BIOFUELS
2021, VOL. 12, NO. 2, 171–186
https://doi.org/10.1080/17597269.2018.1464873

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Low-ILUC-risk rapeseed biodiesel: potential and indirect GHG emission effects in Eastern Romania

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ABSTRACT

Indirect land-use change (ILUC) can have a severe impact on the greenhouse gas (GHG) balance of biofuels. Mitigating ILUC risk is important to avoid additional GHG emissions compared to fossil fuels. This is possible by making surplus land available through land demand reduction and using this for low-ILUC-risk biodiesel production. For a case study in Eastern Romania, we calculated the rapeseed biodiesel potential and the GHG emissions of four measures to make surplus land available in 2020. Four scenarios varying in assumptions on productivity and sustainability in the agricultural sector show the variation in the potential of these measures. We find that using surplus land to produce low-ILUC-risk rapeseed biodiesel has a potential of 3-64 PJ, 1-28% of the projected Romanian transport diesel consumption. The main contribution to this potential comes from yield improvements in crop and livestock production. Average GHG emissions of the ILUC mitigation measures are -11 to 22 g CO_2-eq MJ^{-1} (maximum total lifecycle emissions are 34 g CO_2-eq MJ^{-1}; 60% reduction from fossil fuel reference). This means ILUC mitigation is possible without necessarily missing the GHG emission reduction target, provided that the entire agricultural sector is sustainably intensified, going beyond a focus on biofuel production alone.

ARTICLE HISTORY
Received 27 December 2017
Accepted 28 March 2018

KEYWORDS
Indirect land use change; ILUC mitigation; case study; Eastern Romania; greenhouse gas emissions

Introduction

Bioenergy use is expanding to meet future worldwide energy demand and to reduce greenhouse gas (GHG) emissions [1,2]. However, additional production of biomass for bioenergy in one location could lead to additional agricultural land use elsewhere – through displacement or other market-mediated effects – a process commonly described with the term *indirect land-use change* (ILUC) [3,4]. If this effect leads to conversion of high-carbon-stock lands, such as forests or peatlands, it could offset the GHG emission savings from bioenergy [3,5]. As climate change mitigation is one of the most important drivers of bioenergy demand [6], ILUC and its GHG emissions need to be minimised.

Policymakers have explored several options to prevent ILUC [7,8]. One option is to include an ILUC factor in the biofuels policy that prescribes the GHG emission savings that need to be achieved by the use of biofuel [9,10]. Under such a policy, an additional emission factor would be included in the obligatory GHG emission calculations of a biofuel, in order to account for the ILUC-caused emissions. This factor would reduce the attractiveness of biofuel with a high ILUC impact and several supply chains would likely not meet the desired reduction target, compared to fossil fuels, e.g. 60% in the EU [8,11,12].

As ILUC is an indirect effect, causal relations cannot be established directly and the effects of a counterfactual of no-biomass development cannot be measured. Therefore, models are employed to estimate the size of the ILUC effect and the applicable ILUC factor [13–15]. Studies to calculate the magnitude of the ILUC factor use a partial equilibrium (PE) or computable general equilibrium (CGE) macroeconomic model to compare the global land use in a certain future reference year in a situation with and without additional biofuel production. The differences in additional land use and associated carbon emissions between the two scenarios are then attributed to the production of biofuels as the ILUC factor, thereby combining direct and indirect land-use change [16,17]. These macroeconomic models often distinguish between bioethanol and biodiesel production. The resulting ILUC factors reflect the varying production methods and related carbon emissions for different feedstock crops. However, there are also some important drawbacks. For example, these models are very coarse and cannot link the production in a specific location to its impacts [13,18–21]. Furthermore, they generally do not account for possibilities to mitigate the risk of diverting agricultural production [22].

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Supplemental data for this article can be accessed at https://doi.org/10.1080/17597269.2018.1464873

A second option to limit GHG emissions from ILUC is to reduce the risk of displacement due to bioenergy production expansion. The 2015 ILUC Directive from the European Union [23] opened a policy door to low-ILUC-risk biofuels and tasked the European Commission to set criteria for the identification and certification of biofuels with a low risk of ILUC [23]. Low-ILUC-risk biofuels are biofuels for which it can be demonstrated that the feedstocks have a low chance of displacing other agricultural production [24–27]. Four key measures to reduce the pressure on available agricultural land have been proposed in the literature: (1) above-baseline yield improvement in the entire agricultural sector; (2) chain integration through the use of biofuel co-products to replace other crop production; (3) crop loss reduction; and (4) biofuel feedstock production on under-utilised land [28]. These measures were assessed for their technical biofuel production potential in three previous case studies, considering bioenergy expansion in (1) Hungary [29], (2) a province in Poland [30] and (3) two provinces in Indonesia [31]. The studies in the European setting show it is possible to produce biofuels without expanding agricultural production on high-carbon-stock areas or displacing production to other areas, while still meeting the demand for food, feed, fibre and the current amount of biofuel feedstock [29,30]. In Indonesia this is only the case under certain stringent conditions of low agricultural expansion, enforced land zoning, strong yield growth and improved chain efficiencies [31].

Although these measures aim to prevent GHG emissions from ILUC, implementing the measures can also be a source of GHG emissions, e.g. when increased yields are obtained via increased fertiliser application. To avoid a situation where ILUC mitigation is a larger source of GHG emissions than ILUC itself, it is necessary to better understand the emissions of ILUC mitigation. Therefore, Gerssen-Gondelach et al. [32] calculated the GHG emission balances of the agricultural sector of Lublin province in Poland when producing ethanol from miscanthus with the application of the ILUC mitigation measures. The GHG emissions of the measures were calculated for three intensification pathways that varied in how intensification is implemented. The study showed a significant reduction in overall agricultural GHG emissions in the region is possible only if intensification is done sustainably (i.e. without increased inputs, but based on better practices [32]). An important reason for this finding is the use of the perennial crop miscanthus to produce bioethanol. Miscanthus cultivation leads to lower CH_4 and N_2O emissions than cultivation of other crops. Moreover, if miscanthus is produced on surplus agricultural land, above- and below-ground carbon stocks are generally increased, which leads to a positive GHG emission effect of bioethanol.

However, biodiesel from first-generation vegetable oils from Europe (e.g. rapeseed, sunflower) has higher GHG emissions [33] and higher projected ILUC GHG emissions than ethanol [34], while it is also produced from annual crops that do not sequester carbon in the soil, as for example miscanthus does. Furthermore, the mentioned studies in Europe [29,30,32] focussed on bioethanol crops, whereas in Europe, the production and use of biodiesel is higher than that of bioethanol [35]. Reducing the risk of additional GHG emissions related to ILUC in biodiesel production in the EU is therefore critical.

The objective of this study is therefore to calculate the low-ILUC-risk biodiesel production potential and the associated GHG emissions of the ILUC mitigation measures, differentiating among four intensification pathways. By analysing both the potential and the emissions of low-ILUC-risk measures, we can show the trade-off between reducing the ILUC risk and associated GHG emissions, as these are often ignored [36].

In this study we zoom in on rapeseed for biodiesel production in Eastern Romania (see Figure 1) in 2020, the year of the first (10%) target for renewable energy in transport in the EU [12]. Romania plans to produce 20 PJ of biofuels per year in 2020 according to its National Renewable Energy Action Plan (NREAP) [37], of which 15 PJ will be biodiesel. Although 2020 is not far away, the timeframe 2010–2020 was selected as 2020 is the first milestone of the European Union Renewable Energy Directive (EU RED) [12] and the subsequent ILUC calculations of Laborde are also based on this period [5]. Furthermore, as a theoretical assessment of the low-ILUC-risk potential, this is impacted less by the timeframe of the calculations.

