Universiteit Utrecht

Faculty of Geosciences
Copernicus Institute of
Sustainable Development

ILUC prevention strategies for sustainable biofuels

Case study on the biodiesel production potential from rapeseed with low ILUC risk in Eastern Romania

Marnix Brinkman, Iulia Pişcă, Birka Wicke and André Faaij

Colophon

Authors

Marnix Brinkman	(Copernicus Institute of Sustainable Development, Utrecht University)
Iulia Pişcă	(Copernicus Institute of Sustainable Development, Utrecht University)
Birka Wicke	(Copernicus Institute of Sustainable Development, Utrecht University)
Andre Faaij	(Energy and Sustainability Research Institute, University of Groningen)

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Copernicus Institute of Sustainable Development
Faculty of Geosciences
Utrecht University
Heidelberglaan 2
3584 CS Utrecht
The Netherlands

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Cover photo: Cover photo: Large view at the yellow colza field ©Shutterstock

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C&M [8851], Faculty of Geosciences, Utrecht University

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ABBREVIATIONS

APIA	Agenţia de Plăţi şi Intervenţie pentru Agricultură – Agency for Payments and Interventions in Agriculture
CEE(C)	Central and Eastern Europe(an Countries)
EU	European Union
EU27	European Union before the accession of Croatia.
FAO	Food and Agriculture Organisation
FQD	Fuel Quality Directive
GHG	Greenhouse gas
IIASA	International Institute for Applied System Analysis
INSSE	Institut National de Statistica – National Institute for Statistics
ILUC	Indirect land use change
LCFS	Low Carbon Fuel Standard
LUC	Land use change
RED	Renewable Energy Directive
toe	Ton oil equivalent, 41.87 GJ

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Preface

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

Within the ILUC prevention project, first a general methodology to quantify ILUC prevention measures was developed. Thereafter, four regional case studies were conducted to demonstrate, test and refine this methodology, as well as to assess the availability and reliability of data that are required for the analysis. The case studies also investigated policy and governance options that are relevant in the specific settings. The results were subsequently used to translate the key parameters and pre-conditions into a methodological framework and monitoring and policy options. The case-specific governance options were then used in the development of a general policy framework for governing ILUC mitigation. The present report describes the case study on rapeseed biodiesel production in Eastern Romania, conducted under the umbrella of the ILUC prevention project. Additional case studies focussed on ethanol from Hungarian maize, miscanthus in Poland and palm oil biodiesel in North 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) in collaboration with the Dutch Ministry of Infrastructure and the Environment, and the Port of Rotterdam/Rotterdam Climate Initiative. 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 rapeseed in Eastern Romania presented here, was funded by MVO and FEDIOL.

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 changes (ILUC)** induced by biofuel demand can reduce the greenhouse gas (GHG) emission benefits from the use of biofuels and have become one of the most debated risks associated with the production of bioenergy. **Mitigation and even prevention of ILUC** is therefore essential in making biofuels more sustainable. Because ILUC is the result of the interconnectedness of the bioenergy and agricultural sectors, ILUC prevention also needs to account for the same interconnectedness. Therefore, this case study on quantifying ILUC prevention for rapeseed production in Eastern Romania (Macroregion 2) for conversion to biodiesel accounts for these interactions and takes a holistic approach on the agricultural and bioenergy sectors. **Six key measures to reduce the extent of ILUC, control the type of land use change, and limit greenhouse (GHG) emissions of rapeseed production are investigated**: 1) above baseline increased agricultural crop yield and livestock production efficiencies; 2) increased use of co-products of crop and biofuel production to substitute for other land-based products, such as animal feed; 3) reducing losses in the food and biofuel chains; 4) producing biofuels on under-utilised lands; 5) land zoning of high carbon stock lands (and other important ecosystem functions and services) in order to prevent conversion of these lands; and 6) reducing GHG emissions in the biofuel supply chain. Measures 1-5 are assessed in terms of the low-ILUC-risk production potential of rapeseed biodiesel. For each measure, a *low*, *medium*, and *high* scenario have been defined for above-baseline developments in agricultural productivity, efficiency and land use 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.

The **low-ILUC-risk potential** of rapeseed biodiesel from Eastern Romania can reach 2-16 PJ (68 – 487 million litres) per year in 2020 (see Figure S1), which is in addition to current production. **This is equivalent to 48-344% of the biodiesel target in the Romanian National Renewable Energy Action Plan (NREAP) *disaggregated to the case study region*.** Assuming rapeseed is part of a crop rotation and only produced every four years, in the other years additional biofuels from other feedstock can be produced.

Above-baseline yield development contributes by far the most to this potential (27%-67%). This not only includes yield increases for rapeseed production, but also for all other crops in Eastern Romania. Especially increased maize and wheat yields contribute to the potential. The projected yield increases (e.g. for rapeseed 21%-51% in the period 2010-2020) may seem large at first glance. However, they are considered feasible given the currently large yield gap and the already much higher yields attained in other, comparable regions. To realise these yield increases, **large efforts and investments in the sustainable intensification and modernisation of Romanian agriculture** need to be made. Incentives to invest both in capital and knowledge of farmers in the agricultural sector are required to increase mechanisation, and optimal use of fertilisers and pesticides. Also the recent land reforms by the Romanian government can help to attract investments in the agricultural and land use sectors, and to scale up production.

The second most important measure is taking **currently abandoned agricultural lands** into production, which could contribute 22% to 51% to the low-ILUC-risk potential (Figure S1). A critical issue for the implementation of this measure is to ensure that i) these lands are not currently used (or, if so, that alternative options for allowing this use are found); and ii) abandoned sites that have reforested are not converted. To do so, more (and more spatially explicit) information on the location, current land use and vegetation cover of abandoned agricultural land is needed. This information allows identifying where suitable and available abandoned land is located and helps define strategies for redeveloping them.

This case study demonstrated that the agricultural sector in Eastern Romania can provide **large additional amounts of food, feed, fibre and fuel** in the future without the need for expansion on high carbon stock and high conservation value lands or diverting production to other regions and countries. Thus, the ILUC risk can be mitigated, on the precondition of modernisation and intensification. Only in the low scenario are the proposed measures not enough to completely prevent ILUC. Therefore, in order to prevent ILUC, the agricultural sector needs to be modernised and sustainably intensified, and land zoning needs to be strengthened so that only under-utilised land with low carbon stocks are taken into production. Although this requires large efforts and investments by various actors, particularly achieving considerable yield gains is considered feasible given the current large yield gap and recent land ownership reforms.

This case study was one of **four cases on quantifying *ILUC prevention***. The other case studies (Lublin province in Poland, Hungary, and North-East Kalimantan in Indonesia) also show that a large biofuel (feedstock) production potentials with a low risk of ILUC can be achieved if sufficient efforts and investments are made in modernising and sustainably intensifying the agricultural sector, and if land use policies are strengthened and enforced. This shows that **ILUC as determined in the economic models is not an irreversible fact, but a risk that can be mitigated**. This is possible by taking **a sustainable approach to all land use for food, feed, fibre and fuels production**.

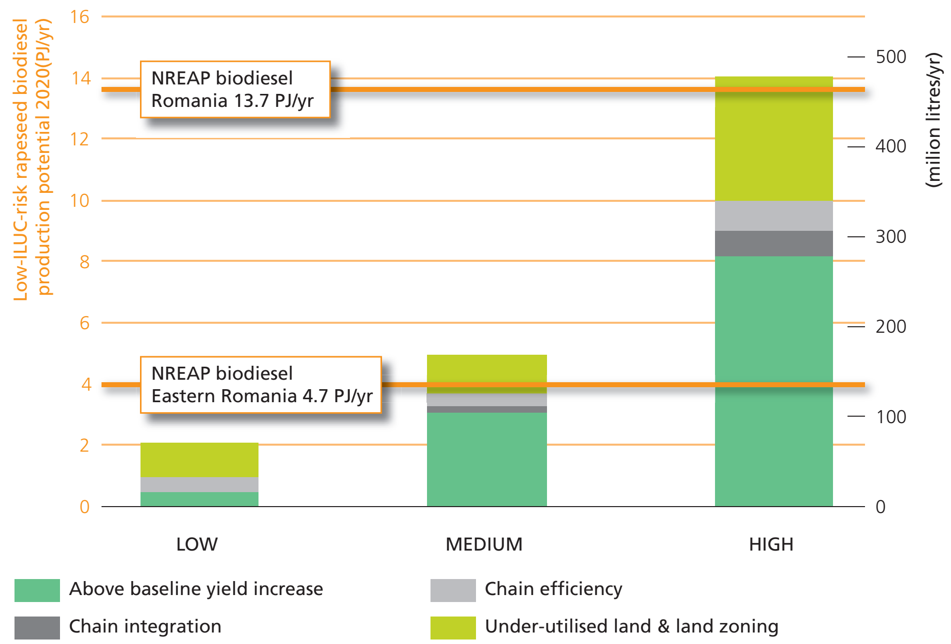

Figure S1 **Low-ILUC-risk biodiesel potential from rapeseed production in Eastern Romania in 2020 as a result of the ILUC prevention measures, compared to the National Renewable Energy Action Plan disaggregated to the region and for the whole country. This potential is additional to the currently existing production.**

1 Introduction

Increased production of biofuels in the last decade, greatly driven by stimulation policies in the United States and European Union, has led to questions around their sustainability. A major issue in policy debates is land use change (LUC) induced by bioenergy production. Particularly debated is the indirect land use change (ILUC), which is caused when agricultural production is diverted to another location in order to accommodate biofuel expansion and which can lead to increased GHG emissions. Since the scientific article by Searchinger *et al.* (2008) showed that the climate impact of biofuels could be worse than fossil fuels, as a result of indirect land use change [1], the topic has been a focus of biofuel research and policy debate. Since 2008 various other studies have been conducted to explore the size of the problem. As ILUC cannot be observed directly, models are used in order to establish the amount of ILUC caused by biofuel policies. Most of these models are complex, non-transparent economic models that consider the effects of an increased biofuel demand on (parts of) the economy. These modelling studies [1–6] have confirmed that increased biofuel demand leads to expansion of agricultural lands and a rise in GHG emissions. However, they found this to occur at a much lower extent than originally postulated by Searchinger *et al.* [1] although it varies largely across studies (see example of maize ethanol in Textbox 1).

Wicke *et al.* (2012) explored the uncertainties in the modelling efforts of ILUC. They found key uncertainties related to the underlying datasets, the amount, location and type of projected LUC, by-/co-products allocation, future production and trade patterns of bioenergy, technological change over time and dynamic nature of LUC [7]. Furthermore shortcomings include a focus on first generation biofuels and insufficient inclusion of the effects of sustainability criteria and land use policies [6]. Until now, little work has been done on how ILUC can be mitigated or even prevented. For example, Bauen *et al.* [7] divided potential policy option into two categories, an ILUC factor approach and an action based approach. The former is a 'penalty' added to biofuels GHG emission performance, to stimulate biofuels with a lower ILUC impact. Msangi *et al.* [8] 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. However, the penalty approach focuses on biofuels alone, while it is clear that ILUC of biofuels is the direct LUC of another activity. Therefore, also these other activities need to be addressed in order to really tackle LUC.

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

Thus, additional work is needed to better assess how ILUC can be mitigated or prevented and how it

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

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

"With respect to maize ethanol production, the initial LUC effect of US maize ethanol was given as 104 g CO_2-equivalent (CO_2e) per megajoule (MJ) (for reference purposes, the emission factor of gasoline is 92 g CO_2e/MJ) [3]. However, the development and improvements of the Global Trade Analysis Project (GTAP) bioenergy model from Purdue University have resulted in a large reduction in the estimates of LUC-related GHG emissions (first to 32 g CO_2e/MJ used in California's Low Carbon Fuel Standard [13] and more recently to 15 g CO_2e/MJ [14,15]. If California's Low Carbon Fuel Standard LUC emission factor of maize ethanol was to be adjusted accordingly, most maize ethanol production would be able to meet the required emission reduction percentage of 10% compared with fossil fuels by 2020 while this is not the case with the current factor of 32 g CO_2e/MJ [13]. The main improvements in the modeling relate to increased spatial resolution, updates in the global economic database used in GTAP (from 2001 to 2006), including pastureland as an option for conversion to bioenergy production, treatment of animal feed co-products, crop yields (both for agricultural crops and bioenergy crops) on existing agricultural land and newly converted land, and the fraction of carbon that is stored for a longer period in wood products [15]. Several of these improvements are related to strategies for mitigating (I)LUC and its effects, such as the type of land being allowed to be converted to bioenergy feedstock production and increasing crop yields and help explain the reduction in LUC-related GHG emissions. Also Al-Riffai *et al.* [16] and, most recently, Laborde [17] have found significantly lower values for maize ethanol than originally proposed. Laborde [17] indicates even lower LUC-related emissions than calculated from the GTAP model, namely 7 g CO_2e/MJ. The model improvements and the changes in results emphasize how sensitive the market equilibrium models are to underlying assumptions and datasets" (Wicke *et al.* 2012). A key aspect of all models used for assessing ILUC is that they are based on historical data and so any future changes that deviate from the historical data (e.g. stricter land use zoning and enforcement to reduce deforestation) are difficult to capture.

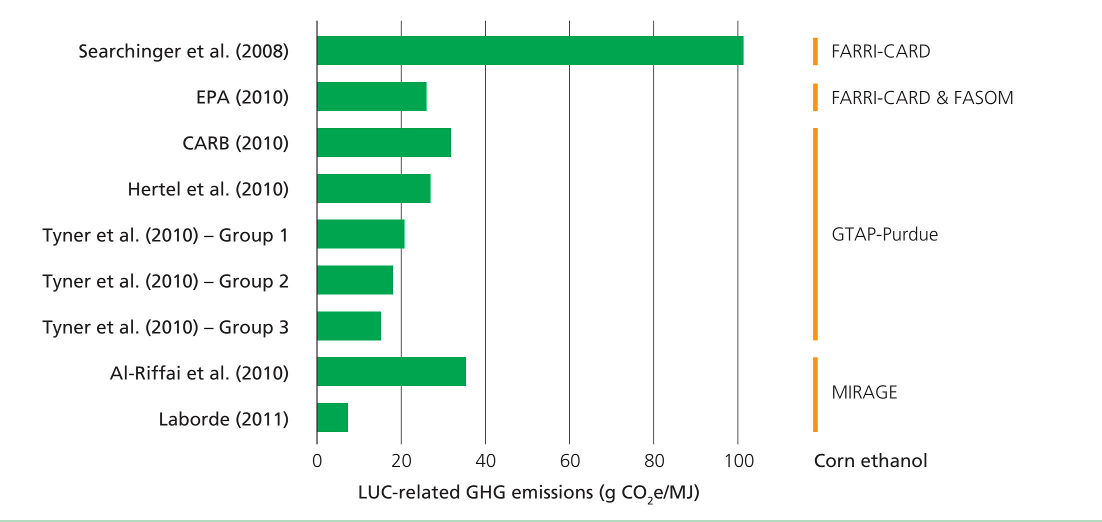

Figure T1 Overview of (direct and indirect) land use change -related greenhouse gas emissions of first generation biofuels determined in the literature (30 year allocation period) (adapted from Wicke et al. 2012).

References used in excerpt and figure: *[3] Searchinger T, Heimlich R, Houghton RA et al. Use of US croplands for biofuels increases greenhouse gases through emissions from land use change. Science 319(5867), 1238-1240 (2008). [13] CARB. Low carbon fuel standard. California Air Resources Board, Sacramento, CA, USA (2010). [14] Hertel TW, Golub AA, Jones AD, O'Hare M, Plevin RJ, Kammen DM. Effects of US maize ethanol on global land use and greenhouse gas emissions: estimating market-mediated responses. BioScience 60(3), 223-231 (2010). [15]Tyner WE, Taheripour F, Zhuang Q, Birur DK, Baldos U. Land use changes and consequent* CO_2 *emissions due to US maize ethanol production: a comprehensive analysis. Center for Global Trade Analysis, Purdue University, West Lafayette, IN, USA (2010). [16] Al-Riffai P, Dimaranan B, Laborde D. Global trade and environmental impact study of the EU biofuels mandate. International Food Policy Research Institute, Washington, DC, USA (2010). [17] Laborde D. Asessing the land use change consequences of European biofuels policies. International Food Policy Research Institute, Washington, DC, USA (2011). [18] EPA. Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. United States Environmental Protection Agency, Washington, DC, USA (2010).*

may be regulated. This is the aim of the *ILUC prevention* project. Under this project, a methodology was developed to assess different ILUC prevention measures in regional case study. This report presents a case study of the application of this methodology to rapeseed for biodiesel production in Eastern Romania. The remainder of the report is structured as follows. Section 2 defines the case study area and describes the characteristics of the current agricultural production in the case study and the biofuel chain that is considered. Section 3 provides a detailed description of the general approach and the specific application to this case study, as well as data inputs. Section 4 presents the results per ILUC prevention measure and for the integrated analysis. Section 5 follows with a discussion of the results, methods and data, including a detailed description of data availability, reliability and quality. Section 6 makes an inventory of key policy and governance options for realizing the ILUC prevention measures in practice. Section 7 finalizes the report with conclusions and recommendations.

2 Case study

2.1 DEFINITION OF CASE STUDY AREA

Romania has received increasing attention from businesses, farmers and governments alike due to the potential for growth in the agricultural sector [9-11]. Particularly Eastern Romania has a large potential for additional agricultural production as it is a relatively underdeveloped region in terms of agriculture so that also agricultural development and intensification may provide large gains in terms of resource efficiency [12,13]. The region of analysis in this case study is therefore chosen to be the Eastern part of Romania. The development regions North East and South East combine into Macroregion 2, presented on the map in Figure 1.

The size of Macroregion 2 is 7.2 million ha, of which 4.4 million hectare is classified as agricultural area. This is about 30% of the agricultural area of Romania. Of Romanian arable land, 34% is located in Macroregion 2, this is 3.2 million hectare.

2.2 AGRICULTURAL SITUATION

Around one third of the agricultural production of Romania takes place in Macroregion 2. The most important crops are maize and wheat, at an average production of 2.9 and 1.8 million tons respectively in the period 2008-2012. Macroregion 2 is one of the key oil seed producing areas, as it produces more than 40% of the countries supply of rapeseed and sunflower seed [12].

Crop yields vary significantly between years, largely as a result of variations in climate. For rapeseed -a break crop- the area in use also changes significantly from year to year. For example, in 2012 the area used by rapeseed was less than a quarter from the area in the previous year.

Figure 1 **Map of the case-study region. The area indicated in dark green is Macroregion 2, consisting of the North East and South East.**

The livestock production in the area has decreased since the end of the communist era. The amount of cows and pigs in the region have decreased by almost 60% between 1990 and 2012 [12]. The amount of sheep has halved and the poultry headcount has lost 30% in the same timeframe. This is also visible in the production statistics. Meat production has decreased by 45%, wool production by 60% and egg production by 15%, although the South East has seen a small increase in the latter.

