**STAR-ProBio**

**Sustainability Transition Assessment and Research of Bio-based Products**

***Grant Agreement Number 727740***

# Deliverable D7.1

# Examination of existing ILUC approaches and their application to bio-based materials

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## REPORT

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# Abstract

The Star-ProBio project aims at identifying and mitigating the risks of negative land use change (LUC) effects associated with production routes of bio-based products. WP7 and task 7.1, specifically, were assigned to the following tasks:

a) Assessing the *status quo* and the key findings of existing approaches to quantify GHG emissions due to direct and indirect land use changes. This is done in order to: identify; categorize; and structure the key drivers and parameters for future strategies, with the final aim of reducing ILUC risks in a developing bio-based economy.
b) Estimating the capacity of the existing models to cover bio-based materials and related feedstocks.
c) Drawing links with standardisation work related to the sustainability of biofuels.
d) Identifying potential additional key drivers from bioeconomy sectors not covered yet within the existing ILUC models such as cascading use.

Subtask a)-d) were performed accordingly through: **literature review and search**; selection and characterisation of key drivers and key parameters; search and comparison of current standardisation work; and formulation of a conceptual model to represent and hold together the selected results.

This deliverable provides indications about the capacity of the current agro-economic models to fit **non-biofuel products** and indicates **limitations, caveats and the extent of adaptation** of the methodology for bio-based products. It summarizes the **key findings and drivers** for ILUC caused by an increasing demand for bio-based products.

Bio-based products are made from raw biomass, ultimately deriving from land cultivation and often implying changes of use. LUC can be either **direct (dLUC) or indirect (ILUC)**. While dLUC can be modelled and measured through conventional and standardised life cycle assessment (LCA) - also known as attributional LCA, or ALCA – ILUC, governed by economic mechanisms, cannot be measured in accordance to current accepted standards.

ILUC approaches were formulated during the debate on biofuel impacts in the first decade of the 2000s and led to three main evaluation approaches:

- Economic models;
- Normative, ruled based methods ;
- Biophysical methods.

All approaches have been considered in the perspective of determining the contribution of bio-based products to cause or accelerate ILUC effects. In this context, WP7 participants established **the link between key drivers of ILUC and standardisation work** related to sustainability criteria for biofuels and biomaterials. Moreover, WP7 participants **identified and categorized** those **key drivers and parameters** involved in ILUC by paying particular attention on economic models and their structure.

No specific contributions on ILUC caused by non-fuel bio-based products have been detected, rather methodological frameworks have been proposed in connection with the life cycle assessment evaluation. The experts' opinion ranges vary widely, from (a) the assumption that a deterministic approach is possible and replicable; and (b) the assumption that replicability is impossible, and, therefore, that no measure of ILUC should be accounted.

WP7 proposes to account for the ILUC effect together with the uncertainty related by shifting from a deterministic perspective to a **risk-based approach.** This is shown using a conceptual model to describe the ILUC process.

Specifically, the proposed conceptual model is composed of:

I. an economic model to predict changes in demands of additional land;
II. an economic-agronomic model explaining land use changes;
III. a geographic-economic model accounting for the geographic distribution of effects at a planetary scale;
IV. an environmental model explaining impacts according to soil organics carbon levels, biodiversity and other land use or land cover original characteristics in the affected areas.

These layers can be thought similarly to IPCC *tiers*, where each tier represents a level of methodological complexity.
The conceptual model focuses on tiers I and II and aims at identifying the main risk factors. All risk factors depend on specific assumptions and conditions, such as crops, specific regional area and baseline values. Risk factors are placed both on the demand side of the economic system and on the supply side.
According to literature, the most representative factors affecting land consumption depend on (i) the sensitivity of domestic markets to price changes – i.e. **demand elasticity** - of the main raw biomass used in end-products; (ii) **the intensive margin**, which is the potential improvement of yield with respect to the yield in the baseline when crops and/or agricultural residues are used for bio-based products.
At a later stage, each risk factor will be assigned a weight and a risk value expressed as a range of differential hectares required. The final result would be an index measuring an ILUC risk on a qualitative base, such as "low-medium-high" or on a 1-to-5 scale.

## Suggested citation

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# 1. Background and objectives

The term bio-based product refers to products wholly or partly derived from biomass, such as plants, trees or animals (the biomass can have undergone physical, chemical or biological treatment) (CEN, 2014).

Bio-based products include a vast range of traditional and innovative materials and substances for purposes other than food and energy such as wood-based and composite materials, bio-plastics, adhesives, lubricants, dyes for paints and many other material categories feeding large economic activities.

There is international recognition that the development of a climate-smart bio-based economy is essential to the continuation of economic growth, reduction of the use of fossil resources and ultimately mitigation of climate change. However, as bio-based products are ultimately obtained from land or sea, care has to be paid when considering additional exploitation.