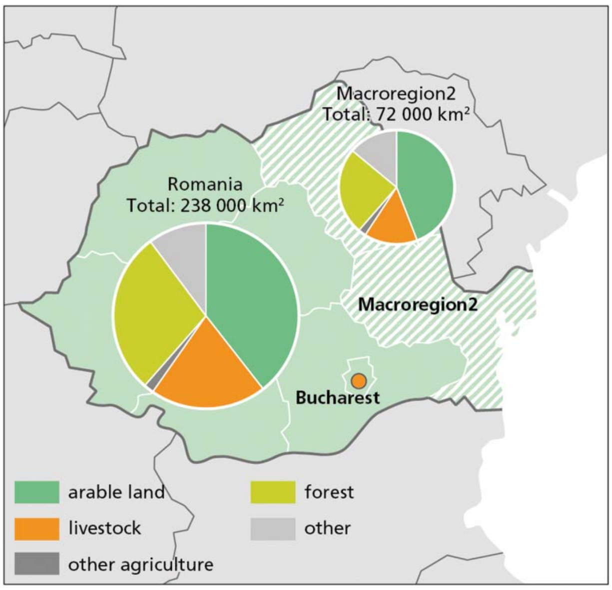

Figure 1. Location of Macroregion 2 in Romania, and key land-use statistics in the country and region [38] (color online).

Romania has received increasing attention from businesses, farmers and governments due to the potential for growth in its agricultural sector [39,40]. Particularly Eastern Romania is currently relatively underdeveloped, with large yield gaps; this means intensification may provide large gains in terms of additional production and resource efficiency [38,41]. The size of Eastern Romania (Macroregiunea doi, in English Macroregion 2) is 72,000 km^2, of which 44,000 km^2 is classified as agricultural area. This is about 30% of the total agricultural area of Romania. The amount of arable land is 32,000 km^2, 34% of the Romanian total. In the period 2008–2012, Macroregion 2 produced 45% of the 615,000 tonne of Romanian rapeseed [38]. Rapeseed has been selected as it is already an important source of domestically produced biodiesel in the EU and, based on the current production, a crop suitable for the region.

Methods and materials

Expansion of biofuel production in Eastern Romania could lead to (high) land-use change GHG emissions if it causes agricultural land expansion through displacement or other market-mediated effects. In this study, we calculated the potential rapeseed biodiesel (PJ yr^{-1}) that Eastern Romania could produce in 2020 with a low risk of ILUC and the associated GHG emissions (g CO_2-eq MJ^{-1} biofuel, hereafter just g CO_2-eq MJ^{-1}). The area available for low-ILUC-risk biofuel production, here called surplus land, comes from agricultural land that has recently been abandoned, or land that currently has an agricultural use, but will not be required anymore in 2020 for the production of food, feed or fibre as a result of intensification and increased resource efficiency. The steps to calculate this area, and the resulting potential for low-ILUC-risk biofuels, are based on Brinkman et al. [28] and described below. A more detailed description of the specific application of the method for this case study can be found in [42].

The first step was to establish the baseline crop production in Eastern Romania in 2020 (see next section). This baseline is the biomass production in 2020 for food, feed, fibre for the growing population and gross domestic product (GDP), and the current amount of biofuel. Any additional demand for biomass for biofuel in the region above this baseline can be a cause of ILUC when it leads to expansion of agricultural land. This means that the baseline production and production of any additional biofuel feedstock needs to take place within the current land use in order to avoid ILUC. In the second step, we calculated the potential effects of four measures to reduce land demand and thereby make land available for biofuel feedstock production. The four measures that were included are (1) above-baseline yield improvement in crop and livestock production; (2) use of rapeseed meal to replace feed crops; (3) decreased losses in crop production; and (4) biofuel feedstock production on abandoned land. The application of these four measures can help to reduce the demand for agricultural land whilst still producing sufficient biomass to meet baseline demand. We did this for four scenarios that varied in their assumptions regarding potential developments in the agricultural sector, in terms of both productivity and sustainability. In the third step, we integrated the results and calculated the total surplus land (km^2) and potential biodiesel production (PJ) on that land. For this, the agricultural land available after covering the baseline biomass production was considered surplus land and available for the production of low-ILUC-risk rapeseed for biodiesel.

For each of the four measures, the resulting GHG emissions were calculated and we used these results to establish the GHG emissions of ILUC mitigation per unit of low-ILUC-risk biofuel (CO_2-eq MJ^{-1}). These indirect emissions need to be at least below 55 g CO_2-eq MJ^{-1} in order to constitute a saving compared to the European rapeseed biodiesel ILUC factor [5]. The complete life-cycle emissions of biofuel production need to be below 34 g CO_2-eq MJ^{-1} in order to adhere to the 60% GHG emission savings compared to the fossil reference (83.8 g CO_2-eq MJ^{-1}) mandated in the EU RED for new biodiesel installations [12]. The life-cycle emissions of rapeseed biodiesel in Romania are on average 20 g CO_2-eq MJ^{-1} for cultivation [43], and in the most optimistic situation 10 g CO_2-eq MJ^{-1} for transport and processing [33]; this leaves a little room to allocate emissions resulting from ILUC mitigation. An overview of how the measures and the GHG emissions relate to each other is presented in Figure 2.

Step 1: Baseline agricultural production in 2020

The projections for the baseline crop production in Eastern Romania in 2020 are taken from the results of the MIRAGE (Modelling International Relationships in Applied General Equilibrium) [5]. This is a computable general equilibrium model developed by the International Food Policy Research Institute (IFPRI). The model projects the effects on supply and demand in all sectors of the global economy in response to an exogenous change (e.g. increased biofuel production), and includes developments such as population growth. Here we used the results from the Biof version of MIRAGE, which was also used for the report of the land-use change consequences of European biofuel policies by Laborde [5]. This report was used by EU policymakers when considering establishing quantitative ILUC factors. For the baseline production, we used the reference situation in which no growth of biofuel production took place compared to the baseline. The results of the MIRAGE model are on the EU27 level. Therefore, the crop production volumes were

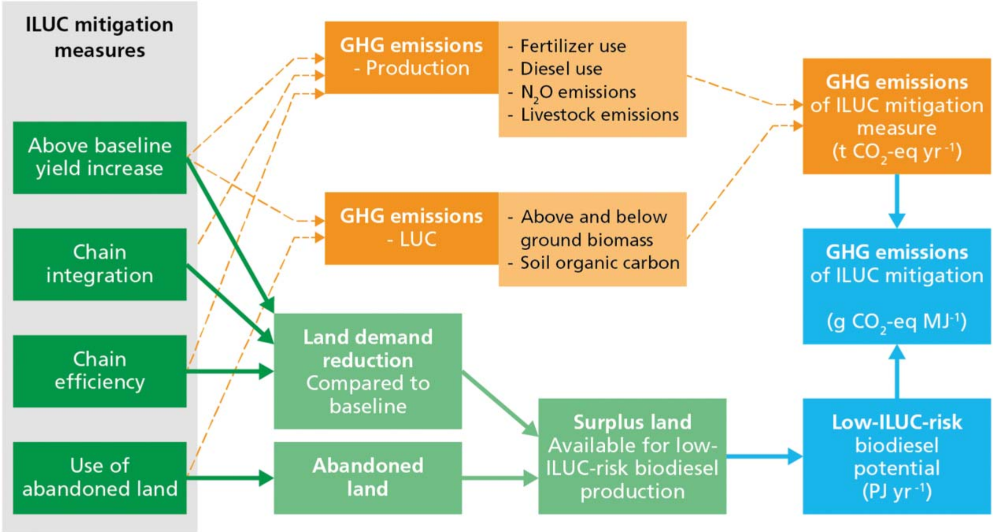

Figure 2. Overview of the surplus land and GHG emissions as a result of the implementation of the indirect land-use change (ILUC) mitigation measures (color online).

disaggregated to Eastern Romania based on the share of the production of each crop (average 2008–2012) in Macroregion 2 within the EU27. For the disaggregation, the crop production data from FAOSTAT [41] and the Romanian national statistics office [38] were used. The total production, yield and area are presented in Table 1. Because of the large uncertainty stemming from the disaggregation, we varied this parameter in the sensitivity analysis that is presented in the results section. We included the eight most important crops in terms of production and area in the region in our analysis. These crops cover nearly 80% of the arable land in Macroregion 2.

In the baseline, demand for cattle increases by 15% until 2020, and the demand for other animal products decreases by 3% [5]. In the same period, the productivity of the cattle sector increases by 10%, and by 6% for other livestock production [5].

