in 2020 that can be achieved by using the surplus lands.

[c] The Joint Research Centre projects a road transport energy use in 2020 of 288 Mtoe (12057 PJ) [56]. The amount that can be produced with low-ILUC-risk is expressed as a percentage of this amount.

4.4 BIOFUEL FEEDSTOCK PRODUCTION ON UNDER-UTILISED LANDS & LAND ZONING

The extra available land that can be used to produce more corn production is shown in Table 19. In the *low* scenario not all the abandoned land is considered as available (see Section 3.4.5), which decreases the potential for corn production and the amount of low-ILUC-risk bio-ethanol that can be produced following this measure.

Table 19 **Potential extra production as a consequence of the utilisation of under used land.**

Scenario	Amount of land available (k ha)	Potential extra corn production (kton/yr) [a]	Amount of ethanol (TJ/yr)	%NREAP [b]	% EU road transport energy 2020 [c]
Low	68	322	2,786	22%	0.02%
Medium	163	773	6,678	52%	0.06%
High	401	2510	21,684	170%	0.18%

[a] The corn production on the land is calculated based on the projected corn yield in 2020 in the MIRAGE model (Section 3.4.1.1).

[b] The NREAP is the National Renewable Energy Action Plan; the column presents the share of the NREAP bioethanol production in 2020 that can be achieved by using the surplus lands.

[d] The Joint Research Centre projects a road transport energy use in 2020 of 288 Mtoe (12057 PJ) [56]. The amount that can be produced with low-ILUC-risk is expressed as a percentage of this amount.

4.5 GHG EMISSIONS

Table 20 presents the results from the BioGrace GHG emission calculation tool for the reference case and the high emissions savings scenario.

Table 20 **Results of the GHG balance calculations in the BioGrace calculation tool.**

Scenario	GHG emissions (g CO_2-eq/MJ $_{ethanol}$)				% reduction [a]
	cultivation	processing	transport	total	
Reference	12.5	25.0	1.8	40.3	53%
High	8.5	25.0	1.8	35.3	58%

[a] Reduction compared to the fossil reference (gasoline) of 83.8 g CO_2-eq/$MJ_{gasoline}$

The results of the greenhouse gas calculations presented in Table 20 indicate it appears the total production chain GHG emissions decrease despite the higher fertiliser application and other measures as a result of the higher productivity. Both the reference and the high savings scenario comply with the GHG emissions savings target compared to regular fossil fuels of 50% defined for post-2017 in the RED [25]. In addition, some more GHG reduction measures are possible (see the discussion in section 5.1.5). However, these are not included in the calculations as they are not expected to be commonly applied by 2020. Note that these calculations do not include any ILUC emissions. This is because the results of the present study show the production of corn can take place without expansion on high carbon stocks lands or diversion of production.

The largest share of GHG emissions in the production process comes from the use of natural gas for heat and electricity production in the ethanol plant. In the low savings scenario, 70% of the GHG emissions come from the processing in the ethanol plant. This includes more than half of the emissions in the plant being deducted as a credit for sold surplus electricity. These values are based on default values from the BioGrace model; the current industry average emission for processing is lower, making the savings compared to fossil fuels higher.

This is not related to land use or agricultural practices. The cultivation of corn accounts for 35% of the emissions, of this fertiliser use and the use of diesel fuel in agricultural machinery contribute the most.

4.6 ANALYSIS INTEGRATION

In the following, the different measures that allow production of additional corn ethanol with low risk of causing ILUC (Section 4.1 to 4.4) are integrated in order to give an overview of the low-ILUC-risk potential of this case study. Figure 6 presents the land use projected to be needed in Hungary in 2020 for demand under the baseline and under the biofuels target (as disaggregated from MIRAGE, see Section 3.2). This is compared to the potential of the various measures to mitigate this effect. The projected expansion of land use in Hungary up to 2020 due to the projected increase in biofuel feedstock is smaller than the surplus available lands generated by ILUC prevention measures in the *low, medium*, and *high* scenario. The land use is projected to increases by 0.27 Mha in Hungary between the current situation and the target (based on disaggregating MIRAGE). The surplus lands in the *low* scenario are 0.36 Mha. This is more than the amount required, which means that the projected production can take place in Hungary without diverting production or expansion on high carbon stock lands and extra low-ILUC-risk biomass can be produced.

The low-ILUC-risk biomass production in Hungary is 3.1 Mt in the low scenario and 13.4 Mt in the high scenario (Table 21). This corn can be used for the production of bioethanol, without causing diversion of production or production on high carbon stock lands. In the *high* scenario, this low-ILUC-risk corn production equates to an increase of 185% over the current corn production in Hungary. This would result in roughly 1% of the EU transport sector energy projected for 2020, or three quarters of fuel ethanol used in Europe today. Figure 7 shows the breakdown of the low-ILUC-risk bioethanol potential by measure. The above baseline yield development is the most important measure to reduce ILUC-risk; accounting for 83% of the total potential in the low scenario and 65% in the high scenario. In addition, especially in the high scenario, producing corn on currently under-utilized land can contribute a large share (30 %) of the low-ILUC risk potential. However, this share is more uncertain, due to the uncertainty in the abandoned lands and their availability and productivity.

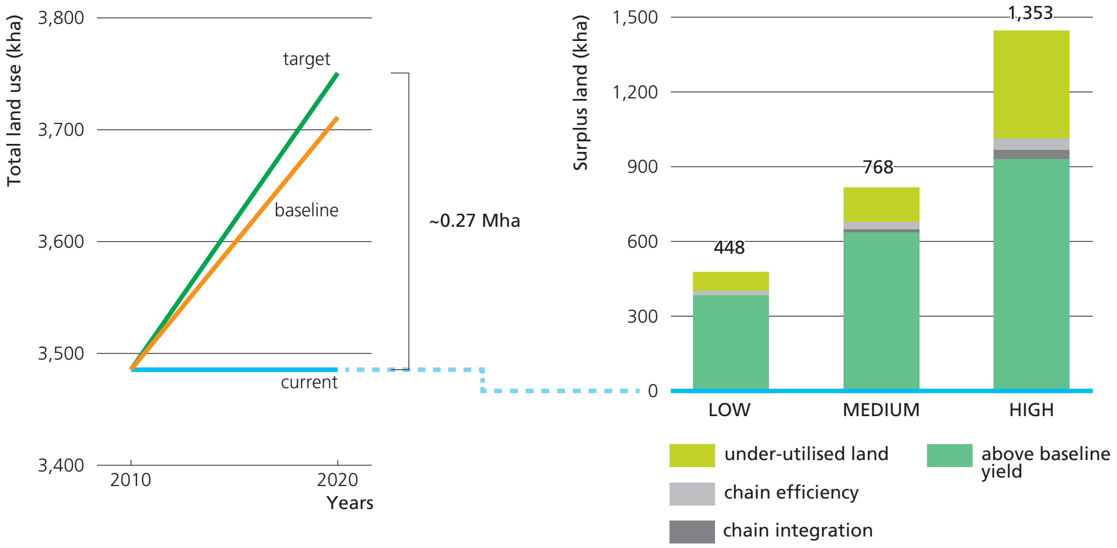

Figure 6 **Comparison of land use change projected in MIRAGE (left panel) with land generated from ILUC prevention measures (right panel). The left panel shows the current and projected (baseline and biofuels target) land use in Hungary for the cultivation of crops according to a disaggregation of results from MIRAGE. The right panel shows the potential of each measure to overcome the gap between the target and current land use.**

