S1. Brief description of the SydILUC Model

The System Dynamics indirect Land Use Change (SydILUC) model is a dynamic causal-descriptive model that estimates future global land demand based on projection of bio-based production policies. It works on a global scale, with yearly time steps, so that the uncertainty related to land use allocation and short-time market changes are eliminated. Since it is a dynamic model, it naturally accounts for feedback loops, delay effects, and time-dependent exogenous variables. It accounts for use of co-products, use of residues, soil organic carbon changes, use of degraded or abandoned land, market effects, changes in agricultural yields, use of waste as an alternative biomass for bio-based material production.

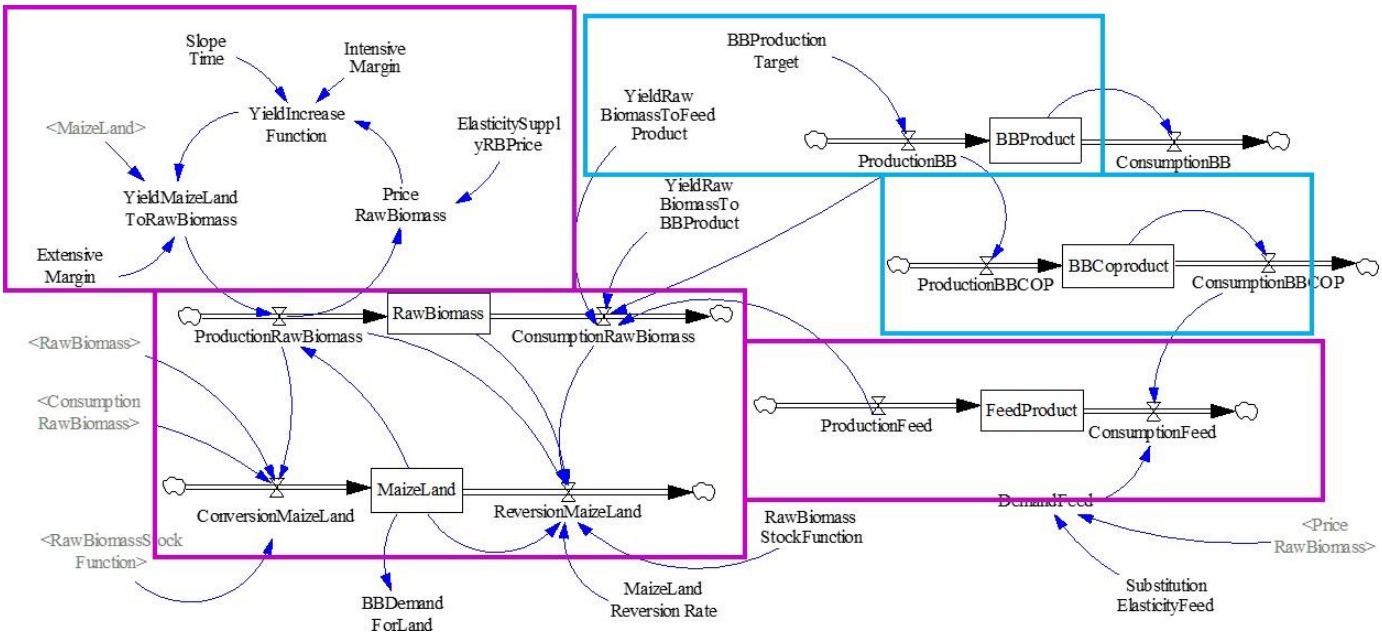


FIGURE S1 THE SIMPLIFIED VERSION OF SYDILUC MODEL; THE SYMBOLS ARE THOSE OF "SYSTEM DYNAMICS". THE LIGHT BLUE BOXES SHOW THE PART OF THE MODEL ACCOUNTING FOR DIFFERENT TYPE OF BIO-BASED PLASTICS, THE PURPLE BOXES SHOW THE PART OF THE MODEL ACCOUNTING FOR THE TYPE OF RAW BIOMASS.

The simplified SydILUC model shows all relevant cause effect and market relationships; these relationships have been calibrated and validated using the FAOSTAT dataset, for the raw biomasses used in the scenarios and exercises (maize, sugar beet pulp, and soybean).

The most relevant relationships include:

(i) the production-driven price equation for raw biomass;
(ii) the effect of crop price on demand from the feed market;
(iii) the effect of crop price on yields (called *intensive margin* in ILUC literature, [1,2]);
(iv) the modelled behaviour of maize yields in time;
(v) the future projections of global maize yields, based on literature review on maize yield forecasts [3–5];
(vi) and the effect on global yields of increasing the extension of land cultivated for maize production (called *extensive margin* in ILUC literature, [6]). The variables related to the different bio-based plastics are: (i) target production of the bio-plastic (in Mt, EU values); (ii) fraction of relevant co-products resulting from the production of the bio-based plastic; (iii) the actual yields of bio-based plastic materials from the feedstock. The data used for PBS and PLA inside the model was condensed from various documents, and was revised together with University of Santiago de Compostela, Spain, to be consistent with the LCA approach used

in WP2; the data for the bio-PUR production was provided by DBFZ, Germany. All the relevant parameters used in the model, together with their source and metadata, can be found in the files "iLUC model - simantics - PBSparameters_v12_EB.xlsx" and "ILUC model - simantics - PLAparameters_v12_EB.xlsx"as supplementary materials, provided on the STAR-ProBio homepage.

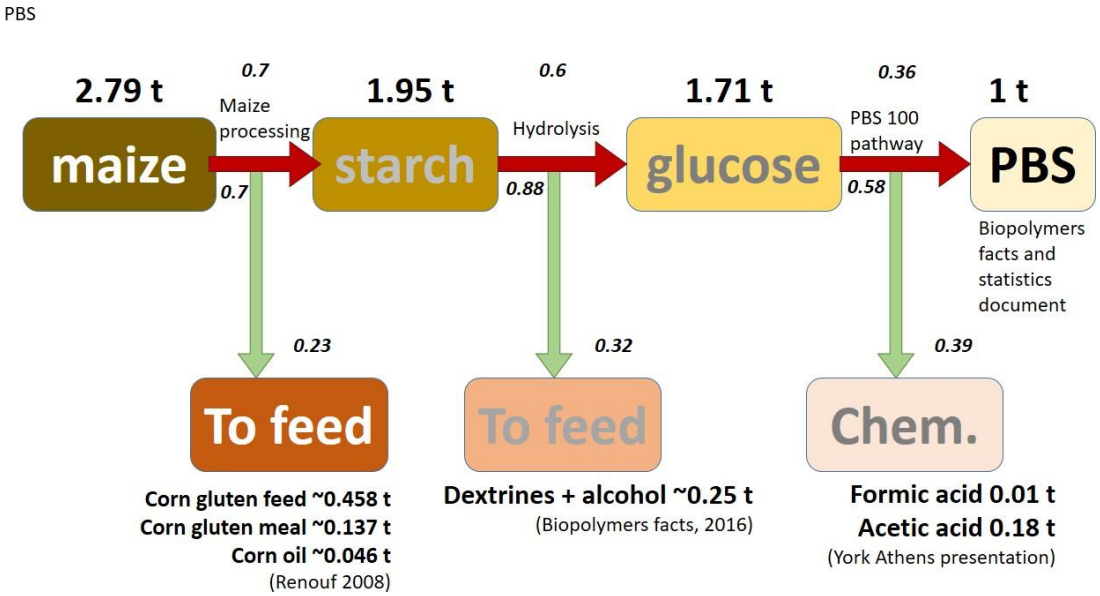


FIGURE S2 PBS PRODUCTION FROM MAIZE, YIELDS OF THE MACRO-PROCESSES AND MAIN CO-PRODUCTS THAT COULD BE USED ON THE MARKET.

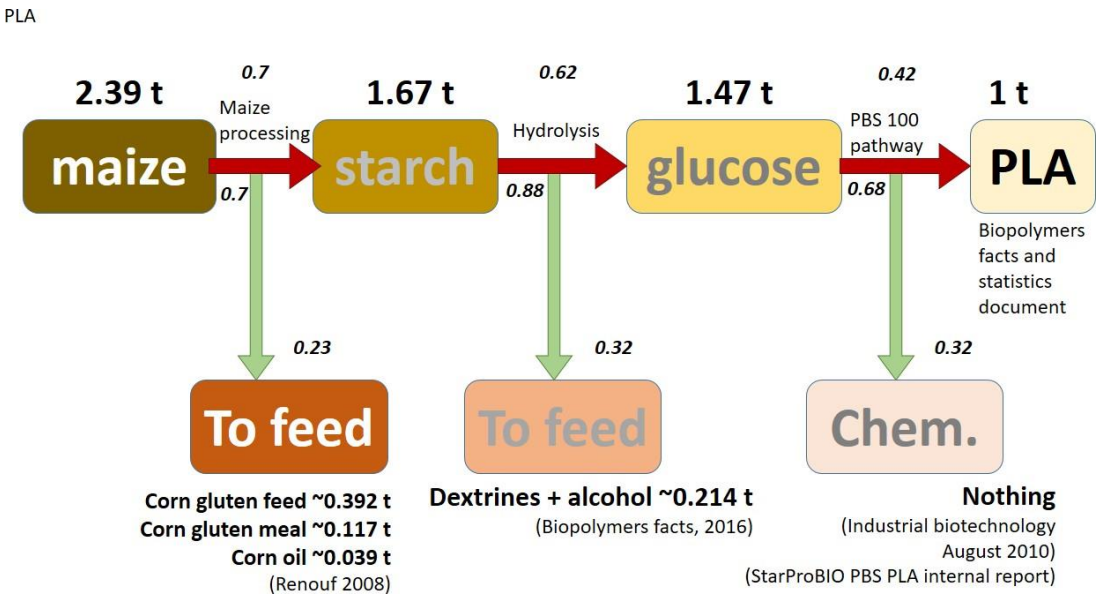


FIGURE S3 PLA PRODUCTION FROM MAIZE, YIELDS OF THE MACRO-PROCESSES AND MAIN CO-PRODUCTS THAT COULD BE USED ON THE MARKET.