Step 2: Bottom-up assessment of measures

The four ILUC mitigation measures aim to reduce the demand for agricultural land and thereby make land available for the production of rapeseed for biodiesel. We used *low*, *medium*, and *high* scenarios for the measures to assess the range of the surplus land for a less or more progressive development in the agricultural sector in Eastern Romania. A *high*+ scenario was used to illustrate the variation in GHG emissions as a result of differences in the intensification method. The *baseline* scenario refers to the conditions that apply to the baseline as defined in step 1 and follow the MIRAGE model. For the *low* scenario we assumed only a little progress in the agricultural sector in Eastern Romania, which is comparable to the recent past, but slightly better than the MIRAGE projections. In the *medium* scenario we assumed that the level of the best county in the region

Table 1. Current (average 2008–2012) and future (2020) crop production, yield and area of eight selected crops in Eastern Romania. Production is for food, feed, fibre and the current amount of biofuels. Current production data and other land use data from the Romanian national statistics institute (INSSE) [38]; 2020 production and yields disaggregated from the MIRAGE model [5], based on the share of production in the EU27 from FAOSTAT [41]. Current cattle milk and beef production from [44]; projections based on Laborde [5].

Crop	Production (kt)	Production 2020 (kt)	Yield 2010 (t ha^{-1})	Yield 2020 (t ha^{-1})	Area 2010 (km^2)	Area 2020 (km^2)
Maize	2923	3283	3.3	3.4	9000	9770
Wheat	1839	2106	2.9	3.0	6410	7140
Sunflower	576	755	1.4	1.6	4140	4710
Barley	476	302	2.6	2.7	1890	1140
Rapeseed	280	434	1.6	1.8	1710	2420
Potatoes	943	598	13.7	14.2	680	420
Oats	98	62	1.6	1.7	600	370
Soybean	68	88	1.7	1.8	400	490
Subtotal					24,820	26,450
Other crops					7280	
Total arable land					32,100	
Meadows and pastures	1459/70[a]	1678/80[a]	3.3/0.4[a]	3.7/0.4[a]	10,850	11,340
Total included agricultural land[b]					35,670	37,790
Forest					18,020	

[a]Cattle milk/beef.
[b]Sum of the included crops and meadows and pastures.

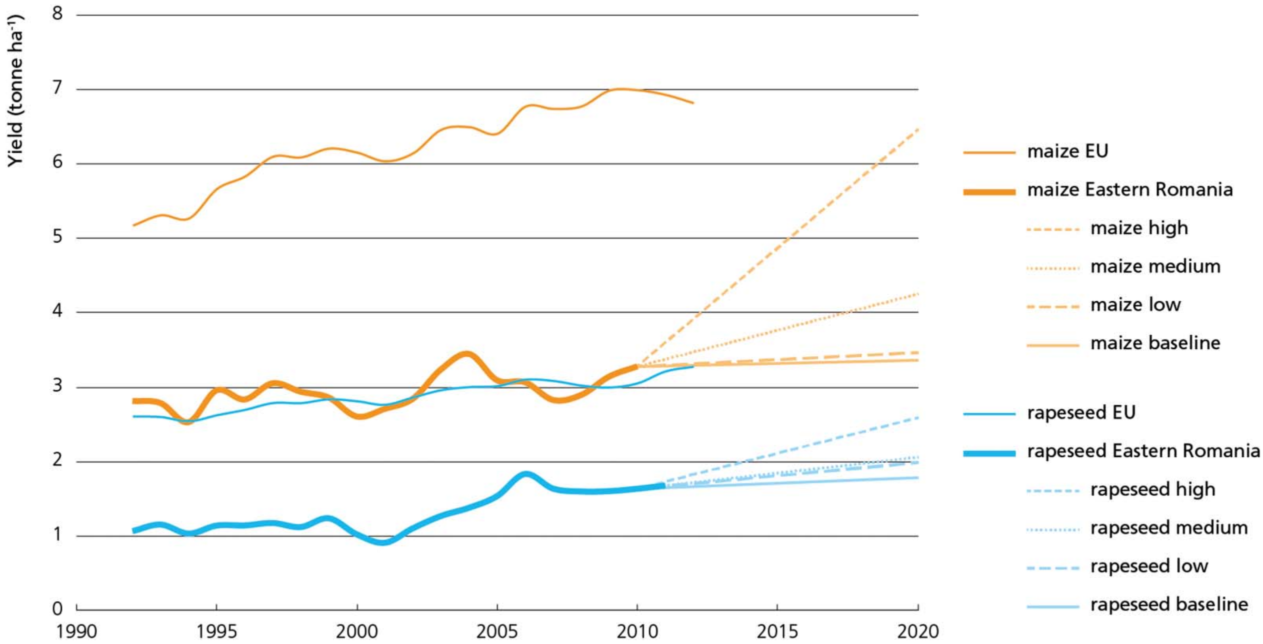

Figure 3. Rapeseed and maize yield development (5-year moving average) in Eastern Romania and the EU27 (1990–2010) [38,41] (color online).

can be achieved by the whole region. In the *high* scenario we assumed progress to the level of neighbouring countries, such as Poland. For the calculation of the surplus land, the *high*+ scenario is identical to the *high* scenario. However, for the GHG emission calculation, we assumed a more sustainable intensification pathway to achieve this potential than in the *high* scenario. For the above-baseline yield measure this was based on Gerssen-Gondelach et al. [32]. The *high* scenario is an optimistic scenario in increasing production potential, but assumes conventional intensification pathways in order to achieve this potential. Conventional intensification relies on increased application of fertilisers, pesticides and mechanisation without increasing efficiency [32]. Previous studies (e.g. [45,46]) showed unsustainable intensification can increase GHG emissions per unit of product. Intensification causing GHG emissions to increase to a level above the ILUC factors would make low-ILUC-risk biofuel superfluous. There are multiple methods for sustainable intensification such as precision farming [47,48], reduced tillage [32], new crop varieties with higher yield, improved drought or pest resistance [49], or better management [45]. An overview of the scenarios is presented in Table S1 in the Supplementary material.

In the GHG emission calculations we included the emissions that are required to achieve each measure (e.g. increase fertiliser use to raise productivity), or the savings that occur due to lower demand (e.g. when reducing losses). In addition, we included GHG emissions of land-use conversion from former land use to rapeseed. For cropland-to-cropland conversion we assumed no land-use change GHG emissions. Following the EU guideline, the land-use change GHG emissions were divided over a 20-year period to account for the fact these occur only once [44].

Above-baseline yield improvement

The current crop yields in Eastern Romania are low compared to the average European yields (see Figure 3). This is a result of the interplay among various elements of which poor mechanisation of agriculture [37], sub-optimal use of fertilisers [50,51] and low pesticide use [52,53] are three main factors. For the *baseline* scenario, the MIRAGE model projects only a small yield increase (see Table 1). For each crop, this yield increase was applied to the current yield (average 2008–2012) in Eastern Romania [38] to calculate the *baseline* yield increase. The *low* scenario extrapolated the linear yield trend in Macroregion 2 in the period 1990–2010 to 2020 [38]. The *medium* scenario assumed that the current best yield for each crop of all 12 counties of Macroregion 2 can be achieved in the whole region by 2020. The yield in the *high* scenario was calculated as the same yield level (as share of the maximum attainable yield, based on the agro-ecological suitability [54]) as is currently achieved in Poland (e.g. for rapeseed this is 52%, up from the current 37%). Increasing yields above the baseline ensures the 2020 baseline crop production requires less land. The difference between the projected agricultural land area and area after the yield increase is surplus land that is assumed to be available for the production of rapeseed for biodiesel.

Livestock intensity in Eastern Romania is also low compared to the rest of the European Union, with only Greece, Bulgaria and the Baltic States having a lower density [41,53]. The index for livestock density was 1.0

livestock units per hectare (average 2008–2012). Livestock units (LU, as defined by Eurostat [55]) make it possible to compare the livestock density between countries with different compositions of the livestock herd. Here we included sheep (0.1 LU) and cattle (1.0 LU) as these are the two most land-demanding types of livestock in Romania. The density was based on livestock numbers (8.2 million sheep and 0.84 million cattle) from the national statistics office [38] and the sum of meadows and pastures in the region [38].

The intensification of livestock production follows the same logic as crop intensification. By increasing the productivity per hectare, less space is required for the production of the same quantity and the surplus area can be used for low-ILUC-risk biofuel production. For the increase in productivity in livestock production the same intensification pathways were used as for the crop yield increase in the *low* (extrapolating trend), *medium* (best county) and *high* (Poland) scenarios. Examples of measures to increase the production intensity are fertilising pastures, shortening of grazing periods and changing livestock diet towards less fibrous compositions [56].