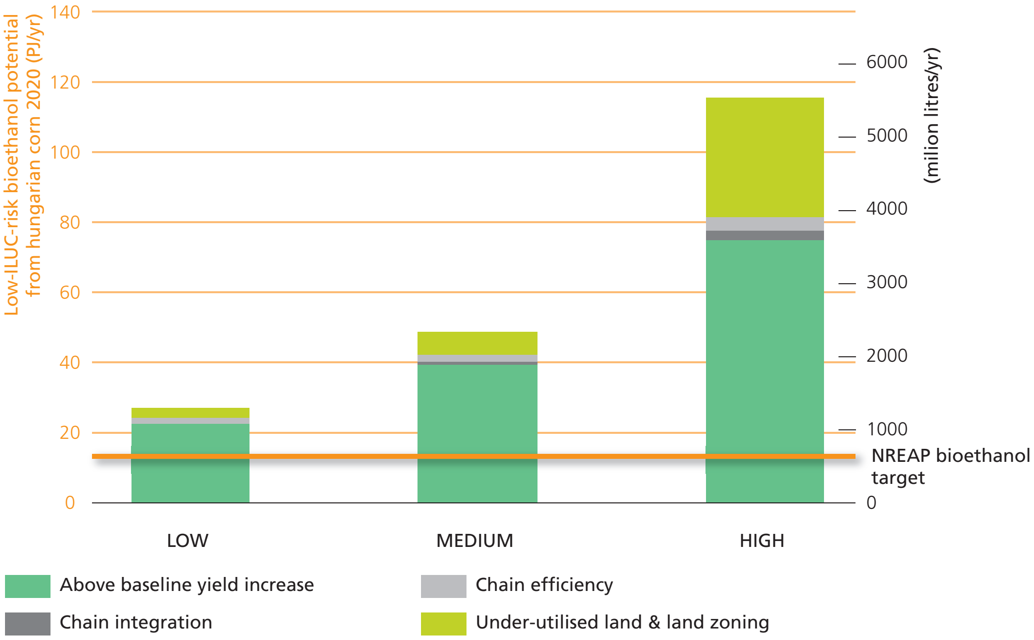

Figure 7 Extra bioethanol production per year for each measure in the *low*, *medium* and *high* scenario

Table 21 Low-ILUC-risk corn production in Hungary and the potential bioethanol production in the *low*, *medium* and *high* scenarios in 2020.

	Low-ILUC-risk corn production (k ton/yr)	Bioethanol production		%NREAP	% EU road transport energy 2020 [b]
		TJ	Millions of litres		
Low	3143	27,155	1.293	213%	0.23%
Medium	5656	48,872	2.327	384%	0.41%
High	13371	115,527	5.501	908%	0.96%

[b] The Joint Research Centre projects a road transport energy use in 2020 of 288 Mtoe (12057 PJ) [56]. The amount that can be produced with low-ILUC-risk is expressed as a percentage of this amount.

5 Discussion

5.1 ILUC PREVENTION MEASURES

5.1.1 Above baseline yield improvements

Yield improvement in the agricultural sector is the most important measure for the production of low-ILUC-risk corn in Hungary. The yield gains to 2020 in the *low, medium* and *high* scenario are in some cases very large. The increases over the current (2010) corn yield in the *low* and *high* scenario are 18% and 61%, respectively (equivalent to 1.6-4.9% annually). This seems a very large increase to achieve in a limited amount of time and therefore requires an explanation for why it is still considered feasible.

First, the last decade (2001-2010 compared to 1991-2000) saw an increase in Hungarian corn yields of 20% and in the 1970s compared to the 1960s the yield growth was 54%. Thus, yield growth rates such as those proposed in the high scenario have been seen before. Furthermore, the Hungarian yield was closer to the world's highest yields in those years than now. Currently the corn yield is around 25% of the world best, at the end of the 1970s it was around 65% of the then best yields [16]. Expressed as a percentage of the current best worldwide corn yield, Hungary would improve to 37% in the high scenario. Second, the yields are compared to currently maximum attainable yields. Research has shown that yield growth is easier to achieve if the yield gap is larger [5657]. For example, a historical comparison of yield developments of key crops and livestock products produced in in Western and Central and Eastern Europe by De Wit *et al.* [58] showed that between 1961 and 2007 the annual yield growth rates ranged between -1% and 6%. The larger yield increases took place in Central and Eastern Europe compared to Western Europe, but they were also the more volatile than in Western Europe. However, the analysis by de Wit et al. [58] also shows periods of very large yield growth are accompanied by stimulating agricultural policies. In Hungary, agricultural production on small family farms is currently predominant for both crops and livestock raising. Although scaling up is thought to be an important approach for increasing yields [58] still other measures are available for increasing smallholder yields. Therefore, stimulating agricultural policies need to specifically address the issues faced by smallholder farmers. For example, improving farm machinery is an important means to increase productivity. However, small family farms often lack (access to) capital needed to be able to invest into modern, more efficient machinery. While cooperatives might help overcome this hurdle in other regions, they are more difficult to implement in Hungary due to the past experiences with cooperatives in the communist period. But also agricultural service companies that rent machinery and help promote mechanisation and precision farming among smallholders will help to increase their yields.

This study also addressed increasing livestock productivity by focusing on grazing animals (i.e. increasing livestock density on pastures). While such a transition could reduce land use by livestock production even further, it also comes with issues related to animal welfare. The consequence of focussing on production intensification for grazing animals is that the surplus areas would be generated from current grasslands. However, converting pastures to cropland is also a form of land use change and can be undesirable in terms of e.g. changes in carbon stocks or biodiversity. This depends on the quality and status of the pastures and the crop that will replace them and crop management. Highly biodiverse or high carbon

stock grasslands should therefore not be considered for conversion to bioenergy. This is for example already accounted for under the rules of the RED, where biofuel production on grasslands that were highly biodiverse in 2008 cannot be taken into account for the targets [25].
An aspect that has not been directly included in the calculations is a rebound effect, when yields and production rise, the crop prices will decrease, thereby creating new demand for agricultural products.