There are two possible ways to increase the volume of bio-based products: (a) through a higher production of primary biomass; or (b) through the use and exploitation of agricultural residues, paper, and waste streams – also known as secondary and tertiary biomass. Current production of bio-based products (such as bioplastic) is mainly from primary biomass, and this would imply competition with food, feed, textile or other traditional. However, as of 2018, the global volume of biomass used for bio-based products is small with respect to the volume used for feed and food; the total land dedicated to growth of biomass for bio-based products is ~1% of the global land area. However, if the aim is to substitute all fossil-based plastic actually on the market with bio-based plastic, the amount of dedicated agricultural land is likely to increase greatly.

Currently the use of residues to make bio-based products such as bioplastics, surfactants, and lubricants is rare. As indicated by many European projects (S2BIOM D8.2, 2015) agro-based crop residues are largely underutilized in the production of bio-based products.

Changes of land uses can be of two types:

a) Direct Land Use Change (dLUC, impact for climate change) is the impact of land use change on climate change results basically from a change in carbon stocks in land. Direct Land Use Change occurs as the results of a transformation from one land use type into another, which takes place in a unique land cover, possibly incurring changes in the carbon stock of that specific land, but not leading to a change in another system. Some possible effects of a change in carbon stock due to land use change are (Fritsche et al. 2010):
- diminished aboveground stock and consequently diminished carbon uptake;
- less carbon input to soil such as litter fall, plant leaches fragmented plant structures;
- carbon losses: exposition of protected organic C to weathering and microbial breakdown, temperature regime of soil change and, ultimately, soil oxidation resulting in an additional $CO_2$ pulse. For details, see Annex VI.

b) Indirect Land Use Change (ILUC or ILUC, impact for climate change) is the impact of land use change on climate change results basically from a change in carbon stocks in land. Indirect Land Use Change occurs when a certain change in land use induces changes outside the system boundaries, i.e. in other land use types; it has been defined as the unintentional negative displacement effect of commodities in the primary sector. ILUC typically occurs when traditionally grown agricultural land is turned over to biomass production for non-agriculture emerging sectors including bio-based products; vast changes are usually driven by policies and economic instruments such as subsidies. It follows that agricultural land expands elsewhere in the world to meet the existing and growing demand for crops for food, feed, and other industrial products. As there is no agreed methodology on indirect land use change in the context of the Environmental Footprint, indirect land use change should not be included in the greenhouse gas calculations in the PEF.

Effects due to *direct* and *indirect* Land Use Changes include increased greenhouse gas (GHG) emissions, biodiversity loss, less infiltration and groundwater reservoir recharge, increased desertification. Provided that both dLUC and ILUC depend on the specific legacy effects stemming from land condition prior and after land use changes, these effects are connected to the 1.1 billion tons of greenhouse gases per year generated because of land use changes (IPCC, 2013). Approximately, almost the 9% of global carbon emissions in 2011 originated from land use changes (LUC) (Le Quéré et al., 2013).

dLUC and ILUC are measured in different ways: while dLUC can be measured directly (e.g. by satellite imagery analysis), ILUC effects cannot; they can only be estimated using large and complex economic models acting at a planetary scale. This made (and still makes) the application of ILUC estimates for biofuels controversial (Muñoz et al., 2015).

By far, modelling of ILUC has received most attention in the context of biofuels production (Searchinger et al., 2008; Fargione et al., 2008; O'Hare et al., 2009; Reinhard, 2009; Schmidt et al., 2009), due to the increasing global interest on implementing policies to increase biofuel use as a mean to reduce GHG emissions.

In Europe and OECD countries the possible negative effects of ILUC from bioenergy production appeared on the political agenda in 2008 after the publication of a scientific study by Searchinger et al. (2008), who estimated that dLUC and ILUC induced by corn ethanol production could cause a doubling of GHG emissions compared with fossil fuels in US. The Joint Research Centre in particular (Marelli et al., 2011; Mulligan et al., 2010; Hiederer et al., 2010) reviewed and compared different approaches for ILUC modelling in order to establish some scientific consensus and define a shared methodology. The attempt to establish such a consensus, common standards and accepted procedures was not successful. As reported by De Rosa et al. (2016) different approaches and models have been proposed in recent years to solve these controversies but a broad consensus on them still needs to be reached. The controversies include the theoretical framework as well as the modelling approaches for the complex global land use dynamics, where difficulties relate to: the identification of the marginal land; establishing the relationship between the demand for agricultural products and land use changes; accounting for the effect of by-products; and the overall level of uncertainty caused by the multiple modelling assumptions.