GHG emissions of above-baseline yield improvement. Crop yield production intensification can lead to increased GHG emissions, -through higher agrochemical application, diesel use in machinery or leaching resulting in nitrous oxide (N_2O) emissions. Still, by reaching a higher productivity, GHG emissions per unit product may decrease, but the net effect depends largely on how intensification is implemented. To calculate the GHG emissions of total agricultural production we used the BioGrace tool [57]. It is developed to calculate GHG emissions of different biofuel production routes and include the cultivation phase of eight different crops. BioGrace was selected as the tool follows the calculation rules for emission values (e.g. global warming potential, GHG emission coefficients) and system boundaries of the EU RED [12]. BioGrace is applied here to calculate the emissions of the cultivation of maize, wheat, rapeseed, soy and sunflower. Because the ILUC mitigation measures only relate to the cultivation phase and not the conversion to biofuel, only the cultivation part of BioGrace was used. Nine sources of emissions (diesel, N fertiliser, manure, CaO fertiliser, K_2O fertiliser, P_2O_5 fertiliser, seed and pesticide use, and the field N_2O emissions) and three additional variables (yield, crop moisture content, seed use and co-products as share of production) are available for this phase in BioGrace. For each crop, a default value is available for all 12 variables [58]. Each combination of these default values is part of the standard production route that corresponds to the default emission values for that specific biofuel production route in the EU RED. This value is based on a typical production case set in a European country.

Table S3 in the Supplementary material presents the BioGrace input values for the *low*, *medium*, *high* and *high+* scenarios. Five of the eight crops addressed in this study are also included in the BioGrace tool, i.e. maize, wheat, rapeseed, sunflower and soy. In 2020, these five crops cover 72% of the arable land or over 90% of the crop land in Eastern Romania that is covered in this study (see Table 1). For the crops that are not included we used the following proxies: for the cereals barley and oats, we used the GHG emissions of wheat, and for potatoes we used the area weighted average of the emissions per hectare of the five included crops. As virtually all GHG emissions in the default set-up of BioGrace come from the NPK fertilisers, the diesel use and the field N_2O emissions (99% of CO_2-eq emissions for rapeseed, over 90% for the others), only the values in these categories were adapted in the calculations for each scenario (see S4 in the Supplementary material). The other variables were not changed from their default values. The input values in the *baseline* were derived from current production in Romania [43,59]. The input values in the *low*, *medium* and *high* scenarios reflect the assumptions in the intensification pathways of these three scenarios as defined in the previous section. For the emissions in the *high+* scenario we used the sustainable intensification pathway as described by Gerssen-Gondelach et al. [32]. For the fertiliser application we used the highest nutrient use efficiency (NUE) for each crop and each fertiliser type. In the sustainable intensification pathway of Gerssen-Gondelach et al., diesel use was 10% lower than in the case of conventional intensification [32]; this assumption was also used here.

For each scenario, BioGrace was used to calculate the emissions per cultivated hectare. Multiplying this by the production area (after the yield increase) gave the total emissions of crop production in Eastern Romania in the *baseline* and in each scenario. The GHG emissions of ILUC mitigation were then calculated as the difference between the emissions in the *baseline* and the emissions in each specific scenario in 2020.

Intensification of extensive livestock production can impact GHG emissions through changes in feed composition and energy use [60–62]. In addition, the conversion of grassland to cropland leads to land-use change GHG emissions. To calculate the GHG impacts of the livestock intensification that was included in the scenarios we used the method developed by Gerssen-Gondelach et al. [32], who based it on multiple reviews [56]. As this method was already applied to the Eastern European context, only the Romanian-specific data differed from the previous study. The GHG emission calculations were limited to cattle as there is insufficient data available to include the effects of sheep production intensification. The GHG emissions for cattle include their most important emission sources: enteric fermentation, feed production, manure management and energy consumption, for both milk and beef production. The data on beef and milk productivity intensification in each scenario are presented in Table 2. Specific data on the emission sources of cattle production are presented in Table S4 in the Supplementary material. This shows the CH_4 emissions from enteric fermentation are responsible for the majority of GHG emissions; these rapidly decline with increasing intensification. The methane emissions of manure management, however, increase significantly with increased intensification. Sustainable intensification in the *high+* scenario was implemented using a 10% lower GHG emission impact compared to the *high* scenario, following the data of Gerssen-Gondelach et al. [32]. Multiplying beef and milk production by the respective GHG emissions per unit product gave the total emissions for each scenario. The GHG emissions of ILUC mitigation were then calculated as the difference between the total GHG emissions in each scenario and the *baseline* GHG emissions.

The land-use change GHG emissions of converting meadows and pastures to crop land were calculated using the Intergovernmental Panel on Climate Change (IPCC) Tier 1 approach [68–70] and the EU guideline on the calculation of land carbon stocks [44]. The GHG emissions of the conversion of grassland to cropland consist of a decrease in soil organic carbon in the topsoil (top 30 cm) and a loss in the above- and belowground biomass. For the soil organic carbon content in the region, we selected the default value (38 t C ha^{-1}) for high-activity clay soils in temperate-dry conditions from the EU guideline [44,71]. This was adapted by multiplying by factors for land use (1), land management (1) and inputs (1) that reflect nominally managed medium-input grasslands. The carbon content of the cropland was calculated by multiplying the same reference soil organic carbon content of the region with factors for land use (0.8), land management (1) and inputs (1.04) that are in line with full-tillage, high input (without manure) agriculture in a temperate-dry climate [44]. For the loss in vegetation – in the form of above- and below-ground biomass – we took the default value for grassland from the EU guideline: 3.3 t C ha^{-1} [44]. In the *high+* scenario we adjusted the factor for land management to reflect a management system without tillage (1.1) that sequesters a higher level of carbon in the soil.

Improved chain integration

Expanding biofuel production also means an increased production of its co-products, which can have a positive indirect effect on land demand [72]. Crushing rapeseed to obtain rapeseed oil yields 59% rapeseed meal [73], which can be used as animal feed and thereby replaces other feed production. This reduces the demand for arable land for feed production and technically creates more space to produce biofuels. As the MIRAGE model already includes a reduction in crop production as a result of the use of rapeseed meal, there was a risk of double counting. We avoided this by increasing the crop production in 2020 (of Table 1) by the same amount that it was reduced in the MIRAGE model due to the use of the rapeseed meal as animal feed [29]. This amount was calculated by multiplying the rapeseed meal production and the replacement rate assumed by Laborde [5], following the description of Brinkman et al. [29].

In the *baseline* no chain integration was assumed to take place. In the *low* scenario we assumed the rapeseed meal to replace the marginal source of protein in feed, which is imported soy [74]. This alleviates the pressure on agricultural land in Brazil and Argentina, the two main soy-producing countries, but does not contribute to the domestic surplus land and low-ILUC-risk biofuel potential. In the *medium* scenario we assumed the current replacement rate in the Romanian feed mix, based on FAOSTAT data. In the *high* scenario we assumed rapeseed meal to replace the marginal source of energy in the feed; in this case, it was domestically produced barley [66]. The data for crop replacement by rapeseed meal are presented in Table 2.

As the land-use savings in the *baseline* were assumed to be zero, we calculated the surplus land in 2020 for each scenario as the replaced crop production divided by the *baseline* yield (from Table 1) of that crop.

GHG emissions of this measure came from the production of rapeseed meal, and GHG savings were achieved through lower production of the displaced crops. Producing rapeseed meal from rapeseed requires energy for transport, drying and processing. This equates to 0.1 kg CO_2-eq kg^{-1} rapeseed meal [75]. The GHG emissions of the crop production that is displaced by the rapeseed meal can be counted as negative GHG emissions of this measure; the GHG emissions of processing of regular feed are neglected as they represent only a small share of the carbon footprint of regular feed production [75]. To calculate this, the crop production reduction in Eastern Romania for each scenario was multiplied by the crop-specific GHG emissions (i.e. the *baseline* from the yield increase measure). The total emissions of this measure were calculated as the sum of the emissions to produce rapeseed meal and the negative emissions from the reduced crop production.