5.1.2 Improved chain integration

In this study we assessed the replacement of feed production from DDGS. In the *low* and *high* scenario, we used two extremes of potential replacement options to illustrate the bandwidth for this measure: in the low scenario, no replacement is assumed to occur in Hungary, while in the high scenario it is assumed that all replacement occurs in Hungary. For the calculation in the *medium* scenario mostly data from the United States is used. It is debatable to what extent the US situation can be applied to Hungary. The market situation and thereby the cost structure of feed is different, this influences decisions on which feed will be used. However, US data is the only available aggregated data for substitution and division of the DDGS to different sectors. For Hungary and Europe only test data are available. Furthermore, the market in Europe is less mature, which makes it harder to draw conclusions on the division of DDGS to the various livestock sectors.

An aspect that has not been included in the calculations is a potential rebound effect in the meat consumption. Increased supply of DDGS can lead to reduced costs in meat production. This can, in turn, lead to increased demand for meat and thus for feed and agricultural land. The macro-economic models include such effects, but it is outside the scope of this research to make estimates of the size of this effect. There are, however, also other benefits from DDGS usage as animal feed, which are not quantified in this research. For example, DDGS also has higher phosphorus, calcium and sulphur levels, which reduce the need for other food supplements [38]. Furthermore, some countries have a preference for yellow chicken meat over white chicken meat. Corn in the diet is an important determinant of that colour.

5.1.3 Increased chain efficiency

Few data sources are available on crop losses in the chain and most are not crop- or sector specific (see Section 3.4.3). Our assessment is that the presented losses, based on the FAO database, are an underestimation of the actual losses. This is based on two key aspects: First, aggregating this data and comparing it to other estimates (e.g. [46,49]) shows this estimate is significantly lower than the others[13]. Second, the losses are expressed as a percentage of the total supply and are multiplied by the future production, which disregards the imports and stock withdrawals. This gives lower future and potential losses. Despite these shortcomings, this method is selected as the FAO is the only crop and country specific data available.

Our estimate of current losses only includes the major crops in Hungary and no animal products, which means that we underestimate the saving potentials. In order to improve the reliability of the results, better data on crop losses (crop, sector and spatially (e.g. county or provincial) more specific) are needed.
In addition, while this study focused on losses up until the consumer, other sources show that the largest losses are with consumers in the form of food waste. Reducing this has a large potential to reduce land use for food and feed production, but this lies outside the scope of this research to include as low-ILUC-risk biofuel production.

5.1.4 Biofuel feedstock on under-utilised lands & Land zoning

As there is no data available on marginal and degraded lands in Hungary, these are excluded from this analysis. Under-utilised land therefore refers to abandoned agricultural land in this case study. More

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[13] In a study for the European Commission to assess the quantity of food loss in the European Union a best estimate for each member state was made [46]. For Hungary this estimate was around 1.8 M ton, of which 1.2 Mt in processing. This is four times as large as the estimate based on the FAOSTAT data. The authors cite as an important limitation to their research that Eurostat data is incomplete and potentially inflated due to inconsistencies in definition [46].

precisely, only abandoned cropland is included because there has been a small increase in the area occupied by meadows. This means the complete decrease in agricultural area is accounted for by decrease in crop land.

The high estimate of available lands is significantly higher than the two other estimates because it considers all abandoned cropland (see also Section 3.4.4 and 3.4.5). However, the available statistics do not indicate why the land was abandoned. Here we assume it is all abandoned land that can be reused or has converted into new forest lands. But there are other potential uses for this abandoned cropland, for example infrastructure and other built-up areas. However, currently 6% of Hungary is covered by built-up areas, this is 543 k ha [59] As population has decreased in the previous decade, any potential expansion of built-up areas is expected to be small.

5.1.5 Lower GHG emissions in the chain

Around one fifth of emissions in the bioethanol production chain are in the cultivation phase (see Table 20). The majority of these emissions stem from the use of fertilisers. The amount that has been used for the calculations in the *reference* is the current average fertilizer use in the Hungarian agricultural sector (from FAOSTAT, [16]). For the *high* scenario, Austrian data for average fertilizer use have been taken. This means these values can be compared. But they might be less representative for the corn ethanol production as it is unknown how this average fertiliser application relates to the average fertiliser use for corn production in Hungary and Austria. In the United States, for example, fertiliser use is higher in corn production than in wheat or soybean production[14].

A major source of GHG emissions is omitted in this calculation tool. During fermentation large amounts of CO_2 are produced and emitted to the air. But this is omitted from the calculations as it is from a biogenic source. However, use of carbon capture and storage technologies might help to sequester this carbon source for long time, thereby creating negative emissions and reducing the carbon footprint of corn ethanol even further [60-62]quality and capture of CO_2.

5.2 DATA UNCERTAINTY [15]

In order to calculate the potential surplus area and low-ILUC-risk biomass availability, several different data sources were used to quantify the measures. As described in the previous sections, sometimes data were lacking. Other times data were available but not at the required spatial or temporal scale or with low reliability. Therefore Table 22 presents an overview of the data sources that have been used and the characteristics, reliability and uncertainty of the data. Especially if no or not-country specific data were available, other assumptions had be made as input for the calculations. The table presents an overview of the uncertainties that are associated with these assumptions or imperfect data sources.

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[14] This is separately reported for four crops by the USDA (corn, wheat, cotton and soybeans) [68]. Nitrogen fertiliser use per hectare is twice as high for corn as for wheat.

[15] The data sources for this case study and the case study on Eastern Romania show a significant overlap and data issues are similar. As a result, this section shows an overlap with the same section in the ILUC prevention case study report on Eastern Romania [65].

Table 22 Data sources and uncertainties for the indicators that we use in the analysis.

Indicator	Data source	Level				Remarks on uncertainty
		local	national	Continental (EU)	world	
Production data (volume)	[16]		X	X	X	Most used source for production data. We do take a five year average in order to correct for influences such as the weather.
	[17]	X	X	X		The Eurostat databases provide the most detailed data on local level, although not all data are provided on that level of detail. Furthermore, not all crops are presented in this database.
	[15]	X	X			Reliability of the national data is unclear. Production volumes might be i) underestimated as a part of agricultural production went on sale on the black market in order to avoid taxes or ii) overestimated by local governments that want to improve their standing.
	[26]	X	X			The German statistics database used for livestock sector provides data on country level and the level of the Bundesländern
Projected future production volumes and yields	[3]			X		As MIRAGE only presents the results at the EU level, the data were disaggregated to Hungary. This creates additional uncertainties as different disaggregation methods can be supplied.
Chain losses	[16]		X	X	X	Considered as the best data available as it is country and crop-specific. However, for some crops or countries no data is available. The methodology is very general and partly consists of applying uniform loss percentages that can be corrected by local experts.
Maximum attainable yield	[63]	X	X	X	X	The IIASA database is spatially explicit, which makes it very well adaptable to a specific case study. However, the data seems to be partially outdated as the yield currently achieved is sometimes higher than the maximum attainable yield. Furthermore, not all crops are included in the database, so that this approach cannot cover all crops.
Future yield	[3]			X		It is only available at EU level; therefore it has to be disaggregated, which increases the uncertainty.
Abandoned land	[16]		X	X	X	No abandoned land statistics are available. Therefore, calculations were made to estimate the abandoned lands. The size and vagueness of the category “other lands”, which comprises everything that is neither agricultural land nor forest, makes this difficult. Also the extent to which forest lands are actually classified as such is unclear. For example, it can be advantageous to not label land as forest because this would mean conservation laws might apply.
	[52]	X	X			The data for the CAP can be deemed reliable, as these are used for the payment of subsidies to farmers that leave their lands outside of production. Although as with other sources fraud can not be ruled out.
DDGS Inclusion rate	[42]		X			The data from Hoffman & Baker is specific for the situation in the US. It is uncertain if that situation can be applied to Hungary.
Substitution rate for DDGS	[43]		X			There have been several feeding tests for Hungary, but these remain specific per livestock type and generalising it to a macro level is difficult.