Such a debate was reflected when accounting for environmental impact through a life cycle assessment (LCA). Two different approaches are available to carry out a LCA study: the *attributional* LCA (ACLA) and the *consequential* LCA (CLCA). ALCA attributes a defined allocation of environmental impacts to a product or process unit. For example, for a solar panel the environmental impacts from the mining, refining, manufacturing, distribution, operation and disposal stages are attributed accordingly. Studies such as Searchinger et al. (2008), however, demonstrated the value of expanding LCA approaches beyond an ALCA, in order to consider wider system effects of change. Approaches to LCA that focus on changes within a system are most frequently referred to as CLCA. Schmidt et al. (2015) in their "a framework for modelling indirect land use changes in Life Cycle Assessment", highlighted the differences between these modelling approaches, while proposing the conceptual framework required for the modelling of ILUC in LCA. Consequential LCA (CLCA) is the natural candidate method for estimating historical emissions from ILUC, because it joins the output of economic and causal-descriptive models and, precisely, it states the consequences for additional raw biomass production. Therefore, CLCA should be used when supporting decisions aimed at changing the amount of indirect land use and for comparing the indirect land use of different alternative products. LCA, which is performed in accordance to the ISO14040 series standard and that is scientific controlled by guides such as the ILCD Handbook (ILCD, 2010), makes transparent all the accounting phases and procedures. Nonetheless, the methods underpinning consequential effects such market effects, refer to the economic and causal-descriptive models above-mentioned, whose analysis is introduced here below. As many of these models are not accepted as universal, the application of CLCA remains difficult.

On this basis, Matthias Finkbeiner (2013) came to the conclusion that ILUC "cannot be included in the LCA or carbon footprint (CF) calculations of biofuels in a scientifically robust and consistent way" due to the fact that:

- "Indirect land use change cannot be observed or measured";
- "The ILUC quantification is based on theoretical models that mainly rely on hypothetical assumptions and market predictions"
- "There are basically no primary data available for ILUC calculations; there is hardly any resolution with regard to individual crops or regions. The data quality underlying ILUC factors is significantly lower than any other data used for LCA and CF"

On the other hand, ILUC may contribute substantially to the overall environmental impacts of bio-based materials, as the majority of them are derived from renewable raw materials and not from wastes. Bio-based materials entail both land use-related impacts (such as effects on biodiversity, soil organic matter, soil erosion) and environmental impacts; the latters are lower than conventional materials only if GHG emissions from ILUC are neglected (Weiss et al., 2012).

Building on these foundations, all WP7 participants of task 7.1 were assigned to the following tasks:

a) assess the status quo and the key findings of existing approaches to quantify GHG emissions due to dLUC and ILUC changes in order to identify, categorize and structure the key drivers and parameters for future strategies to reduce ILUC risks in a developing bio-based economy;
b) estimate the capacity of the existing models to cover bio-based materials and related feedstock;
c) draw links with standardisation work related to the sustainability of biofuels;
d) identify potential additional key drivers from bioeconomy's sectors not yet covered within the existing ILUC models, such as cascading use.

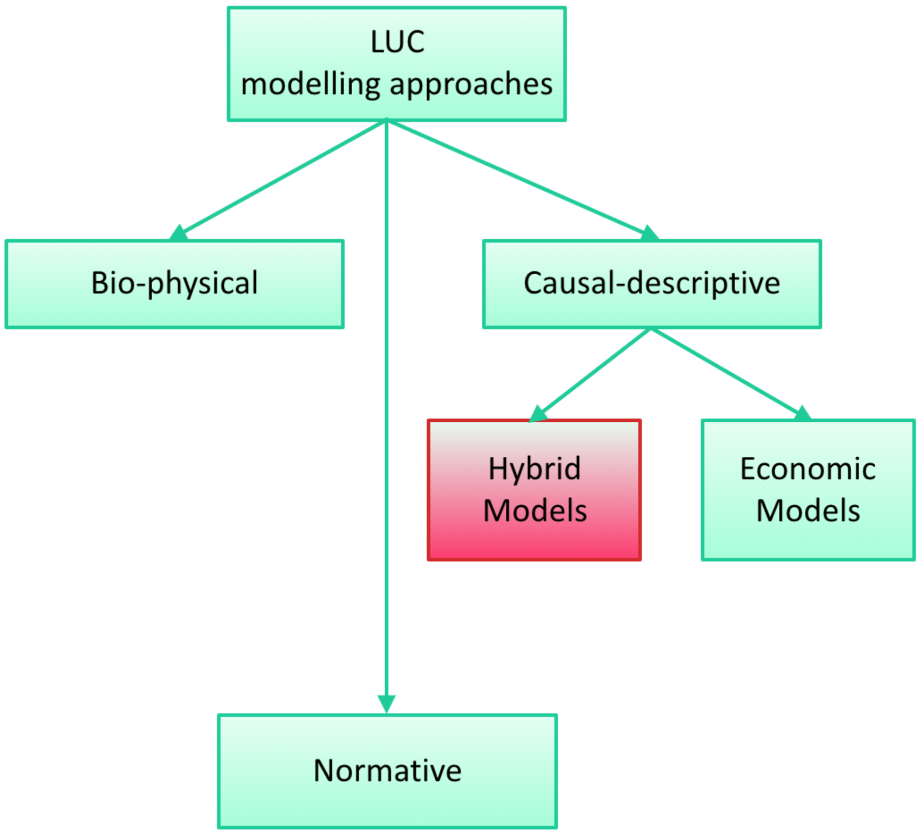
## 2. Review of existing approaches

This section assesses the status quo and the key findings of existing approaches to quantify GHG emissions due to dLUC and ILUC. This is done in order to identify, categorize and structure the key drivers and parameters for future strategies to reduce ILUC risks in a developing bio-based economy.