Reduced agricultural losses

Current pre-consumer losses in the agricultural chain for the eight selected crops range in Romania from 0.9% of the total domestic supply for wheat (EU average: 2.5%) to 8.9% for barley (EU average: 2.1%). These are country average data (2008–2012) from FAOSTAT as there are no region-specific data available [41]. Crop losses unnecessarily increase the land requirement to meet the demand; eliminating these losses would therefore make more land available for other uses [76]. The *baseline* assumption here was that the losses would not change. In the *low* scenario we assumed that the pre-consumer losses keep declining at the same pace as in the period 2000–2012. In the *medium* scenario the average losses in the Central and Eastern European member states of the EU were assumed to be achievable in Romania. The *high* scenario considered the losses in Poland to be achieved in Eastern Romania in 2020. The assumed losses for each scenario are presented in Table 2.

Following Gerssen-Gondelach et al. [32], we only included the GHG emission reduction from reduced crop production. Further savings from reduced transport and storage are expected to be negligible. The GHG emission effects associated with the reduced crop production as a result of the lower losses were calculated following the crop-specific emission factors as calculated for the yield increase measure.

Abandoned land

The agricultural land area utilised in Romania decreased after the fall of the communist regime as a result of low profitability, ambiguity of land ownership, lack of governmental support and poor mechanisation [77]. These lands have not been taken back into production, but doing so is an effective way to limit the risk of ILUC and high land-use change GHG emissions. This is under the condition that these abandoned lands do not have high carbon stocks or other (conservation) value [18]. The amount of land classified as abandoned in Eastern Romania is presented in Table S2 in the Supplementary material. The data were derived from the national agricultural census of 2010. In the *baseline* we assumed no use of abandoned lands. The *low* and *medium* scenarios only included plots of abandoned land larger than 50 and 20 ha, respectively, as small plots are more difficult to take into production. The *high* scenario assumes all plots of abandoned land to be available for crop production (1100 km^2). To account for possible lower productivity of abandoned land, we assumed a yield of 50%, 75% and 99% of the *baseline* productivity in the *low*, *medium* and *high* scenarios, respectively. This range corresponds to the uncertainty range for yield on marginal lands as also used by Laborde [5].

Bringing abandoned land back into production leads to GHG emission from the carbon stock lost due to the conversion of abandoned land to cropland. The carbon stock changes were calculated as in the case of grassland conversion. For abandoned land, the soil carbon content data were the same as those used for grassland [44]; the factors for land use (1), management (1.1) and inputs (1) were adopted to reflect abandonment. For cropland, the same factors were used as previously described for grassland to cropland conversion, including the higher management factor in the *high+* scenario. For biomass present on abandoned land, for vegetation we assumed shrub growth on the land (7.4 t C ha^{-1}). A part of the abandoned land can be in transition to forest, which would be associated with higher GHG emissions [78,79]. However, our analysis of the land use based on satellite images (see [42]) showed a continuous two-way conversion of lands in Eastern Romania, going from agriculture to forest and vice versa. This indicates that carbon stock growth in biomass on abandoned land is limited. Furthermore, as the abandoned lands were assessed on the ground by the statistics office during the land census of 2010 [80], it was assumed the conversion to forest land had not yet been started.

Step 3: Integration and comparison

In the third step, the total surplus land and the production potential of low-ILUC-risk biofuel were calculated. Figure 4 shows how the results of the four measures were integrated to calculate the total surplus land. Starting from the current agricultural land use, in seven consecutive steps the changes to land requirements as a result of increased crop demand and the application of the ILUC mitigation measures were included. The available abandoned lands were considered additional supply. As the measures also impact each other (e.g. more surplus land means higher availability of meal) a few iterative steps were made to also include these effects. As a result of these calculations, we obtained the total amount of surplus land in Eastern Romania after the implementation of each of the measures. This land was assumed to be available for low-ILUC-risk rapeseed for biofuel production. The amount of biodiesel produced was calculated assuming the average Romanian rapeseed crushing efficiency (2008–2012) of 39% [73] and a 98% biodiesel conversion yield [81].

ILUC mitigation GHG emissions

The total GHG effect of ILUC mitigation was calculated similarly to that for land use by integrating the various measures. The GHG emission change in the *low*, *medium* and *high* scenarios was fully attributed to the low-ILUC-risk biofuel production in Macroregion 2. We compared the results for each measure and the integrated result (in g CO_2-eq MJ^{-1}) to the 55 g CO_2-eq MJ^{-1}, the ILUC factor for rapeseed biodiesel as reported by [5].

Data

Table 2 presents the data for the calculations of the surplus land of the four measures in Eastern Romania, in the *baseline* and *low*, *medium* and *high* scenarios. The data in S4 in the Supplementary materials are the input values to BioGrace for the calculation of the GHG

Table 2. Input data for the calculation of the surplus land of the four measures in the *baseline* and the three scenarios. Surplus land in the *high+* scenario is the same as in the *high* scenario. Assumptions for each scenario are explained in the main text and summarised in Table S1 of the Supplementary material.

ILUC risk mitigation measure			Scenario: Baseline	Low	Medium	High (+)
Above-baseline yield increase	Yields 2020 (t ha^{-1})	Maize	3.4 [a]	3.5 [b]	4.3 [c]	6.1 [d]
		Wheat	3.0	3.1	3	3.5
		Sunflower	1.6	1.5	2	1.6
		Barley	2.7	3.2	3	3.1
		Rapeseed	1.8	2.0	2	2.5
		Potatoes	14	12	15	17.0
		Oats	1.7	1.7	2	2.4
		Soybean	1.8	2.0	2.1	1.6
	Livestock units (ha^{-1})		1.0 [e]	1.0 [f]	1.6 [g]	1.8 [h]
	Cow milk productivity (m^3 y^{-1})		3.7 [i]	3.6 [j]	3.7 [k]	4.9 [l]
	Cow beef productivity (kg)		173 [m]	178 [n]	176 [o]	226 [p]
Chain integration	Products replaced by one tonne of rapeseed meal (t)		None	Soymeal: 0.89 [q]	Maize: 0.63; wheat: 0.7; barley: 0.03; potatoes: 0.04; oats: 0.03; soymeal: 0.04 [r]	Maize: 0.95; wheat: 0.98; barley: 1.1; potato: 3.8 [s]
Reduced losses	Losses 2020 as mass fraction (%)	Maize	1.4 [t]	0.94 [u]	1.4 [v]	1.4 [w]
		Wheat	0.9	0.37	0.9	0.9
		Sunflower	4.0	3.73	3.0	2.7
		Barley	8.9	8.70	3.7	3.8
		Rapeseed	1.5	1.49	1.5	1.5
		Potatoes	4.4	2.74	4.4	4.4
		Oats	2.1	2.08	2.1	2.1
		Soybean	0.5	1.06	1.1	1.1
Abandoned lands	Assumed area available (ha)		0 [x]	> 50	> 20	All
	Assumed productivity as share of average yield (%)		0 [y]	50	75	99