6 Policy and governance options to realize the ILUC mitigation potential [16]

Production of biofuel feedstock with a low risk of causing ILUC requires that in the production region future supply of food, feed, fibre and fuel is guaranteed without expanding production onto high carbon stock lands (or other areas important for biodiversity or ecosystem services), or diverting the production to other regions. This case study shows low-ILUC-risk biomass production in Hungary is possible. However, in order to realise the calculated potentials, multiple policy measures need to be implemented. This section outlines the most important policy measures that can be taken in Hungary.

6.1 YIELD IMPROVEMENTS

Agricultural yield improvements were the main measure to increase the biomass production without leading to any adverse land use changes in this case study on Hungary. Policy should therefore focus on this aspect. While there are many concrete measures that can be taken in this respect, two key aspects are important for yield improvements. First, policy measures should not only focus on corn production, but on all crop and livestock production. Although corn production is the main agricultural product in Hungary, yields of all crops can and have to improve in order to reach the low-ILUC-risk biomass potentials presented in this study. Second, policy measures must specifically address smallholder farmers. Promoting agricultural service companies or cooperatives can make equipment, data and purchasing power for agricultural inputs available to smallholders so to share the investment costs and risks. Farmers can be educated on the benefits of the use of better equipment, fertilisers and other chemicals. Land reform to increase the size of farms could help to improve the productivity of machinery and labour, although this is not currently favoured in Hungary. Therefore specific focus on how to increase productivity on small farmers is needed.

6.2 IMPROVED CHAIN INTEGRATION

DDGS is already sold to farmers and in widespread use, so policies to improve its implementation are not required. However, it would be beneficial to stimulate the replacement of low yield crops, as this leads to the highest land savings. Foreign land savings, (i.e. from soymeal) are not included in this research and do not count towards the low-ILUC-risk biomass production potential. Nevertheless, this does not mean there are no savings abroad. And it could even be argued that i) the savings abroad are larger due to the lower yield and 2) the threat of deforestation is larger in important soy meal producing countries such as Brazil and Argentina.

Sustainable use of other co-products (e.g. stover and corn oil) can increase resource efficiency. Recently new production facilities that use corn stover for second generation biofuel production have come

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16 The policy recommendation for this case and the Eastern Romanian case study [65] are very similar. Therefore, the sections on policy measures in both reports show overlap.

online in the United States [64]. While less or slower developments are seen in Europe, the use of crop residues for biofuels can add to the low-ILUC-risk potential. Important is that only crop residues are applied for bioenergy that are not already used for other purposes and functions (such as livestock feed and bedding, maintenance of soil carbon stocks or prevention of soil erosion).

6.3 IMPROVED CHAIN EFFICIENCY

Decreasing losses in the food chain requires more stimulation. The EU has a 50% reduction target until 2020, but this is mostly focused on households, which fall outside the scope of this research. The losses in the rest of the production chain are estimated as quite low, but sufficient data is lacking. In order to make a more precise assessment, data availability and reliability need to be improved. As with the yield improvements, also for the improved chain efficiency the policies should focus on all crops and not only on corn.

6.4 BIOFUEL FEEDSTOCK ON UNDERUTILISED LAND

For under-utilised lands the most critical issues are i) the amount of land that is available and ii) the potential competition with other land uses, such as reforestation. Analyses suggest abandoned land has been converted to forest, but is not registered as such [53,65]. This would mean conversion of these abandoned lands can have a negative impact on the carbon balance (and other unwanted environmental impacts) and should therefore be avoided. More research is needed to improve the understanding of current land use. A good land registry with detailed information on land use (extensive and intensive), land cover and biophysical aspects would make it easier to identify suitable and available abandoned land and help directing sustainable investments to the right places. Furthermore, such data will then help informed decision making one land use (zoning) policies.

7 Monitoring ILUC and ILUC prevention measures

An important aspect of policies is to monitor their effectiveness. Table 23 and Table 24 present the parameters that are ideally monitored in order to assess the effectiveness of general land use (change) and specific ILUC prevention policies. The indicators in Table 23 are related to agricultural production and land use and can help to determine whether the policy measures are effective to limit unwanted land use change. The parameters presented in Table 24 can help assess the specific policy measures and keep track of whether the policy measures are on track. Desired frequency and spatial scale are suggested for each parameter. The tables also present the purpose of the monitoring in the form of questions that could be answered with sufficient monitoring of the proposed parameters. The parameters listed in Table 23 and Table 24 are explained in more detail.

More accurate measurements on land use can help to keep track of land expansion within the region in order to prevent large-scale expansion on high carbon stock lands (or other environmentally sensitive areas). The land use and land use change can be monitored with a combination of field measurements and using satellite and other remote sensing data. The purpose of monitoring land use is to identify the under-utilised lands in Hungary to track to what extent these are taken into production, and to identify and then stop unwanted forest cover and biodiverse grassland changes to cropland. Furthermore estimation of the carbon stocks should be included in monitoring. Currently, accurate data for this is lacking. For example, the case study on ILUC prevention in Eastern Romania showed a discrepancy between the official land use statistics and satellite data [65]. Furthermore the satellite data showed that between three measurements land was converted back-and-forth between agriculture and forest, which increases the importance of good land zoning policy and enforcement. Knowledge on where new forests are is vital to implement effective zoning policies. In addition, land that is abandoned or set-aside according to the statistics can be used in practice for extensive uses such as livestock herding. A yearly update of the data ensures these are up to date and helps to better track land use expansion.