To do so, the capacity of the existing models to take into account bio-based materials and related feedstock has been reported. The approach will draw from existing models and key findings (e.g. JRC, IFPRI and models such as GLOBIOM, LANDSHIFT, etc.) and deterministic approaches developed for ILUCILUC quantification from changes in soil (above-and below ground biomass), resulting from global land use changes caused by the production of biofuels.

On this subject, De Rosa et al. (2016) accomplished a review of Land Use Change models. In De Rosa's work, a distinction was made between LUC Economic Equilibrium Model (EEM), Causal-Descriptive Model (CDM) and role-based normative Model (NM). Here a different classification is proposed (Figure 1).

*Figure 1: Modelling frameworks and respective sub-categories here adopted (redrawn from De Rosa et al., 2016). The conceptual model elaborated within Star-ProBio is intended as a hybrid model (highlighted in red)*

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As observed by De Rosa, any sharp distinction between LUC modelling frameworks can be disputed, "since analyses of land transformation rely on interdisciplinary knowledge: bio-physical models may be integrated in other methodologies to incorporate geo-spatial information, especially on land cover, land availability land characteristics and suitability; economic information may be used to describe market trends and relationships between substitutable products; and normative models also ground their role-based approach on information drawn from statistical analysis and studies of different nature".

## 2.1 Causal-Descriptive: economic and hybrid models

A Causal Descriptive model (CDM) is a generic model that describes future states of a system based on cause-effect relationships. Economic Models are considered as a sub-group of CDMs where the cause-effect relationships are focused on changes in demand and supply curves for quantities and prices.

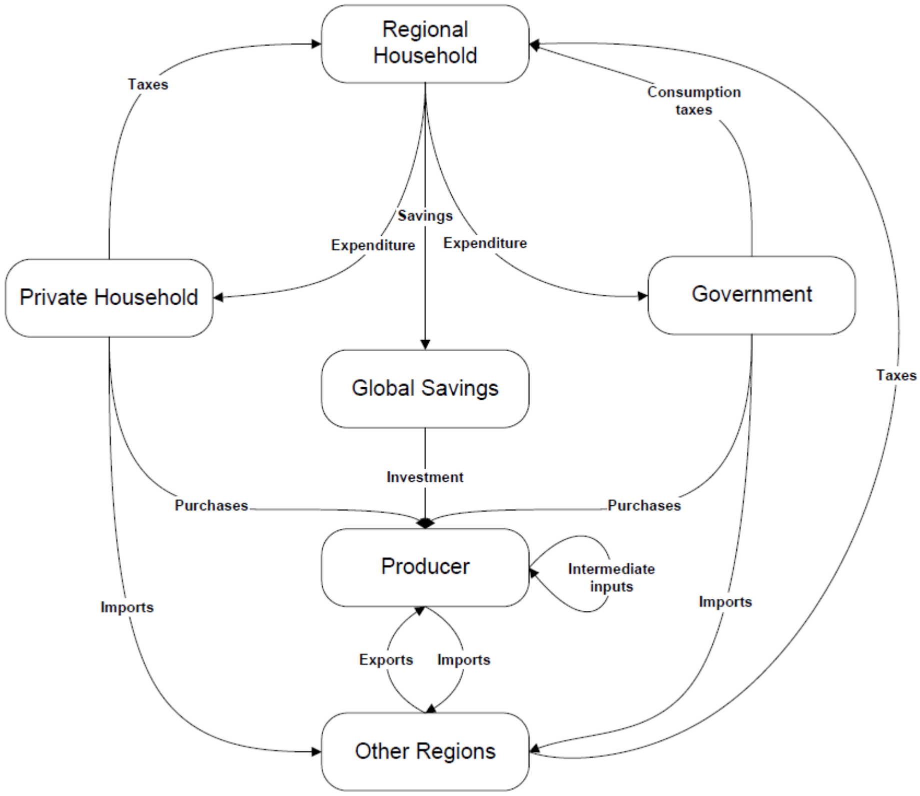
### 2.1.1 Economic models

As clearly explained by Hertel et al. (2010), most of the economic models are based on the concept of *general equilibrium*, which establishes a link between demand for land/crops and deforestation/intensification/reduced consumption. Leon Walras (1834-1910) recognized that there are various markets for any commodity and service and that these markets interact in complex ways each other so that, in simple words, everything depends on everything else.