The model was implemented in a system dynamic framework, and was later calibrated and validated using FAOSTAT data. A number of simulations were conducted using the validated model in order to estimate the ILUC risk related to the increase in production of the bio-based plastics considered for the case studies in the STAR-ProBio project. These simulations are the core for the parameterization needed to get a useful assessment tool for the STAR-ProBio project.

It is important to remember that, at this stage, the model is:

a) global (the whole world production is taken into consideration to avoid problems in prediction of land increase due to import-export effects, the so called "shift of the burden");
b) available for maize, sugar beet and soybean, with maize being the most relevant crop for bio-based materials production at the moment.

In the examples below, only maize will be addressed for brevity.

S1.1 Development of the model

The model was developed starting from the main structure of ILUC models emerged from the JRC. study on ILUC [1,7,8] and from the literature review conducted in StarProBio deliverable 7.1. The most relevant and common features across different models were adapted to the system dynamic framework and implemented on a first approximation based on the maize market. Maize was selected as the first crop analysed since a wealth of literature already exists on the topic. The first version of the working model (SydILUC model 21) included the processes of *intensive margin*, the change of agricultural yields influenced by changes in crop price, and of *extensive margin*, the change of agricultural yields influenced by expansion of cropland on less suitable land. Moreover, the co-product utilization was included.

After calibration and test of the market relationships using FAOSTAT dataset and market data, temporal trends in agricultural yields and silos functions to account for the adjustment of maize market to changes in maize stocks were introduced in the SydILUC version 29. The model behaviour in time was then, extensively calibrated and validated in order to test its predictive capability. The output of WP2 LCA analysis on PLA and PBS production from maize was, then, used to adapt the model to the specific scenarios (SydILUC versions 32 and 33), and local sensitivity analyses were conducted on both to study their behaviours. Residue use, waste, erosion and SOC were included in version 34. A modified version of the model, reducing its parameter dimensionality and adapted to account for low ILUC risk practices, was developed (version 35) and used to obtain the ILUC risk tool. Finally, two other biomasses (sugar beet and soybean) and one additional bio-material (bio-PUR) were included in the model and implemented the ILUC risk tool.

S1.2 Main processes modelled in of the SydILUC Model

The price of maize on the global market is mainly driven by the production (supply driven); this is due to the high demand rate for a global crop with increasing population and changes in diets. The actual price of the main global crops is somehow controlled by an oligopoly of global cereal traders, and influenced by national subsidy policy, so that it remainsmostly stable [9]. From FAOSTAT yearly data, however, a correlation can be found between global supply of maize (production plus stock) and maize price; hence, a dependence was derived using econometrics functions for the globalyearly price of maize dependent on stock and production of maize. Stock comes from the maize produced in one year and not used; production adjusts yearly to stock quantities so that the maize in the "global silos" is kept close to zero (FAOSTAT data). The Feed market behaviour is dependent on the so called elasticity of substitution for the price of thecrop transformed into feed product: an increase in feed product price makes other competing biomasses more competitive as feed. Substitution elasticities are the percentage change in the ratio of two competing inputs (*e.g.* feed1 and feed 2) used in response to a percentage change in their prices. It measures the market response to a change in price by changing demand, and are typically high for the feed sector. They are, instead, very low for the food sector, which, therefore, was neglected in the present study. Moreover, in the case of maize uses, food represent only the 20
% of total uses, while feed the 65 %.

Two relevant features coming from ILUC modelling literature are the intensive and extensive margins. Intensive margin relates to the effects of changes in crop prices on agricultural yields, the rationale being that, when higher prices are paid for the crop, then the producer is incentivised to increase yields by increasing fertilizer, pesticide and irrigation applications. However, even if this may be true at local scale, the statistical analysis on global data shows no correlation

between crop prices and global yields: other important factors such as land rights, transportation, knowledge transfer, purchasing power seem more relevant in determining global yields. Agricultural sciences literature shows that global crop yields are increasing linearly in time, independently of crop prices, subsidies, incentives, changes in demand. Therefore, the time trends of crops identified in scientific literature was included in the model. Extensive margin represents the assumption that the most suitable land for the production of a certain crop is probably already in use, and, therefore, any expansion of crop land will be conducted on land less suitable for agriculture (or for the production of that particular crop), with the results that the global average yield of the crop will decrease. In the model the extensive margin was set in the model as [6] did: the yield of converted cropland over the initial crop land extension is only 0.66 times the normal agricultural yield.

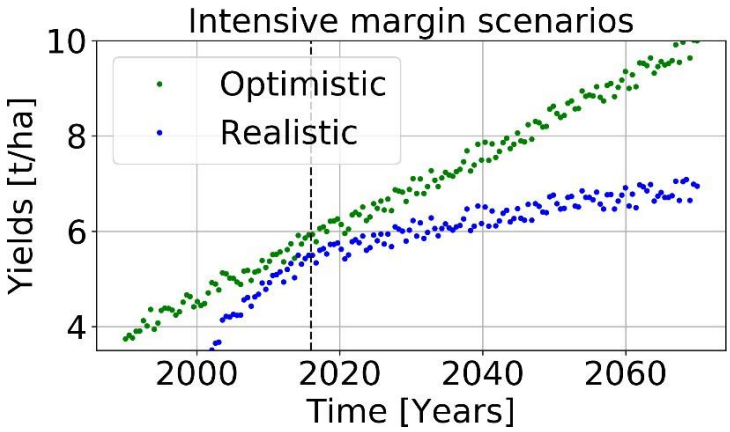


FIGURE S4 FUTURE PROJECTION OF YIELDS AS USED IN THE SYDILUC MODEL (VERSION 29-32) FOR THE OPTIMISTIC AND REALISTIC SCENARIOS.

In SydILUC version 34 use of residues, erosion and SOC changes were introduced. Agricultural residues are produced together with the main crop, but are assumed not to drive agricultural production; some examples are wheat straw, maize stover, sugar beet pulp. They are partially used in the feed sector as animal feed or as material, and partially left on the field as a source of organic carbon in the soil. Therefore, when used to produce bio-based materials, the relevant parameters are: the yields of transformation from residue to bio-material (usually lower than the respective yields of the main crop), the effect on SOC, and the competition with the feed sector. In the SydILUC model, the competition with the feed sector is accounted with substitution elasticities for the agricultural residue relative to the feed sector. Erosion is a global issue, resulting in a net loss of soil and in land degradation. Erosion is influenced by SOC: SOC increase soil structural stability and resistance to direct erosion by wind and water. Intensive agricultural practices have high agricultural yields, but usually increase soil erosion decreasing soil resistance to precipitation events, and tend to decrease SOC; conservation agricultural practices, instead, increase SOC (by leaving agricultural residues on the field) and decrease erosion (by implementing soil protection practices). The increase in SOC due to land use practices is simplified in the model in order to account for the high uncertainty in such process; a certain land use practice can potentially: increase, decrease or not change SOC.

The main objective of the SydILUC model is to estimate the change in land demand caused by an increase of bio-based material production in the future. The case studies of the STAR-ProBio project focused on bio-plastics, so the bio-based material taken into consideration for the SydILUC model were bio-PLA, PBS and PUR. In order to test the model, it was assumed that a policy would be put in place where the fossil-based plastics in use would have to be substituted up to a prescribed percentage with bio-plastics. The amount of fossil-based plastic to substitute depends, then, on: the scale of the substitution (only in EU? For the whole world?), the 10 years trend in plastic consumption changes, and the time horizon for the substitution. So, if the substitution of 50% of fossil-based plastic in the EU was the target by 2050, the amount of bio-plastic to produce after 30 years (starting in 2020) of policy would be the actual use of fossil-based plastics in the EU modified by the trend (to get the fossil-based plastic used in the EU in 2050) divided by two. Some ideas of

the masses involved are given in Table S1 . It was assumed that the increase in bio-based plastic from actual level to target level is linear in time; this, however, can be easily changed in the model.