Table 23 **Main parameters to be monitored in Hungary to ascertain no unwanted land use change takes place.**

Parameter	Purpose of monitoring	Desired frequency	Desire spatial scale
Land use	Is any land use expansion taking place? Are under-utilised lands taken into production? How much under-utilised land is still available? Are forests, biodiverse grasslands or other important ecosystem service areas converted to crop production?	Yearly	Spatially explicit
Production volume	Production developing as projected?	Yearly (at a five year average)	Country level
Trade balance	No major increase in imports of agricultural products or processed goods? Or decrease in exports? Decrease in soy and other feed imports?	Yearly (at a five year average)	Country level
Agricultural prices	Absolute price stability? Relative price stability?	Seasonal	Country level

Table 24 **Parameters to assess the effectiveness of the ILUC prevention measures.**

Parameter	Purpose of monitoring	Desired frequency	Desire spatial scale
Yields	Is the yield increase in the different crops as high as desired?	Yearly (at a five year average)	Country level (incl. ranges)
Investments	Are investments in machinery increasing?	Yearly	Country level
Fertiliser use	Is fertiliser use in Hungary increasing? Is it at the level of the rest of Europe? Is it used in bulk or in precision farming?	Yearly	Country level (incl. ranges), crop-specific
Pesticide use	Is pesticide use in Hungary increasing? Is it at the level of other European countries?	Yearly	Country level
Chain losses	How high are the losses? Are they reducing as much as expected?	Continuously	Crop specific at country level
Development of under-utilised lands	How much abandoned land exists and where? What quantity is being taken into production and for what? Where is reforestation taking place and what are the carbon stocks? Where are abandoned areas used extensively and for what purpose?	Yearly	Spatially explicit
Quality of degraded lands	Is crop production possible on these lands? What yields can be achieved on the degraded lands?	Yearly	Spatially explicit
Quantity of degraded lands	How much degraded land is available and where? How much is taken into production?	Yearly	Spatially explicit
Feed use	How much DDGS is included in the feed? What and how much does it replace?	Yearly	Feed specific country level

The production volume of the major crops needs to be monitored in order to establish whether the projections from the model are accurate. Too low production can simply be a consequence of decreasing worldwide demand; or it can be a precursor of increased imports or reduced exports and thereby increased risk of undesired land use change as the extra production needs to take place outside Hungary. Too high production could indicate increasing demand, not accounted for in the model. This risks unwanted land expansion on e.g. high carbon stock lands in Hungary.

Agricultural prices need to be monitored as well. Large price increases in Hungary can indicate too low production to cover food, feed, fibre and fuel demand, thereby not fulfilling one of the basic principles of the approach taken in this project. In addition, rising prices can trigger indirect land use change through market-mediated effects. Pressure from the market can act as an incentive to increase the supply of a specific crop, thereby diverting production of other crops to other regions, which could lead to land use change elsewhere. Agricultural prices should be monitored on a seasonal basis. Farmers cannot respond immediately to changes in market conditions, they will have to wait to the next growing season to adjust production.

It should be stressed that one parameter is not sufficient in order to assess the development of the ILUC risk. The parameters should be considered in relation to each other for effective monitoring.

Crop yield data are already collected by the national statistics office [15], EUROSTAT [17] and FAOSTAT [16]. This is sufficient to monitor the average yield developments. But more data on the variation in yields (e.g. yield ranges on national, provincial and county level and yields for different producers such as large vs. smallholder farms) are useful to identify areas that need additional attention for increasing yields. It should be noted that the yearly yield changes are less relevant as these are strongly influenced by weather patterns. Therefore, a five year average is more useful to assess improvements in the Hungarian agricultural sector. As threshold value[17] for the parameter, the potential above baseline yields are a good value. When the actual yield is below the potential value, it denotes the potential low-ILUC-risk biomass production from these measures cannot be achieved. Thus, biofuel production should be reduced or additional measures must be taken in order to prevent ILUC.

As previously mentioned measures to increase the yields include increased mechanisation, modernizing farm equipment and improved fertiliser use. FAOSTAT [16] and the World Bank [12] already keep records of investments, mechanisation and fertiliser use in agriculture. These data are often not up-to-date. However, if collected yearly, they could be a proxy for the yield improvements. Particularly fertilizer use and pesticide use data can be used to assess the environmental impacts of the changes in the agricultural sector. Monitoring how (much) it is used and applied for different crops will help to identify areas of improvements.

The first step for monitoring crop losses in Hungary would be to establish the current losses, as no accurate crop-specific data is available at the moment. With continuous monitoring of the losses in the supply chain, it is possible to assess if the reduction matches the target.

The development of abandoned lands needs to be monitored to see how much land is available and to see if it is taken into production. Spatially explicit data would ideally be used for this. For example, if the amount of abandoned land increases at the expense of agricultural land, forest might in turn be converted to agricultural land to produce food crops. This type of information is not currently shown in the agricultural land statistics, and therefore underlines the importance of considering all land use and land use change in Hungary. It also shows the usefulness of spatially explicit data when assessing the available lands.

Ethanol production from Hungarian-grown corn can take place in many countries. For DDGS a similar situation occurs, the DDGS can be used in Hungary and replace Hungarian agricultural production, but this is not certain. For monitoring we suggest to consider the share of each feed crop in the Hungarian feed mix, this enables the establishment of how much feed is replaced by the use of DDGS and where this feed originated. As the animal feed mix is continuously changing, a yearly overview of feed use is needed.

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[17] Where applicable, a threshold value per parameter is defined. These values identify the level and bandwidth within which the parameter should be in order to keep on the track of producing low-ILUC-risk biomass.

8 Conclusions

This case study assessed the potential bioethanol production from Hungarian corn with a low risk of ILUC in 2020. The potential production of low-ILUC-risk bioethanol from Hungarian corn ranges between 25-109 PJ (1.2 to 5.2 billion litres) in the *low*, *medium* and *high* scenario. This is 200 to 860% of the bioethanol production target specified in the National Renewable Energy Action Plan (NREAP) for Hungary in 2020 and equates to roughly 1% of EU transport sector energy or 75% the amount of fuel ethanol being used in the EU today. The analysis accounted for additional production of food, feed and fibre so that this biofuel potential comes without the need for expansion on high carbon stock lands (or other environmentally sensitive areas) or diversion of production to another location.

Increasing yields above the baseline is the most important measure for realising the potential. Depending on the scenario, 49%-79% of the low-ILUC-risk potential comes from yield increases. Although the yield increases applied in this study are high (for corn: 18%-61% growth in comparison to the present yield), they are considered feasible given the currently high yield gap in Hungary. The importance of yield increases in the low-ILUC-risk potential suggests the focus of policy and company efforts should also be on yield increases. This should not only target corn but all crops as only about 50% of the low-ILUC-risk biofuel potential from yield increases comes from improvements in corn yields, the rest comes from increasing yields of other crops. Currently, agricultural management practices in Hungary lag behind those in Western Europe, with lower mechanisation and inefficient fertiliser and pesticide use. Optimising fertiliser use can improve production and thereby decrease GHG emissions per unit of crop. However, at the moment farmers often lack capital, knowledge and incentives to invest in agricultural productivity. Therefore, policies to improve the yield need to stimulate and provide incentives these investments in order to improve mechanisation and proper use of fertilisers and pesticides. Thereby, performance of the agricultural sector as a whole can be increased and GHG emission savings from biofuels raised.