Di Lucia et al. (2012), then, defined economic equilibrium models like "equations that define the quantitative relation between supply, demand, and price and a broad database". These models consider factors like land prices, maps of land suitability, proximity to infrastructure, existing cultivation, by-products, reduced food consumption (demand change), yield effects, crop switching and area response, as well as land use change emissions (Schmidt et al., 2015). These models normally assume that any land expansion first displaces abandoned or fallow cropland and grassland, before forests are converted.

To assess bio-based products and their sustainability, as observed by Prins et al. (2014), one needs to define what happens in a world without bio-based products (or without policies specifically related to bio-based products). Different assumptions in the reference scenario cause differences in calculated ILUCILUC emissions. To make all assumptions and conditions operative, economists have to simplify it sufficiently to derive predictions and conclusions. There are two ways to do this. Theorists typically cut-off the dimensionality and/or focusing on just a few parts of the system. An alternative approach keeps the complex structure, while simplifying the characterization of economic behaviour and solving the whole system numerically. The approach can address the whole global economy or single specific sectors. A Computable General Equilibrium (CGE) modelling would consider the whole global economy (Figure 2).

*Figure 2: The simplified structure of the global trade analysis project (GTAP), a well-known computable general equilibrium model.*




Partial Equilibrium (PE) models focus on specific sectors of the economy, with more detail then general equilibrium models. As an example, GLOBIOM is a global recursive dynamic partial equilibrium model with a bottom-up representation of agricultural, forestry and bioenergy sectors. The model is global because it covers 57 countries and regions worldwide (EU-28 plus 27 countries and regions in the rest of the world); the model is recursive because effects are computed by running the model through years and by observing feedbacks. Sectors covered by GLOBIOM are agriculture, forestry and bioenergy, with their supply side production functions, their markets and the demand side. The model is therefore a partial equilibrium model, as opposed to general equilibrium, because not all goods, factors or agents are represented in this approach. Hence, it is designed to address issues affecting land use based sectors, and considers that situation in the rest of the economy remains unchanged (*ceteris paribus*). The model chosen, in part, determines the outcome, because many assumptions are implicitly included in the model structure and parameters.

Both CGE and PE models look for a new equilibrium in the economy. CGE models look for a new equilibrium by diluting the impacts over the whole global economy. Although this dilution over the global economy actually occurs in reality, one should be aware that this process might be stronger in some sector (Prins et al., 2014). As an example, CGE models contain two approaches for dealing with trade. In the first, a single world-market is considered (*Integrated World Market Approach*), according to which products from all regions are assumed to be of uniform quality. In this approach, increased demand is evenly distributed over existing production areas; this approach is used by Searchinger et al. (2008b) according to Golub and Hertel (2012). The second approach, the *Armington approach*, assumes that products are of heterogeneous quality. This assumption implies a much more rigid composition of trade; the biggest impact of increased production is in the region itself (Golub and Hertel, 2012).

Several partial (PE) or computable general-equilibrium (CGE) models have been developed, such as GTAP, FAPRI-CARD, AGLINKCOSIMO, LEITAP, IMPACT, etc. (Bauen et al., 2010;

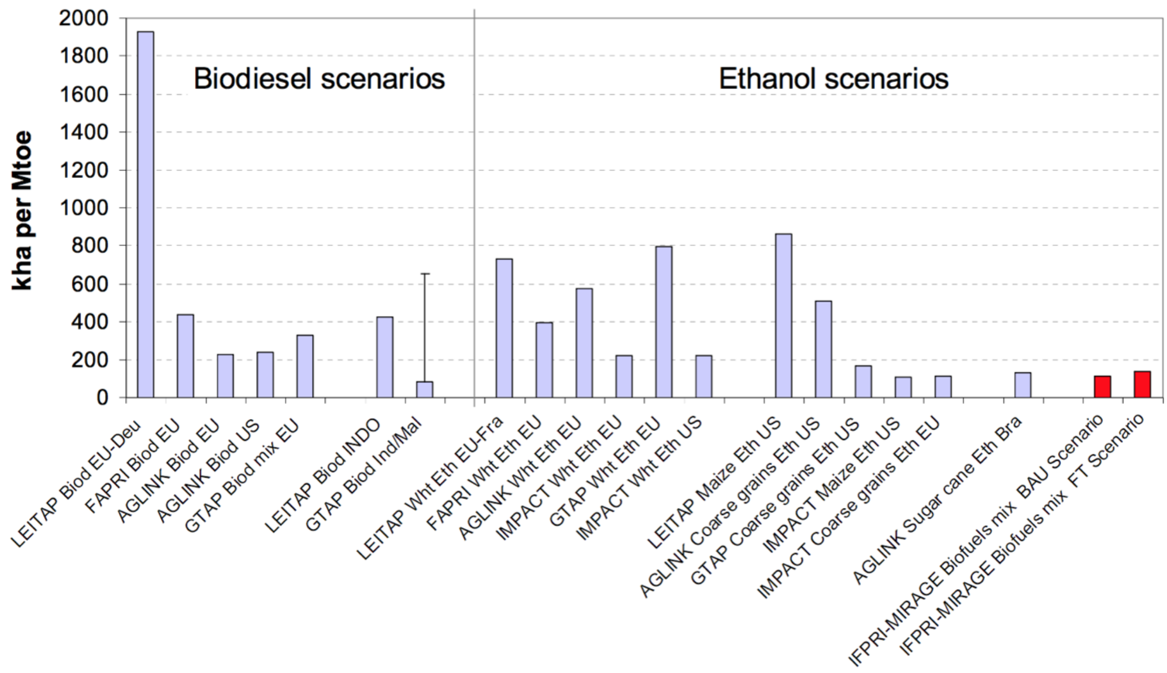
Edwards et al., 2010; Report et al., 2011; Al-Riffai et al., 2010; Delzeit and Klepper, 2011; Fritsche et al., 2010; Nassar et al., 2011). Other economic models include the CAPRI model (Leip et al., 2010) and the FAPRI model (Searchinger et al., 2008).