Agriculture is dominated by a large number of smallholders and a small number of large farms. This stems from the land rights reconstruction after the end of the communist era. This has led to a very large number of very small farms in the country that are barely sufficient of subsistence farming [14]. The average farm size in Eastern Romania is 3.1 ha, slightly below the national average, compared to an average in Central and Eastern Europe of 6.7 ha and 14.5 ha in the EU27 [15]. In the South East the farms are larger at 5.8 ha, but in the North East these are only 1.8 ha. The 4,000 (0.4%) largest farms (those over 100ha in size) in Eastern Romania own 55% of the land, whereas 72% of the smallest farms, with less than 2 ha, cover only 13% of the arable land. This contributes to the low income situation in Macroregion 2, the lowest in the country [12]. Most of these subsistence farms are eligible for direct payments under the European Common Agricultural Policy (CAP).

Fertiliser use, as the sum of nitrogen, phosphorus, phosphate, potassium and potash per hectare of arable land is in Romania the lowest of the whole EU [15]. An average of 63 kilogram fertiliser per hectare is applied in Romania. This is a little over one third of the EU27 average. Mechanisation, measured as number of tractors per 100 km^2, is 200 in Romania, the lowest in the EU except for Bulgaria and at a quarter of the average for the whole EU28 [16].

2.3 POLICY CONTEXT

The Romanian policy context for biofuels can be categorized in two sets of policies. The first set of biofuel policies was adopted in 2003 supporting the production of energy from renewable sources through a Green Certificate subsidy scheme [17]. In 2005, more specific provisions were adopted indicating the targeted renewable energy mix and specifically the biofuel mix ambitions (2% by 2007 and 5.75% by the end of 2010). The biofuel mix targets are updated in accordance to the general EU biofuel targets. In 2006 the fiscal policy managing the energy crops subsidy schemes was adopted, boosting the cultivation of energy crops and rapeseed especially in Romania ever since [17].

A second set of policies proceeded from the agricultural sector where energy crops needed to be regulated. In 2006 the Ministry for Agriculture and Rural Development (MARD) introduced a set of monitoring instruments that the National Cadaster Agency (ANCPI) and APIA (Agency for Payments

Table 1 Policy context for energy crops in Romania.

Law	General stipulations
No 443/2003	Promotes the production of energy from renewable sources among which also biomass through a Green Certificate scheme
No 1844/2005	Establishes the biofuel mix targets to 2% till 2007 and 5.75% till 2010; Amendments law no 456/2007 confirming the biofuel mix 5.75% by 2010.
No 125/2006	Approval of direct and national complementary subsidy schemes starting 2007; Revision of law no 36/1991 changes in agricultural unions and other agricultural associations
No 246/2008	Implementation method, specific conditions and eligible criteria for the application of direct payments scheme and national complementary subsidy schemes for biomass sector. Focus was directed to agro-environment and poor areas, although this was not strictly defined.
No 74/2010 And No 756/2010	Governmental financial support scheme for farmers and the methodology for awarding the financial incentives for agriculture (Complementary National Direct Payments and Subsidy Premiums)

and Interventions in Agriculture) would need to monitor and report on. The data collected contains information about the spatial distribution of the land areas cultivated, the type of crops harvested, and basic agricultural management techniques [18]. The data collected is not available for public use and it is currently employed for internal processing at ministry level [18]. Table 1 gives an overview of the current renewable energy and biomass policies in Romania.

In agriculture, the subsidy schemes are managed by the Agency for Payments and Interventions in Agriculture (APIA). The aforementioned subsidy schemes have proven to be effective in stimulating the agricultural output [19]. One consequence of this programme is reflected directly on rapeseed which became twice as profitable for farmers as compared to most cereal crops [20]. The financial subsidies are awarded based on a number of requirements including: minimum area harvested, minimum fertilizer use, pest and crop management reporting. The pest reporting takes the form if pest identification and quantitative reporting of the amount of pesticides applied [18].

Romania has also incentives for farmers outside the context of biofuel feedstock production. Direct payments stemming from the European Common Agricultural Policy are used as income support for the large number of farmers in the country [14]. In addition, there are also incentives for smallholders to exit the farming business and to sell the farm and the land in order for it to be used by other farmers, if the farm size is qualified as unsustainably small. This has lead to a small increase in the past years in the average farm size [14,21].

2.4 BIOFUEL CHAIN

Rapeseed is often used as a break crop. A break crop is used as a break in the crop cycle which can generate a number of benefits, including reduced chances of disease and fertilising benefits. Subsequently crops are expected to have higher yields after a break crop [22,23]. Being a break crop also means rapeseed is only planted once every three to five years. With the rising profitability of rapeseed cultivation, the rotation time has been coming down. In this research we assume a four year crop cycle.

Then harvesting and storing of rapeseed is associated with marginal losses (less than 1%). The seeds do not require refrigeration and the moisture content is too low to germinate. In the mill the seeds are crushed to produce the rapeseed oil. The crushing efficiency in Romania is around 39% (38.8-39.0) [24]. The rest of the seeds and the left-over oil are processed into oil seed cake or rapeseed meal. Rapeseed meal production is 580 kg per ton of crushed rapeseed [24].

The last step is to produce biodiesel from the rapeseed oil. By a process of transesterification the rapeseed oil is combined with methanol to form rape methyl ester (RME) biodiesel. This process also produces glycerine at a rate of 0.105 ton per ton biodiesel [25]. Conversion takes place at a low temperature and has an efficiency of 98% [26]. In Figure 2 the biofuel production chain is depicted [27].

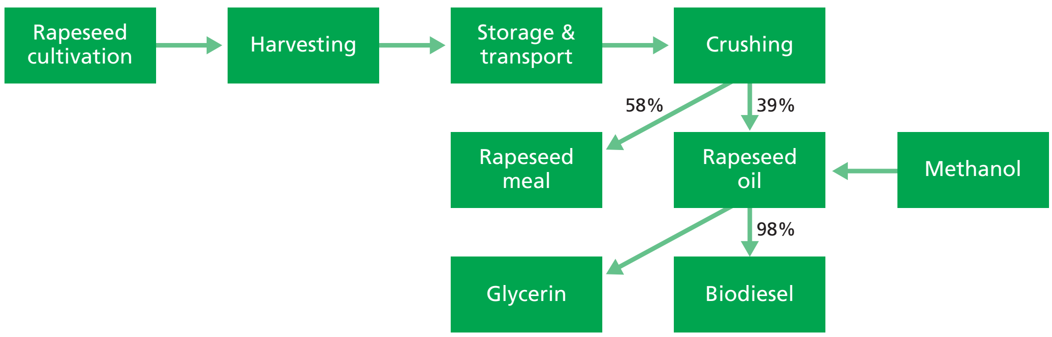

Figure 2 **Schematic representation of the biofuel production chain. Besides biodiesel, the main co-products are glycerin and rapeseed meal.**

3 Methods & materials

3.1 GENERAL APPROACH

The approach applied here was developed by Brinkman *et al.* [28]. It here aims at analysing and quantifying ILUC prevention measures by assessing i) how much additional biofuel feedstock can be produced with these measures (herein after also called low-ILUC-risk potential) in a specific region in the future, and ii) how this production potential compares to the biofuel feedstock target of that region. The approach is based on a combination of a top-down and bottom-up approach, and distinguishes three main steps (Figure 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 feedstocks for biofuels needed to meet the biofuels mandate. The difference between the target and baseline (Figure 1) is the extra production due to the biofuel requirements (whether directly caused by increased demand for meeting the mandate or induced by increased crop prices due to the mandate). In the economic models, this amount is projected to cause LUC. In our approach, we assess how different measures related to sustainable intensification and modernization of the agricultural sector and proper land zoning can

1 The biomass production baseline refers to the developments as a result of projected energy prices and economic growth. The baseline assumes biofuel production to remain approximately constant at current levels - although small variations may occur due to price developments in the baseline.
2 The target projection applies the same developments in energy prices and economic growth as in the baseline but adds a specific biofuel mandate.
3 Economic models assessing the indirect effects from biofuels do not distinguish indirect from direct LUC, so that total LUC induced by a biofuel mandate is modeled.

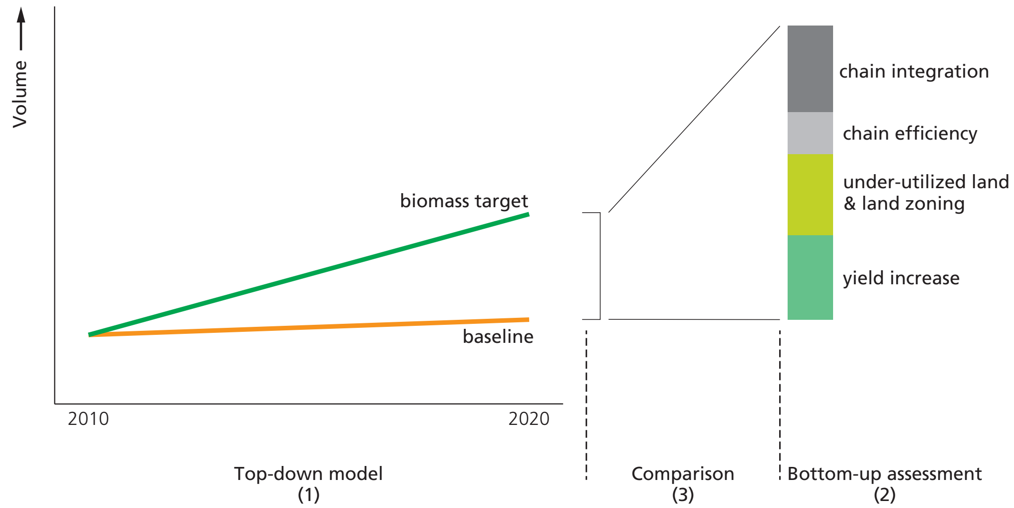

Figure 3 General approach to analyse and quantify biomass production potential with low ILUC risks. The approach consists of three steps: 1) top-down establishment of additional biomass production in the target scenario in 2020 compared to the baseline scenario, 2) bottom-up assessment of potential biomass 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 (Modeling 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 (EU RED), based on the National Renewable Energy Action Plans [4]. Three scenarios are implemented: one reference scenario (here also referred to as baseline), which assumes no additional biofuel demand; and two scenarios for implementing the biofuels mandate, which are defined by the

4 We specifically refer to *undesired* LUC here because not all LUC is undesirable. For example, using degraded land for woody and grassy bioenergy feedstock production can result in the re-vegetation and restoration of that land and can have positive impacts on e.g. carbon stocks, water quality and availability (Wicke *et al.* 2012).

5 The model version MIRAGE-Biof is applied in in this study. For clarity reasons, MIRAGE-Biof is referred to as MIRAGE in the remaining report.

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

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

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

Each step is described in more detail in the following sections. Each section first provides the methodology used in all case studies and then explains in a sub-section the application and input data used in the case study specific to this report.

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 32 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 and vice versa. Although this may not hold true for the long term, for the timeframe considered in this study (2020) these assumptions are likely to hold.

Equation 1

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

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

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

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

In the previous years (2008-2012) Eastern Romania produced on average 280 k ton of rapeseed [12]. This accounts for 1.4% of the total EU rapeseed production in the same period [13]. The MIRAGE model projects a baseline production of 27 mega ton rapeseed in the EU27, and 30 mega ton as the target [4]. Eastern Romania can therefore be expected to be responsible for the production of 380 and 434 kton rapeseed in the baseline and target respectively. Note that is not only for biodiesel, but for all applications of rapeseed. Currently (2010-2013) 31% of the rapeseed production in Romania is crushed to produce rapeseed oil, at a crushing efficiency of 39% [24]. In 2011 one third of the vegetable oils in the EU27 were used for biodiesel production.

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.

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 33 in appendix B). Translating the production target for the crop category to the specific crop is based on the share of the current production of that crop within the category.

With regard to livestock production, the importance of the livestock sector in the case study region is assessed by parameters such as the area of land under pasture and meadow, livestock population, and current production of milk and beef. Poultry and pigs are not grazing animals and are mainly fed with processed feed. The land use (change) related to this feed is already taken into account by assessing agricultural crops. Cattle production is closely related to the use of meadows and pastures. Thus, the area of meadows and pastures that can become available for bioenergy production mainly depends on changes in cattle production.

Table 2 Selected crops for assessment of the ILUC prevention measures in Eastern Romania, production and area data based on national statistics [12].

Crop	Area (kha)	% of total arable land (2012)	% of total agricultural area (2012)	Average production (k ton) 2008-2012
Maize	900	28%	20%	2923
Wheat	641	20%	14%	1839
Sunflower seed	414	13%	9%	576
Barley	189	6%	4%	476
Rapeseed	171	5%	4%	280
Potatoes	68	2%	2%	943
Oats	60	2%	1%	98
Soy beans	40	1%	1%	68
Total Crops	2584	80%	57%	7304
Permanent pastures and meadows	1082		24%	
Total	3666		81%	

Table 3 Crop-specific projected production in 2020 in the baseline and target scenarios.

Crop	Current production (k ton)	2020 projected production baseline (k ton)	2020 projected production target (k ton)
Maize	2923	3311	3283
Wheat	1839	2116	2105
Sunflower seed	576	710	755
Barley	476	303	302
Rapeseed	280	381	434
Potatoes	943	600	598
Oats	98	62	62
Soy beans	68	89	88

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 2 presents an overview of the production of the ten most important crops in the Eastern Romania that will be considered in the analysis. The crops cover around 80% of the arable land in the region.

3.4 POTENTIAL BIOMASS PRODUCTION PER ILUC MITIGATION MEASURE

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

- **Above baseline yield development:** increases in agricultural crop yield and livestock production efficiencies above the baseline projection result in a reduction of agricultural land required for crop and livestock production (assuming the production volume remains constant). On the resulting surplus land area, biomass can be produced with low ILUC risk. Yield increases can be achieved by, for example, improved fertilizer application, mechanization and intensification of animal farming.
- **Improved chain integration:** integration of the biofuel chain in food and feed production. Examples of integration are multi-functional land use practices like agroforestry and the use of biofuel by-/co-products as animal feed. Such approaches increase the total output per hectare and reduce the demand for land.
- **Increased chain efficiencies:** Improving the efficiency of agricultural and bioenergy supply chains increases the productivity per hectare. Efficiencies can be improved through, for example, reduction of losses in storage and transport, and improvement of conversion and processing efficiencies.
- **Biofuel feedstock production on under-utilized lands:** under-utilized lands include set-aside land, abandoned land, degraded land, marginal lands and other land that does not currently provide services, i.e., “unused lands” [29]. This, often low-productive, land can be used to cultivate extra biomass for bioenergy.
- **Land zoning:** land zoning helps avoid the use of land with high carbon stocks, biodiversity or other ecosystem services for biofuel feedstock production. Land zoning is often combined with the measure on under-utilized land in order to define what is under-utilized and when is it available for conversion.
- **Lower GHG emissions in the biofuel supply chain:** improve the sustainability of the biofuel production system through, for example, better fertilizer application or measures to increase soil carbon sequestration.

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

In the following subsections, we describe how each measure is assessed. In the analysis of the measures, we apply three scenarios (*low, medium, high*) in order to indicate the variability and uncertainty in the data and test its effect on the results. In order to prevent ILUC from biofuel production, the performance of each measure needs to be better than in the baseline developments (e.g. baseline projections of MIRAGE or extrapolation of historical trends). The scenarios *low, medium and high*, therefore, refer to low, medium, high developments above this baseline, respectively. The *low* scenario is thus still an improvement compared to the current situation and baseline scenario[6]. The scenarios per measures are described in detail in the sections below.

3.4.1 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. 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_{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;
$Y_{\mathrm{baseline,i}}$ – projected baseline yield for crop i (tonne/ha/yr);
$Y_{\mathrm{ABY,i}}$ – projected above-baseline yield for crop i (tonne/ha/yr);
P – projected baseline production (tonne) for crop i, as derived from the MIRAGE baseline scenario.

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

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

Equation 3

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

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

The potential gains of yield growth are large for Romanian rapeseed crops. Compared to other European countries with a large rapeseed production, such as Poland, France and Germany, yields are significantly lower [30]. This difference is illustrated in Figure 4. Important to note is that this is not only an issue of rapeseed, but also of all other crops [12,13].

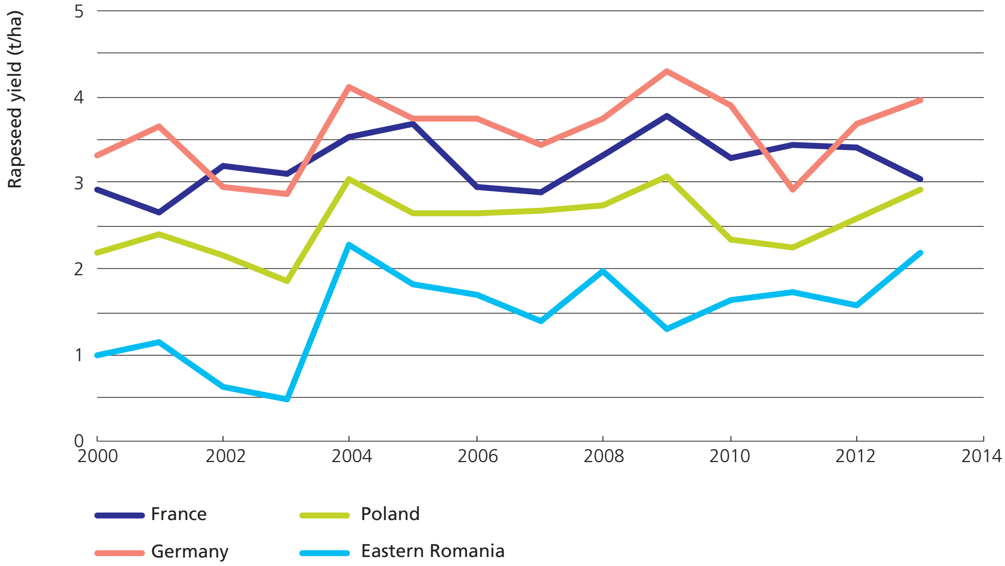

Figure 4 **Rapeseed yield development (2000-2013) in four selected countries. Yields in Eastern Romania are significantly lower than in other countries [12,13]. The jump in the data in 2003 in Romania has to do with access to European subsidies for agriculture, that were first available in that year [31].**

The low yield is further illustrated by looking at the yield gap. The yield gap is the difference between the potential yield (illustrated for rapeseed in Figure 5), that is solely based on the biophysical situation (soil, climate condition), and the actual yield. The actual yield is determined by two important factors: the biophysical situation and the agricultural practices. By improving the latter a larger part of the potential yield can be achieved. Comparing the maximum attainable yield of rapeseed (4.4 t/ha for the period 2000-2005)[7] with the corresponding actual yield (1.6 t/ha, obtained from [12]) indicates that there is a large yield gap in Romania. When looking at spatially explicit data, the yield gap for Eastern Romanian rapeseed in 2000-2005 ranges from 25-55% of the potential rain-fed yield [32]. Figure 5 and Figure 6 illustrate the potential yield and yield gap in Eastern Romania.