The second most important measure is the use of abandoned agricultural land, which can provide additional low-ILUC-risk corn production for bioethanol ranging from 12% to 30% of the total low-ILUC-risk bioethanol potential. Land use policies stimulating the use of currently under-utilised lands is therefore also important for preventing ILUC. However, there is some uncertainty about the abandoned lands in Hungary. More insights are required in the exact location, possible current (extensive) uses and quality of the abandoned lands in order to ensure stimulation of only abandoned land that is under-utilised and has low carbon stocks.

As indicated for the ILUC prevention measures on increasing yields and use of under-utilised land above, the low-ILUC-risk potential will not come about autonomously and a large effort is required for the potentials to be realised. For this it is important to take a sustainable approach to the entire agricultural sector and its modernisation and sustainable intensification and land use. As part of these efforts, monitoring of developments in the Hungarian agricultural sector is necessary in order to ascertain that the policy options have sufficient effect on increasing the productivity and preventing unwanted land use change. Key parameters for monitoring are related to land use and land use change (e.g. land use, quality of abandoned lands) and implementation of land use change prevention measures (e.g. yields,

investments, fertiliser use, production volumes, agricultural prices, losses). More work is needed to define thresholds for these parameters, which can help indicate when future expansion should be prevented.
A key characteristic of indirect land use change is that it takes place at other locations than the bioenergy production. We show in this case study that bioethanol from Hungarian corn can significantly increase with a low risk of diverting production to other locations or expanding on high carbon stock and high conservation value lands. The other case studies conducted in this project (Eastern Romania, Lublin (Poland) and North and East Kalimantan (Indonesia)) show similar results, supporting the claim that ILUC prevention is possible. Each region has its own specificities, but they all can provide food, feed, fibre and fuel within the area of the current agricultural lands and under-utilised lands. For the different settings that we tested in these case studies (first and second generation, bioethanol and biodiesel, in Europe and outside Europe), ILUC prevention measures result in enough additional biofuel production potentials that regional targets can be met and in some cases that even biofuels or its feedstock can be exported to other regions, thereby reducing the pressure on land use elsewhere. This requires large efforts and investments in the agricultural sector, and strengthening and enforcement of land use policies in each region. But this also means that ILUC is not an irreversible fact but is a risk that can be mitigated. This is possible by taking a sustainable approach to all land use for food, feed, fibre and fuels.

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Appendix A Current production in Hungary

Table 25 Current agricultural production in Hungary, based on FAOSTAT data [16].

Crop	Production (kton)								Average 2008-2012
	2005	2006	2007	2008	2009	2010	2011	2012	
Corn	9.050	8.282	4.027	8.897	7.528	6.985	7.992	4.742	7.229
Wheat	5.088	4.376	3.987	5.631	4.419	3.745	4.107	3.740	4.328
Sunflower seed	1.108	1.181	1.060	1.468	1.256	970	1.375	1.317	1.277
Barley	1.190	1.075	1.018	1.467	1.064	944	988	996	1.092
Sugar beet	3.516	2.454	1.693	573	737	819	856	770	751
Potatoes	657	564	563	684	561	440	600	511	559
Rapeseed	283	338	486	655	579	531	527	415	541
Oats	157	151	125	182	111	118	129	140	136
Rye	107	99	81	112	73	78	75	78	83
Soybeans	78	85	54	74	72	85	95	68	79

Table 26 Yearly production of meat, milk and eggs in Hungary in 2011, based on FAO data.

Livestock product	Production (kton)
Milk, whole fresh cow	1,712
Meat indigenous, pig	425
Meat indigenous, chicken	272
Eggs, hen, in shell	137
Meat indigenous, turkey	63
Meat indigenous, duck	59
Meat indigenous, cattle	59
Meat indigenous, geese	24
Meat indigenous, sheep	7.0
Meat indigenous, rabbit	5.6
Eggs, other bird, in shell	3.9

Table 27 Number of animals in Hungary in 2011, based on FAO and national statistics data.

Livestock product	Headcount
Chickens	31,848,000
Ducks	5,813,000
Pigs	2,956,000[a]
Sheep	1,147,000[a]
Cattle	682,000
-of which dairy	309,000
-of which beef	373,000[b]
Goats	75,000
Horses	65,000

[a] 2012 (national statistics office)

[b] the amount of beef cattle are not specified in the statistics, but takes here as the difference between the total cattle stock and the amount of dairy cows.

Table 28 Land use in Hungary for agricultural production of the most important crops, based on FAOSTAT data [16].

Crop	Production (k hectare)								Average 2008-2012
	2005	2006	2007	2008	2009	2010	2011	2012	
Corn	1,198	1,215	1,079	1,192	1,177	1,079	1,230	1,190	1,170
Wheat	1,131	1,075	1,111	1,126	1,146	1,011	978	1,063	1,080
Sunflower seed	511	534	513	550	535	502	580	615	542
Barley	317	293	321	330	321	281	261	276	300
Sugar beet	62	47	41	10	14	14	15	17	27
Potatoes	25	23	25	25	22	20	21	22	23
Rapeseed	122	142	225	247	261	259	234	165	207
Oats	62	59	60	61	52	51	54	53	57
Rye	42	39	40	44	40	37	33	35	39
Soybeans	34	36	33	28	32	38	41	41	35

Table 29 Agricultural yields in Hungary, based on FAOSTAT data [16].

Crop	Yield (ton/hectare/yr)									Average 2008-2012
	2005	2006	2007	2008	2009	2010	2011	2012	2013[a]	
Corn	7.6	6.8	3.7	7.5	6.4	6.5	6.5	4.0	5.4	6.1
Wheat	4.5	4.1	3.6	5.0	3.9	3.7	4.2	3.5	4.6	4.1
Sunflower seed	2.2	2.2	2.1	2.7	2.3	1.9	2.4	2.1	2.5	2.2
Barley	3.8	3.7	3.2	4.5	3.3	3.4	3.8	3.6	4.1	3.6
Sugar beet	57.0	52.4	41.1	59.7	53.6	59.1	57.1	44.5	50.0	53.1
Potatoes	25.9	25.0	22.2	26.9	25.1	21.7	28.6	23.1	21.8	24.8
Rapeseed	2.3	2.4	2.2	2.7	2.2	2.0	2.3	2.5	2.6	2.3
Oats	2.5	2.5	2.1	3.0	2.1	2.3	2.4	2.7	2.7	2.5
Rye	2.6	2.5	2.0	2.6	1.8	2.1	2.3	2.2	3.0	2.3
Soybeans	2.3	2.4	1.6	2.6	2.3	2.3	2.3	1.7	1.9	2.2

[a] Although 2013 data has become available since the start of the case study, these are not included in the calculations. For many sources these are not yet available.