An extensive review of the pros and cons of the different model has been prepared by the JRC (2010) following an international workshop organised by the JRC itself, in collaboration with the European Environment Agency (EEA) and OECD (Paris, early 2009). JRC brought together worldwide experts and modellers to discuss various modelling approaches and to develop a joint platform for comparing results between different modelling groups. As a follow-up, the JRC prepared an economic meta-model made up of parameters reported by the different modelling groups. The considered models were the following:

- GTAP (CGE);
- AGLINK-COSIMO (PE);
- DART (CGE);
- FAPRI-CARD (PE);
- IFPRI-IMPACT (PE);
- CAPRI (PE);
- LEITAP (CGE).

The compared application of these models to different feedstock led to the results shown in *Figure 3*.

*Figure 3: Marginal changes in area (expressed as thousand hectares, kHa, per million tonnes of equivalent oil - Mtoe) for all of the considered models and scenarios, as found in Mulligan et al., 2010*




The level of detail of direct and indirect land use change emissions may strongly vary among different studies. Factors considered in such models include many assumptions on different agricultural yields, yield improvements, land rents, global changes in deforestation correlated to agricultural growth, and other factors. Also, as observed by Hiederer *et al*. (2010), when comparing different results, it has to be kept in mind that there are high levels of uncertainty involved in each step of the calculation chain, starting from the economic model results, spatial allocation, land use/cover and other input data up to the above- and below-ground biomass values applied. As an example, in some regions the spatial allocation procedure has experienced difficulties in distributing the total amount of hectares reported by the economic models because the total surface of naturally suitable land is less than the area given by the economic models. Therefore, results have to be interpreted with caution.

### 2.1.2 Hybrid Models

Hybrid CDMs models integrate biological and physical land characteristics, yields and land suitability data, economic properties such as elasticities, statistical data. On these bases, cause-effect relationships are established and the related impacts quantified. According to De Rosa, they tend to be simpler than economic models, thus reducing the computational effort and data requirement, and they appear conceptually easier. Hybrid models do not exclude economic aspects that drive the supply/demand patterns; rather, they forecast future production and consumption patterns based on current market trends and assumptions on agriculture supply/demand trajectories. Based on this scenario, future land uses and their geographic origin can be estimated. The approach proposed in Star-ProBio belongs to this category.

### 2.2 Normative, rule-based models

Normative rules characterised LUC models trough standards/guidelines, rather than causalities. The normative, rule-based models include (Schmidt et al., 2015; Finkbeiner, 2013):

- **Generic LCA standards and guidelines,** such as ISO standards on life cycle assessment (14040:2006, ISO 14044:2006), EC Product Environmental Footprint (PEF) Guide (EC, 2013), ILCD Handbook (ILCD, 2010), French Labelling Scheme (BP X30-323 series, AFNOR)
- **Generic carbon footprint (CF) standards and guidelines,** such as the ISO technical specification on carbon footprinting (ISO/TS 14067:2013), GHG Protocol Product Standard (WRI/WBCSD, 2011), PAS 2050 (BSI, 2011)

Currently, while all documents account for dLUC (where the focus is on the historical land cover of the specific plot of occupied land during the last 20 years), none of them provide a methodology to quantify ILUCILUC emissions and include them in a carbon footprint of life cycle assessment. According to Finkbeiner (2013), neither LCAs nor carbon footprint calculations should include ILUCILUC, because accounting methods are currently not scientifically robust and internationally accepted.