This large yield gap is the result of an interplay of various factors. Of which poor mechanization of agriculture [33], sub-optimal use of fertilization [34-36] and low pesticide use [15,16] are three main factors. In the following, we briefly describe the issues.

Sub-optimal use of fertilizer is related to farmers using only small amounts of fertilizer and the fertilizer mix being sub-optimal. Several studies have evaluated optimal fertilizer use for rapeseed production in

7 Obtained from IIASA [32], see Appendix D for a description of how this data is derived.

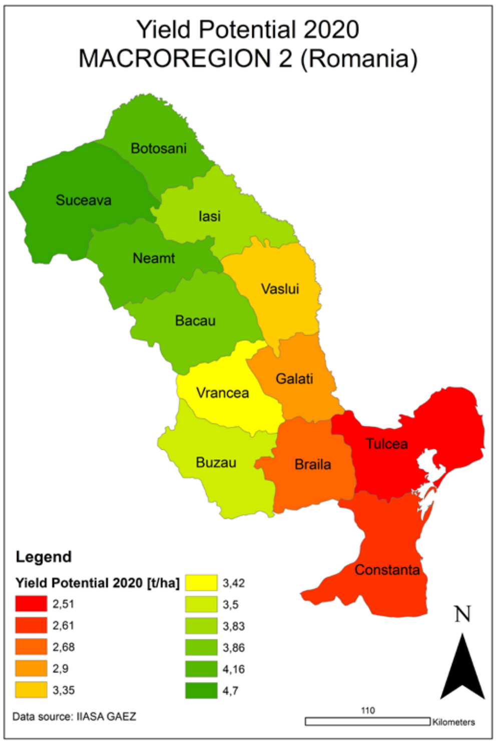

Figure 5 **Maximum attainable yields in Eastern Romania for period 2000-2005, based on the Global Agro Ecological Zones model from IIASA [32].**

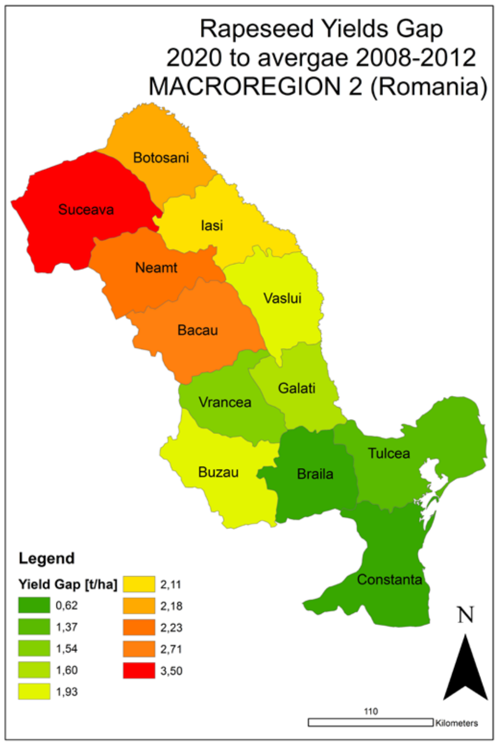

Figure 6 **Yield gap in Eastern Romania. The figure illustrates the difference between the maximum attainable rainfed yield and the current yield, based on the Global Agro Ecological Zones model from IIASA [32].**

Romania [34-36], and found partially different results on the amount and combination of fertilizers. However, a more important reason for differences between the optimal and current fertiliser application is a lack of knowledge of (especially small-scale) farmers. Knowledge of proper fertilizer application is complicated by variability due to soil and other condition [34], while farmers are not well trained to know how much and when to apply the fertiliser. Key factors for improving yields are thus the application of optimal fertilizer and its timing/frequency, and increased capacity building for farmers. EUROSTAT and FAOSTAT data show the application of fertiliser in Romania is only at 25-30% of the EU average for nitrogen fertilisers, for phosphate the percentage is even lower (10-20%) and for potash a bit higher (50-60%), but still far below the European average [13,15].

Low mechanization of agricultural practices was identified as another key factor for low yields in Romania. The mechanisation of Romanian agriculture is reckoned to be among the lowest in Europe and has changed only little between 2006 and 2014 [15,16]. An indicator is the available funds for equipment investments per farmers, which is €350 in Romania and on average in Europe €9,100 [15,16]. A reason for the poor technological development of the agricultural system is a lack of support for agriculture after the fall of the Communist regime [37]. The absorption rate of EU Structural Funds[8] for agricultural developments in Romania, which could help reduce this problem, lags behind other EU countries due to policy delays and insufficient co-funding for project [37,38].

Other agricultural practices that can be improved include the use of pesticides, tillage and the use of the appropriate seed and plant varieties [30]. Pesticides help to protect crops against pests such as fungi and

8 The EU Structural Funds are part of the EU Cohesion policy, which aims at reducing intra-European and sub-national disparities in economic, social and territorial aspects [79].

insects in order to reduce the losses on the field due to such pests. The use of pesticides in Romania is low compared to the European average. For most types (insecticides, herbicides) the application has risen to around 50-60% of the European average, but for fungicides and bactericides it is still at less than a third of EU average [13].

Regarding plant varieties, a distinction is made between open pollinated rapeseed and hybrid rapeseed varieties. According to a study by Chiriac *et al.* [30] on the performance of different rapeseed varieties available on the Romanian market, there is a clear preference for hybrid varieties due to their better yield performance which compensates for the costs of additional fertilizer needs. However, hybrid varieties have several shortcomings that require attention when further increasing yields in the future. These aspects include the higher water requirements (while there is little irrigation infrastructure available in Romania [13]) and hybrid varieties being less well adapted to local conditions than open pollinated rapeseeds. This is also a reason why open pollinated varieties are still in demand [39].

The size of the yield gains that can be achieved in Eastern Romania depends on an intricate combination of factors that are hard to quantify separately. Therefore, a scenario approach was taken for assessing potential yields gains and its effect on land savings and biodiesel production. In order to provide a range of potential yield increases, we investigated i) past yield trends in Romania and neighbouring countries, ii) current yields in regions with comparable biophysical condition, iii) yield projections in the literature and iv) the maximum attainable yield (see Appendix C for a description of the various yield scenarios). Based on this range, a low, medium and high yield development scenario were formulated. The various assumptions for the future yield scenarios are provided in Table 4.

Table 5 presents the potential rapeseed yields in the different scenarios, that were defined above. For comparison purposes, current yields and projected yields based on MIRAGE target are also presented. In

Table 4 **Low, middle and high yield development scenarios and their key characteristics.**

Scenario		Description
Low	Yield trend Eastern Romania 1990-2012	Extrapolating the crop-specific linear yield trend in Eastern Romania of the period 1990-2012 to 2020. Yield data is taken from the National Statistics Office [12].
Medium	Best counties Eastern Romania	For each crop the yield of the best county is extrapolated to the whole macro region. Data are taken from Eurostat [15] and the Romanian National Statistics Office [12]. For those crops where no county level data is available, best regional average yields for Eastern Romania in the period 2008-2012 are assumed.
High	% Poland	Ratio of the maximum attainable yield and actual yield currently achieved in Poland applied to the maximum attainable yield in Romania[a]. Poland is also an Eastern European Country, with a history under communist control between 1945 and the start of the 1990s. However, Poland joined the EU three years prior the Romania and the agricultural sector is further developed using more fertilisers, pesticides and machinery [13,15,16].

[a] For a description of how this ratio is obtained, see Appendix D

Table 5 **Crop yields in 2020 for maize, wheat and rapeseed in the three scenarios.**

Scenario	Maize yield (t/ha)	Wheat yield (t/ha)	Rapeseed yield (t/ha)
Current [a]	3.3 (1.9-4.5)	2.9 (2.6-3.7)	1.6 (1.3-2.0)
MIRAGE [b]	3.4	3.0	1.8
Low	3.5	3.1	2.0
Medium	4.3	3.4	2.1
High	6.5	3.8	2.5

[a] Average 2008-2012 [13]. Range based on the best and worst county in the area.
[b] Disaggregated from the EU27 level to Romania based on the current ratio of the Romanian yield to the EU27 average (data from FAO, [13]), assuming that the ratio stays the same.

addition to rapeseed, also maize and wheat yields are shown as illustrations of how other crop yields are projected to develop.

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[9] or liters 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 liters milk per year);

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

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

Equation 5

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

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

A_{ABS} – total meadow and pasture area (ha) that is required to produce the same amount of milk or beef as in the

9 Beef production also includes the production of veal.

baseline applying an above-baseline scenario for cattle density and/or productivity;

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

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

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

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

Eastern Romania has a very low intensity in agriculture. This is also reflected in the low productivity in the livestock sector. Table 6 gives an overview of the assumptions for the intensification of the livestock sector in Eastern Romania that are used in this research. The data for these scenarios is presented in Table 7.

Table 6 **Potential productivity increase in the livestock sector.**

Scenario		Description
Low	Current productivity Romania	The Eastern part of Romania lags slightly behind the rest of the country with regards to the livestock productivity and intensity. There are no reasons why Eastern Romania cannot catch-up with the rest of the country.
Middle	Highest historical productivity in Romania	From the FAOSTAT database [13] the maximum productivity per cow in Romania the period 1961-2012 will be considered as a productivity that can be achieved in Macroregion 2.
High	Current productivity in Poland	Poland was, like Romania, under communist rule before 1990. The decline after 1990 has been lower than in Romania and the current productivity is significantly higher than in Romania. The amount of heads per hectare is currently five times higher in Poland than in Romania, and the productivity per cow around a third.

Table 7 **Above baseline productivity in cattle farming.**

	Milk (l/cow/year)	Meat (kg/carcass)	Density (heads/hecatre)
Current	3,414	158[a]	0.68
Low	3,484	158	0.68
Middle	3,667	174	1.60
High	4,864	242	1.78

[a] no separate statistics for Eastern Romania are available, therefore the country average is used.

3.4.2 Improved chain integration

The production of biofuels generates various co-products (e.g. distiller grains solubles (DGS), oilseed meal, glycerine, and straw or stover). Following the principles of consequential LCA (see Textbox 2), these co-products can be argued to reduce land demand and thereby help prevent ILUC.
A first step in the analysis is an inventory of the co-products produced in the biofuel supply chain, the amount generated and the current usage. In the assessment, a distinction is made between co-products from the crop production and from the biofuel production. Co-products from the crop production are the crop residues[10]; for example, wheat straw, maize 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) [40,41] The amount of residues generated is calculated with Equation 7.

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

Equation 7

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

Where $P_{\text{crop residues}}$ – amount of crop residues for the biofuel crop (tonne);
Y – crop yields (tonne/ha);
RPR – residue-to-crop ratio (tonne residue/tonne product);
SRF – sustainable removal fraction (%);
A – area under crop cultivation for biofuel production (ha).

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

Equation 8

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

Where $P_{\text{co-products}}$ – amount of co-products generated from biofuel production (tonne);
P_{biofuels} – biofuel production volume in the region (tonne);
CE – feedstock-to-biofuel conversion efficiency (tonne biofuel per tonne feedstock);
CPF – the co – product factor is the amount of co-products produced per tonne feedstock (tonne co-product per tonne feedstock).

The second step is to assess the potential use of the co-products and the rates at which they can replace other products. Potential uses for agricultural crop residues are the production of second generation biofuels or electricity. When the crop residue is suitable for the production second generation biofuels,

TEXTBOX 2: CONSEQUENTIAL LCA

Life Cycle Assessment (LCA) is a technique used to gain insight in the environmental performance of a product or service over its complete life cycle, from cradle to grave. In a consequential LCA also the consequences that are outside the direct production chain are considered, as opposed to an attributional LCA that only considers the direct impacts in the production chain. One of the differences between attributional and consequential LCA is how they handle co-products. In an attributional LCA, a portion of the environmental impacts are assigned to the co-products, based on their energy or economic value. In a consequential LCA, the effect on the whole system is considered, by expanding the area of analysis from the specific production chain to include the savings of not producing other products. That means, it can be used to determine the environmental benefits of reduced production of other products. Consequential LCA is especially relevant when the effects of a change are considered [42–47].

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.

an estimate of the low-ILUC-risk biofuel potential from crop residues is made in order to assess how residues compare to other ILUC prevention measures assessed in this study. This is done by converting the amount of crop residues (as determined with Equation 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 10;
SR – substitution ratio (tonne feed crop substituted per tonne co-product), which depends on the type of co-product and what it replaces.

Equation 10

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

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 11;
$Y_{\text{feed crops}}$ – 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.

An overview of the co- and by-products from the rapeseed biodiesel production and their main characteristics are presented in Table 8.

Table 8 Overview of the co/by products of rapeseed biodiesel production and the production stage where these are produced [50,51].

Co-/by-product	Origin	(Potential) use/function	Other characteristics or aspects important for ILUC prevention analysis
Straw	field	Nutrients for soil, stall bedding, animal feed	brittle and tends to crumble during collection
Rapeseed meal/ rapeseed cake	crushing	Animal feed	Already included in the ILUC models
Glycerin	transesterification	Animal feed, cosmetics, pharmaceuticals, combustion	Highest value applications are not related to land use

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

The use of dried distiller grains with solubles (DDGS) and oilseed meal as animal feed is already incorporated in MIRAGE. In the model, the production target for some crops is reduced as a result of the production of these co-products. Although substitution by co-products for feed is better than in other models, MIRAGE still does not account for the complexity of feed requirements in defining the substitution mechanism (for a short review, see e.g. Südekum et al. 2013, [48]). At the same time, an analysis of the co-product factor used in MIRAGE and other literature (e.g. [1,6,49]) indicates that MIRAGE applies values much higher than the literature for some biofuels 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 3.3) 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, maize DDGS, sunflower meal and rapeseed meal. A complicating factor is that the extra production of DDGS or oil seed meal not only reduces the demand for maize, wheat and soy, but also for other types of DDGS and oil seed meal. This means that an assumed reduction in DDGS or meal production of one biofuel chain increases the demand for other types of DDGS and meal. For reasons of simplicity, we assume this to be covered by higher production of maize, wheat and soymeal as these three crops are produced for feed, while DDGS and meal are merely co-products.
2. *Adding the amount of feed saved by using co-products to the production projections* of wheat, maize and soy meal (as defined in Section 3.2 and 3.3), as if no co-products would be used.

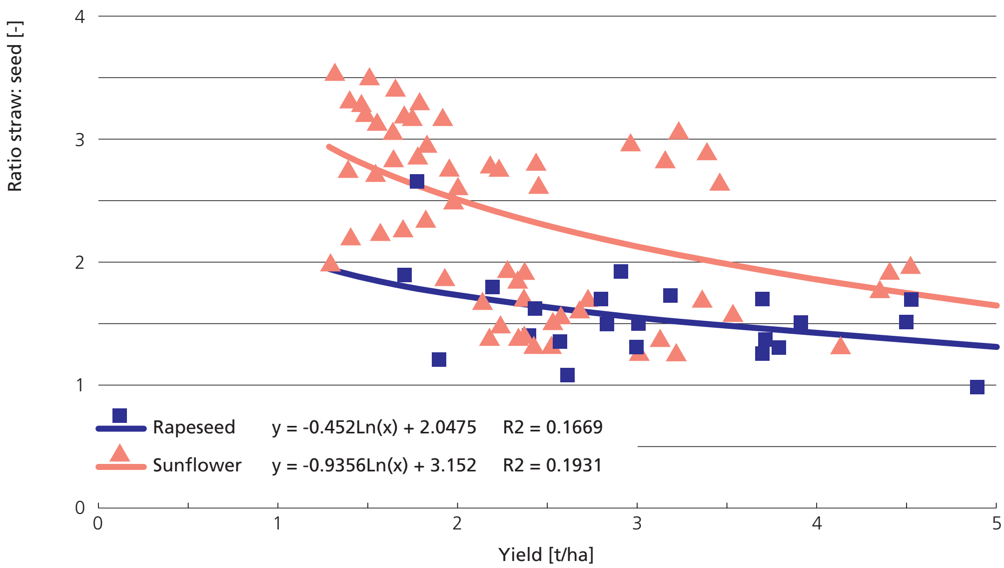

Figure 7 **Straw to grain ratio, rapeseed and sunflower [51, p 1997].**

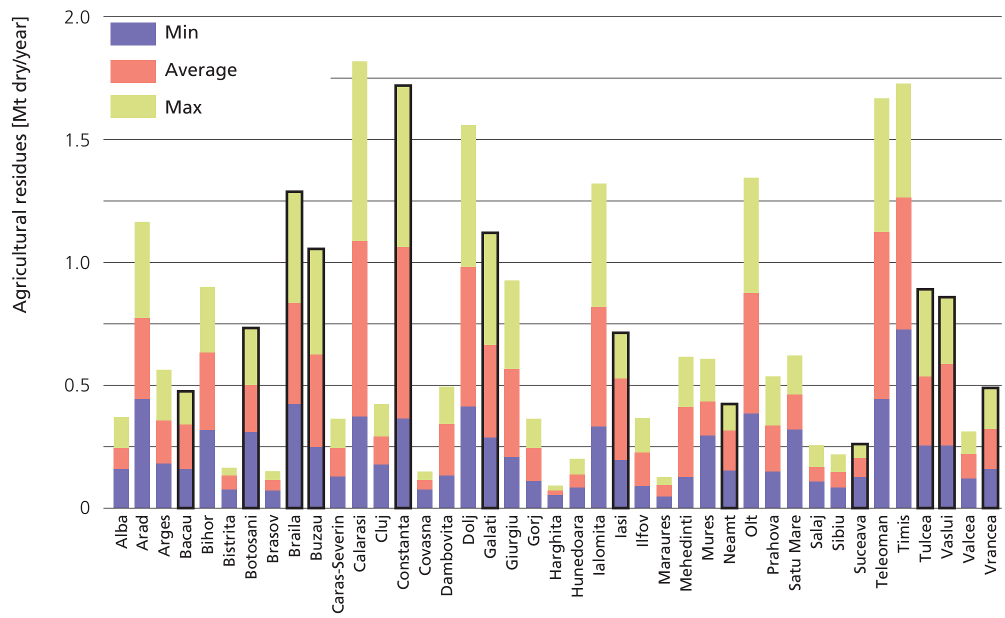

Figure 8 **Production of agricultural residues in Romania [51, p 1997]. Bacau, Botosani, Iasi, Neamt, Suceava, Vaslui, Braila, Buzau, Constanta, Galati, Tulcea and Vrancea (indicated by the boxes) are counties in the Eastern region of Romania.**

The production of co-products from crop production is in this case limited to rapeseed straw. Scarlat *et al.* [51] have assessed residue availability of various crops for Romania. Based on a number of literature references, they estimated a residue-to-yield ratio for rapeseed of 1.2 to 1.98 kg straw/kg seed depending on the yield (see Figure 7). They also estimated an availability factor -the share of the straw that can be harvested and utilised- for rapeseed straw of 50% [51].