TABLE S1 APPROXIMATE 2016 PLASTIC PRODUCTION AND FUTURE PROJECTIONS USED IN THE MODEL, BASED ON "PLASTICS EUROPE" AND "EUROPEAN BIOPLASTICS".

PLASTIC PRODUCTION (MT)	E.U.	WORLD	PBS	PLA
ACTUAL (2016)	60	335	0.1	0.21
FUTURE (2050)	173	1000	-	-

S1.3 SydILUC Model calibration and validation: example with for maize

We calibrated the model using FAOSTAT and market time-series of the main input and output variables for that part, and then validated the whole model to estimate its ability to predict future changes in land demand. There are various ways to calibrate a model; in this case we were interested in estimating the predictive ability of the model, so we decided to use the FAOSTAT time-series of global Maize price, production, stock change, uses, yields and dedicated cropland for both calibration and validation. The FAOSTAT dataset was divided into two subsets: the calibration subset consisting of years from 1991 to 2006, and the validation subset, consisting of years from 2007 to 2017. First, we used the model with the initial parameters found in the literature to predict the trends in the dataset, then we changed these parameters (and relationships) in order to get results similar to the observation in the calibration dataset, and finally we run the model for the validation period as well and compared results with observations.

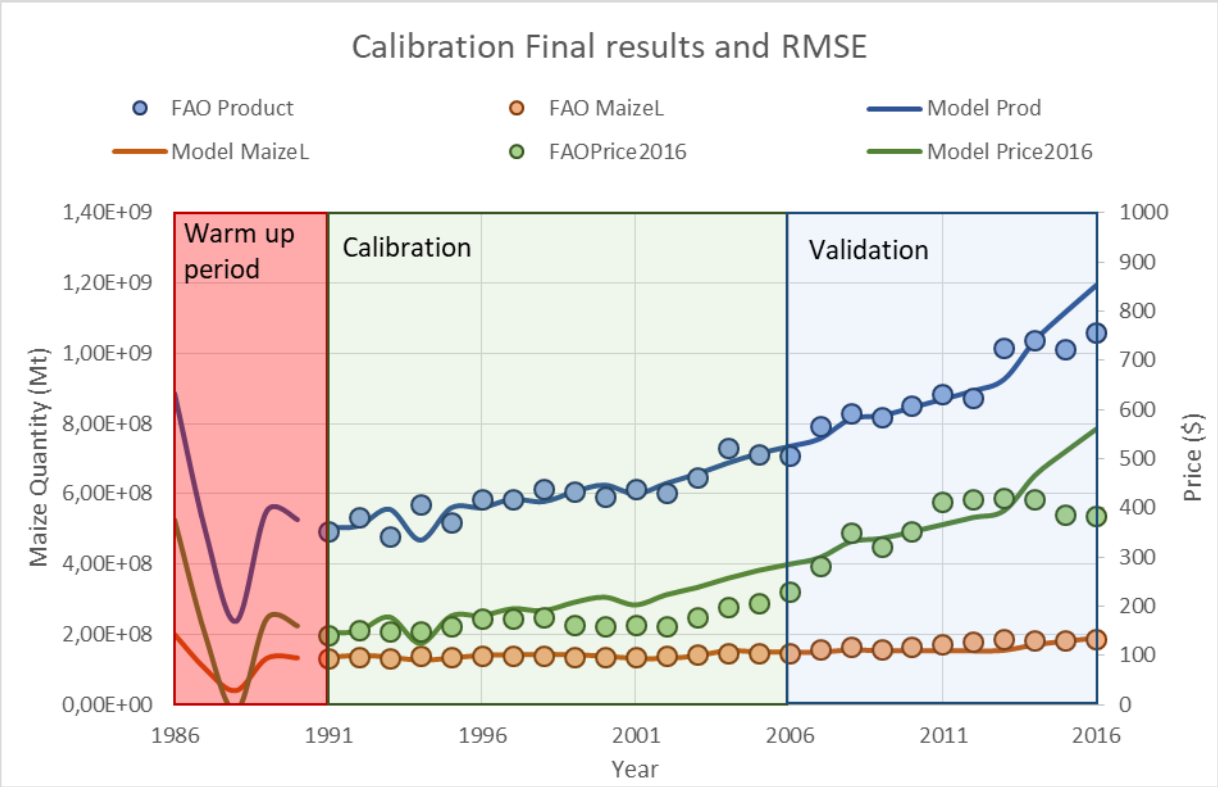


FIGURE S5 RESULTS OF THE VALIDATION CARRIED ON THE CALIBRATED MODEL, SHOWING THE INITIAL WARM UP OF THE MODEL (I.E. THE TIME IN WHICH THE MODEL REACHES EQUILIBRIUM INITIAL CONDITIONS), CALIBRATION PERIOD (SHOWING THE BEST FIT WITH FAOSTAT DATA) AND VALIDATION PERIOD (THE ACTUAL RESULT).

Figure shows that the modelled trends follow closely the observed trends, especially for the agricultural part of the model (mainly the maize land change). After an initial period of wide fluctuations, due to random initial conditions, the model equilibrates quickly to the observed values: this shows that the model is not influenced much by the initial conditions. Then, the main trends are modelled correctly, even though the model does miss the some minor fluctuations visible in the dataset. These fluctuations are likely due to exogenous variables (weather, geo-politics, and fuel prices) and cannot be modelled in our framework.

S2 ILUC risk assessment examples of bio-based polymers for Maize

The following chapter deals with potential implementation pathways of the ILUC additionality measures within the supply chain of bio-based products, i.e. bioplastics. For this purpose, case studies relevant for the STAR-ProBio project will be analysed with the ILUC risk tool in order to demonstrate its applicability.

S2.1 Baseline simulations:

The results of the baseline simulations are shown in Figure. The differences between the two plastics is minimal, even though they have different production yields, different co-product production and different initial production rates. The most important factor influencing the future need for maize agricultural land expansion is the projection of future yields. Note that, for a target production of 173 Mt of plastics in 2050, both maize yields scenarios give "negative maize land expansion" after 100 years; this means that, in the model simulations, future yields are enough to offset the increase in demand for maize feedstock for the set policy bio-based production target. However, remember that these projections are for substitution of all plastics in EU, but on a global maize production. A more interesting simulation should account for global plastic substitution (1000 Mt); this, however, goes beyond the scope of the present study.

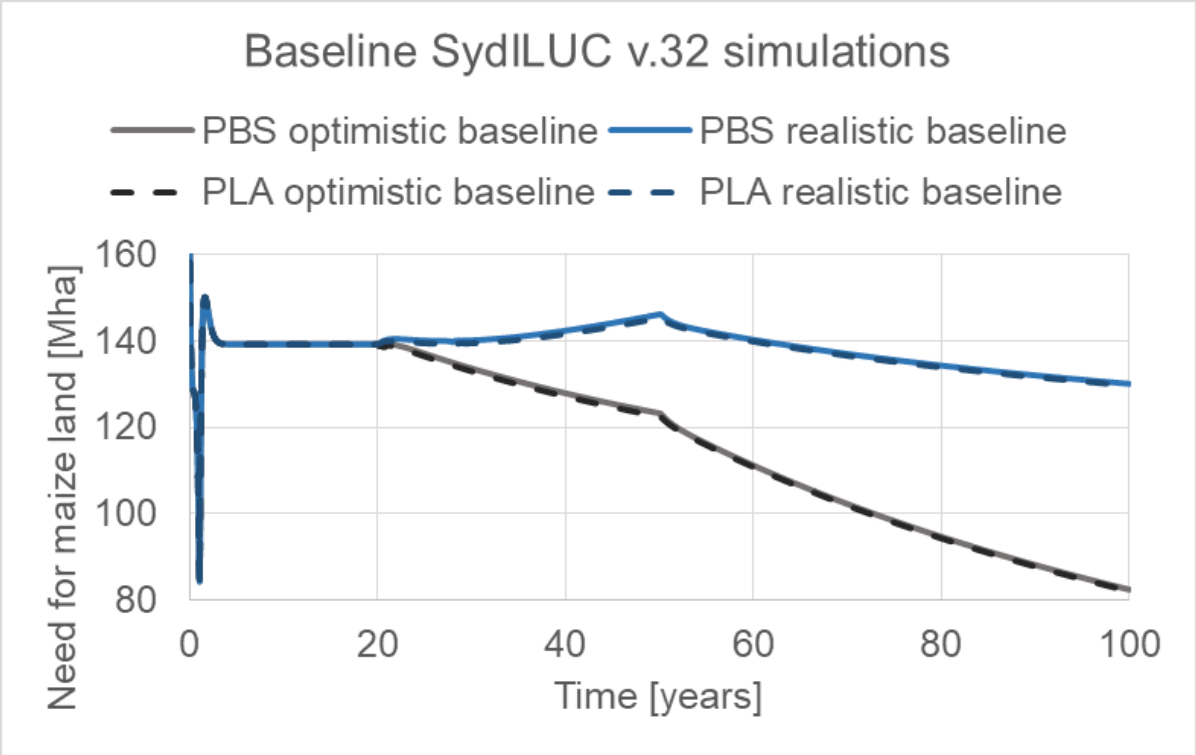


FIGURE S6 SYDILUC OUTPUT TIME SERIES OF CHANGES IN NEED FOR LAND CULTIVATED TO MAIZE IN ORDER TO REACH THE TARGET PRODUCTION OF SUBSTITUTING ALL E.U. FOSSIL PLASTICS WITH BIO-BASED PLASTICS, FOR PLA AND PBS, FOR THE OPTIMISTIC AND REALISTIC SCENARIO. THE POLICY FOR THE INCREASE IN BIO-BASED MATERIAL STOPS IN SIMULATION YEAR 2050, SO THIS IS WHERE THE ILUC RISK IS CALCULATED. SINCE THE DEMAND FOR LAND PROJECTED FOR THE OPTIMISTIC BASELINE IS LOWER THAN THE INITIAL CROP LAND, IT IS ASSIGNED TO THE LOWEST ILUC RISK CLASS.