[a]Calculated from MIRAGE baseline projections for the EU27 [5]. Growth percentages from MIRAGE were applied to the current (average 2008–2012) yields in Eastern Romania that were derived from the national statistics database [38].
[b]The linear yield trend per crop since 1990 in Eastern Romania (data from national statistics [38]) was calculated and extrapolated to 2020.
[c]Yield in the county of Eastern Romania with the highest yield for that crop; data from the national statistics office [38].
[d]The ratio between the maximum attainable yield and the current yield in Poland (FAOSTAT data, average 2008–2012 [41]) was multiplied by the maximum attainable yield in Eastern Romania. The maximum attainable yield was derived from the Global Agroecological Ecological Zones (GAEZ) data from the International Institute of Applied System Analysis (IIASA) [54] following the descriptions in [42,29].
[e]The sum of the number of bovine animals and sheep in Macroregion 2 [38] multiplied by their respective livestock units (1 and 0.1) [55] divided by the sum of the meadows and pasture areas in Macroregion 2 [38]. Average for 2008–2012.
[f]Linear extrapolation of the trend (1995–2012) for livestock density in Macroregion 2, data before 1995 show a very rapid decline resulting from the reduction in livestock after the collapse of the communist regime.
[g]The density in the county with the second highest density (Botosani), because the county with the highest density, Braila, is an outlier (2.2) compared to the rest of the counties.
[h]Density in Poland, based on FAOSTAT data [41].
[i]Current productivity was calculated as the total milk production in Macroregion 2 (excluding consumption by calves), divided by the total lactating bovines [38]. This was increased with the projected increase in cattle productivity of 10% from MIRAGE [5].
[j]Extrapolating the trend of average milk productivity per cow in Macroregion 2 (2004–2012) to 2020.
[k]Highest average productivity in Macroregion2 is achieved in Galati.
[l]The milk yield per cow in Poland from FAOSTAT [41].
[m]Carcass weight in Romania [41] (average 2008–2012). As no macroregional level data is available, national data were used. This was increased with the projected increase in cattle productivity of 10% from MIRAGE [5].
[n]Extrapolating the national trend (2004–2012) in carcass weight to 2020.
[o]In 2015 the living weight of slaughtered animals in Sud Est was 313 kg [83]. Using national data for living weight of slaughtered animals [38] and FAOSTAT data for carcass weight [41], we calculated the average national ratio between living weight and carcass weight (0.56). Multiplying this ratio by the living weight in Sud Est gave the highest productivity in the region.
[p]Average (2008–2012) carcass weight in Poland [41].
[q]Protein content of rapeseed meal is 33%; for soymeal this is 48% [63]. Replacing it at equal rates and assuming 1.3 t soy is needed for a ton of soymeal [5] gave a replacement rate of 0.89 t soy t^{-1} rapeseed meal. All soymeal was assumed to be imported from Argentina and Brazil, the largest producers and exporters of soy to Europe [64].
[r]The current average feed mix is taken from FAOSTAT [41] (average 2008–2012).
[s]The digestible energy content of rapeseed meal is 13.8 GJ t^{-1}[66]. Replacement by energy content of barley = 13.0 GJ t^{-1}, wheat = 14.1 GJ t^{-1}, potato = 3.66 GJ t^{-1} and maize = 14.6 GJ t^{-1} [66]. Water content conversion data from [65]. Crop replacement in order of the lowest yield to maximise the surplus land.
[t]Current losses are reported by FAOSTAT, but are only at the country level. Therefore, the average (2008–2012) losses for Romania as a whole were used to calculate the current losses in Macroregion 2. The losses were expressed as the share of the total supply (sum of production, imports and stock withdrawals) of the crop in Romania.
[u]The per-crop linear extrapolation of the losses, expressed as the share of the baseline production.
[v]Per-crop average losses found in the seven central and eastern European EU countries (Bulgaria, Czechia, Hungary, Poland, Romania, Slovakia, Slovenia), average FAOSTAT data 2008–2012 [41].
[w]Per-crop average losses in Poland (2008–2012) [41].
[x]For the availability of the abandoned lands (Table S4), we assumed in the high case all abandoned lands to be available, but for the medium case only those larger than 20 ha, and in the low case only those larger than 50 ha.
[y]We assumed a marginal yield ratio for productivity on abandoned lands similar to the uncertainty analysis of Laborde [5], who used an uncertainty bandwidth of 50% to 99%, with an average of 75%.

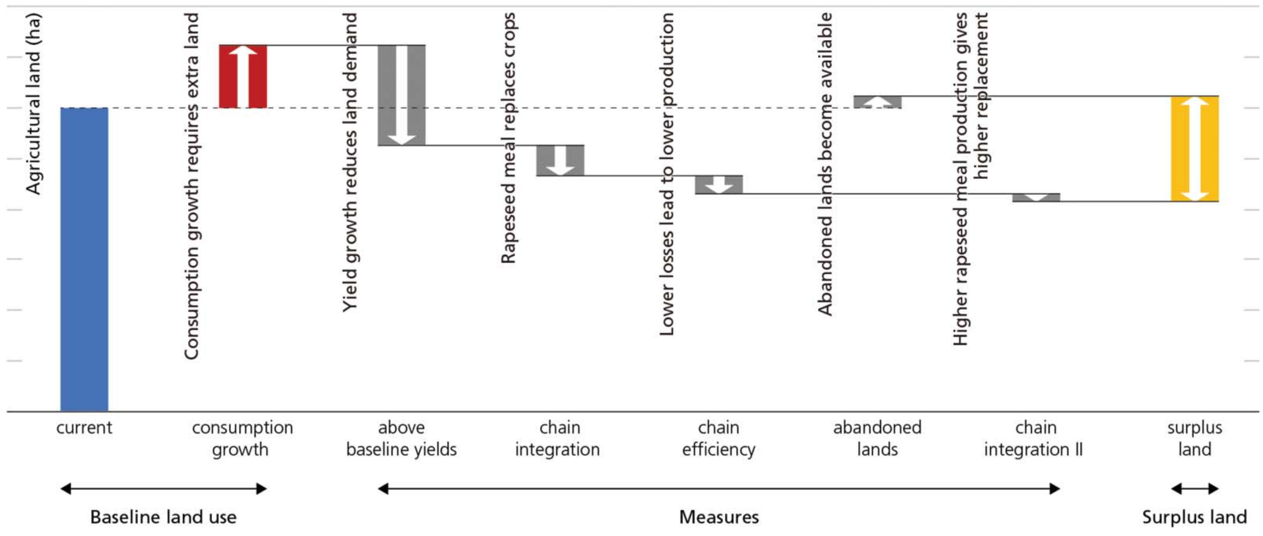

Figure 4. Schematic overview of the calculation steps to determine the surplus land. The current agricultural land (left bar) and additional land to meet growing demand (second bar) give the *baseline* land use in 2030. The indirect land-use change (ILUC) mitigation measures (middle bars) reduce this demand or increase supply of land. The surplus land (right bar) can be used for the production of biodiesel (color online).

emissions of the above-baseline crop yield increase. The data for GHG emissions of above-baseline livestock yield increase are presented in S5 in the Supplementary material.

We performed a sensitivity analysis on the most uncertain parameters of this study. For this we varied the value of the parameter to establish the effect on the low-ILUC-risk potential and ILUC mitigation GHG emissions.

Results

The surplus land that can become available from implementing the four ILUC mitigation measures in Eastern Romania, the resulting low-ILUC-risk biodiesel potential and the associated GHG emissions are presented in Figure 5 for *low*, *medium* and *high* scenarios. For the *high* scenario two variants are shown for the GHG emissions. These are the regular *high* scenario and a *high*+ scenario for which we assume the same low-ILUC-risk biodiesel potentials, but where we assume intensification takes place sustainably, reducing the associated GHG emissions. The potential surplus land of all four measures is between 2000 km^2 (*low*) and 18,000 km^2 (*high*). This corresponds to 6–43% of the current agricultural area in the region. In addition to the domestic surplus land, there is also additional surplus land abroad. This comes from the replacement of imported soy by rapeseed meal in the *low* and *medium* scenarios of the chain integration measure. This is a maximum of 400 km^2 and is not included in the calculations of low-ILUC-risk rapeseed biodiesel potential, as it is outside the region. Using all domestic surplus land for low-ILUC-risk rapeseed

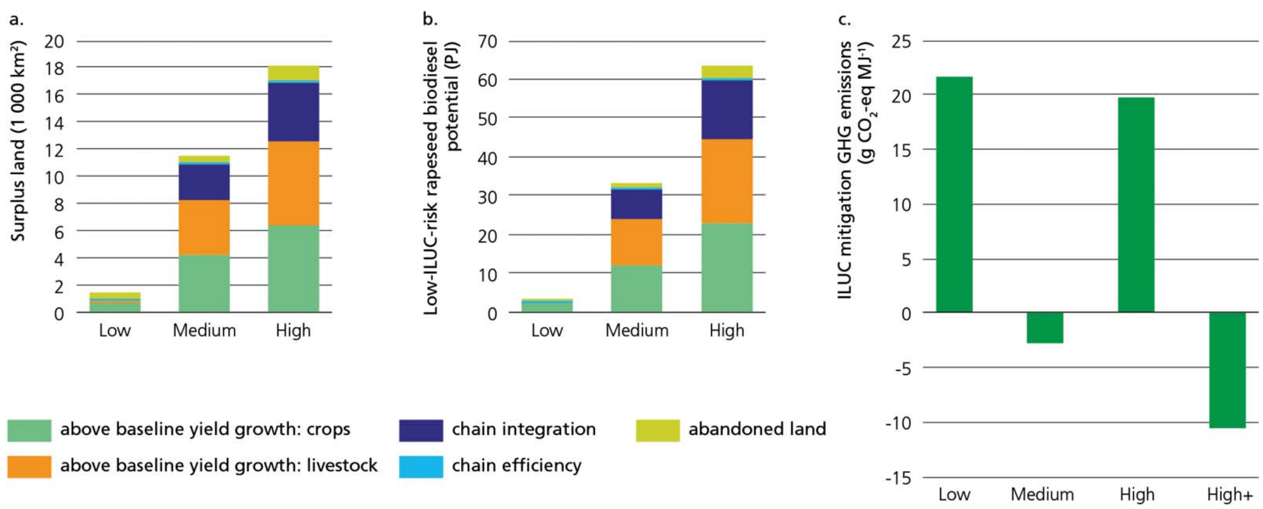

Figure 5. (a) Surplus land in the *low*, *medium* and *high* scenarios as a result of the measures. (b) Potential low-indirect land-use change (ILUC)-risk rapeseed biofuel production. (c) ILUC mitigation GHG emissions for the four scenarios. Note that the surplus land and low-ILUC-risk biodiesel potential in the *high*+ are the same as in the *high* scenario (color online).