Residue availability in Romania is estimated in Scarlat *et al.* [51] as shown in Figure 8. The total average production is 19 Mt dry matter (dm) per year, with a minimum of 10 Mt dm per year and a maximum of 27 Mt dm per year (minimum and maximum are based on annual variation of crop production in the period of 2000 to 2006). The contribution by rapeseed straw is not specified, but can be calculated based on rapeseed crop production statistics.

In practice, rapeseed straw is often not harvested. It is brittle and tends to crumble during collection, it is more likely to be ploughed back into the soil to preserve the nutrients than that it is harvested [52]. However, there are claims that it can be collected and used for animal bedding, animal feed and second generation fuel or electricity.

For crushing the main co-product is rapeseed meal. 59% of the weight of the rapeseed input comes out as rapeseed meal [24]. Different assumptions can be made on the replacement of animal feed by rapeseed meal (see Table 9). The *low* and *high* scenario are the two extremes; in the *low* scenario all land use savings are assumed to be abroad, and therefore no savings in Eastern Romania. In the *high* scenario all land use savings are domestic and

3.4.3 Increased production chain efficiency

Food losses and food waste are often thought to be around half of the food produced [56]. 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 [57,58]. Although the gains of limiting food waste could be very large, it would involve behavioural changes by consumers. This falls outside the

Table 9 **Description of the substitution scenarios as a result of expanding rapemeal use.**

Scenario		Description
Low	Protein content rapeseed	Following the methodology of Reinhart and Zah [47] and Schmidt et al. [53] it is assumed the marginal protein source(soymeal) will be replaced by the increased use of rapeseed meal. Rapeseed meal has a protein content of 33%, whereas soybean meal has a protein content of 44% [54] .
Medium	Historical trend feed market	From the historical trend of the feed market in Europe (2006-2011), the historical substitution of feed by the increased use of rapeseed meal will be determined. Rapeseed meal was a quarter of the total increase of feed. A quarter of the decrease in other feed products will therefore be attributed to the rapeseed meal. The three main replaced products are wheat (0.176 t/t meal), soybean meal (0.194 t/t) and barley (0.081 t/t). The data are the feed data from FAOSTAT [13].
High	Energy content rapeseed	Following the methodology of Reinhart and Zah [47] and Schmidt *et al.* [53] it is assumed the marginal energy source (barley) will be replaced by the increased use of rapeseed meal. The energy content of barley is 8.68 MJ/kg, for rapemeal this is 9.31 MJ/kg [55].

Table 10 **Substitution factor for various crops as a result of the inclusion of rape seed meal (see Table 9 for underlying assumptions and references).**

	Wheat replaced (t/t rapemeal)	Soy replaced (t/t rapemeal)	Barley replaced (t/t rapemeal)	Other crops (t/t rapemeal)
Protein content rapeseed	0	0.75	0	0
Historical trend feed market	0.176	0.194	0.081	0.235 [a]
Energy content rapeseed	0	0	1.07	0

[a] amongst others sugar beet and palm kernel cake.

scope of this project. However, in the agricultural supply chain in industrialized countries, there is also still potential for improvement. Therefore, this ILUC mitigation measure on increasing chain efficiency addresses the reduction of losses in transport, storage, (un)loading, etc. Reducing the losses in the chain between production and consumption will help to fulfil food demand with less land. Thereby, surplus land is generated that could be used for biofuel production (as described in Equation 13 and Equation 14).

Equation 13

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

Where $P_{saved,i}$ – 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);

$\mathrm{L}_{i,\mathrm{baseline}}$ – share of biomass lost in the food chain in the baseline (without efficiency improvements) (%);

$\mathrm{L}_{\mathrm{i,reduced}}$ – share of biomass lost in the food chain in 2020 after efficiency improvements (%).

Equation 14

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

Where $SA_{\mathrm{efficiency}}$ – surplus area generated from chain efficiency improvements (tonne);

$P_{\mathrm{saved},i}$ – 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).

Current losses for specifically Eastern Romania are not separately reported. Previous research has already shown losses in Central and Eastern Europe are often higher than in Western European countries, due to less well developed infrastructure and agriculture [57,58]. For the losses in the chain data from FAOSTAT [13] are used, these give an overview of the losses in the production chain, excluding agriculture and households.

The companies already assessed the losses in the biodiesel chain and found these are low. The advantage of rapeseed over other crops is that it does not need refrigerated storage and it will not go off as some food crops with a short expiration date have. This makes storage and transport easier and reduces the losses in the biofuel production chain, compared to many food crops. In Western Europe most losses are at household level, whereas in Eastern Europe losses tend to be larger in distribution, as households are less likely to waste food and distribution networks are less well developed.

We use FAOSTAT data to determine the current losses in Eastern Romania. Since the data are country specific, we assume the losses in Eastern Romania are equal to the rest of the country. The advantage of the FAOSTAT data is that these are crop and country-specific [13]. This makes it possible to make a comparison in the losses between different countries and crops. This shows Romania is already at forefront of efficiency in CEE for wheat production, with average losses (2008-2012) of only 0.6%, compared to 4.2% for the whole region.

The scenarios for the reduction of losses in the production chain are presented in Table 11. Table 12 gives a summary of the current and potential losses for maize and wheat, the most important crops in the region, and rapeseed.

Table 11 Scenarios for the reduction in agricultural losses is Eastern Romania. These do not only apply to rapeseed production, but to all agricultural crops in the country.

Name		Description
Low	Best CEE	For each crop the current lowest loss in Central and Eastern European EU countries will be taken as the potential for Eastern Romania. Romania lays in Eastern Europe and for this scenario we expect it to be able to reduce the losses for each crop to the best level now. For wheat the losses in Romania are already the lowest in CEE.
Middle	50% reduction	The European Commission has set a target to decrease food waste by 50% in 2020 [59]. For the medium scenario we assume the loss reduction will be shared equally over the whole production chain and the losses here will be halved.
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 Eastern Romania.

Table 12 Current and potential future lsoses in the low, medium and high scenario for maize, wheat and rapeseed.

Scenario	Maize	Wheat	Rapeseed
Current	1.4%	0.6%	1.2%
Low	1.2%	0.6%	0.3%
Medium	0.7%	0.3%	0.6%
High	0.1%	0.3%	0.3%

3.4.4 Biofuel feedstock production on under-utilized lands

Under-utilized land includes set-aside land, abandoned land, marginal lands or degraded land. The share of this land type that does not provide other services (e.g. agriculture, biodiversity, high carbon stocks or other ecosystem services) – i.e., "unused lands" [29] – can be used for the production of biomass with low risk of ILUC. To define the amount of under-utilized land available in the case study area, information about location and extent of these types of land, its current uses and functions, and its suitability for the biofuel feedstock investigated in the case study is needed. Partially, this information may be found in statistics and existing literature, but in some cases spatially explicit analysis is used. For determining the amount of extra biofuel feedstock production from using this type of land, also its productivity needs to be assessed. In most cases, this is expected to be lower than average. Therefore, a marginal yield factor is applied (Equation 15). However, not in all cases yields on under-utilized land are actually lower than on agricultural land as it depends on the soil and climate conditions. For example, abandoned land in Eastern Europe does not necessarily have lower yields than agricultural land in use because abandonment was related to the structural changes due to the collapse of the Soviet Union [37]. 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 15

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

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

In some cases of degraded lands, the re-vegetation of the land (particularly if by cultivation of perennial crops) can lead to net storage of carbon in the soil, thereby increasing the GHG emission performance of the biofuel (see also Section 3.4.6). The assessment of the potential to use under-utilised lands in Eastern Romania for rapeseed cultivation is split in three aspects: 1) the use of abandoned lands; 2) the use of degraded lands and 3) the use of marginal lands. All three can reduce the pressure on agricultural or natural and contribute to an production increase [7,60].

Abandoned agricultural lands are those lands which were "previously used for agricultural crop production or as pasture but that has been abandoned and not converted to forest or urban areas" [7]. In general, land abandonment can arise as a result of low profitability [61], lack of governmental support [18], poor mechanisation [37] and a combination of urbanisation and ageing of the rural population [37]. In addition, in the case of Romania, the initial abandonment of land was a consequence of structural socio-economic changes, which then triggered a degradation of the land due to the lack of maintenance. The abandoned land were taken over by shrubs and bushes that left lower quality land after removal [37]. The changes in land ownership also led to land abandonment.

The agricultural land area utilized in Romania after the fall of the Communist regime decreased dramatically as a result of low profitability, ambiguity on land ownership and poor mechanization [37]. The transition period, which followed the fall of the regime, was characterized by economic decline [62] accompanied by three rounds of land restitutions which proved complex. The transfer of property rights of agricultural land, from the state to individuals, was a very complex process, but by 2005 the individual land ownership was up to almost 95% from 9% in 1990 [37].

Table 13 **Abandoned lands by county and size in Macroregion 2, based on the data from National Agricultural Census in 2010 [12].**

County	0-2 ha	2-5 ha	5-10 ha	10-20 ha	20-30 ha	30-50 ha	50-100 ha	>100 ha	Total ha
Bacau	3,435	7,061	3,877	1,124	225	224	246	8,383	**24,575**
Botosani	1,468	2,867	1,077	381	115	216	119	5,870	**12,113**
Braila	231	227	141	51	32	27	183	7,044	**7,935**
Buzau	1,036	1,188	426	160	77	116	49	840	**3,892**
Constanta	387	572	641	199	156	157	197	7,282	**9,591**
Galati	1,381	1,794	947	266	59	84	217	2,740	**7,488**
Iasi	1,572	2,162	706	215	82	95	211	4,136	**9,178**
Neamt	1,051	1,070	352	266	78	48	24	2,390	**5,280**
Suceava	590	619	195	106	55	24	19	779	**2,386**
Tulcea	1,070	756	271	147	51	102	53	4,641	**7,092**
Vaslui	1,674	5,830	3,136	602	47	52	192	4,469	**16,003**
Vrancea	1,229	1,912	734	187	53	101	111	2,489	**6,816**
Total Macro-region 2	**15,123**	**26,057**	**12,503**	**3,706**	**1,030**	**1,246**	**1,621**	**51,062**	**112,348**

Despite land ownership issues being settled, the amount of abandoned land lands remained stable between 2000 and 2010 [12]. This reflected the low profitability of agriculture and the poor mechanization of the sector that still weigh heavily in the decision to not pursue agriculture as an economic activity in Eastern Romania.

In general, data on abandoned land in Romania is collected once every four years with a national census. It is important to note that in the case of Romania, the data made available is exclusively on abandoned agricultural land and therefore separated from abandoned pasture land, which is not separately reported [18]. The most recent census conducted in 2010/2011 by the Romanian National Institute of Statistics (INSSE) defines abandoned lands as "agricultural land which was not integrated in the area harvested in the reference year, nor in the crop rotation cycle, and it is not looked after. This type of land can be still cultivated by standard agricultural practices" [12]. The data available on abandoned lands was published in the census report and reported in Table 13.

Under the definition available in the national statistics inventory ***degraded land*** includes the following categories: *non-agricultural lands* and *degraded and unproductive land*. Non-agricultural land includes forest and other areas with woody vegetation, marshes and reed areas, land communication infrastructure, railways, unfinished constructions or abandoned constructions, and other degraded and unproductive lands. The degraded and unproductive land consists of eroded land and barren land (rocky areas, debris, salt crusting lands, sandy areas, ravines, gullies, streams, bogs, pits). This means the definition is much broader than lands that can be potentially taken into production and includes land that is not suitable or available for agricultural production. Therefor we do not further incorporate it in our calculations, Appendix G expands on the definition of degraded land.

The data of the National Statistics Institute of Romania does not include a separate category for ***marginal lands***. In addition, local experts (e.g. APIA, agricultural research institute) said the low yields on the marginal lands make this category less interesting than abandoned agricultural lands. We will therefore not include the marginal lands in the analysis. Thus, the under-utilized land area used in this analysis only covers abandoned lands as shown in Table 14. Given that particularly small plots of land are not economically attractive, we apply different scenarios on the availability of land to account for this (see Table 14).

Table 14 **Scenerios for the availability and quality of the abandoned lands.**

Scenario	Marginal yield factor (% of average yield)	Available area
Low	75% (this is the average in the uncertainty analysis of Laborde [4])	Only large plots (>50 ha) are available
Medium	75% (this is the average used in Laborde [4])	Only the plots larger than 20 ha are available
High	99% (this is the upper limit in the uncertainty analysis of Laborde [4])	All lands are available

Following Equation 13, the marginal yield factor should be determined. This factor is the ratio between the average yields and the yields on the extra land that is taken into production. It is assumed that the abandoned land could be of a lower quality. In the scenario analysis, we apply a range of marginal yield factors, 75% in the low and medium scenario; 99% in the high scenario. Laborde uses a range of 50%-99% in the sensitivity analysis [4], however a marginal yield factor of 50% is not considered economically viable and will mean those lands are not taken into production.

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 existing nature conservation regulations and plans for the expansion of protected areas in the case study region are taken into account.

This measure is closely linked to the previous measure, i.e. biofuel feedstock production on under-utilized land, as it can limit the amount of under-utilized land that could be available for biofuels production. Therefore, in some case studies, the analyses of these two measures are linked. In this study this measure is incorporated in the under-utilised lands measure. In the analysis of the under-utilised lands (section 3.4.4) only abandoned agricultural lands are considered. The analysis of Schierhorn [63] showed abandoned lands in Eastern Europe have a chance to convert back to forest and thereby building-up significant carbon stocks. However, by only counting the lands that are assessed as abandoned agricultural lands, we avoid including these high carbon stock lands. In Appendix H we show the dynamics of the land use changes between 2000 and 2010 in eight counties in Macroregion 2. This shows there is a conversion from arable and shrub land to forest (46 kha), although the conversion the other way round is larger (55 kha).

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
- fertilizer management in the crop cultivation (type and amount of fertilizer)
- consumption of fossil energy during crop production (e.g. due to use of machinery)
- transportation method(s) and distances
- GHG emissions from feedstock conversion and credits from co-products
- biofuel end-use (e.g. transport to refueling station)

For Eastern Romania we made an overview of existing literature on GHG emissions of rapeseed biodiesel production and a number of measures that can be taken to reduce these.

3.4.7 Analysis integration

Having evaluated the individual measures, the total potential biomass production with a low ILUC risk is analysed (Figure 9). 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-utilized land. For the assessment of the potential on under-utilized land a potentially lower yield on under-utilized land compared to surplus agricultural land is considered.
- The improvements in the chain efficiency for food and biofuel production result in making surplus land area available for biofuel feedstock production. The biofuel chain efficiency is also used in the conversion of feedstock to biofuel low-ILUC-risk potential.
- Land zoning affects the availability of under-utilized land by excluding certain land areas (e.g. primary and secondary forest, other high carbon stock land, high conservation value areas, protected areas or other land not legally available for the production of biomass) and land biophysically unsuitable for the specific crop assessed in the case study.
- Land zoning also affects the availability of surplus agricultural. Although one might consider all surplus agricultural land to be available for biofuel feedstock since it is already in

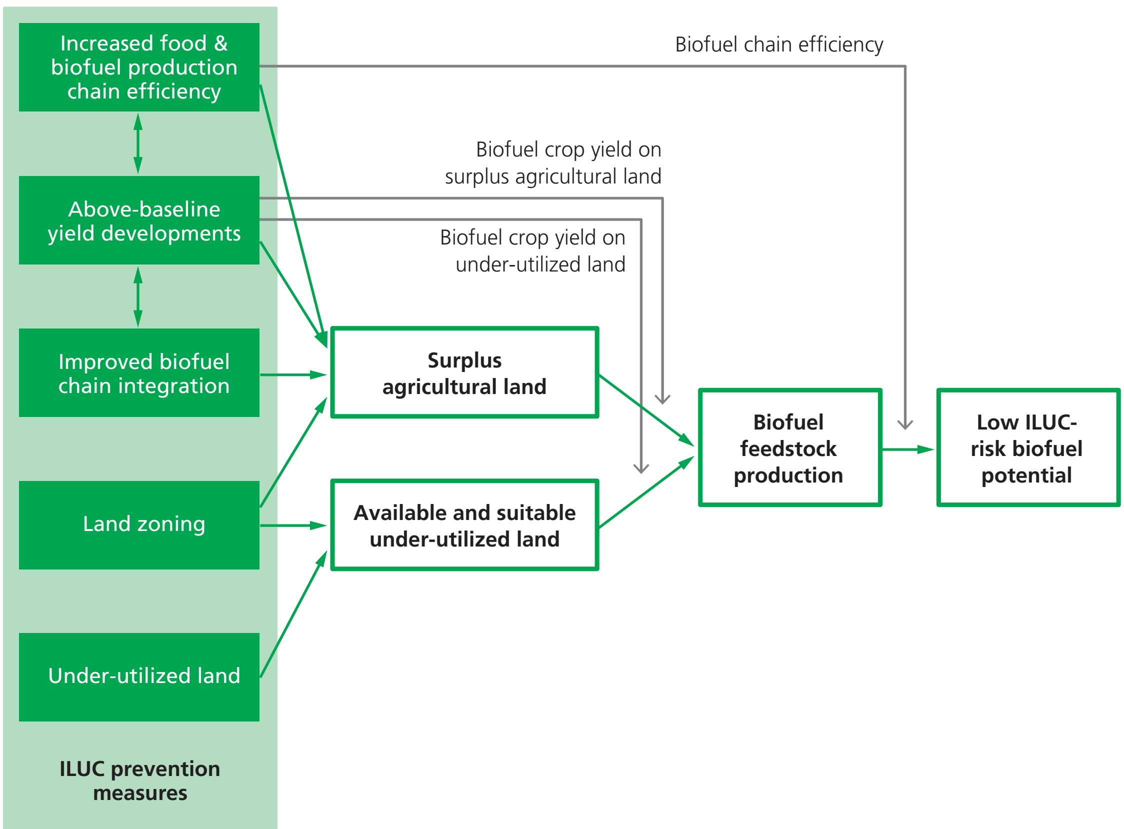

Figure 9 Schematic illustration of integrated analysis

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

To establish the potential to produce low-ILUC-risk biomass the measures applied to Eastern Romania are integrated, as the measures can enhance or exclude each other. The three scenarios and the underlying assumptions are presented in Table 15.

Table 15 **Assumptions in the low, medium and high scenarios.**

	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 Eastern Romania based on the current yield in Eastern Romania as a share of the current EU27 average.	No change in the productivity per animal or hectare.	None [a]	No change in the losses	Underutilised lands will remain non-productive.
Low	Crop yields keep increasing at the average linear rate in the period 1961-2011	The region improves to the current average level of the country.	Replacement based on the protein content of rapemeal (i.e. ratio between protein content in rapemeal and and imported soymeal).	Gain the same level of chain losses (per crop) as the current best CEE country	Abandoned plots of land that are larger than 50 ha are taken into production at 75% of average yield.
Medium	Current yield of the best county in Eastern Romania assumed possible for the whole region.	The best historical productivity in Romania.	Replacement based on historical replacement data (FAO)	Meet the EU target to half the current losses.	Abandoned plots larger than 20 ha are included, at 75% of average yield
High	The ratio between the current yield in Poland and the maximum attainable yield is applied to the maximum attainable yield in Eastern Romania.	The current productivity in Poland.	Replacement based on the energy content of rapeseed meal (i.e. ratio between energy content rapemeal and domestic barley)	Gain the same level of chain losses (per crop) as the current best EU country	All abandoned lands are available, at 99% of average yield.