S2.2 Bio-based plastic production target effect on need for crop land

The change in need for maize land due to increase in bio-based plastics production after 100 years is shown in Figure for PBS and in Figure for PLA. The production of relatively (with respect to world future needs) small amounts of plastics is not related to an expansion in maize land, meaning that the ILUC risk is low at those target production levels. This is due, essentially, to the increase in global maize yields, which balances the increased consumption of maize feedstock: notice that the optimistic projections reach the zero line (above which ILUC risk is not zero) for larger target bio-based plastic production. The exact value of bio-based material policy target that triggers an increase in maize land global area is reported in Table for both PBS and PLA. It is possible to appreciate both the small differences between the two plastics at small policy target values (110, 170 Mt) and the big effect of the co-products on the need for new maize land.

TABLE S2 BIOBASED MATERIAL POLICY TARGET AT WHICH MAIZE LAND AREA INCREASES WITH RESPECT TO 2016 VALUE, FOR BOTH PBS AND PLA, AFTER 100 YEARS OF SIMULATION.

BIOBASED MATERIAL	OPTIMISTIC	OPTIMISTIC NO COP	REALISTIC	REALISTIC NO COP
PBS	410.1	230.1	170.1	110
PLA	430.21	270.21	170.21	110.21

The effect of co-product utilization is that it decreases the risk of ILUC, since it substitute the need of maize feedstock for animal feed. The effect of the co-products starts to increase with increasing production of bio-based plastics, reaches a maximum effect in lowering ILUC risk around a policy production target of ~400 Mt, then decreases, and finally has no effect whatsoever at ~900 Mt.Figure shows the reason behind this decrease in ILUC lowering effect of co-products for policy productions > 400 Mt: since the demand of animal feed is kept fixed in time (following the *ceteris paribus* concept), large productions of bio-based plastics result in an amount of co-product large enough to completely substitute conventional animal feed. This is unrealistic, since: (a) maize feedstock is not only used for animal feed, but also food, seed and other uses; (b) demand for animal feed will probably increase in the future, since there is an increasing global demand for meat consumption.

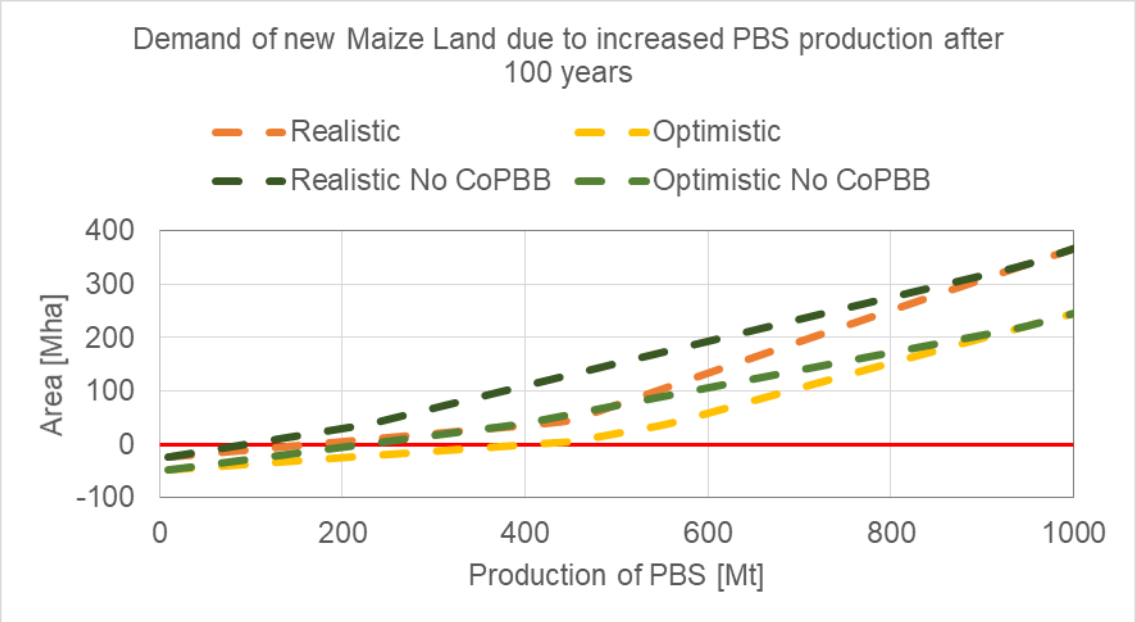


FIGURE S7 NEED FOR MAIZE AGRICULTURAL LAND WITH RESPECT TO TARGET PRODUCTION OF PBS IN 2050. THE RESULTS ARE SHOWN FOR THE REALISTIC AND OPTIMISTIC SCENARIO, AND FOR THE CO-PRODUCT UTILIZATION AND NO CO-PRODUCT UTILIZATION SCENARIO.

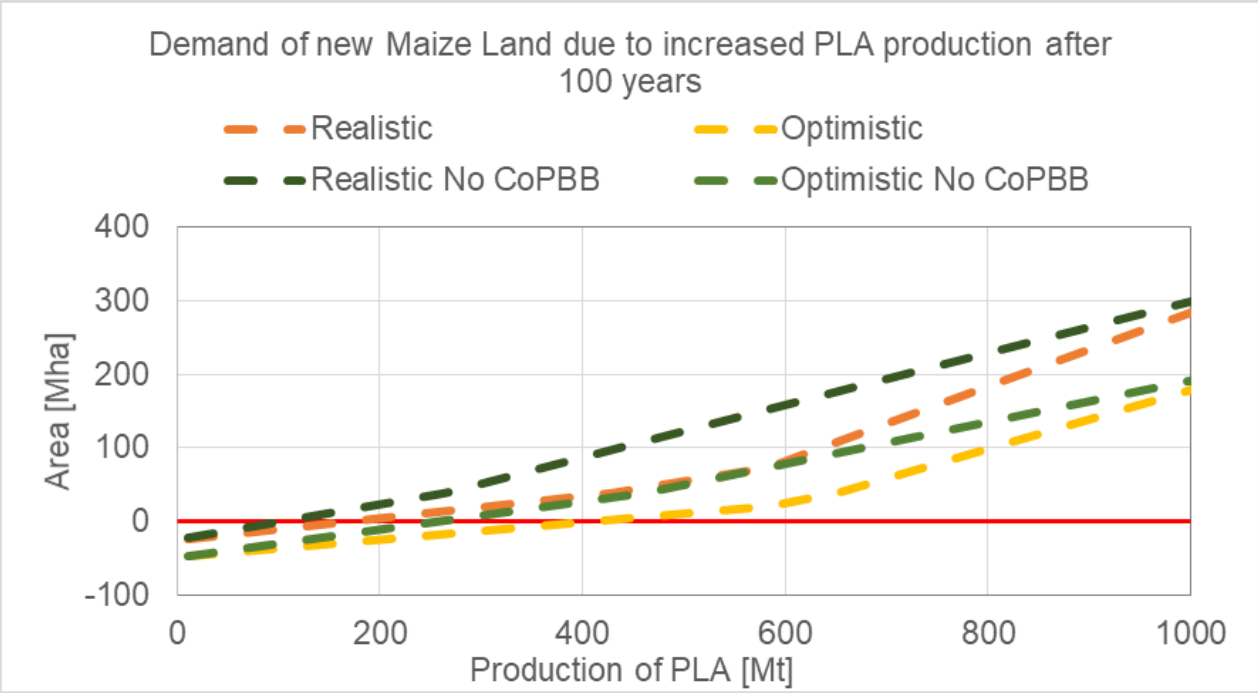


FIGURE S8 NEED FOR MAIZE AGRICULTURAL LAND WITH RESPECT TO TARGET PRODUCTION OF PLA IN 2050. THE RESULTS ARE SHOWN FOR THE REALISTIC AND OPTIMISTIC SCENARIO, AND FOR THE CO-PRODUCT UTILIZATION AND NO CO-PRODUCT UTILIZATION SCENARIO.