**A large and complete description of the link between the key drivers of ILUC and the standardisation work related to the sustainability of biofuels and biomaterials is reported in Annex 1.**

## 2.3 Other approaches: biophysical balances

Other ILUC approaches include the biophysical models that have been developed with different degrees of complexity in several cases (Audsley et al., 2010; Bird et al., 2013; Cederberg et al., 2011). The biophysical models attempt to establish a link between the demand for land/crops and deforestation/intensification with the use of physical data on crop yields, and statistical data on deforestation and land use changes. For example, Audsley et al., (2009) identify one of the driving factors of LUC as commercial agriculture. Based on this, the share of global annual GHG emissions from land use changes that is caused by agriculture is evenly distributed on all agricultural lands on a hectare basis. This method resulted in a single emissions factor for agricultural land, i.e. 1.43 t $CO_2$-eq./hectare of agricultural land used.

# 3. Analysis of relevant parameters and indicators

This section aims at categorize and structure the key drivers and parameters for future strategies to reduce ILUC risks. Building on the review of existing approaches, each STAR-ProBio participant involved in task 7.1 carried out a literature review of selected papers. In particular, the relevant key findings for ILUC quantification, and other potential additional key drivers from bioeconomy sectors not covered yet within the existing ILUC models (e.g. cascading use[1], etc.), have been analysed. Furthermore, the links between the ILUC key findings with standardisation work related to the sustainability of biofuels and biomaterials (cf ISO/PC 248, CEN/TC 383- specifically WG 3) have been identified.

## 3.1 Meta-analysis of recurring key drivers and parameters

Building on previous meta-analysis such as the ones performed by JRC and other works (Witzke et al., 2010; De Rosa et al., 2016), preliminary key drivers and parameters have been identified as indicators and defined. These indicators were preliminary identified as key drivers in scientific articles studying ILUC effects for biofuel production and were used as an example in order to verify their occurrence and their specific definition and use through the 14 scientific papers. The selected indicators are universal enough to apply to bio-based products as well as to biofuels.

The review has been carried out on 14 scientific papers developed for ILUC quantification from changes in soil (above-and below ground biomass) resulting from global land use changes caused by the production of biofuels and biomaterials. The template for the evaluation is reported in the Annex II and the most relevant indicators that have to be considered are shown in the Table 1. These indicators were preliminary identified as key drivers, and were used as an example in order to verify their occurrence, specific definition and use through the 14 scientific papers.

[1] Cascading use is the efficient utilisation of resources by using residues and recycled materials for material use to extend total biomass availability within a given system. In a single stage cascade, biomass is processed into a product and, after its use phase, this product is used once more for energy purposes; in a multi-stage cascade, biomass is processed into a product and this product is used at least once more in material form before disposal or recovery for energy purposes. This term has been challenged in recent meeting of CEN in January 2018 and the term multi productivity has been proposed instead.

*Table 1: Example of indicators to be considered in the literature review*

| Relevant indicators | Description |
|---|---|
| **Intensive margin** | Potential improvement of yield with respect to the yield in the baseline when crops and/or agricultural residues are used for bio-based products |
| **Land suitability** | Potential loss of yield due to land less suitable for crops intended for bio-based products (aka **extensive margin**) |
| **Demand elasticity** | The percentage change in quantity demanded in response to a one percent change in price |
| **Export (Trade elasticity – Trade share)** | Trade elasticity: The direct correlation between the relative change in the price of a commodity and the resulting relative change in the export rate demand of the same commodity.<br><br>Trade share: percentage of commodities exported |
| **Supply elasticity** | The direct correlation between the relative change in the price of a commodity and the resulting relative change in the supply demand of the same commodity |
| **Land price** | Observed land rents |

The goal of this exercise was to gain an in depth comprehension of the cause-effect interplay among these factors and to decide if they could be used as key drivers and parameters useful to the purpose of a risk approach for bio-based products.

Taking into account the preliminary analysis conducted in WP1, the review shows that the majority of the papers consider the intensive margin and land suitability as relevant indicators (86%), followed by the demand elasticity (price changes) (79%), export factor (57%), supply elasticity (50%) and land price (14%). Intensive margin, demand elasticity and export are also defined as risk factors, an indicator that should be prioritised (Table 2).

The result of the analysis shows that most of the selected papers have a global approach and assess biofuels as the principal bio-based product. The feedstock considered are, mainly, starch crops, sugar crops, oilseed crops and wood.

The intensive margin is the indicator with the most evident opposite effect on the ILUC approach.

*Table 2: Relevant indicators/variables for the ILUC analysis, its effects on the ILUC and its relevance in term of priority*

| Indicators/ Relevant variables | Considered (Y)/14 total | Considered (%) | Relevance / Priority (Risk Factors) |
|---|---|---|---|
| **Intensive margin** | **12** | **86%** | 8 |
| **Land suitability** | **12** | **86%** | 2 |
| **Price changes (demand elasticity)** | **11** | **79%** | 8 |
| **Export (Trade elasticity- Trade share)** | **8** | **57%** | 7 |
| **Supply elasticity** | **7** | **50%** | 4 |
| **Land price** | **2** | **14%** | 0 |
| | | | |
| **Geographic location** | Global (4); USA (3); South America and Asia (2); UK (1); Europe (1); USA, Europe, South East Asia, Africa and Brazil (1) | | |