Figure 8 Total corn production in Hungary, per region in 2013. The planes in the south and east are clearly more important agricultural areas in terms of total production. Data are from the national statistics office.

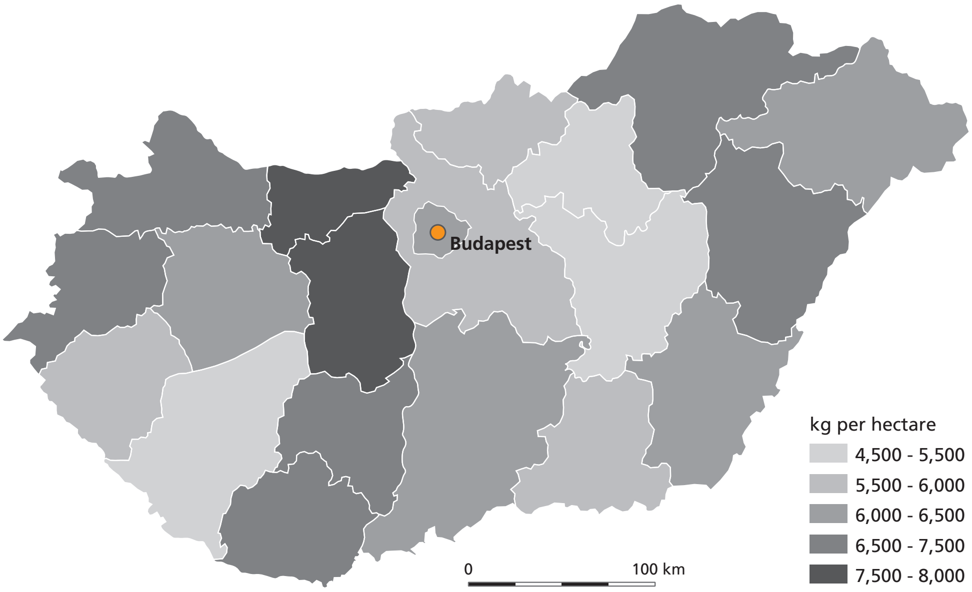

Figure 9 Regional division of the corn yield in Hungary, 2011 data from the national statistics office [15].

Appendix B Region and crop aggregation in MIRAGE

Table 30 **Regional aggregation in MIRAGE [2,3]driven initially by oil price hikes and the need for greater energy security. Support measures were established in many countries in recognition of the potential of biofuel development in reducing dependence on fossil fuels, increasing farm revenues, and generating less environmental damage through lower greenhouse gas (GHG.**

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 31 **Crop aggregation in MIRAGE [2,3]driven initially by oil price hikes and the need for greater energy security. Support measures were established in many countries in recognition of the potential of biofuel development in reducing dependence on fossil fuels, increasing farm revenues, and generating less environmental damage through lower greenhouse gas (GHG.**

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

Table 32 Aggregation of crops in the MIRAGE model.

Crop	Category
Corn	Corn
Wheat	Wheat
Sunflower seed	Sunflower
Barley	Other crops
Sugar beet	Sugar_cb
Potatoes	Other Crops
Rapeseed	Rapeseed
Oats	Other Crops
Rye	Other Crops
Soybeans	Soybeans

Appendix C Maximum attainable yield

The crop yield in an area depends on a combination of biophysical factors such as the soil and climate, combined with the management practices. Management practices are the factors related to agriculture that are decided by the farmers, e.g. the quality of the seed, mechanisation, use of fertilisers and pesticide use. Contrary to soil and climate conditions, that are given and cannot be changed, the management practice in a country can be improved. To estimate how much the yields in Hungary could rise, a comparison will be made with other countries. However, the soil and management conditions in other countries are different from Hungary; the yields are therefore not directly comparable. To tackle this, we express the yields as a percentage of the maximum attainable yield in the different areas to show the improvement potential in Hungary. The assumption is, if certain ratios can be achieved in one country, these can be achieved in other countries as well, irrespective of the biophysical conditions. This does require the management practices improve, for example by stimulating policies and investments in the agricultural sector.

In order to establish the potential of yield improvement for ILUC prevention, we make a comparison between the maximum attainable yield and the current yield. The maximum attainable yield is a limit based on local condition and best practices and describes the maximum crop production. Following the methodology of Smeets *et al.* [66] the average maximum attainable yield for Hungary can be calculated, based on the IIASA Global Agro-ecological Zone (GAEZ) database [63].

In the IIASA GAEZ database, Hungary is divided into 1606 grid cells. For each crop the crop suitability is determined for rain-fed high-input agriculture in the 2020s. The suitability falls in either one of nine categories: Very high (suitability larger than 85); High (>70); Good (>55); Medium (>40); Moderate (>25); Marginal (>10); Very Marginal (>0); Not suitable (0) and water. For each grid-cell also a crop-specific agro-climatic maximum attainable yield is available[18].

Grid cells with a higher than average quantity of forest (22%), with more than 15% build-up area or less than 50% cultivated area are excluded in order to avoid an over-estimation of the available lands. The total area in the database that complies with these limitation is 5419 k ha, which is almost equal to the current agricultural area of 5518 k ha (FAOSTAT average 2008-2012, [16]).

Smeets *et al.* (2004) assume for each crop that production will take place on the most suitable land [66]. Only if too little land in the highest category is available, less suitable land will be used. In 30 iterative steps, all the future production is allocated to the best available land. After allocating the baseline see production (Table 2, p.18) to the land the average maximum attainable yield is calculated by dividing the production by the required land. Table 33 presents the maximum attainable yield for each crop and the ratio between the maximum attainable yield and the current yield (from FAOSTAT [16]).

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[18] The maximum attainable yields are presented by IIASA in dry weight, whereas the FAOSTAT data (that we for the other calculations), includes the water content of the crops. The water content of the crops presented in the GAEZ methodology document is used for the conversion [69].

This shows the productivity is currently between 35 and 60% of the maximum attainable, only the sugar beet yield is significantly higher.

Using the same methodology, the maximum attainable yield in Austria and Poland has been assessed. Austria is a neighbouring country, but with an agricultural sector that is much further developed: using more fertilisers, pesticides and machinery [12]. Poland is like Hungary a large agricultural country that transformed from a communist regime to a market economy at the start of the 1990s and also gained EU membership in 2004. Fertiliser use and mechanisation are higher in Poland than in Hungary; pesticide use is comparable [12,16,17]. The data here illustrate the case that Eastern European countries can improve their management practices and achieve higher yields.

The results, presented in Table 34, show Austria realises a much higher share of the maximum attainable yields, at 40–75%.