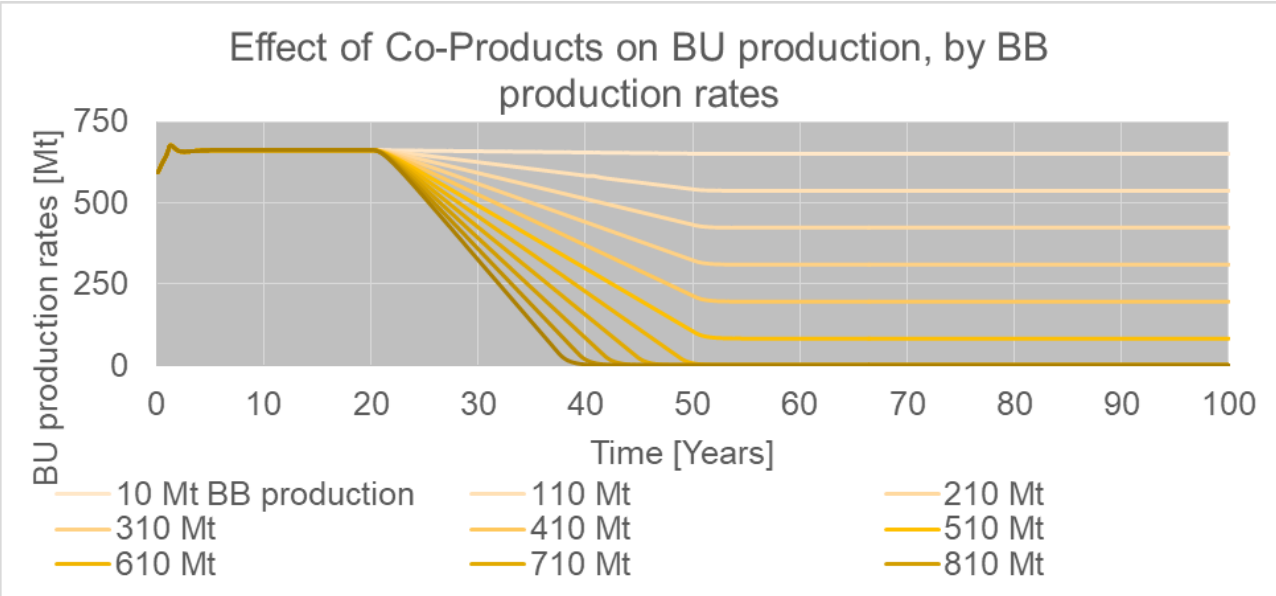


FIGURE S9 SYDILUC PREDICTED TIME-SERIES OF BU (FEED) PRODUCTION RATES AS AFFECTED BY DIFFERENT LEVELS OF BIO-BASED PLASTIC PRODUCTION, BASED ON THE ASSUMPTION THAT ALL RELEVANT CO-PRODUCTS WILL BE USED TO OFFSET NEED FOR FEED. ANOTHER ASSUMPTION IS THAT ACTUAL NEED FOR FEED WILL NOT INCREASE IN THE FUTURE (LIKELY UNREALISTIC, SINCE MEAT CONSUMPTION IS INCREASING WORLDWIDE).

A comparison of the effect on maize land expansion due to increased bio-based plastic production between PBS and PLA is shown in Figure . The levels of plastic production in 2016 and future projection for 2050 for both the E.U. and the world are shown as reference values. The main difference between the two plastics can be appreciated only for large production rates (~450 Mt, well over actual global plastic production).

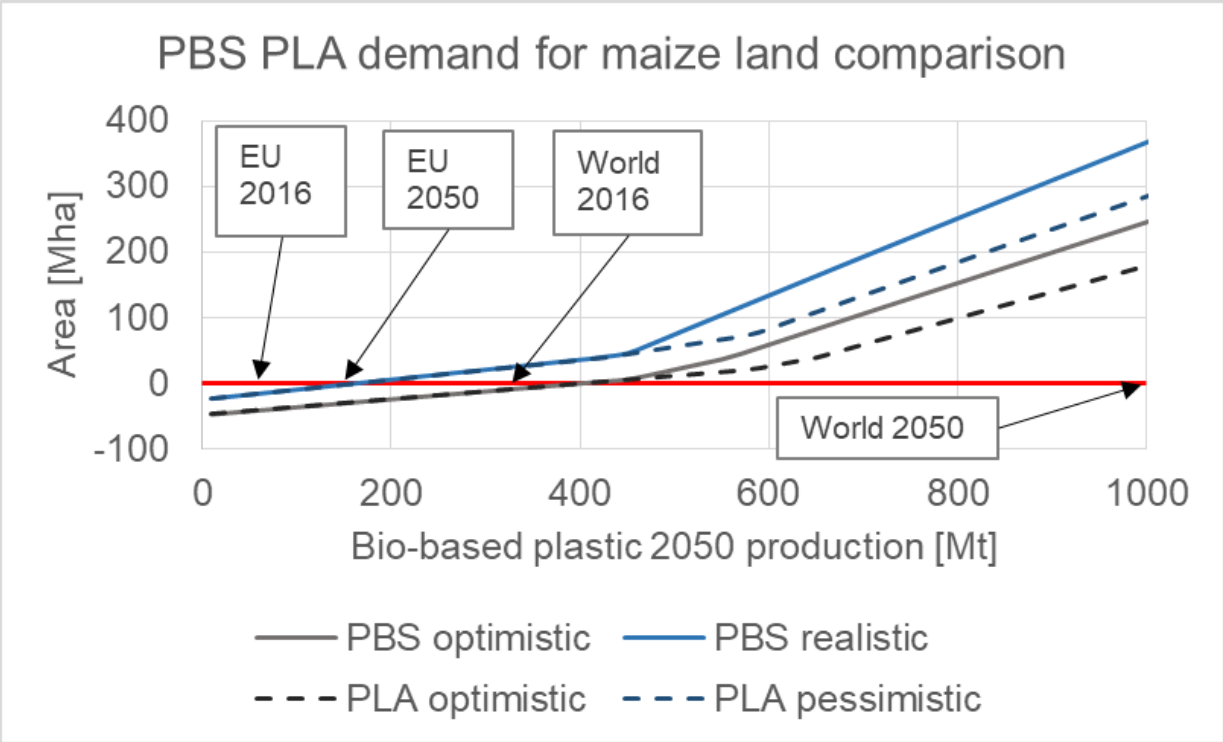


FIGURE S10 COMPARISON OF CHANGE IN NEEDED MAIZE LAND FOR THE TWO YIELDS SCENARIOS, FOR DIFFERENT TARGET 2050 PRODUCTION FOR PBS AND PLA.

S2.3 Local OAT sensitivity analysis to assess the effect of changing the parameters' values

Since the sensitivity analysis showed similar results for both bio-based plastics, we present here only the results for the PBS plastic (PLA results show similar behaviour). In Figure, the effect of different policy targets for bio-based PBS production is shown, with a behaviour similar to what is seen also in Figure, S8 Figure In b), it is possible to see the effect of the co-product on increase in need of maize land: not only the model is sensitive to this factor, but it can be the difference between having or not an ILUC risk. In c) it is shown that the model is not very sensitive to initial conditions of maize land extension; the only effect is visible for initial maize land of 160, corresponding to the increase in maize land that triggers the extensive margin effect. The latter is shown in f): the model is insensitive to it, since the increase in maize land needed in the baseline simulation remains below the value that triggers it (i.e. remains below the initial maize land value). d) and e) show the effects of changing the coefficients of yields projections in time and maize price: as discussed before, the future projections of maize yields have a great impact on the model predictions. The price coefficient, however, has a relatively small effect, and, above all, there is no direct observation of any effect of price on maize yields (see the calibration document). The effects of the yields of feed product and bio-based material production from one unit of maize feedstock on the need for maize land after 100 years are shown in g) and h). The effects are not negligible, but only for very small, unrealistic values, that are not relevant in the reality (they are not economically viable). Thus, the most important factors having an effect on the model results are the co-products and the yields future projections; special care, thus, should be taken to properly estimate these model inputs.