[a] the MIRAGE model includes the use of meal, but this effect is excluded from this analysis (see Textbox 3).

4 Results

The results of the calculations are presented in this section. For each ILUC prevention measure we present several metrics for the *low*, *medium*, and *high* scenarios. First, the surplus lands, that come available. Second, the amount of rapeseed that can be theoretically produced on this land, if one quarter (due to the four year crop-rotation) of that land would be used for rapeseed production. Thirdly the low-ILUC-risk biodiesel that could be produced from this rapeseed. Fourth, a comparison of this biodiesel production to the target set in the National Renewable Energy Action Plan (NREAP) for Romania [33]. The last is expressed both for the whole country, and disaggregated to Macroregion 2, based on the amount of arable land in the region.

4.1 ABOVE BASELINE YIELD DEVELOPMENT

The reduced demand for land and potential extra production as a result of the yield increases is presented in Table 16, below. It also presents a comparison of the additional biodiesel production from this surplus land and the National Renewable Action Plan in order to indicate the effect of this measure.

The analysis shows that yield increases has a large potential to make land available for biofuel production. However, the effect varies strongly with the scenarios – increasing yields based on historic trends (*low scenario*) only would result in being able to produce 4% of the NREAP biodiesel target for Romania. However, the *high scenario* shows that increasing yields could result in up to 49% of the NREAP. For this scenario it is assume that Romania can increase yields to reach a similar ratio of actual to maximum attainable yield as in Poland (57% for rapeseed, 35-62% for the other crops). Although this is a significant increase in yields compared to the current situation, the absolute yield is still low compared to other rapeseed producing regions (see also the discussion on the feasibility of these assumptions, Section 5.1.1).

Table 16 Land demand reduction from higher crop yields and resulting extra production of rapeseed if the lands will be in use every four years.

	Surplus lands (k ha) due to reduced demand in:					Extra production		Share NREAP [b]	Share regionally disaggregated NREAP [b]
	Total	Maize	Wheat	Rape-seed	Other crops	Rape-seed	Biodiesel (TJ)		
Low	71	28	34	23	-14	35	510	4%	11%
Medium	415	210	88	32	86	214	3,100	23%	66%
High	727	468	155	70	34	457	6,624	49%	142%

[a] Estimate based on the assumption that one fourth of the available lands will be used for rapeseed cultivation each year as rapeseed will only be planted once every four years.
[b] According to the National Renewable Energy Action Plan (NREAP), Romania is set to produce 326 ktoe (13.7 PJ) of biodiesel [33]. Disaggregating this based on the percentage of arable land, Macroregion 2 is projected to produce 111 ktoe of biodiesel. The percentage here presents the share of the NREAP that this measure could achieve.

Table 17 **Surplus land available due to increase in livestock yields and potential rapeseed and biodiesel production on these lands.**

Scenario	Surplus lands (k ha)	Potential extra rapeseed production (k t) [a]	Extra biodiesel production (TJ) [b]	Share NREAP biodiesel [c]	Share regionally disaggregated NREAP biodiesel [c]
Low	13	6	84	1%	2%
Middle	99	44	641	5%	14%
High	396	178	2,575	19%	55%

[a] Estimate based on the assumption that one fourth of the available lands will be used for rapeseed cultivation each year as rapeseed will only be planted once every four years. The yield on the land is the projected yield from the MIRAGE model.
[b] Conversion from rapeseed to oil efficiency of 40% and oil to biodiesel 98%.
[c] According to the National Renewable Energy Action Plan (NREAP), Romania is set to produce 326 ktoe (13.7 PJ) of biodiesel [33]. Disaggregating this based on the percentage of arable land, Macroregion 2 is projected to produce 111 ktoe of biodiesel. The percentage here presents the share of the NREAP that this measure could achieve.

It should also be stressed the main share of the surplus lands does not come from the yield increases in the rapeseed cultivation alone. The yield increases in maize and wheat cultivation account for more surplus lands. In the *medium scenario* these two crops account for 87% of the surplus lands, mainly due to the large share of total agricultural production these two crops cover. In the *low scenario* the other crops lead to a negative land surplus, this means more land would be required for the cultivation of these crops when the Eastern Romanian yield trend would continue compared to the projected yield.

The amount of surplus land as a result of the yield increase in the livestock sector are much smaller compared to the increased crop productivity (see Table 17). The amount of land involved in livestock grazing is smaller than crop lands and the expected yield increases are not as large as in the crop sector.

4.2 IMPROVED CHAIN INTEGRATION

Table 18 presents the surplus land area as a result of the use of rapeseed meal as livestock feed in the livestock sector in Eastern Romania in the *low*, *medium* and *high* scenarios.

The land surplus in the historical trend (*medium scenario*) is both domestic (due to a reduction in wheat, sugar beet and barley) and abroad (due to the replacement of soymeal). The share of maize and maize

Table 18 **Domestic and foreign surplus land as a result of the use of rapeseed meal as an animal feed in different scenarios. The potential rapeseed production is corrected for a crop rotation cycle with rapeseed production once every four years.**

Scenario	Domestic surplus land (k ha)	Potential extra rapeseed production domestically (k ton)	Land surplus abroad (k ha)	Extra biodiesel production (TJ) [b]	Share NREAP biodiesel [c]	Share regionally disaggregated NREAP biodiesel [c]
Low	0	0	68.5	0	0	3%
Medium	4	2	17	28	1%	4%
High	27	12	0	178	4%	7%

[a] Estimate based on the assumption that one fourth of the available lands will be used for rapeseed cultivation each year as rapeseed will only be planted once every four years. The yield on the land is the projected yield from the MIRAGE model.
[b] Conversion from rapeseed to oil efficiency of 40% and oil to biodiesel 98%.
[c] According to the National Renewable Energy Action Plan (NREAP), Romania is set to produce 326 ktoe (13.7 PJ) of biodiesel [33]. Disaggregating this based on the percentage of arable land, Macroregion 2 is projected to produce 111 ktoe of biodiesel. The percentage here presents the share of the NREAP that this measure could achieve.

products in the total feedmix increased in the selected period. The land demand reduction abroad is the result of reduction of soy meal and palm oil kernel cake use.
Straw and glycerine are also co-products from the production chain, but are not included in this analysis. These do not replace land based products or only outside Eastern Romania. Glycerin applications in e.g. pharmaceuticals are most likely to replace palm oil and ploughed back straw can reduce fertiliser use. These are however extra benefits from the production of biodiesel.

4.3 IMPROVED CHAIN EFFICIENCY

The surplus area resulting from increased efficiencies and potential production if the land would be used once every four years for rapeseed cultivation are presented in Table 19. The surplus land available presented in Table 19 is based on reduced losses for all crops (see Table 11), not only for those presented here.

Table 19 **Loss reduction and potential production on surplus lands in Eastern Romania.**

Scenario	Reduction in losses, by crop (k ton)				Surplus land available (k ha)	Potential extra rapeseed production (k ton) [a]	Extra biodiesel production (TJ) [b]	Share NREAP [c]	Share regionally dis-aggregated NREAP [c]
	maize	wheat	rape-seed	other crops					
Low	8	0	4	30	18	11	162	1%	3%
Medium	23	7	3	20	19	12	175	1%	4%
High	44	7	4	36	34	21	307	2%	7%

[a] Estimate based on the assumption that one fourth of the available lands will be used for rapeseed cultivation each year as rapeseed will only be planted once every four years. The yield on the land is the projected yield from the MIRAGE model.
[b] Conversion from rapeseed to oil efficiency of 40% and oil to biodiesel 98%.
[c] According to the National Renewable Energy Action Plan (NREAP), Romania is set to produce 326 ktoe (13.7 PJ) of biodiesel [33]. Disaggregating this based on the percentage of arable land, Macroregion 2 is projected to produce 111 ktoe of biodiesel. The percentage here presents the share of the NREAP that this measure could achieve.

4.4 USE OF UNDER-UTILISED LANDS & LAND ZONING

Table 20 presents the available abandoned lands in Eastern Romania in the three scenarios. In addition, it gives the annual production of rapeseed if the land would be used once every four years and the share of the biodiesel production of Romania in the National Renewable Action Plan that can be covered by this production.

Table 20 **Extra lands available for the production of rapeseed and the production achieved on these.**

Scenario	Land available (kha)	Production (k ton rapeseed) [a]	Biodiesel production (TJ) [b]	Share NREAP [c]	Share regionally disaggregated NREAP [c]
Low	53	18	257	2%	6%
Medium	55	18	268	2%	6%
High	112	50	723	5%	15%

[a] Estimate based on the assumption that one fourth of the available lands will be used for rapeseed cultivation each year as rapeseed will only be planted once every four years. The yield is a percentage of the projected yield from the MIRAGE model.
[b] Conversion from rapeseed to oil efficiency of 40% and oil to biodiesel 98%.
[c] According to the National Renewable Energy Action Plan (NREAP), Romania is set to produce 326 ktoe (13.7 PJ) of biodiesel [33]. Disaggregating this based on the percentage of arable land, Macroregion 2 is projected to produce 111 ktoe of biodiesel. The percentage here presents the share of the NREAP that this measure could achieve.

Although the *low scenario* only includes abandoned plots of land larger than 50 ha and the *medium scenario* also plots between 20 and 50 hectares, the difference in available land is very limited. The amount available is similar, only inclusion of plots smaller than 20 ha adds a large amount of land and at a higher assumed yield, which explains the much higher rapeseed and biodiesel production.

4.5 LOWER GHG EMISSIONS IN THE PRODUCTION CHAIN

Previous estimates of the GHG emissions throughout the rapeseed production chain are presented in Table 21. These show the reduction in GHG emissions compared to fossil fuels varies between 20 and 82 percent, with most studies between 40 and 50%. This is a huge range and depends on various factors. The first is the inclusion of land use change (including both direct or indirect) that increases the emissions significantly, thereby decreasing the GHG savings compared to fossil fuels. Another aspect that plays an important role is the rapeseed yield. The savings in 2013, when the weather was good and yields were high, are significantly higher than those in 2014 [64]. This shows that the yield improvement is not only useful to increase the low-ILUC-risk potential, but also to increase the GHG emission savings compared to fossil fuels. Also the use of the co-products rapeseed cake and glycerine can strongly affect the results as shown in the study by Felten *et al.* (2013).

For the GHG emissions, three main phases can be distinguished in the production chain of rapeseed biodiesel: cultivation of rapeseed, conversion of rapeseed in the production plant to biodiesel and transport. The last category contributes only a small fraction towards the total GHG emissions in the production chain [25,66]. Most emissions are in cultivation and processing.

Table 21 Overview of GHG emissions of rapeseed biodiesel production and associated emission reduction compared to fossil fuel.

Reference	Year	GHG emissions (g CO_2-eq/MJ)	Life cycle emission savings (% compared to fossil fuel) [a]	Remarks
Ifeu [65]	2007	45	46	78.1 g CO_2-eq/MJ if DLUC of forest conversion is included
Hoefnagels *et al.* [66]	2010	45	50	Using other allocation methods could half the emissions. [b]
IPCA [67]	2010	39-49	42-53	Cultivation data Romania specific from government source. Processing and transport default RED values.
Pehnelt & Vietze [26]	2013	64-67	20-23	Calculations for Romania. Savings are low, due to low yield.
Felten [68]	2013	15-60	29-82	Most optimistic replacement by rapeseed cake and glycerine gives very high savings. No land use change included.
Schmitz (ISCC) [64]	2014	36-46	41-58	German data for 2013 and 2014. The highest savings are from 2013. It is not based on own research.
Biograce [25]	2011	52	38	Default value from the BioGrace calculation tool, that complies with the calculation methods defined in the EU Renewable Energy Directive.

[a] Comparing this to the GHG emissions associated with 1 MJ regular diesel (83.8 g CO2/MJ) gives the reduction, presented in the fourth column.
[b] The allocation of emissions to the co-products has a major impact on the greenhouse gas footprint of biodiesel. The emissions range between 25 g CO_2-eq/MJ for allocation based on system expansion to 45 g CO_2-eq/MJ for allocation based on market value.

The emissions from cultivation can be further divided into two categories: agricultural practices (e.g. fertiliser use, energy for equipment etc.) and land use change. Within the cultivation stage, the use of diesel and fertilisers are the main sources of GHG emissions. A key aspect in Romania is that fertilizer application -and thereby their emission- is low, which is also reflected in the yields. However, for increasing yields while minimizing nitrous oxide emissions, fertiliser use must be optimized. Optimised use refers to the right combination of fertilizer types, quantity and timing of application. Another important source of the GHG emissions is the use of diesel fuel in agricultural machinery. There is no country specific data available for this, although mechanisation is low in Romania, it is likely these machines are older and less efficient, thereby increasing the GHG emissions.

The other emissions from the cultivation phase, those from land use change, can be divided into direct and indirect LUC emissions. In this study, indirect land use change emissions are not included because we show in this study that it is possible to produce rapeseed in Eastern Romania with a low risk of diverting production to other regions or to high carbon stock lands. Also direct conversion of high carbon stock areas for rapeseed production is not considered acceptable in this study. While direct land use change is unavoidable in the case of large scale expansion of rapeseed production in Eastern Romania, in this study, direct land use conversions are from one type of cropland to another type of cropland. This is generally considered to have no or very low GHG emission implications. In the case of taking degraded lands into production for biofuel feedstock, a GHG emission credit could be received, such as the EU-RED's 29 g CO_2-eq./MJ emission bonus. However, in this case study on Romania, use of degraded land is not considered likely so that an emission credit is not awarded.

4.6 INTEGRATION

The results of the integration of the measures is shown in Figure 10 in terms of surplus available land area generated from ILUC prevention measures in Eastern Romania in 2020. Comparing this to the total land use in Eastern Romania in 2020 projected by MIRAGE (Figure 10) indicates that more land area can be made available in the *medium* and *high scenario* than is projected to be needed by MIRAGE. Therefore, additional production can take place without causing (indirect) land use change.

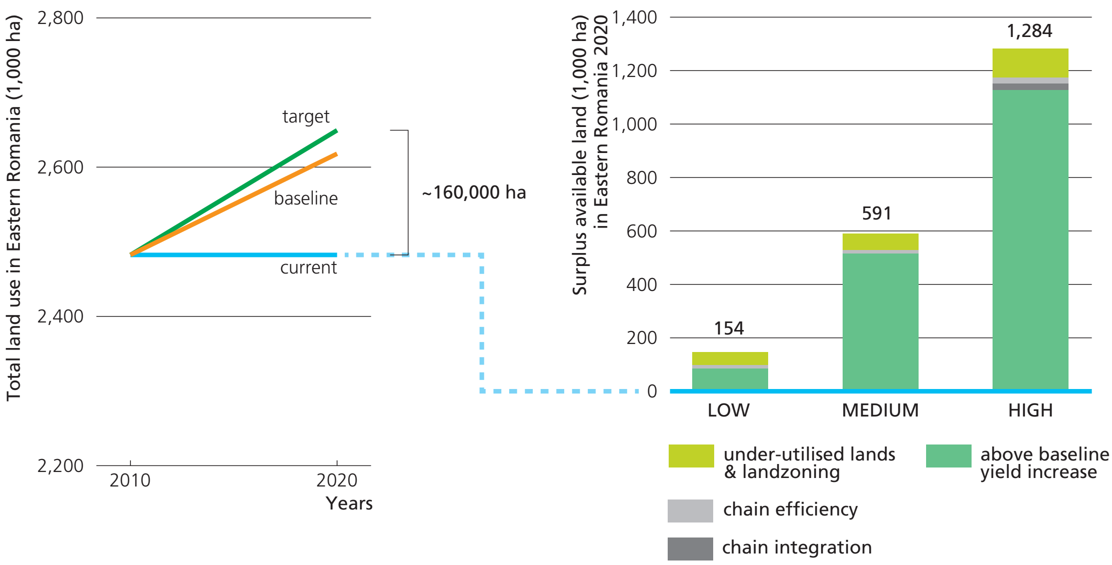

Figure 10 The left pane shows the total land use (in 1000 hectares) in 2010 and the projected land use in 2020 in Eastern Romania. The right pane presents the surplus available lands in 2020 in Eastern Romania after integration of the ILUC prevention measures. The difference between the target and the current land area should be covered by the surplus area in order to avoid undesirable LUC.

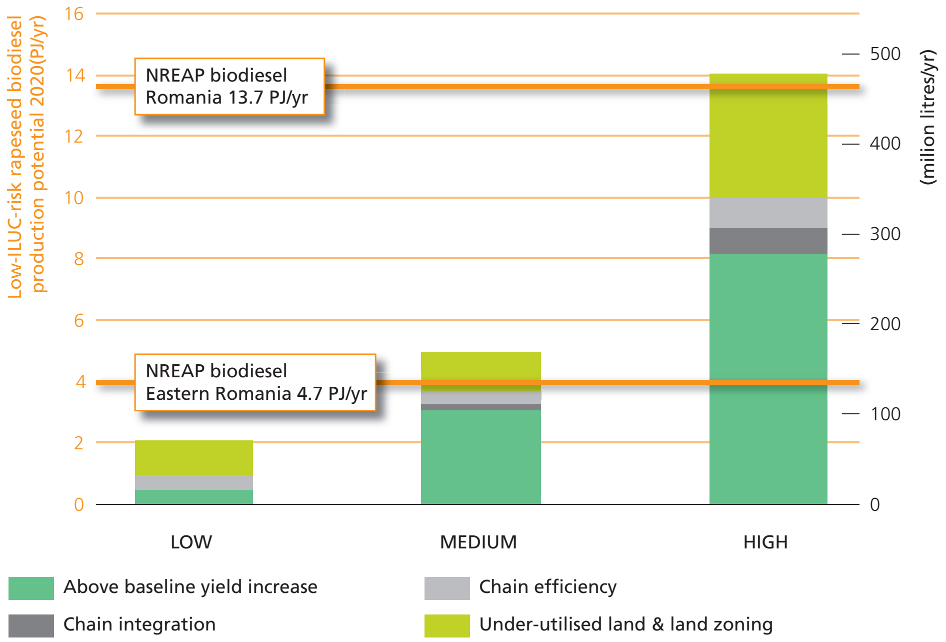

Figure 11 **Low-ILUC-risk biodiesel production potential in 2020 in Eastern Romania, after integration of the ILUC prevention measures. The two lines indicate the National Renwable Energy Action Plan target for biodiesel in Romania and disaggregated in Eastern Romania.**

Based on the surplus available land, Figure 11 presents the low-ILUC-risk biodiesel production in Macroregion 2 of Romania in 2020. In the *high scenario* the low-ILUC-risk biofuel production is 118% of the amount of biodiesel defined in the national Renewable Energy Action Plan (NREAP) of Romania. This number rises to 344% of the NREAP target for the region if we disaggregate it based on the amount of arable land in Eastern Romania compared to the whole country. For the *medium* and *low* scenario these are 42%, 123% and 48% and 16% respectively. Note that this is extra production in addition to the production projected by the MIRAGE model.