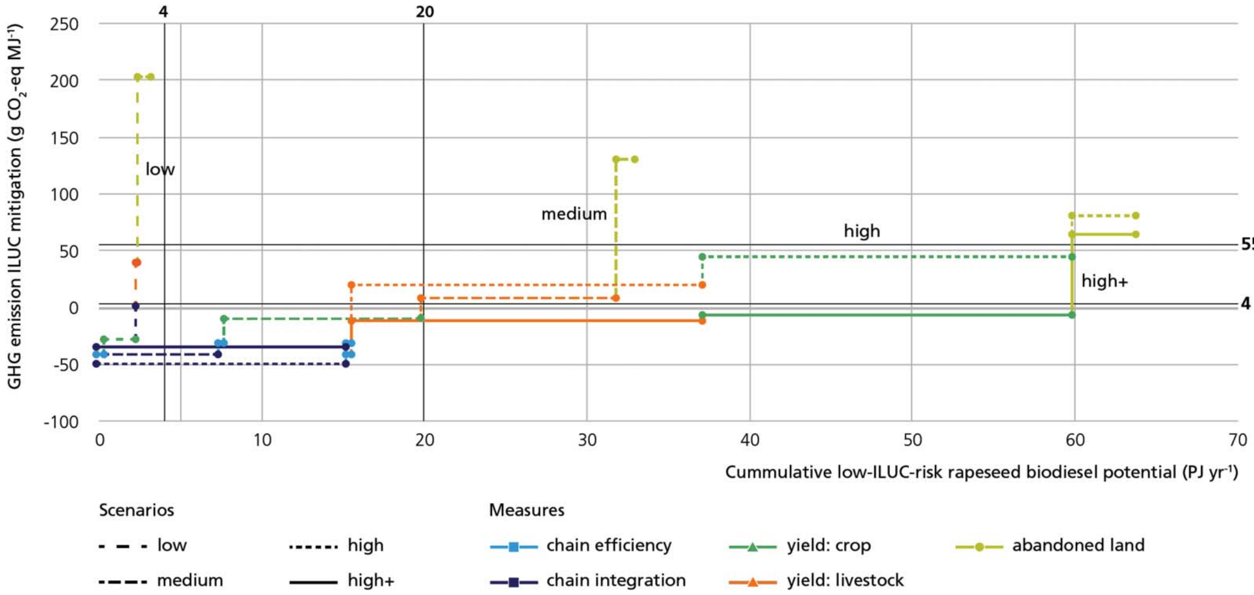

Figure 6. Potential and GHG emissions of the indirect land-use change (ILUC) mitigation measures in all scenarios. ILUC GHG emissions of oilseeds are 55 g CO_2-eq MJ^{-1} [5]. The margin between total direct and indirect life-cycle emissions of biodiesel production and the threshold value to achieve the mandated reduction compared to fossil fuels is 4 g CO_2-eq MJ^{-1}. The vertical lines indicate the National Renewable Energy Action Plan (NREAP) [37] biofuel projected production in Romania (right), and disaggregated to Macroregion 2 (left) (color online).

biodiesel production can yield a total potential production of 3–67 PJ. This is up to 30% of the 224 PJ projected total diesel consumption in Romanian transport in 2020 [37,53]. The low-ILUC-risk biodiesel potential is 15–340% of the NREAP biofuel target for the whole country, or 45–1000% when disaggregating the NREAP production to Macroregion 2 (disaggregation based on the region's share of Romanian arable land).

The GHG emissions to make the surplus land available are on average 28, −6 and 12 g CO_2-eq MJ^{-1} in the *low*, *medium* and *high* scenarios, respectively. In the *high*+ scenario that focussed on sustainable intensification, the GHG emissions are significantly reduced, to −12 g CO_2-eq MJ^{-1}. This is mainly the effect of lower GHG emissions of above-baseline yield improvement because of lower fertiliser and diesel use. The ILUC factor for rapeseed biodiesel as calculated by Laborde is 55 g CO_2-eq MJ^{-1} [5]. This means making surplus land available for low-ILUC-risk rapeseed biodiesel can be done without additional GHG emissions compared to ILUC.

To put this in perspective, the complete life-cycle GHG emission for biodiesel produced from Eastern Romanian rapeseed, excluding the land-use change emission, amounts to 30 g CO_2-eq MJ^{-1} in the most favourable case. The maximum emission to be able to meet a 60% reduction from the fossil reference (83.8 g CO_2-eq MJ^{-1}) set by the European Commission is 34 g CO_2-eq MJ^{-1} [12]. The small margin of 4 g CO_2-eq MJ^{-1} between the two means that when the ILUC-risk mitigation GHG emissions are included in the life-cycle calculations, only those measures can be implemented that are associated with near-zero or negative GHG emissions. This would mean the low-ILUC-risk biodiesel potential decreases to 2.2 PJ in the *low* scenario to 15 PJ (*high*), 20 PJ (*medium*) or 59 PJ in the *high*+ scenario. Thus, only the *medium* and *high*+ scenarios can meet the national biofuel target of 20 PJ and fulfil the emission reduction criteria, as the *high* scenario has GHG emissions too large to be viable. This is also apparent from Figure 6, which shows the combination of the low-ILUC-risk potential and the associated GHG emissions. The negative GHG emissions for some measures indicate those measures that make land available through lower crop production (e.g. lower losses means lower required production) or where the production increases faster than the per-unit GHG emissions.

Above-baseline yield development for crops and livestock is the most important measure in terms of surplus land and low-ILUC-risk rapeseed biodiesel potential in each scenario. Between 55% and 72% of the total surplus land comes from yield increases in the low to high scenarios. The yield increases in maize, wheat and livestock contribute most to the availability of surplus land. As the gap between actual and potential yields is large and only limited yield increases are projected in the baseline, the potential for above-baseline yield increase in crop and livestock production can lead to a large potential. The baseline yield development and above-baseline yield development are also the parameters most affecting the final outcome. A small change in yield can have a large impact on the low-ILUC-risk rapeseed biodiesel potential and the GHG emissions, as illustrated in Figure 7. It should be noted that a 20% change in the baseline yield can

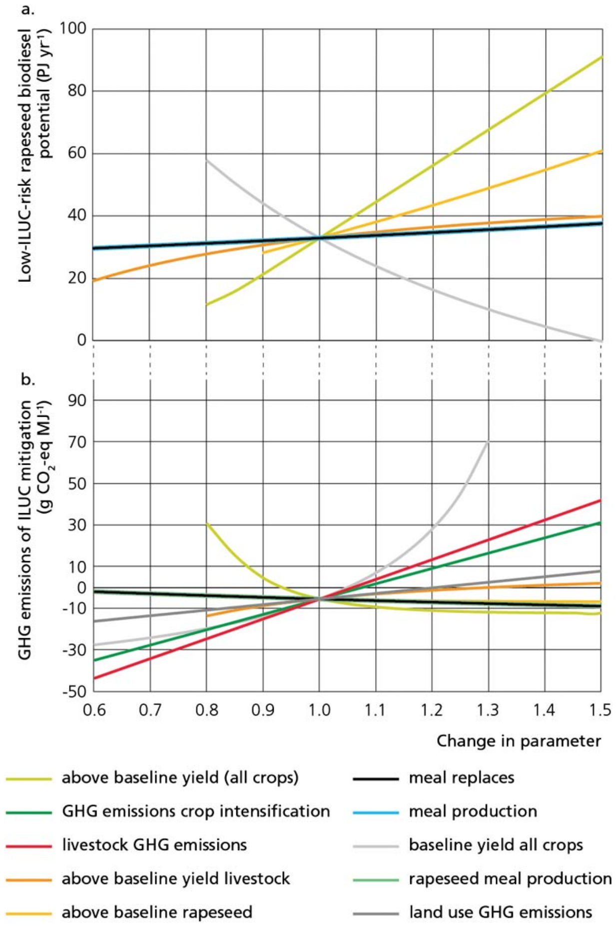

Figure 7. (a) Sensitivity of the low-indirect land-use change (ILUC)-risk biodiesel potential, and (b) sensitivity of the GHG emissions of the ILUC mitigation measures to a change in various parameters in the *medium* scenario (color online).