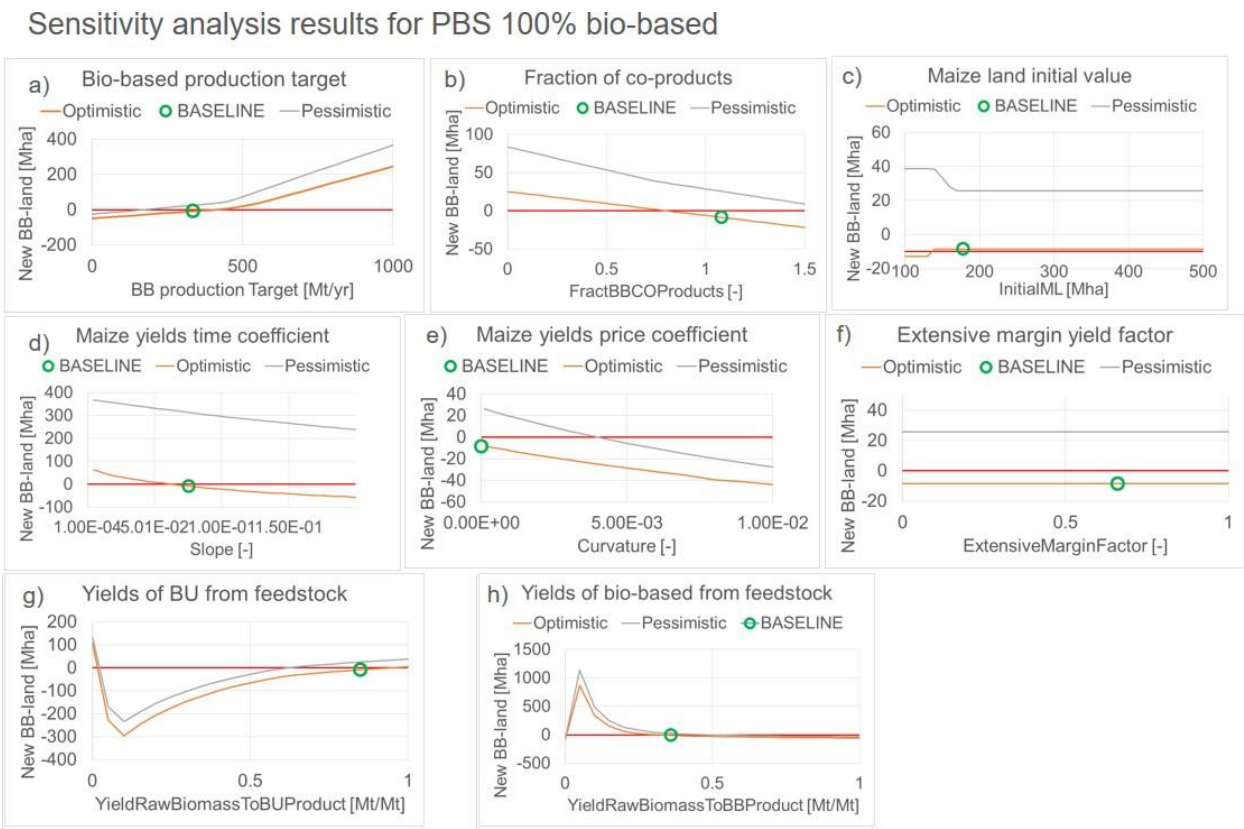


FIGURE S11 RESULTS OF THE LOCAL OAT SENSITIVITY ANALYSIS FOR THE PBS SYDILUC V32 SIMULATIONS. CHANGES OF REQUIRED MAIZE LAND WITH RESPECT TO: A) BIO-BASED PLASTIC (PBS) POLICY 2050 PRODUCTION TARGET; B) FRACTION OF CO-PRODUCTS OBTAINED FOR EVERY UNIT OF PBS; C) INITIAL GLOBAL AGRICULTURAL AREA DEDICATED TO MAIZE CULTIVATION; D) SLOPE COEFFICIENT OF THE MAIZE YIELD INCREASE IN TIME; E) SLOPE COEFFICIENT OF THE MAIZE YIELD INCREASE WITH CHANGES IN MAIZE PRICE; F) MAIZE YIELDS OF THE NEW LAND CULTIVATED WITH MAIZE (EXTENSIVE MARGIN); G) YIELDS OF BU PRODUCT OBTAINED FROM A UNIT OF MAIZE FEEDSTOCK; H) YIELDS OF BIO-BASED PLASTIC (PBS) OBTAINED FROM A UNIT OF MAIZE FEEDSTOCK.

As a conclusion, it is possible to say that, for small values of policy target for increase in bio-based plastic production, the model predicts either no or very small ILUC risk. Large ILUC risks are predicted from the global model, however, whenever the scale of production target is increased as much as to have an effect on the global projected plastic production in 2050: if we want really to substitute fossil plastics with bio-based plastics, the ILUC risk is non negligible. The most important factors determining the model predictions are the future projections of maize yields and the use of co-products to decrease ILUC risk. The model gives similar results for different plastics based on starch feedstock; the results could be potentially different for organic oil based plastics.

S3 Scenarios design to test the ILUC risk tool

S3.1 Introduction

The goal of these scenarios is to recreate a real-world example of the application of the ILUC risk tool. This means representing how a possible end user (a crop producer, a bioplastic producer, etc…) could use the tool, and the difficulties he/she could face. Hence, we aim at simulating the approach for different end users, in different situations, and as realistically as possible (given the limited time we have). Another goal is to produce a workable "tutorial" on how to use the tool for crop producers and auditors, to be included in the eventual manual.

It was decided to design 2 possible scenarios:

1. A farmer growing maize in Iowa (a biomass producer), with the default production practices of Iowa. This farmer will try to decrease her ILUC risk by: (a) increasing her yield trends, and (b) making use of previously abandoned land. This is done to test how the LIIB could be applied in real world scenarios.
2. A farmer in Romania, again growing maize, and again trying to reduce her ILUC risk by increasing crop yields and making use of abandoned land. This is done to study how the situation can change in a different region of the world, while keeping the scenario in a region from which data is available.

S3.2 Scenario data

I include in this document a working table with all the parameters for the different scenarios, that will eventually be filled in by me (for the baseline, default scenario description, at least from the tool point of view) and by DBFZ (for the LIIB application scenarios).

Scenario	Actual yield [t ha^{-1} $year^{-1}$] 2016	Yield gap [t ha^{-1} $year^{-1}$] 2016	Yield trend [t ha^{-1} $year^{-2}$] 2016	Co-product used	Type of unused land	Yield increase [t ha^{-1} $year^{-2}$]	Crop produced on former abandoned land [t $year^{-1}$]
1	12.74	3.7	0.13	100%	Mines, small underdev.	0.03	38.61
2	4.17	8.07	0.057	0%	Policy/economic	0.047	35.93

Scenario	Production yield	Use of Co-product	Use of residues	Use of waste	Use of agricultural residues in production [kg/kg]	Yields of production from intermediate product [kg/kg]
3	Standard for PLA	Yes but not for feed	No – only R&D	No – only R&D	0.6	0.83

S3.3 Scenario description:

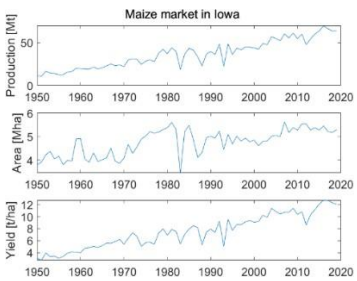
S3.3.1 Scenario 1

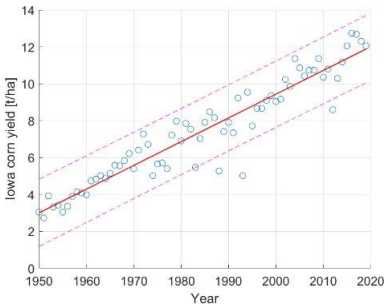
Iowa is the biggest USA producer of Corn, producing ~20% of US corn. The average yield is 1.11 times the USA yield. Area harvested is 15.7% of total USA. Since Iowa is a farmer state, and corn is the main crop produced, there is a strong push to use it efficiently and promote it on a national level. The ILUC problem, for example, is framed as "fuel vs food price", and solved by showing that production of corn for fuel instead of food or feed do not change maize food prices (which is true, but not what ILUC is about). The corn agricultural production is heavily mechanized and ~70% of farms are managed in some way using computers (USDA). There is plenty of information on Corn production in US, coming from USDA. The main use of the corn growth is for bio-ethanol production (39% of the total IOWA production, 30% of USA), the second is for livestock feed (21% of IOWA production). Sweet corn for human consumption makes only 1% of total production.

The main co-product of Corn production in the USA is dry distillers grain soluble (DDGS), which is sold for livestock feed, being rich in proteins (Maize meal). Hence, it is feasible to assume that the use of co-product as feed is almost complete.

The Maize market in Iowa is growing, in production (linearly), in Area (stabilized in the last decade, though) and in trends (with a dip corresponding to 2012 price crisis, due to high volatility of USA agriculture). 2016 production, area and yields were, respectively: 69.6 Mt, 5.5 Mha, 12.74 t ha^{-1} $year^{-1}$. Yield potential for the USA is 13.99; the estimate for the zone closer to Iowa is at the border with Nebraska (no data for Iowa), with a value of ~15 t ha^{-1}; this means that the yield gap is ~3.7 t ha^{-1}. The yield increase trend looks linear, with coeff = 0.1286 t ha^{-1} $year^{-2}$; with R^2 = 0.898.

Unused/abandoned land in Iowa consist of: abandoned (coal) mines, undeveloped land 700 ha only. Indeed satellite images show a heavily cultivated landscape, with only few "free" area around rivers and mines. This is to be expected, due to the high productivity, value and morphological homogeneity of the state.