From both figures it appears the above baseline yield development and use of under-utilised lands are the measures with the largest potential. The yield lead to 54-87% of the surplus area, whereas it is 9-34% for the under-utilised lands. The effect of the chain efficiencies is smaller in the *medium* than in the *low* scenario because the land demand reduction is larger when yields are lower. In this case the effect of the yields is larger than the effect of increased savings.

As the surplus lands in the *medium* and *high* scenario are higher than the difference between the projected current land use and the projected land use in 2020 in target, the production can take place without undesired land use change. Only the surplus lands in the *low* scenario are smaller than required, which means there is a risk of indirect land use change.

5 Discussion

5.1 ILUC PREVENTION MEASURES

5.1.1 Yield improvement

The results show that above baseline yield improvements are an important source of low ILUC risk biomass (Table 16). Up to 49% of Romanian NREAP target for biodiesel production can be produced extra in Eastern Romania if the agricultural practice could get to the standard of Poland. Although underlying yield increases (especially for maize, rapeseed and oats) are large compared to the current situation, several arguments can be given for why this is still expected to be feasible in this case study. First, the projected absolute yield even in the *high scenario* is still low compared to current yields in other regions (see Figure 12). The yield projection in the *low, medium* and *high* scenario are lower than the current yields in Hungary, Poland and Germany. The difference is predominately caused by the difference in agricultural practices; whereas the differences in biophysical conditions are much smaller.

Second the work of Gerssen-Gondelach *et al.* [69] indicates that yield growth rates also depend on the size of the yield gap – higher yield growth rates are easier to achieve in regions with high yield gaps and vice versa. Given the high yield gap in Romania, large yield growth rates are considered feasible.

Third, previous studies have shown that large increases in yields have been possible in the past (see for example, de Wit *et al.* [70] for Europe or Gerssen-Gondelach *et al.* [69] for an analysis of seven countries across the world that are large food producers or are considered to have a large biomass producing potential). Both studies show that a key factor in yield improvements is agricultural policy. De Wit *et al.* showed there is a clear correlation between stimulating policies, such as intervention prices and yield increases. The opposite effect was also observed: yield decreases when such policies were abolished. This implies that long-term contracts and guaranteed prices offered by biomass buyers can help to improve yields.

And fourth, given recent changes in land ownership (as described in Section 3.4.4) and renewed interest for investments in the agricultural sector in Romania, higher yield increases than in the recent past may be expected.

In addition, the analysis of reduced demand for land from increased crop yields shows that gains will not come from stimulation in the rapeseed sector alone, but instead require improving yields of the other key agricultural crops. As shown in Table 16, maize and wheat yields affect land demand reduction more than rapeseed. This is the result of larger surface areas occupied by these crops. Therefore, any policy should take a broad scope in terms of what crops to address and not narrow down on rapeseed yield improvements alone.

Related with the yield growth is the decrease in the crop rotation period, which will further increase the rapeseed production in Macroregion 2. It is expected higher yields and thereby higher revenues will make rapeseed production more profitable. This provides an incentive to reduce the crop rotation cycle

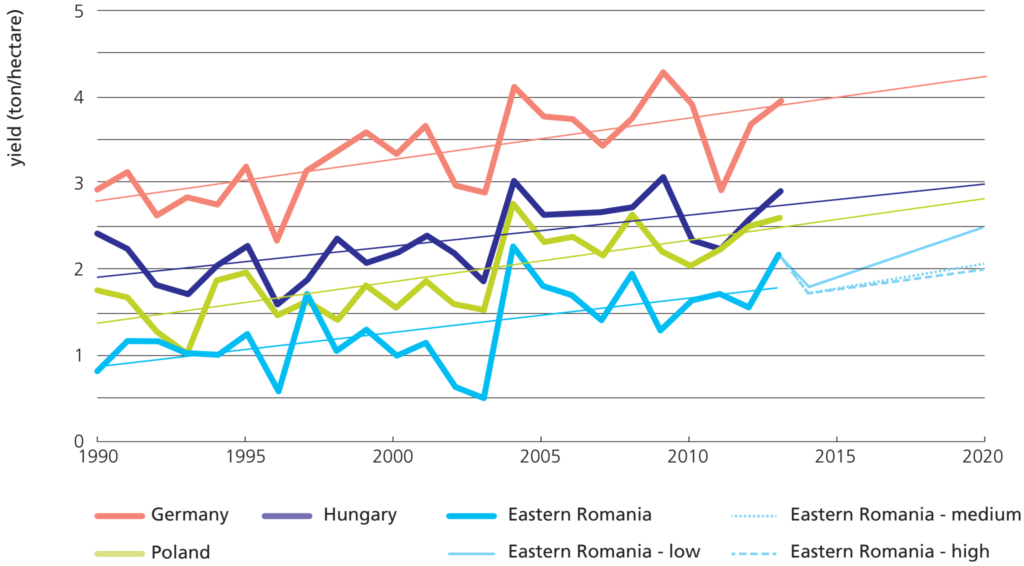

Figure 12 Rapeseed yield development in the *low, medium* and *high* scenario compared to the yields in other European countries.

to three years. This could increase the low-ILUC-risk biodiesel production potential by a maximum of one third, in practice it is a bit lower at 0.2-3.4 PJ. Conversely, increasing the crop rotation to five years, would reduce the low-ILUC-risk biodiesel production by 0.13-2.0 PJ.

Furthermore, in the three years in the crop rotation cycle that are not reserved for rapeseed, the saved lands will in reality be used for other agricultural production. This means production of other crops would be even higher than presented in this study.

5.1.2 Chain integration

Chain integration in Eastern Romania now includes only the use of rapemeal as animal feed. The meal is expected to reduce the demand for feed crops and thereby make land available for rapeseed production. Other co-products can also be used to reduce the demand for agricultural products and thereby for land. However, the straw from crop cultivation is brittle and hard to collect for other applications. It is used for bedding in stables, but this would only replace other co-products. Ploughing back the straw and the nutrients into the soil has a fertilising effect and can help to increase future yields on that soil, with reduced artificial fertiliser use. This effect cannot be related to land use. The same holds true for the use of glycerine, this can be used in pharmaceuticals and other higher value applications. This may replace palm oil, but will not replace other agricultural products from Eastern Romania.

Both straw and glycerine can be used in animal feed as well, but no data on the replacement of other agricultural products was found.

5.1.3 Chain efficiency

The results in Table 19 show the extra rapeseed production if the food and biofuel chain are more efficient and losses therein are reduced. The reduced losses lead to lower demand for crop production, which makes more land available for rapeseed cultivation. Although the largest losses in the food chain are expected to be at the consumers [57,58], we excluded these from the analysis as this falls outside the scope of agriculture and bioenergy.

The FAO data that is used to estimate current losses only includes the sectors between agriculture and households. This means much larger gains than presented here can be expected in the future if also household food waste will be reduced. Although the FAO provides the only crop-specific loss data these are country-specific so not for the Macroregion 2. In this study the share of a crop that is lost in Macroregion 2 is assumed to be the same as the share in the whole country. As the Eastern part of Romania slightly lags behind the rest of the country economically it can be expected losses in the chain will be above the national average, but there is no data to quantify this assumption. Another question that can be raised is where to allocate the benefits of the reduced losses. The food market is international and few (food) crops will remain specifically in eastern Romania. When food losses are reduced (e.g. by better storage facilities outside the region) to what extent can the benefits still be accounted for in Macroregion 2? We assumed all reduced demand reduces land demand in Eastern Romania following the same principles of consequential analysis (see Textbox 2 on page 28).

This measure again shows the importance of an integrated perspective. The savings that can be achieved in only the biodiesel production chain are limited to three to four thousand ton. Including maize, wheat and other food chains can further increase the extra rapeseed production. Efforts should therefore not be limited to the rapeseed production, but include all major crops in Eastern Romania.

5.1.4 Under-utilized lands and land zoning

In the *high scenario*, the abandoned lands in Eastern Romania can provide up to 5% of the annual biodiesel production in the National Renewable Energy Action Plan. This assumes all lands that were without an owner in 2010 can be used, no matter the size and at almost the same yield as the regional average. In practice, smaller plots of land will be harder to take into production and are less likely to do so at the same yields, as mechanisation will not pay-off at a small plot of land.

Data on abandoned lands is only available from the 2010 agricultural census. Although this is the most recent data, the agricultural situation in the region has changed in recent years. For example, land ownership for foreigners is no longer outlawed, which can increase demand for land. Availability for more recent data on abandoned land is expected to become available in 2015 as the new census is currently underway.

This study relies on the local statistics on abandoned land, which do not indicate corresponding carbon stocks. This is why the carbon stocks of abandoned lands are not considered in the analysis. However, carbon stocks of the abandoned lands can be significant if trees are growing on the land. But it is sometimes politically preferable to classify land as abandoned agricultural land, instead of the forest that it actually is. This has to do with environmental regulations, that make it harder to use these lands in the future. This can lead to potentially large carbon emissions if carbon stocks are not accounted for in the assessment [15]. Therefore, in the further assessment of this measure, it is merged with the better land zoning measure so that potentially high carbon land can be excluded from the analysis. In terms of land zoning, the study already excludes the lands that are marginal or otherwise not in use, such as The Danube Delta Natural Reservation, a large natural conservation area in the south east of the region.

In Appendix H we made an analysis of the differences in land use data between the national statistics database and satellite imaging. This shows there is a significant difference between the two sources, especially in the amount of forest land in Eastern Romania. Furthermore, it appears forest land is not a fixed stock, but it is more dynamic. Through the years land, that was used in agriculture until recently, is added to the forest, while at the same time forest land is converted to agricultural land.

5.1.5 Lower GHG emissions

GHG emission savings in the production chain can be achieved at various points. A report by the German Biodiesel Research Center presented a number of potential GHG emissions savings in the production chain [71]. For example, they suggest the use of biodiesel to replace regular diesel to reduce the fossil fuel use. In addition, they advise the use of other synthetic nitrogen fertilisers, that cause fewer GHG emissions during production or where NO_2 emissions in the field are lower. The last suggestion is also underlined in a report for IEA Task 39 [72]. O'Connor [72] also adds the benefits of no-till farming due to a reduction in fuel use and a build-up in soil organic carbon. The GHG emissions of the conversion of rapeseed to biodiesel can be reduced by switching to renewable energy and switching to the use of bio-based methanol.

Regarding the allocation of emissions to the co-products, GHG emissions are allocated to the various products on basis of their energy content. However, glycerine has a high economic value relative to its energy value [26]. This means that economic allocation would reduce the share of emissions allocated to biodiesel. Other allocation decisions include the use of the rapeseed straw. Currently, this is ploughed back in the soil and offers a fertiliser benefit for the next crop in the crop rotation cycle, reduces the need for other fertilisers (by 27 kg N/ha, [25]) and thereby reduces the GHG emissions. The straw might in the future also be used for second generation ethanol production, which means a share of the GHG emissions of the rapeseed cultivation could be allocated to the straw and thereby improve the GHG balance for biodiesel even further. The data to calculate the impact of applying all these measures -switch to biodiesel, use other fertilisers, no-till farming, use of bio-based methanol, use of straw for bioethanol- to Eastern Romania lacks, but O'Connor [72] estimates that it can reduce the emissions in the production chain by up to 34%, compared to his reference in 2005. Majer and Oehmichen [71] find in their optimal scenario -in which the reduction measures are fully implemented- a reduction of 28 percent point compared to the default emission reduction from the Renewable Energy Directive. This is a total emission reduction of 55% compared to fossil fuels.

5.2 DATA UNCERTAINTY [11]

In order to calculate the potential surplus area and low-ILUC-risk biomass availability several different data sources have been used to quantify the measures. Not all data is available or only at a higher level of aggregation than needed for the case study. Table 22 presents an overview of the data sources that have been used for the indicators, their characteristics, and reliability and uncertainty of the data. Especially if no data was available or only not country specific data other assumptions have to be made as input for the calculations. The table presents an overview of the related uncertainties.

11 The data sources for this case study and the case study on Hungary overlap partly and data issues are similar. Therefore this section partly overlaps with the same section in the report on Hungary [80].

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

Indicator	Data source	Level				Remarks on uncertainty
		local	national	Contnental (EU)	world	
Historical production data	FAOSTAT[13]		X	X	X	Reliable source used for historical production and yield data. A five year average is taken in most cases in order to correct for influences such as bad weather that can have a large impact on the production data of one specific year. Data at sub-national level is not available.
	EUROSTAT[15]	X	X	X		Reliable source for country and sub-national data (NUTS2 and NUTS3 level).
	INSSE [12]	X	X			Has data available up to county level, however the accessibility of the database is low due to website being down often.
Future production	MIRAGE [4]			X		As MIRAGE only presents the results at the EU level, the data should be disaggregated, which creates a lot of uncertainty.
Crop losses	FAOSTAT [13]		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	IIASA/FAO GAEZ [32]	X	X	X	X	The IIASA/FAO GAEZ database is spatially explicit, which makes it very well adaptable to a specific situation. 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 this methodology cannot cover all crops. Although spatially explicit, no selection smaller than country level can be made, which means GIS analysis is required to process that data.
Future yield	MIRAGE [4]			X		The yield projection from the MIRAGE model is only available at EU level; therefore it has to be disaggregated to the level of Macroregion 2, which increases the uncertainty.
Abandoned land	Cadaster [73]	X	X			Although officially publically accessible data, a specific request had to be made. It can be considered as the most reliable data to establish the amounts of abandoned land, as it is based on land census where each plot of land was counted.
Replacement rate	FAOSTAT [13]					Only available aggregated numbers on the replacement of feed types. Replacement likely to be influenced by external factors. Increased availability of meal can also influence prices and thereby the inclusion.

6 Policies[12]

To prevent a region from causing indirect land use change, it should be able to provide the future supply of food, feed, fibre and fuel without expanding production onto high carbon stock lands or divert the production to other regions. This case study shows low-ILUC-risk biomass production in Eastern Romania is possible under these conditions. 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 Eastern Romania in order to stimulate low-ILUC-risk biofuel production and the monitoring options (section 6.6) to keep track of the developments.

Table 23 presents a summary of the most important policy options per measure.

Table 23 Summary of policy and governance options for the key ILUC prevention measures and rapeseed production in Eastern Romania.

Measure or goal	Policy and goverancne options
Above baseline yield development	- Stimulate sustainable intensification of agricultural sector - Provide training for farmers on appropriate chemical use - Offer more certainty to farmers to incentivise investment - Evaluate options for land reform to stimulate investment in the agricultural sector - Stimulate mechanisation of the agricultural sector by increasing knowledge of farmers and ability to invest e.g. by use of cooperations
Increased chain integration	Already implemented
Increased food chain efficiency	- provide insight in size and cause of food losses - stimulate exchange of best practices to reduce chain losses
Biofuel feedstock production on under utilised land & land zoning	- provide insight in the size, location and quality of abandoned lands - identify and protect high carbon stock lands - improve the profitability of agriculture in order to incentivise taking into production abandoned lands or raise land prices to stimulate sales of abandoned land

6.1 YIELD IMPROVEMENTS

Agricultural yield improvements are the main measure to increase the biomass production, without leading to any adverse land use change. Policy should therefore focus on this aspect. There are many measures that can be taken in this respect (see Table 23). The important issue is that these should not only focus on the rapeseed production alone, but on the entire agricultural sector. Yields of all crops have to improve in order to reach the presented low-ILUC-risk biomass potentials from this research. Especially maize and wheat, as the main crops in this region, present a large share of the required yield improvements.

Investments in better equipment for smallholders can be stimulated by promoting cooperatives, to share the investment costs and the risk. Farmers can be educated on the benefits of the use of fertilisers and other chemicals. Land reform to increase the size of farms could help to improve the productivity of machinery and labour. Long-term contracts can reduce the risk for farmers and stimulate investment in equipment to improve yields.

6.2 IMPROVED CHAIN INTEGRATION

To promote improved chain integration no specific policies are required. The rapeseed meal is already been sold to livestock farmers and in widespread use. It would be beneficial to stimulate the replacement of low yield crops, as this leads to the highest land surplus. However, foreign land demand reduction (i.e. from soymeal), is not included in this research and does not count towards the low-ILUC-risk biomass production potential. This does not mean there is no land surplus; it could be argued the demand decrease abroad is larger and from a carbon perspective more important, but this is not considered in this research.

As meal is a good alternative on the feed market no stimulating policies are required. Chain integration of other co-products (e.g. straw, glycerin) requires a more stimulating environment.

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 lacks. In order to make a good assumption, data sources need to be improved, also to see to what extent the losses are reduced. As with the yield improvements, also for the improved chain efficiency the policies should focus on all crops and not only on the rapeseed sector as the losses occur throughout the sector and only improving biofuel chain will not suffice.

6.4 BIOFUEL FEEDSTOCK ON UNDERUTILISED LAND AND LAND ZONING

For under-utilised lands the most critical issue is the amount of land that is available and potential competition with other land uses such as reforestation. Analyses suggest abandoned lands have been converted to forestry, but are not registered as such. This would mean conversion of these abandoned lands can have undesirable impact on the carbon balance. Policies should be put in place to get a good overview of the current land use in order to prevent such problems. A good land registry also makes it easier to see where the abandoned lands are and make them better accessible to agricultural production. The results show this could potentially be the second largest source of lands for low-ILUC risk biomass production.

6.5 GHG EMISSION REDUCTION

The improvement of the GHG footprint of rapeseed biodiesel production will already benefit from the other policy measures. Sustainable intensification of the crop production to stimulate yield growth, will also reduce the GHG emissions per unit of biofuel. This would require a decoupling of yield improvement and growth of fertiliser use. The use of abandoned lands for biofuel production already gives a credit in the GHG balance calculations, so this is related to the measures to use under-utilised lands.

6.6 MONITORING

An important aspect of policies is to monitor their effectiveness. Table 24 and Table 25 present the parameters that should ideally be monitored in order to assess the effectiveness of the policies. Table 24 focusses on the parameters directly related to land use and possible undesired expansion, whereas Table 25 presents an overview of the parameters that are related to the ILUC prevention measures. The parameters presented in the second table can help to assess the specific policy measures and keep track if the suggested policy measures are on track. The parameters from the first table can help to determine whether land use change is taking place or production is diverted to other locations as a result of the production in Eastern Romania.

The desired frequency and spatial scale are suggested for each parameter. For some parameters less specific data might also be sufficient, although this could reduce the accuracy. Where applicable, also thresholds per parameter have been defined. These identify the level and bandwidth within which the parameter should be, in order to keep on the track of producing low ILUC-risk biomass.