Table 33 **Maximum attainable yield (t/ha) in Hungary, based on rain-fed high input agriculture in the 2020s (based on GAEZ reference), compared to the current yield (based on FAOSTAT data [16]).**

Crop	Maximum attainable yield (t/ha)	Current yield (t/ha)	Current yield as share of the maximum attainable yield (%)
Corn	10.4	6.2	59%
Wheat	10.5	4.1	38%
Sunflower	4.4	2.3	52%
Barley	10.6	3.7	35%
Sugar beet	57.7	54.8	95%
Potato	42.0	25.1	60%
Rapeseed	4.5	2.3	52%
oats	4.8	2.5	52%
Rye	6.2	2.2	35%
Soy	4.7	2.2	47%

Table 34 **Current percentage of maximum attainable yields in for Poland and Austria as examples of the comparison. For almost all crops Austria achieves a higher ratio of actual yield to maximum attainable yield, suggesting their agricultural practices are more advanced and that these levels are achievable. The results of Poland are used as an illustration how the ration varies between the two countries.**

Crop	Poland			Austria		
	Maximum attainable yield	Current yield	Ratio	Maximum attainable yield	Current yield	Ratio
Corn	10.4	6.5	62%	10.9	10.4	96%
Wheat	11.7	4.1	35%	11.7	5.2	44%
Sunflower	4.7	1.7	37%	4.7	2.6	56%
Barley	11.7	3.3	29%	11.7	4.9	42%
Sugar beet	62.7	53.2	85%	65.8	69.6	106% [a]
Potato	43.9	19.9	45%	43.8	31.9	73%
Rapeseed	4.6	2.7	57%	4.7	3.1	66%
Oats	5.2	2.6	50%	5.4	4.0	74%
Rye	6.6	2.6	40%	6.6	4.0	61%
Soy	3.9	1.6	40%	4.5	2.7	60%

[a] this is an outlier that is presumably caused by the high absolute yield and from small differences in the water content of the sugarbeet.

Appendix D Use of DDGS

Table 35 Substitution rates of DDGS to corn and Soybeans. The numbers are livestock sector specific. This means the total substitution is the sum within one livestock category. Replaced amounts in t/t DDGS.

	Beef cattle		Dairy cows				Poultry			Pigs	
	Corn	Soy meal	Corn	Soy meal	Sunflower meal	Rape meal	Corn	Soy meal	Sunflower oil	Corn	Soy meal
Laborde [3] [b]			.11	.51	.05	.21					
Wisner [38]	.99	.22	.45	0			.60	.21		.77	.11
Hoffman & Baker #1 [42]	1	0	.45	.55			.51	.50		.89	.10
Hoffman & Baker #2 [42]	1.2	0	.73	.63			.61	.44		.70	.30
University of Pannonia [43]			.38	.31	.56	.27	.61	.44	-.05[a]	.59	.38

[a] more sunflower oil will be consumed, in order to compensate for a decrease in fat.

[b] Laborde distinguishes between cattle and other animals.

Table 36 Division of the DDGS to four livestock sectors.

Scenario	Description	% beef	% dairy	% poultry	% pigs
Laborde	In the report of Laborde the assumed division between cattle and other livestock is almost equal.	50%		50%	
Current division US	Based on the data by Wisner [38], the average division to the livestock sectors in the period 2009-2012 will be used.	53%	34%	5%	7%
Cattle	Pannonia indicated the product is marketed at use in the cattle sector. Therefore a scenario with only use for beef cattle and dairy cows, the ratio between these is the ratio in occurrence in Hungary, see Table 27.	45%	55%	0%	0%
Beef	All DDGS is used in the beef sector.	100%	0%	0%	0%
Dairy	All DDGS is used in the dairy sector.	0%	100%	0%	0%
Pigs	All DDGS is fed to pigs.	0%	0%	100%	0%
Poultry	All DDGS is used in the poultry sector.	0%	0%	0%	100%

The use of DDGS as an animal feed can reduce the requirement to produce other crops. Table 37 and Table 38 present the land use savings and potential extra domestic corn and ethanol production as the result of increasing the DDGS use by 1000 ton. Table 37 gives the results for the changes in the DDGS substitution rate, the inclusion rate is the current division in the US. In Table 38 the inclusion rates are varied, the substitution rate based on the data from Wisner [38].

Table 37 **Land-use savings and potential extra corn and ethanol production due to an increase in DDGS production of 1000 ton for various substitution scenarios.**

Scenario	Total surplus land (ha)	Of which domestic (ha)	Of which abroad (ha)	Extra domestic corn [a] production (t)	extra domestic ethanol production (TJ)
Laborde	568	334	234	2109	18727
Wisner	152	110	42	693	6154
Hoffman & Baker #1	240	110	130	698	6194
Hoffman & Baker #2	297	149	148	942	8361
Pannonia University					

[a] The extra corn production is calculated based on the projected corn yield.

[b] The division of the DDGS tot the sectors is based on the current division in the US, except for the Laborde scenario which is based on the division in the MIRAGE model.

Table 38 **The potential extra corn and ethanol production as a result of an expansion in DDGS production of 1000 ton. The scenarios are the various DDGS inclusion rates.**

Scenario	Total surplus land (ha)	Of which domestic (ha)	Of which abroad (ha)	Extra domestic corn production (ton)	extra domestic ethanol production (TJ)
Current division US	178	120	58	762	6763
Cattle	152	110	42	693	6154
Beef	251	157	94	990	8791
Dairy	71	71	0	450	3996
Pigs	169	122	47	770	6838
Poultry	185	95	90	600	5328

[a] The substitution rate for all the scenarios is based on the replacement rates of Wisner.

At a projected production of 161 k ton DDGS the total land savings and extra potential production in the best and worst-case scenarios DDGS substitution and inclusion rates are presented in Table 39.

Table 39 **Land savings and extra potential to produce corn in Hungary and ethanol from this.**

	Worst case	Best case
DDGS production (t)	161	
Total land savings (k ha)	115	520
Land savings in Hungary (k ha)	115	357
Land savings abroad (k ha)	0	246
Extra corn production in Hungary (kton)	72	162
Extra ethanol production (TJ)	645.8	1435

Appendix E Chain losses

Table 40 **overview of current chain losses in Hungary, Central and Eastern Europe and the EU27 [16].**

	Corn	Wheat	Sunflower seed	Barley	Sugar beet	Potatoes	Rapeseed	Oats	Rye
Current losses Hungary	2.10%	1.84%	0.86%	n/a [b]	n/a	2.68%	0.28%	0.84%	1.35%
Current CEE average [a]	4.43%	4.20%	1.58%	3.20%	0.34%	3.63%	1.93%	4.22%	3.44%
Current EU average	2.33%	2.11%	1.39%	1.86%	0.59%	4.42%	1.99%	2.72%	2.77%
Best CEE	1.17%	0.64%	0.48%	0.71%	0.34%	0.63%	0.28%	0.70%	1.28%
Best EU	0.09%	0.30%	0.05%	0.08%	0.34%	0.63%	0.28%	0.32%	1.08%

[a] CEE is the average of Poland, Romania, Hungary, Slovenia, Slovakia and Bulgaria.
[b] In case data is not available, average data from CEE are used for the calculations.