Additionality practices

In this chapter, the implementation of two additionality practices is described on an example of a corn farm in Iowa, USA. The illustrated practices are increased agricultural crop yield and the biomass cultivation on former unused/abandoned land. Both practices are applied for testing the applicability of the ILUC Risk Tool. Therefore, the selected examples are fictional and the data bases on assumptions, which are realistically as possible.

increased agricultural crop yield

To test the tool, the corn yield increase of the farm in the year of interest is assumed on the basic of the average annual crop yield growth rate (% $year^{-1}$) for the USA taken from literature. According to Gerssen-Gondelach et al. 2015 it ranges from 1.2% to 1.3% for corn. Assuming the actual yield of 12.74 t ha^{-1} $year^{-1}$ is the yield of the farm, the farm can increase its yield in this year by ~0.16 t ha^{-1} $year^{-1}$ after the implementation of the yield improvement measure. Thus, the farm can harvest 12.9 t ha^{-1} in this year. The farm decided to apply the yield improvement measure of better adapted crop varieties and improvements in plant breeding. This measure has the benefit to support climate change adaptation, too (Underwood et al. 2013). The corn production needs to take place at an existing cultivation site of the farm. Thus, the farm needs to demonstrate, that the corn production results from the application of the better adapted crop varieties and improvements in plant breeding. Most importantly, the attained yield needs to be additional compared to a

business-as-usual scenario and therefore above a specific baseline yield. Hence, the low iLUC risk yield of corn needs to be above the actual yield plus the yield trend. This means it needs to be above 12.87 t ha^{-1} $year^{-1}$ corn of the farm. Thus, the low ilUC risk yield is 0.03 t ha^{-1} $year^{-1}$.

Biomass cultivation on unused/abandoned land

The farm plans to cultivate further corn at an unused/abandoned area. It finds a plot a few miles away from the farm. The unused plot of interest is only 3 ha large, because the overall area of undeveloped land with 700 ha in Iowa is very small.

As a precondition, the farm needs to demonstrate that the cultivation of the claimed land is additional to the business-as-usual scenario. In the case of the farm in Iowa, it is very likely that the plot of unused/abandoned land is in a region characterized by agricultural expansion. Thus, the area of undeveloped land is very small, as mentioned above. Furthermore, a recent study refers to a tripled cropland expansion in Iowa in the period from 2006 to 2016 (Lu et al. 2018). Hence, the farm can only demonstrate that the claimed unused/abandoned land is additional, if one of the following requirements are met:

- Reduction of cultivated land in the region in each of the previous five years;
- Availability of large amounts of land with more favourable conditions;
- The abandoned land in a specific region is the consequence of degradation and the cultivation of land in that degraded state is not common practice in the region.

If the land was not cultivated within the last 30 years and in a degraded or contaminated state, one of the following requirements need to be fulfilled:

- Regulatory barriers exist, which prevent the supply of biomass from that land;
- Demonstration, that the cultivation of land in that state is not common practice in the region.

We assume that the plot of unused/abandoned land fulfils the requirement that large amounts of land with more favorable conditions are available in Iowa. Thus, the farm can demonstrate that the cultivation of the plot is additional compared to a business-as-usual scenario.

The unused/abandoned land of interest must fit in the definition of unused/abandoned land. The claimed plot can be defined as abandoned land, because it was used in the past for agriculture or pasture purposes and was not converted to forest or urban areas. Thus, it was not used for other provisioning services currently and during the past 5 years and has low carbon stocks and a limited biodiversity value. Because the abandoned land is located in a region of agricultural expansion, the farm needs to demonstrate that in the region exists enough potentially available land, which is suitable for agricultural expansion. Hence, the farm needs to document that compared to annual rates of agricultural expansion, enough or a large supply of potentially available land in the region exist, which is suitable for corn cultivation.

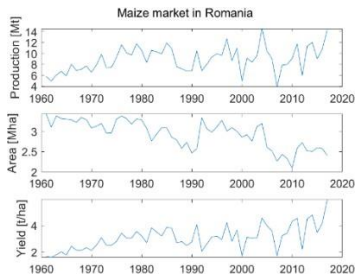
In the next step, the farm needs to conducted a site specific investigation. This investigation comprises of two assessment steps. In the first step, a regulatory assessment has to be conducted. According to this assessment, the abandoned land needs to have the legal status to be used for agricultural purposes. Furthermore, the farm needs to respect traditional and/or customary land use rights.

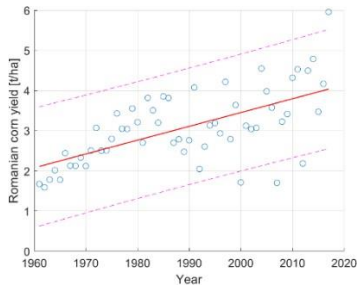
The regulatory assessment needs to be complemented by a land cover and utilization assessment. This assessment determines the land cover and land use of the last five years with remote sensing and geo-information methods and data. It investigates the vegetation profile of the claimed abandoned land. The satellite image indicates that the plot is located at a former agricultural used land with plots of similar characteristics around it. Hence, the corn cultivated at the claimed unused land can be assessed as low iLUC risk biomass. To calculate the amount of biomass, which can be produced at the plot the actual yield of 12.74 t ha^{-1} $year^{-1}$ plus the yield trend of 0.13 t ha^{-1} $year^{-2}$ is multiplied with the plot size of 3 ha. Thus, the corn produced on the former abandoned land is 38.61 t.

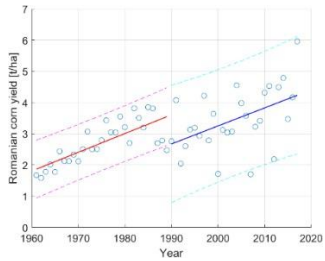
S3.3.2 Scenario 2

Romania Corn production is not completely mechanized, many fields are still managed by hand or using animal power. Fields themselves tend to be, generally, small, and divided into parcels. Some bigger fields exists, but they are not the average. This information comes from direct observation and expert opinions, plus from a check from Satellite Images. Transportation is a big issue, due to the lack of highways (only around the capital Bucharest); the main road system consists of 2 ways 2 lanes roads, prone to potholes, works, and traffic. The agricultural residues are usually left on the field, and often burned. The Corn produced is sold mainly in Europe, especially to Spain, as it is.

Corn Romania production in 2016 (10.74 Mt) was 18% of EU production (56.65 Mt). Production varies widely, and experienced a decrease around years '80s till 2000s, then grew again. Area harvested is actually decreasing (it seems Romania is shifting to wheat production – the old staple food of Transylvania, a kind of polenta, becoming less common). 2016 corn harvested area in Romania was 2.59 Mha, 33.6% of EU 2016 corn area (7.67 Mha). Yields (Romania yield 2016= 4.17 t/ha; 46.57% of EU 2016 mean yield=8.95%) are increasing as in the rest of the world, but variance is high, seemingly from droughts (Sole24 ore). All in all, it seems a crop that won't experience much change in the future, unless there is a proper policy for that. The Yield trend estimated with data 1960-2016 (0.0344 t ha^{-1} $year^{-2}$) has low R^2 (0.39),as expected by looking at the graphic. It is evident that, at the end of 1980s, there was a shift in agricultural corn production, leading to much higher variance and an overall change in the yield increase. A better analysis (focusing on pre and after 1989 yields) shows yield trends 0.06 t ha^{-1} $year^{-2}$ (R^2 = 0.59) and 0.057 t ha^{-1} $year^{-2}$ (R^2 =0.23). (showing, by the way, that yield trends are not heavily affected by policy – absolute yields and yield variability are affected by policy
– or is it climate change?-, instead). Potential yields (Yp) for Romania are 12.24 t/ha, so that yield gap is 8.07 t/ha.







After 1991, a land reform sought to privatize land resources owned by the state, with the goal to restitute them to pre-collectivization owners. However, the restitution was capped at 10 ha. This resulted in small parchment of land owned by every family (probably a reason for decreasing urbanization in Romania?). By 2004 97% of land was privately owned. [source: Permanent Representation of Romania to the European Union- in Romanian]. However, since Rumanian population is actively decreasing due to both low fertility rate and high emigration rates, and because of low productivity, remoteness (mountainous regions), socio-economic factors; agricultural land is partly abandoned, and is projected to be abandoned even more by 2030 (JRC policy insight, 2018). Hence, abandoned land seems to have a policy-driven characteristic in Romania, and it seems that better road connections, land rights policy and agricultural production organization could reverse that, without affecting social structures negatively.