Table 24 **Main parameters to be monitored in Eastern Romania to assess undesired land use change.**

Parameter	Purpose of monitoring	Desired frequency	Desired spatial scale
Land use	Is any land use expansion is taking place? Are the under-utilised lands are taken into production? How much under-utilised land is still available?	Yearly	Spatially explicit/ country level
Production volume	Production developing as projected? Higher production might mean risk of land use expansion in the region. Lower production can also indicate diversion of production or failure to provide food, feed, fibre and fuel.	Yearly (at a five year average)	Local level
Trade balance	No major increase in imports of agricultural products or processed goods? Decrease in soy and other feed imports?	Yearly (at a five year average)	Country level
Agricultural prices	Absolute price stability? Relative price stability?	Yearly	Country level

Land use can be accurately monitored with on the ground field measurements or by using satellite and other remote sensing data. This could be combined with ground trothing, in order to verify the measurements. The purpose to monitor the land use would be to identify the under-utilised lands in Macroregion 2 and to track to what extent these are taken into production. Furthermore estimation of the carbon stocks should be included in monitoring. Currently accurate data for this lacks, which makes it harder to use land zoning effectively. 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. We saw a discrepancy between the official land use statistics and satellite data (see section 5.1.4 and Appendix H). In addition, land was converted back-and-forth between agriculture and forest which increases the importance of good land zoning policy and enforcement, but knowledge on where new forests are, is vital in order to know which areas to avoid. In addition, land that is abandoned or set-aside according to the statistics can be used in practice for extensive livestock herding. Therefore ground trothing is an important component of the monitoring.

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. Alternatively it can also be a precursor of increased imports or reduced exports and thereby increased risk of undesired land use change. Too high production could indicate increasing demand, not accounted for in the model, risking land expansion on high carbon stock lands in Eastern Romania.

Agricultural prices need to be monitored as well. Large price increases in Romania can indicate too low production to cover food, feed, fibre and fuel demand, thereby not fulfilling one of the basic principles of the method. 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. This should be monitored on a yearly basis as seasonal changes are likely to occur anyway. The preferred spatial scale for this data is the case study region, but these data era already collected at a country level and due to the characteristics of a globalised market no large differences between national and regional prices is expected.

For the trade balances Eastern Romania is preferably considered as a closed entity with formal import and export statistics to ascertain no changes in the trade balance occur. This is however not viable for small regions. Therefore country level data need to be considered. Increased imports to the region indicate production is not sufficient and extra bioenergy production will likely displace other production.

Table 25 Parameters to assess effectivity of the ILUC prevention measures.

Parameter	Purpose of monitoring	Desired frequency	Desired spatial scale
Yields	Is the yield increase in all crops as high as desired?	Yearly (at a five year average)	Regional level
Investments	Are investments in machinery increasing?	Yearly	Regional level
Fertiliser use	Is fertiliser use in Eastern Romania increasing? Is it at the level of the rest of Europe?	Yearly	Regional level
Pesticide use	Is pesticide use in Eastern Romania increasing? Is it at the level of other European countries?	Yearly	Regional level
Waste/losses	How high are the losses? Are they reducing as much as expected?	Continuously	Crop specific at regional level
Development of under-utilised lands	How much land is abandoned? What quantity is being used? Is reforestation taking place?	Yearly	Spatial explicit
Quality of degraded lands	Is crop production possible on these lands? What yields can be achieved on the degraded lands?	Once	Spatial explicit
Quantity of degraded lands	How much degraded land is available? How much is taken into production?	Yearly	Spatial explicit
Feed use	How much rapemeal is included in the feed? How much does it replace?	Yearly	Feed specific regional level

The crop yield data are already collected by the national statistics office, EUROSTAT and FAOSTAT. This is sufficient to monitor the yield development. This does, however, not give insight in the variation between farmers in the region. In order to know the least productive farmers, we need to know more details than the average for the region. It should be noted that the yearly yield changes are not very significant as these are mostly led by weather patterns, rather than improvements in the agricultural sector. Therefore a five year average is more useful to consider. As threshold value for the parameter, the potential above baseline yields from the *low*, *medium*, and *high* scenario are a good values. When actual yield growth is below the potential value, it denotes the potential low ILUC-risk biomass production cannot be achieved. This would mean the biomass production might be a risk to cause ILUC. This should mean production should stop or an extra effort needs to be made to increase the yields.

Measures to increase the yields include increased mechanisation and increased fertiliser use. FAOSTAT and Worldbank already keep records of investments, mechanisation and fertiliser use in agriculture. These data are often not up to date, but if collected yearly, they could be a proxy for the yield improvements. When these do not increase significantly, the yield improvement targets are unlikely to be met. Currently these data are on country level, rather than regional level. For monitoring the developments in Eastern

Romania regional data is preferred. However, country data can act as a good proxy for the developments in the agricultural sector in the whole country, as it is likely policies have a national scope.

The first step for monitoring crop losses in Eastern Romania 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 food supply chain it is possible to assess if the reduction matches the target. Again, all data is currently collected on country level or higher. However, it is expected this is be a good proxy for the losses data in Eastern Romania.

The development of abandoned lands needs to be monitored to see how much land is available and to see if it decreases as expected. Ideally this provides spatial explicit data. If abandoned land increases at the expense of agricultural land, forest might in turn be converted to agricultural land to produce the maize. This does not show in the statistics, and therefore underlines the importance of using spatially explicit data when assessing the available lands. This needs to be monitored every year.

As the feed mix in a region is continuously changing, a yearly overview of feed use is needed. This should include the share of each crop within the feed mix. An overview of the feed market allowes us to establish how much feed is replaced by the use of rapemeal in the feed mix.

7 Conclusions

This case study assessed the low-ILUC-risk production potential of rapeseed and biodiesel in Romania's Macroregion 2, the Eastern part of Romania. Six measures have been analysed that reduce the extent of ILUC, control the type of land use change and limit GHG impacts of biofuels. The potential to reduce land use demand and produce more biofuel have been assessed for a *low*, *medium* and *high* scenario. These scenarios refer to developments in agricultural resource efficiency, productivity and sustainable land use above the business as usual scenario. In 2020, a total area of 154-1,284 thousand hectares can become available as a result of these measures. Compared to 160 thousand hectares that the economic model MIRAGE projects to be additionally needed to accommodate all food, feed, fibre and fuel production in Romania. This means the production in Eastern Romania can take place without the need of diverting production to other regions, or expanding on high carbon stock lands. Considering the land will be used once every four years for rapeseed cultivation, annual biodiesel production can increase by an extra 2-16 PJ (60-434 million litres). To give an indication of the size of this; it is 48% to 344% of the National Renewable Energy Action Plan (NREAP) biodiesel target disaggregated to Macroregion 2 based on the share of arable land in the region.

To reach this potential, especially yield increases in crop cultivation and livestock raising are important. 27% to 67% of the potential extra rapeseed production comes from land made available as a result of above baseline yield increases. The second most important measure is taking currently abandoned lands into production at 8%-30% of the potential.

However, the extra production will not come about autonomously. Policies have to be implemented in order to achieve this extra production. The key in this is to take a sustainable approach to all agricultural production for food and non-food purposes. The interconnectedness of bioenergy and agriculture means this has to be reflected in the ILUC prevention policies, by not only focussing on energy crops, but including all crops. The indirect land use change from expansion of bioenergy crops is direct land use change of other -food- crops elsewhere. Furthermore addressing resource efficiency and productivity increases only in rapeseed production are not sufficient to cover the whole projected agricultural production expansion. However, when also addressing other key crops the projected expansion can be met.

As yield increases are the most important measure that can be taken to reach the required production, the focus of policy, and company efforts and investments should also be on this aspect. To increase yields, agriculture in Eastern Romania needs to modernise. Current management practices lag behind Western Europe and other Central and Eastern European countries, with regards to mechanisation, fertiliser use and pesticide use. This has largely to do with a lack of capital investment and knowledge. Farmers do not always have the technical knowledge and incentives to to modernise. Also the use of under-utilised land, here specifically abandoned agricultural land, contributes significantly to the low-ILUC-risk potential determined in this study. Taking abandoned lands into production requires knowledge on their exact location, size, ownership and possible extensive uses that can only be detected with field visits. This helps to facilitate taking the land into production. Thus, land use data are required in addition to policies to stimulate and support the use of these lands by providing incentives for the current owners to take the land into production or sell or lease it to others that are willing to use the land.

Future developments in this sector need to be monitored in order to ascertain that policy options have sufficient effect to increase the productivity of Eastern Romania and prevent undesired land use change. Monitoring falls into two categories: 1) monitoring land use change and 2) monitoring the effectiveness of the policy options to assess whether implementation is on track. These monitoring tools can then be used to keep a close eye on the developments in Eastern Romania and stop expansion of biofuel production if the risk of undesired land use change is likely to occur.

Taking a holistic approach on the agriculture and biofuel sectors, our assessment shows that modernised agriculture in Eastern Romania allows meeting food and feed demand and increasing biomass production for energy purposes significantly without diverting production to other regions or onto high carbon stock areas. This modernisation contributes to low-ILUC-risk biofuels production, but also to increased performance of the agricultural sector as a whole and to the income of farmers and owners of currently under-utilised land.

A key characteristic of indirect land use change is that it takes place at other locations than the bioenergy feedstock production. We show in this case study that biofuel production in Eastern Romania 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 on Hungary, Lublin (Poland), and North and East Kalimantan (Indonesia) show similar results. 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 feedstocks can be exported to other regions, thereby reducing the pressure on land use abroad. This requires large efforts and investments in the agricultural sector, and strengthening and enforcement of land use policies in each region. But it shows that ILUC as determined in the economic models is not an irreversible fact, but a risk that can be mitigated. This is possible by taking a sustainable approach to all land use for food, feed, fibre and fuels production.

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Appendix A Current agricultural practices

Table 26 **Number of farms in Romania, Macroregion 2 and North and South East. The percentages denote the share of that size within the total number of farms in that region.**

	Romania		East		North East		South East	
Zero ha	land area (ha)	%	land area (ha)	%	land area (ha)	%	land area (ha)	%
Less than 2 ha	1,833,850	66.5%	683,650	72.5%	476,660	73.7%	206,990	69.9%
From 2 to 4.9 ha	678,020	24.6%	202,080	21.4%	138,060	21.3%	64,020	21.6%
From 5 to 9.9 ha	171,650	6.2%	37,640	4.0%	22,970	3.6%	14,670	5.0%
From 10 to 19.9 ha	40,310	1.5%	8,870	0.9%	4,850	0.7%	4,020	1.4%
From 20 to 29.9 ha	8,790	0.3%	2,480	0.3%	1,230	0.2%	1,250	0.4%
From 30 to 49.9 ha	7,350	0.3%	2,270	0.2%	1,050	0.2%	1,220	0.4%
From 50 to 99.9 ha	6,480	0.2%	2,110	0.2%	800	0.1%	1,310	0.4%
100 ha or over	10,480	0.4%	3,890	0.4%	1,140	0.2%	2,750	0.9%
Total (ha)	2,756,930	100%	942,990	100%	646,760	100%	296,230	100%

Table 27 **Amount of arable land (in hectare) in Romania, Macroregion 2, and the north and South East that is owned by various farm sizes. The percentages denote the amount of arable land in that region that falls in each farm size.**

	Romania		East		North East		South East	
Zero ha	land area (ha)	%	land area (ha)	%	land area (ha)	0,0%	land area (ha)	%
Less than 2 ha	1,040,130	12.5%	384,890	13.2%	268,170	22.5%	116,720	6.8%
From 2 to 4.9 ha	1,398,650	16.8%	428,660	14.7%	281,750	23.6%	146,910	8.6%
From 5 to 9.9 ha	708,120	8.5%	169,890	5.8%	93,870	7.9%	76,020	4.4%
From 10 to 19.9 ha	340,430	4.1%	83,090	2.9%	37,360	3.1%	45,730	2.7%
From 20 to 29.9 ha	147,250	1.8%	41,400	1.4%	15,840	1.3%	25,560	1.5%
From 30 to 49.9 ha	198,220	2.4%	64,210	2.2%	23,350	2.0%	40,860	2.4%
From 50 to 99.9 ha	333,170	4.0%	120,710	4.1%	38,330	3.2%	82,380	4.8%
100 ha or over	4,140,450	49.8%	1,616,370	55.6%	434,780	36.4%	1,181,590	68.9%
	8,306,420	100%	2,909,220	100%	1,193,450	100%	1,715,770	100%

Table 28 **Crop production in Macroregion 2 in the period 2005-2012 [12].**

Crop	Production (kton)								average 2008-2012	As percentage of country wide production
	2005	2006	2007	2008	2009	2010	2011	2012		
Maize	3,960	3,278	1,077	2,725	2,529	3,121	4,421	1,817	2,923	34%
Wheat	1,809	1,388	827	2,329	1,490	1,860	2,035	1,521	1,847	30%
Potatoes	1,085	1,158	859	957	1,048	861	1,145	703	943	27%
Sunflower	651	743	280	520	478	536	767	582	576	43%
Barley	272	204	175	443	444	596	528	371	476	40%
Water melons and melons	395	325	198	275	331	321	288	209	285	46%
Rapeseed	86	77	221	377	273	394	296	60	280	45%
White cabbage	356	326	246	284	286	261	279	281	278	28%
Tomatoes	214	281	233	271	260	280	334	231	275	35%
Sugar beet	177	403	228	228	226	244	195	262	231	31%

Table 29 **Number of animals in Macroregion 2 in 2012 [12].**

Animal	number
Chicken	25,136,118
Sheep	2,654,405
Pigs	1,384,077
Goats	523,365
Cattle	438,046
Horses	242,130

Table 30 **Area required for the most important crops in Macroregion 2 in the period 2005-2012 [12].**

Crop	Area (k ha)								average 2008-2012
	2005	2006	2007	2008	2009	2010	2011	2012	
Maize	1,059	1,001	942	898	864	765	980	995	900
Wheat	602	466	543	669	660	684	559	649	644
Potatoes	81	77	68	72	68	68	66	64	68
Sunflower	453	473	393	378	375	345	468	507	414
Barley	140	93	148	145	205	236	174	182	189
Water melons and melons	19	17	15	14	17	15	13	13	14
Rapeseed	47	45	157	192	211	243	172	39	171
White cabbage	22	13	12	14	13	12	13	13	13
Tomatoes	15	16	16	17	16	17	18	16	17
Sugar beet	8	15	11	8	7	7	6	11	8

Table 31 **Yield data for ten important crops in Macroregion 2 in the period 2005-2012.**

Crop	yield (t/ha)								average 2008-2012
	2005	2006	2007	2008	2009	2010	2011	2012	
Maize	3.7	3.3	1.1	3.0	2.9	4.1	4.5	1.8	3.3
Wheat	3.0	3.0	1.5	3.5	2.3	2.7	3.6	2.3	2.9
Potatoes	13.4	15.0	12.7	13.1	15.1	12.4	17.1	10.7	13.7
Sunflower	1.4	1.6	0.7	1.4	1.3	1.6	1.6	1.2	1.4
Barley	1.9	2.2	1.2	3.1	2.2	2.5	3.0	2.0	2.6
Water melons and melons	20.7	19.2	13.3	20.2	19.9	21.7	21.5	15.7	19.8
Rapeseed	1.8	1.7	1.4	2.0	1.3	1.6	1.7	1.6	1.6
White cabbage	16.2	25.2	20.4	21.0	22.1	21.1	21.9	20.9	21.4
Tomatoes	14.7	17.6	15.0	16.2	16.1	16.7	18.6	14.0	16.3
Sugar beet	21.7	26.8	20.0	30.0	30.8	34.0	31.7	23.7	30.1

Appendix B MIRAGE Disaggregation

Table 32 **Regional aggregation in MIRAGE.**

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

Table 33 **Crop aggregation in MIRAGE.**

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

Appendix C Yield Scenarios

Table 34 **Potential future yield scenarios and their key characteristics.**

Scenario	Description
Regional yield trend 2001-2010	The crop-specific linear yield trend in Macroregion 2 in the period 2001-2010 is extended until 2020, based on national statistics [12].
Regional yield trend 1990-2012	The crop-specific linear yield trend in Macroregion 2 in the period 1990-2012 is extended until 2020, based on national statistics [12].
National yield trend	The linear yield trend in Romania for each crop in the period 1960-2012, based of FAO statistics [13].
Best counties Eastern Romania	For each crop the yield from the best performing county (average 2008-2012). National statistics data will be used [12].
Best counties Romania	For each crop the yield from the best performing county (average 2008-2012). National statistics data will be used [12].
Refuel Ukraine	From the REFUEL study on yields in Ukraine, where a 5.2% annual increase for all crops is assumed in the period 2000-2030 [70]. This is a very high growth estimate, but for maize and rapeseed in Ukraine the growth in the period 2000-2010 has been 72% and 104% respectively.
Poland	Average yields (2008-2012) from Poland [13].
%Poland	Ratio of the maximum attainable yield and actual yield currently achieved in Poland applied to the maximum attainable yield in Romania [12,13,15,32]. Poland is also an Eastern European country, with a history under communist control between 1945 and the start of the 1990s. However, Poland joined the EU three years prior the Romania and the agricultural sector is further developed using more fertilisers, pesticides and machinery [13,15,16].
Hungary	Average yield (2008-2012) for Hungary, based on FAOSTAT data. Hungary was in a similar position as Romania before the end of the communist era in Central and Eastern Europe, but now achieves higher yields.
France	Average yield (2008-2012) for France, based on FAOSTAT data. The agricultural sector in France is significantly better developed than in Romania; for energy crops they also have a lead as development started earlier. This leads to higher yields irrespective of soil and climatic conditions.
Germany	Average yield (2008-2012) for Germany, based on FAOSTAT data. Like France Germany has a clear lead compared to Romania in agricultural practice and yields.
1%	An average yearly growth rate of 1%
2%	An average yearly growth rate of 2%
3%	An average yearly growth rate of 3%

Table 35 Crop yields for maize and rapeseed in the various scenarios.

Scenario	Maize yield (t/ha)	Rapeseed yield (t/ha)
Regional yield trend 2001-2010	3.7	2.5
Regional yield trend 1990-2012	3.5	2.0
National yield trend	3.5	1.7
Best counties Eastern Romania	4.3	2.1
Best counties Romania	4.4	2.2
Refuel Ukraine	4.9	2.5
Poland	6.5	2.6
%Poland	6.5	2.5
Hungary	6.2	2.3
France	9.3	3.4
Germany	9.8	3.7
1%	3.6	1.8
2%	4.0	2.0
3%	4.4	2.2

Table 36 Results for the various scenarios, expressed in surplus land available, specified for maize, wheat and rapeseed and the potential; extra production that can be realised if these lands are used once every four years.