reduce the gap to zero and reduce the amount of surplus land from this measure to zero. A lower above-baseline yield for rapeseed amplifies this effect, as lower rapeseed yield means lower biodiesel feedstock production on the available surplus land. Lower yield increases would also mean the GHG emissions of crop intensification are spread over a smaller amount of low-ILUC risk biodiesel potential, thereby increasing the GHG emission per unit of low-ILUC-risk biodiesel.

Although the GHG emissions of crop yield improvement are high (75% average increase in the *high* scenario) these are compensated by higher yields, leading to lower emissions per unit crop produced. The same is true for intensification of livestock production [32]. The GHG emissions of livestock intensification are higher as a result of the emissions of converting grassland to cropland. The conversion of meadows and pastures in Eastern Romania to cropland is associated with GHG emissions of 34–63 g CO_2-eq MJ^{-1}. These emissions are, however, partly compensated by the lower GHG emissions in livestock production, leading to lower net emissions of this measure. The LUC emissions of grassland to cropland conversion are allocated here to the low-ILUC-risk GHG emission factor, to account for the GHG emissions of reducing the ILUC risk. However, a problem of double counting occurs if these are included in the direct life-cycle emission of biodiesel production.

Discussion and conclusion

Indirect land-use change can have a severe impact on the GHG emission balance of biofuel production. In this case study, we calculated the potential to produce low-ILUC-risk biodiesel from Eastern Romanian rapeseed, and analysed the GHG emissions associated with the underlying measures to minimise the risk of ILUC (i.e. above-baseline yield increase, use of rapeseed meal to replace animal feed, reduced losses in the agricultural production chain, and the use of abandoned land). The results emphasise that ILUC mitigation is possible while still fulfilling a GHG emission reduction target of 60% compared to fossil fuels. However, this is only achieved when the entire agricultural sector is sustainably intensified, going beyond a focus on biofuel production alone. Key discussion points and conclusions are identified as follows.

Yield improvements of crops and livestock are crucial to reduce the ILUC risk. Yield growth is the most important measure in all scenarios and is responsible for up to three quarters of the surplus land. However, the extrapolation of current trends in crop and livestock yield, as assumed in the *low* scenario, is insufficient to reach the regionally disaggregated NREAP target without a risk of causing ILUC. Thus, to be able to mitigate the risk of ILUC, crop and livestock yields have to grow faster than in the recent past. A comparison of the development in actual Eastern Romanian crop yields in the period 2010–2016 with the projected yields in the scenarios reveals yield increases are higher than in the past: in 2016 most crops are already above the yield levels projected in the scenarios [38]. Moreover, historic data on crop yield levels in Europe show that it is possible to achieve many continuous years of high yield growth. This high yield growth was even achieved when the yield gap was smaller than it is now [41,67,82]. An additional benefit of high yield growth is that higher yields for rapeseed also mean more biodiesel feedstock production on the surplus land.

Low-ILUC-risk biodiesel production is feasible with low GHG emissions of ILUC mitigation measures under specific conditions. ILUC mitigation requires intensification and modernisation of the agricultural sector and putting under-utilised land into production. It should be avoided that GHG emissions from these ILUC mitigation measures increase total GHG emissions compared to ILUC itself. Furthermore, emissions should be low enough that the total direct and indirect life-cycle emissions of biodiesel production stay below the threshold value to achieve the mandated reduction compared to fossil fuels (i.e. 60% reduction in EU RED). We show this is possible in this case study. The mitigation measures with low GHG emissions can provide more than the regionally disaggregated biofuel target for Eastern Romania. To avoid high emissions, strict limitations apply. These limitations relate to the level of yield growth, need for sustainable intensification and consideration of the carbon stocks of the surplus land. Reducing crop losses and replacing animal feed with rapeseed meal can be qualified as no-regret options. These measures have a positive ILUC mitigation potential and, in all scenarios, reduce GHG emissions compared to the baseline.

Sustainable intensification of the whole agricultural sector is required. The *high* and *high+* scenarios result in the same amount of surplus land, but the lower emissions in the *high+* scenario mean sustainable intensification can contribute towards meeting the 60% GHG emission reduction target for biofuel. In contrast, in the *high* scenario, the emissions from fertiliser use and the rest of the cultivation phase increase to a level such that the GHG emissions of the ILUC mitigation measures are only just below those of ILUC itself, and far above the threshold value for GHG emissions reduction compared to fossil fuel. The optimal scenario is one where the agricultural intensification leads to faster yield growth than GHG emission growth, as that situation reduces emissions compared with the baseline.

To ensure low GHG emissions of the ILUC mitigation measures, the type and carbon stocks of the surplus land need to be considered. The conversion of abandoned land and grassland to cropland can have high associated GHG emissions. When abandoned land is covered by shrubs or vegetation with larger carbon stocks, the GHG emissions of conversion to cropland can offset the gains from mitigating ILUC. The abandoned land included in the surplus land calculations was recently abandoned, which means carbon stocks in vegetation will be limited [78]. As a result of the relatively low share of this measure within the calculated surplus land, the impact on low-ILUC-risk potential is limited. The conversion of grassland to cropland also has high associated GHG emissions and is much more important than abandoned land in terms of ILUC mitigation potential. However, the intensification of livestock production that makes these surplus lands available is expected to reduce GHG emissions and thereby offset the land-use change effects and related emissions.

ILUC mitigation requires a holistic approach to the agricultural sector. ILUC is an indirect effect of the expansion of biofuel production, which ripples through the agricultural sector and affects land use far outside the location of the biofuel production. Mitigating the ILUC risk therefore also works in this interplay of agriculture, land use and bioenergy: the combination of the ILUC mitigation measures aims at improving the whole agricultural sector and reducing its land use. This is not limited to biofuel feedstock production. As the GHG emissions of the ILUC mitigation measures also occur in the rest of the agricultural sector, it is important to consider this sector as a whole. This means evaluating and monitoring the progress of ILUC mitigation should focus on the broader agricultural sector to avoid underestimation of ILUC mitigation effects. Furthermore, as this study's results are based on a post-model analysis of the MIRAGE model results, the market-mediated effects of the ILUC mitigation measures are not included. Understanding the full implications of ILUC mitigation, including its own indirect impacts, is an important topic for future research. This helps ensure ILUC mitigation strategies are effective and contribute to lowering GHG emissions.

Acknowledgements

The authors are grateful for the help of Iulia Pişcă with gathering Romanian-specific information and with GIS. Sarah Gerssen-Gondelach was generous enough to share her data on agricultural intensification. This study was partially conducted under the umbrella of the ILUC prevention project, which was funded by the Netherlands Enterprise Agency, the Dutch Ministry of Infrastructure and the Environment, the Dutch Sustainable Biomass Commission, the Rotterdam Climate Initiative/Port of Rotterdam and the Netherlands Oils and Fats Industry Association MVO. Additional funding came from the Be-Basic R&D Program, which was granted a FES subsidy from the Dutch Ministry of Economic Affairs, Agriculture and Innovation (ELI). We are thankful to Margot Stoete for her help with the illustrations.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Rijksdienst voor Ondernemend Nederland; Ministerie voor Infrastructuur en Milieu; BE-Basic; Rotterdam Climate Initiative/Port of Rotterdam; and Commissie Duurzame Biomassa.

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