Additionality practices

In this scenario, the same two additionality practices, like in the scenario of the farm in Iowa above, are tested at the example of a corn producing farm in Romania. This is done to compare the applicability of the ILUC Risk Tool under different conditions and to illustrate the potential effect of the implementation of the additionality practices increased agricultural crop yield and the biomass cultivation on unused/abandoned land. Like in the scenario above, the selected examples are fictional and the data bases on assumptions, which reflects the reality in the best possible way.

increased agricultural crop yield

For the test of the tool, the yield increase of the Romanian corn farm is assumed on the basis of information from the literature. According to Gerssen-Gondelach et al. (2015) in countries or regions with a large yield gap a higher yield increase due to the implementation of yield improvement measures can be realized. Because the yield gap of corn with 8.97 t ha^{-1} in Romania is much larger than in the first scenario in Iowa, we assume for the example of the Romanian corn producing farm a doubled average annual crop yield growth rate (% $year^{-1}$) of 2.4% to 2.6%. To calculate the yield increase we use the same way like in the scenario 1. If we assume, that the actual yield of the farm is 4.17 t ha^{-1} $year^{-1}$,the yield increase is ~0.104 t ha^{-1} $year^{-1}$ after the implementation of the yield improvement measure. Hence, the Romanian corn producing farm can harvest 4.274 t ha^{-1} in this year. To improve the yield, the farm implements the measure of reduced tillage and soil conservation. By application of this yield improvement measure, the farm can increase the corn production in accordance to the concept of sustainable agricultural intensification (Scherer et al. 2018). Like in the scenario 1, the low iLUC risk corn needs to be produced additional compared to a business-as-usual scenario. Thus, the low iLUC risk yield of the cultivated corn needs to be above the actual yield plus the yield trend of the Romanian farm. Therefore, the increased yield of the farm needs to be above 4.227 t ha^{-1} $year^{-1}$ corn. Hence, the low ilUC risk yield is 0.047 t ha^{-1} $year^{-1}$.

BIOMASS CULTIVATION ON UNUSED/ABANDONED LAND

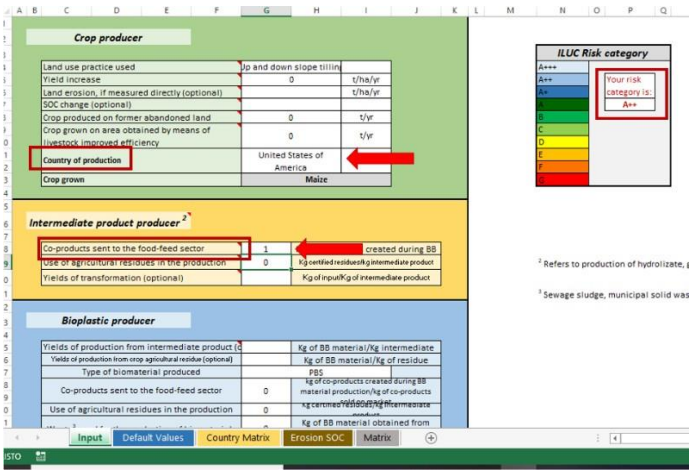
The second additionality practice the farm applies, is the biomass cultivation on unused land. The Romanian farm takes a plot of 8.5 ha in a hilly region of Romania into cultivation. The unused/abandoned land fulfils the requirements of a former agricultural used land, which was abandoned over 7 years ago. It has the legal status to be used for agricultural purposes. Other land user with traditional or customary land use right cannot be observed at the land. The site-specific investigation shows that the land is only sparse covered with vegetation. Therefore, it has only a small carbon stock and reduced value to enhance the biodiversity in the region. Furthermore, the farm can demonstrate that the use of the

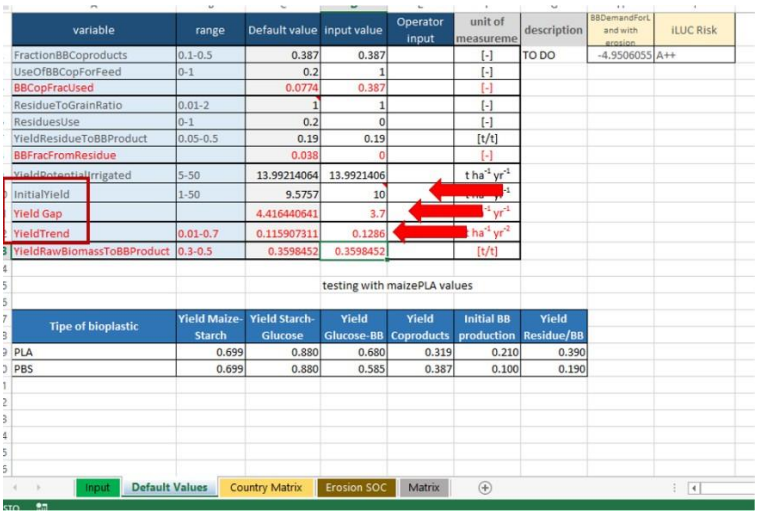
land is additional, because relatively large areas in the region are available for agricultural production in favourable conditions. As mentioned above, the agricultural land in Romania is partly abandoned and an increase in abandoned land is projected in the near future. Therefore, we assume that the plot is located in an agricultural shrinkage region and fulfils the requirement for additionality demonstration mentioned above. The farm can claim the corn cultivated at the former abandoned land as low iLUC risk biomass. The calculation of the amount of low iLUC risk corn, which can be produced at the plot is similar to the methodology in scenario 1. Hence, the actual yield of 4.17 t ha^{-1} $year^{-1}$ plus the yield trend of 0.057 t ha^{-1} $year^{-2}$ is multiplied with the plot size of 8.5 ha. As the result, the corn produced on the former abandoned land is 35.93 t.

S3.4 Results:

S3.4.1 Scenario 1:

First, the data collected from literature should be used to prepare the baseline situation, that is, the actual iLUC risk level of the production of PBS (or PLA) from maize produced in a standard way in Iowa. So, in the first page of the tool, under the "country" are, USA should be selected, and then, since all the co-products are already used in Iowa, That should be set to 1 as well. Then, for the more specific information on agricultural yields, the values of yield gap, initial yields and yield trend should be changed directly in the "default values" page, as shown. The resulting iLUC risk, with respect to the global production of maize for PBS, is A++.





variable	range	Default value	input value	Operator input	unit of measureme	description	BBDemandForL and with erosion	iLUC Risk
FractionBBCoproducts	0.1-0.5	0.387	0.387		[-]	TO DO	-4.9506055	A++
UseOfBBCopForFeed	0-1	0.2	1		[-]			
BBCopFracUsed		0.0774	0.387		[-]			
ResidueToGrainRatio	0.01-2	1	1		[-]			
ResiduesUse	0-1	0.2	0		[-]			
YieldResidueToBBProduct	0.05-0.5	0.19	0.19		[t/t]			
BBFracFromResidue		0.038	0		[-]			
YieldPotentialIrrigated	5-50	13.99214064	13.9921406		t ha^{-1} yr^{-1}			
InitialYield	1-50	9.5757	10		[illegible]			
Yield Gap		4.416440641	3.7		[illegible] yr^{-1}			
YieldTrend	0.01-0.7	0.115907311	0.1286		[illegible] ha^{-1} yr^{-2}			
YieldRawBiomassToBBProduct	0.3-0.5	0.3598452	0.3598452		[t/t]			

testing with maizePLA values

Tipe of bioplastic	Yield Maize-Starch	Yield Starch-Glucose	Yield Glucose-BB	Yield Coproducts	Initial BB production	Yield Residue/BB
PLA	0.699	0.880	0.680	0.319	0.210	0.390
PBS	0.699	0.880	0.585	0.387	0.100	0.190

Input | Default Values | Country Matrix | Erosion SOC | Matrix

Then, the application of the low iLUC risk practices is evaluated. When the additionality measure of "Yield increase" is set to 0.03 t ha-1 yr-1, the iLUC risk class does not change (it is already low, and this change has no effect on the definition

of the iLUC risk class). To properly project the increase in crop production from use of abandoned land, said increase at farm level should be translated to national level, first dividing by farm production (which is very high in Iowa, 20% of national product for the whole state, with 92300 farms) and then multiplied by country production: $\frac{38.6\ t}{69.6\ 10^6\ t/92300} \cdot 348\ 10^6\ t = 17.8\ 10^6\ t$

Which has the effect of lowering the iLUC risk level to A+++

S3.4.2 Scenario 2:

Selecting the default values for Romania on the Maize iLUC risk tool, and then changing the values in the "Default Values" page for the agricultural yields (initial, gap and trend) as presented above, yields the iLUC risk class F. This is due to the low overall yields, so that the increase in production means a big area is needed. However, since the agricultural yields are far from their potential value, the additionality measure for the yield increase has a big impact on the iLUC risk class, lowering it to C. The increase in farm production by expanding on abandoned land has also a large impact, being the typical farm small and, hence, 8.5 ha being a large increase in individual farm, so that, if every farm was expanding that much, this would easily fill all the unused land. This would result in further lowering the iLUC risk to A++.

Note:

The ILUC risk output of the tool is not absolute, i.e. a low-ILUC risk soy bean biomass can still result in more ILUC than a high-ILUC risk maize biomass. The different biomasses are comparable only when the average estimate of land demand change projection (with standard deviation uncertainty) is compared between biomasses. The two outputs (absolute and relative) have been kept separated in order to appreciate the relative effect of the implementation of the LIIB practices in reducing ILUC risk.

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