Scenario	Surplus land available (k ha)					Extra production rapeseed (k ton)	Extra production biodiesel (TJ)	% NREAP
	Total	Maize	Wheat	Rapeseed	Other crops			
Regional yield trend 2001-2010	346	84	148	66	48	213	3,086	23%
Regional yield trend 1990-2012	14	50	40	-15	-61	6	84	1%
National yield trend	415	210	88	32	86	214	3,100	23%
Best counties Eastern Romania	666	231	245	41	149	360	5,217	38%
Best counties Romania	321	141	106	21	53	158	2,287	17%
Refuel CEE	787	309	228	65	185	482	6,998	51%
Poland	826	468	199	75	83	537	7,785	57%
%Poland	727	468	155	70	34	457	6,624	49%
Hungary	907	444	194	57	213	530	7,690	56%
France	1,443	622	410	116	295	1,244	18,038	132%
Germany	1,427	640	433	125	229	1,324	19,198	141%
1%	122	70	54	2	-4	55	800	6%
2%	359	155	116	25	64	179	2,592	19%
3%	571	231	171	45	124	314	4,550	33%

Appendix D 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 Romania could rise, a comparison will be made with other countries. However, the soil and management conditions in other countries are different from Romania, 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 Romania. 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.

GAEZ – Global Agro Ecological Zones [32] is an interrogative web service providing data on the agronomical upper limit for the production of individual crops under given agro-climatic, soil and terrain conditions for a specific level of agricultural inputs and management conditions. For the purpose of this analysis we have chosen rapeseed in Romania. The resolution of the data is 5 arc-min (10 km). The yield gaps and yield potential have been estimated by comparing potential attainable yields and production, and actual yields and production from downscaling year 2000 and 2005 statistics [74]. Yield potential is computed with regard to temperature and radiation regimes prevailing in the respective area analysed. The main characteristics reflected in the model are:

(i) length of growth cycle,
(ii) minimum temperature requirement for emergence,
(iii) maximum rate of photosynthesis,
(iv) respiration rates as a function of temperature,
(v) length of yield formation periods,
(vi) leaf area index,
(vii) harvest index,
(viii) crop adaptability group,
(ix) sensitivity of crop growth cycle to heat provision
(x) a simple procedure to account for the difference in levels of atmospheric CO_2

The downscaling method is needed for allocation of aggregate national production values to individual grid cells to use available evidence from geo-spatial information.

The yield data is presented in dry weight for which a conversion factor of 0.9 is applied [74](p. 97).

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.* [75], the average maximum attainable yield for Romania can be calculated based on the IIASA Global Agro-ecological Zone (GAEZ) database [32].

In the GAEZ database, Romania is divided into 3964 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.[12]

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 [12]. Smeets *et al.* (2004) assume for each crop that production will take place on the most suitable land [75]. 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 production to the land, the average maximum attainable yield is calculated by dividing the production by the required land. Table 37 presents the maximum attainable yield for each crop and the ratio between the maximum attainable yield and the current yield (from FAOSTAT [13]).

This shows the productivity is currently between 23% and 42% of the maximum attainable. Using the same methodology, the maximum attainable yield in Austria and Poland has been assessed. Poland is like Romania a large agricultural country, that transformed from a communist regime to a market economy at the start of the 1990s, but gained EU membership already in 2004, compared to 2007. Fertiliser use, mechanisation and pesticide use are higher in Poland than in Romania [13,15,16].

Table 37 Maximum attainable yield (t/ha) in Romania, based on rain-fed high input agriculture in the 2020s (based on GAEZ reference), compared to the current yield (based on FAOSTAT data [13]).

Crop	Maximum attainable yield (t/ha)	Current yield (t/ha)	Current yield as share of the maximum attainable yield (%)
Maize	10.3	3.3	32%
Wheat	10.6	2.9	27%
Sunflower	4.3	1.4	32%
Barley	10.9	2.6	23%
Potato	37.3	13.7	37%
Rapeseed	4.4	1.6	37%
oats	5.0	1.6	33%
Soy	4.1	1.7	42%

12 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 (10% for rapeseed) presented in the GAEZ methodology document is used for the conversion [74].

Table 38 **Current percentage of maximum attainable yields in Poland and Austria as an 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.**

Crop	Poland			Austria		
	Maximum attainable yield	Current yield	ratio	Maximum attainable yield	Current yield	ratio
Maize	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%
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%
Soy	3.9	1.6	40%	4.5	2.7	60%

Appendix E Fertiliser use

A study conducted by the Romanian agronomists Halmajan *et al.* [34] highlighted that the best fertilizer use is not based on the application of one type in a high dose, but on the combination and right application of a mix of fertilizers. A collaboration among a series of university agricultural research centres in Romania, researched the potential yield increase of various fertilizer combinations. The results indicate that the required fertilizer mix combines ammonium sulphate ($(NH_4)_2SO_4$), phosphorus (P_2O_5), nitrogen (N) and sulphur (S), each of the above being applied at different times during the season. The study found the problem to be twofold in Romania. The farmers use only a small amount of fertilisers and the fertiliser mix is not optimal.

A recent corporate study performed in Romania looked into the same rapeseed varieties (autumn rapeseeds) analysing yield performance depending on breed [36]. The fertilizer use indicated 200 kg/ha of N and undisclosed quantities for P_2O_5 and S as the best mix. Furthermore, the study indicates the use of boron and manganese as fertilizing minerals used in the crop growth, without reference on the amounts and enhancing properties.

Some fine tuning on fertilizer use are suggested in the above mentioned studies with focus on soil pH adjustments and N fertilizer timing. The corrections on soil pH can be tacked by using ammonium sulfate before sowing [34], especially after a wheat crop which usually leaves a high soil pH. Nitrogen fertilizer is suggested to be deployed at different periods in time depending on the uptake conditions of the plant. The study of Vasile *et al.* [35] generalised that 30-40% of the N fertilizer to be applied before sowing as rapeseed crops use it in the first crop growth stages, while 60-70% to be applied before plant elongation begins. This generalization is confirmed by the field study of Crudu & Toma [36] who complement these findings with the observation that a third round up nutrient uptake occurs during early fruiting. Though, there is no indication on the relative amount of nutrient uptake in this latter phase. A comparison in the findings between the two studies is presented in Table 39.

Table 39 **Fertilizer applied for best case yield as presented in the studies of Halmajan *et al.* (2007) and Crudu&Toma (2013) [34,36].**

Fertilizer	Fertilizer mix	
	Halmajan et al. (2007)	Crudu & Toma (2013)
Phosphorus (P_2O_5)	80 kg/ha	Undisclosed quantities
Nitrogen (N)	100 kg/ha	200 kg/ha
Sulphur (S)	60 kg/ha	Not mentioned
Ammonium sulfate $(NH_4)_2SO_4$	Not mentioned	Not mentioned

Appendix F Rapeseed varieties

A distinction is made between open pollinated rapeseed varieties and hybrid rapeseed varieties. In the following, we describe both varieties and their advantages and disadvantages.

The open pollinated (OP) rapeseed varieties are seeds produced from natural, random pollination carried out by wind, birds or insects, resulting in naturally varied plants. Open pollination depends on the natural factors affecting the pollination process. Once a flower is pollinated with alien pollen certain traits will be altered. As such, the success of open pollinated seeds rests on isolating the right open pollinated crops to get to the best varieties.

Hybrid (H) rapeseeds are often spontaneously and randomly created in nature when OP plants are naturally cross-pollinated with other related varieties. The advantage of growing hybrids is that genetic material from two different plants can be crossed generating new desirable traits in the hybrid seed. The limitation with the open pollination is that these traits cannot be activated by inbreeding related plants. Hybrid seeds are generally more advantageous over open pollinated seeds because they can be formed in lesser time, requiring low-tech and involving lower costs. The activation of the desired traits with hybrids for example, occurs already after the first generation unlike for open pollination seeds which can take five to six generations before the process is consolidated in the genetic material. The effect of the better breeding techniques are rapeseed plants that have a higher oil yield than open pollinated varieties, despite the a series of shortcomings. The shortcomings include higher water and fertiliser requirements and the plants are less well adapted to local conditions. Furthermore, farmers need to purchase new seeds every year seeds, as differentiating hybrid traits are lost through pollination.

An overview of the available seed varieties in Romania is presented in Table 40.

Table 40 **Rapeseed varieties cultivated in Romania; OP = open pollinated variety; H = hybrid variety [30].**

Company *	Cultivar	Company *	Cultivar
Biocrop	Primus (H)	**Monsanto Romania**	Extend (H)
	Compass (H)		Exagone (H)
	Hammer (H)		DK Example (H)
	Dynastie (H)		
	WRH 352 (H)		
Causade Semences Romania	Tripti CS (H)	**Pioneer Hi-Bred Romania**	PR46W30 (H)
	Scelni CS (H)		PR44W29 (H)
	Nodari CS (H)		PR45D05 (H)
	Intense CS (H)		PR46W21 (H)
SD – Seeds	Judie (OP)		PR45D03 (H)
	Hycolor (H)		PR44D06 (H)
	Recordie (H)		PR46W14 (H)
	Goldie (OP)	**Saaten Union Romania**	Vectra (H)
	Ecarlate (OP)		Rohan (H)
Euralis Semences	ES Danube (H)		Finesse (H)
	ES Neptune (H)		Merano (H)
	EC Centurio (H)		Astrada (H)
	ES Mercure (H)		Visby (H)
ITC	Diana (OP)		Noblesse (OP)
	Perla (OP)		Bellevue (OP)
	Doina (OP)		Hercules (H)
KWS Seminte	Turan (H)		Orkan (OP)
	Brutus (H)	**Sumiagro Romania (Rustica)**	ES Betty (H)
	Traviata (H)		Olano (H)
	Triangle (H)		ES Hydromel (H)
	Trassilo (H)		ES Alias (H)

Appendix G Under-utilised lands

Degraded lands

Degraded land is *"land that has experienced the long-term loss of ecosystem function and services caused by disturbances from which the system cannot recover unaided"* [7]. This definition is not fully representative in the Romanian statistics, which defines degraded and unproductive land as "degraded and eroded land, barren land: rocky areas, debris, salt crusting lands, sandy areas, ravines, gullies, streams, bogs, pits, and other degraded lands" (Personal correspondence with Tomulescu V. Maria Gabriela, from the Romanian National Institute of Statistics (INSSE)) [76]. Furthermore, the institute integrates these lands in the 'non-agricultural lands' category, which implies that this land class covers extremely degraded land, which has low chances of being integrated into the agricultural circuit. The aggregate of non-agricultural land is defined by the INSSE as "forest and other area with woody vegetation, marshes and reed areas, land communication infrastructure, railways, unfinished constructions or abandoned constructions, and other degraded and unproductive lands". As such, the non-agricultural lands category takes in the degraded and unproductive land, as represented also in Figure 14, below.

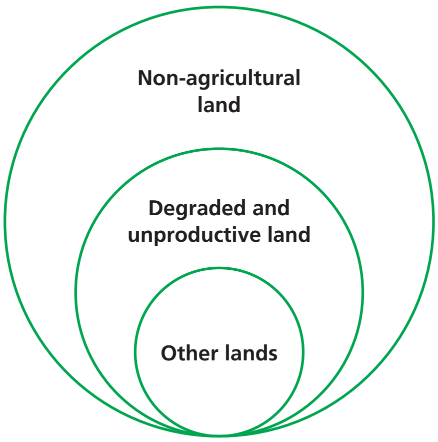

Figure 14 **Illustration of the definitions and how they relate to each other according to the land use classes by INSSE.**

The phone interviews conducted with the personnel from INSSE suggested that from the various elements included in the definition, only 'woody vegetation' and 'abandoned constructions' could be of interest for our research. After the communist regime collapsed in Romania (1989), large amounts of land were left uncultivated because of socio-economic structural changes in the society. Some of these lands (especially the ones in the vicinity of young forests), were taken over by ecosystem succession processes, and are currently in the process of converting to woody areas. The same socio-economic structural changes had an impact on the former collectivisation centres. These were abandoned, together with the land areas around them. Personal communication with Craciun S. Valerica (INSSE) suggests that the abandoned buildings referred to in the definition are these collectivisation centres. In spite of this clarification, little can be said about the magnitude of these lands in the total '*non-agricultural land*' category.

Another aspect that does not become apparent from the data but was stressed by the experts is that the lands in 'private ownership' are preferred over lands in 'public ownership' as potential areas to be cultivated with rapeseed in Romania. The government has little incentives to get this land in production, in contrast to private owners who more willing to invest in improving the quality of the soil, for returns.

Marginal Lands

Marginal lands are those lands on which "cost-effective food and feed production is not currently possible under the given site conditions and cultivations techniques" [7]. These type of lands could be reinstated into functional agricultural land "with the introduction of new technologies or changes in the cost structure". Thus marginal lands are an economic concept which can be activated with an economic opportunity such as increase in demand for rapeseed oil accompanied by an increase in rapeseed oil price.

From the phone interviews conducted with employees of the National Statistics Institute (INSSE), it became clear that 'marginal lands' do not exist as a classification cluster in Romania. They argued that this stems from the fact that during the communist regime, the land use was strictly divided into use categories, and this did not include marginal lands. To this day, the use of 'marginal lands' is inexistent in the classification of INSSE. Furthermore, the prospects of these lands being used for any agricultural activity was deemed unrealistic. The INSSE employee explained that given the vast areas of abandoned agricultural lands, this category has the highest potential for usage (Personal correspondence with Tomulescu V. Maria Gabriela, INSSE).

The only estimate on the available 'marginal land' in Europe and Romania was found in a paper by Fischer *et al.* (2010).

Abandoned lands

So far, the data gathering was performed by collection of interview figures, and is presented in Table 41, below.

Table 41 Estimates of the amount of abandoned land available in Romania in various counties and the whole country.

Source	Type of source	Level	Area (k ha) Value	Area (as percentage of agricultural area)	Year
Zeci de mii de hectare de teren agricol din Tulcea sunt abandonate, 2011	News article – Tulcea county	County	60 kha	16%	2011
Sucevenii primesc subventii agricole si pentru suprafetele abadonate, 2011	News article – Suceava county (APIA – Angela Corolueca)	County	0.766 kha*	0%	2011
Pârloaga ocupă, în prezent, peste 20% din suprafaţa agricolă a ţării, 2012	News article	Country	3069 kha	21%	2012
Situatia terenurilor agricole nelucrate, la octombrie 2011, 2011	News article – Interview with director APIA (Florin Marius Faur) over the abandoned agricultural lands in Romania	Country	353 kha*	2%	2011
Recensamantul General Agricol, 2011	General Census	Country	888 kha*	6%	2011

*These sources are deemed most reliable from the data collected

Appendix H Satellite data

To illustrate the differences between the statistics and practice in Eastern Romania and the associated problems to establish the current land use, we made a comparison between the land use data from the national statistics database (INSSE) and the global land cover model (GLC30m) [12,77]. This model is based on satellite images on a 30m grid cell size. Table 42 presents the comparison between the two data sources. The differences in total area between the two sources comes from the curvature of the tiles which needs to omit a number of cells; while the national statistics works with a stretched image which needs to add some cells to fully flatten the image. The difference in the surface area of the water can be largely explained by the fact that a part of the border of the region is water. The difference in agricultural land (arable land, pasture land and vineyards, compared to cultivated land and grassland) is 100 kha, relatively small. The largest and most noteworthy difference are in the amount of forest (190 kha, 15%) and build-up area (140 k ha, 40%). Although there will be differences in definition of the land use classes it shows the current land use is not an objectively established fact.

Table 42 Comparison between land use statistics from the national statistics database [12] and the Global Land Cover model [77] (GLC30m). As this is only to show the concept not all counties in eastern Romania have been included in this analysis. We used Bacau, Botosani, Iasi, Neamt, Suceava, Vaslui, Galati and Vrancea.

INSSE 2010	Area (ha)	Area (ha)	Global land cover model 2010
Arable land	1,822,997	2,503,135	Cultivated land
Pastureland	813,478	108,416	Grassland
Vineyards	76,926		
Forest	1,495,838	1,305,243	Forest
Water	100,633	38,556	Water
Constructions	202,678	346,588	Artificial lands
Degraded land	104,768		
		13,367	Barren land
		75,828	Shrub
		37,481	Wetlands
Total	**4,617,318**	**4,428,614**	

Changes in land use

In addition to the differences in land use data from various sources at one moment in time, we also tried to establish the site-specific variation over the years. For this we used three sources of satellite imaging. The CORINE database from 2000 and 2006 and the Global Land Cover model from 2010. Unfortunately none of the databases was available for all the years, which makes it impossible to make a direct comparison between these years. Table 43 presents the characteristics of the CORINE land use data set [78] and the Global Land Cover model [77].

Table 43 **Characteristics of the two sources for the satellite imaging datasets.**

Dataset characteristics	CORINE land use	Global Land Cover
Year	2000/2006	2010
Input	Satellite and national statistics refinements	Satellite
Resolution	100m	30m
Classes	41	10

The aim of our analysis is to identify potential overgrown agricultural areas in eight Romanian counties in Macroregion 2. First the classification of the land use was aggregated into four – the same- classes for both databases. The selected classes comprise 78% of the land area. Each class was assigned a number (see Table 44) such that any combination of two numbers will yield a unique value. The maps were aggregated to a 300m resolution, to satisfy computation criteria.

Table 44 **Classification in the two databases and the relevant ID numbers.**

Class	Classification ID 2000/2006	Classification ID 2010
Arable land	1	2
Forest	3	9
Shrub	5	11
Pasture/Grassland	7	13

The next step was to multiply the number assigned to each grid cell in the first year by the number in the same grid cell in the last year. This yields a unique set of combinations (see Table 45) that show all the land use changes that have taken place in that specific period. The advantage of using this method over regular statistics is that we can not only see the stock changes in a land use class, but also the inflow and outflow dynamics.

The analysis of the results in Table 45 shows 60-62% of the land area did not undergo any changes between 2000/2006-2010. This means 15-17% of the surface area in the eight counties saw its land use change. Although the net change in forestry was only 44 k ha in the period 2000-2010, based on the satellite images, twice as much forest is now in another class, but this is compensated by changes from other classes (mostly arable land and shrub land) to forest.

Table 45 **Set of possible combinations, the site-specific changes and the associated area in the periods 2000-2010 and 2006-2010.**

Value	Classes	Dynamics 2000-2010 area (ha)	Dynamics 2006-2010 area (ha)
2	**No change – agriculture**		713,500
9	Arable land into forest	25,780	33,000
11	Arable land into shrub	1,530	3,900
13	Arable land into grassland	18,940	15,700
6	Forest into arable land	38,190	38,100
27	**No change – forest**	-	737,600
33	Forest into shrub	14,380	32,930
39	Forest into grassland	50,230	39,680
10	Shrub into arable land	16,460	16,320
45	Shrub into forest	20,590	38,720
55	**No change – shrub**	-	50,500
65	Shrub into grassland	31,520	13,270
14	Grassland into arable land	258,690	221,400
63	Grassland into forest	12,450	14,850
77	Grassland into shrub	1,590	6,020
91	**No change – grassland**	-	6,000