## 3.2 Relevant indicators for the ILUC estimations

**INTENSIVE MARGIN: Potential improvement of yield with respect to the yield in the baseline when crops and/or agricultural residues are used for bio-based products**

Increase in feedstock demand for biofuels will lead to increase of area cultivated (area expansion) and/or an intensification (yield increase) (Wicke et al., 2014). In fact, as crop price increases, the economically-optimum spending on all inputs (e.g. fertilizers; units in $ per tonne of crop) increases, and this, in general, is expected to result in higher yields per tonne of crop (Mulligan et al., 2010). In this term, economic theory assumes that price influences yield variation in both short- and long-terms. In short-terms and in case of prices increase, agricultural yields may be improved by applying more N fertilizers (increasing amount and/or improving the timing of application), through better weed and pest management and switching varieties grown. Longer-term influences are due to price-induced technological progress, as more R&D are triggered by positively trending prices (Mulligan et al., 2010; Wicke et al., 2014).

**LAND SUITABILITY – aka EXTENSIVE MARGIN: Potential loss of yield due to land less suitable for crops intended for bio-based products (aka extensive margin)**

An increasing demand for biomass results in an area expansion of biomass production, and this may be associated with lower agricultural yields due to expansion on land less suitable for certain types of crops (extensification of farming) (Wicke et al., 2014). This results in different effects. On the one hand, in case of a cropland converted to another type of cropland (e.g. soybean to corn) the yield change can be either positive or negative, depending on the relative land productivity measured by land rents. On the other hand, in case of conversion of pastures and/or forests to croplands, the yield change is always negative, with a computable, global, average factor of 0.66 for the ratio between new and previous yields (Mulligan et al., 2010).

**DEMAND & SUPPLY ELASTICITIES - PRICE CHANGES: The percentage change in quantity demanded & supplied in response to a one percent change in price**

The relationship between biofuel production change and ILUC depends on price-elasticity (Sanchez et al., 2012). If more biofuels from crops are produced to fulfil renewable energy targets, demand for these crops rises as well. Following the basic law of supply and demand, increased demand compared to supply leads to a price increase of the crop (Valin et al., 2015).

However, increasing feedstock prices might reduce demand in other sectors and reduce pressure on land (Wicke et al., 2014; Mulligan et al., 2010). Specifically, in the input producing sectors, the more inelastic the demand in competing markets, the greater will be the increase in total quantity supplied of the input *ceteris paribus*. For instance, a corn ethanol mandate will lead to higher global consumption of corn when corn demand for food consumption is inelastic, especially in comparison to when it is less inelastic. The increase in agricultural land use will, in turn, be higher when food demand is inelastic, compared to when it is less inelastic, which indicates a higher vulnerability to harmful indirect effects. In the final-output sector, the more inelastic the supply of substitutes, the greater will be the rebound effect on consumption *ceteris paribus*. An ethanol mandate reduces the demand for gasoline, which reduces the derived demand for oil and lower oil price. The more inelastic the supply of oil, the smaller will be the reduction in the quantity of oil supplied. Some authors show that the prices changes are directly related  the emission related to LUC (Rajagopal and Zilberman, 2013). In fact, the change of food crops into energy biomass production results in the increase of crop prices, crop-dedicated agricultural land and crop-related LUC emissions (Searchinger et al., 2008).

All this considered, Bauen et al. (2010) appointed some limitation of price-based analyses: 1) demand is not the only factor affecting commodity price; 2) price alone is not sufficient to increase yields; 3) the effect of prices takes several years to be reflected in yield and land use changes.

**EXPORT - TRADE ELASTICITY, TRADE SHARE: Trade elasticity: The direct correlation between the relative change in the price of a commodity and the resulting relative change in the export rate demand of the same commodity.**

“The stickiness of the composition of trade depends on the elasticities of substitution among imports from different sources” (Mulligan et al., 2010). The increase of crop production useful to fulfil specific policy targets (e.g. renewable energy targets) would lead agricultural exports to decline sharply (compared to what they would otherwise be at the time). Decrease of export is related to the increase of emissions by LUC in other regions. On the other hand, the countries which import agricultural commodities would need to increase the area for those crops (Searchinger et al. 2008).

In other words, during a market shock event, all trade flows can adjust, but the macroeconomic trade surplus/deficit are maintained constant. Therefore, some real exchange appreciation can occur in some regions, and we may face contraction of agricultural exports for some of the countries that provide the key feedstock. In this case, we face a double source of land reallocation: direct competition effect (the price of studied feedstock increases, the land rent increases for this crop, and other crops are displaced) and the external account effect (additional exports of the key product in volume plus increase of the world price of this commodity will increase export values). Depending on the hierarchy of import demand elasticities across products and regions, some exports will decrease (and they can be land-intensive) or some imports may expand (and they can save local use of land) (Laborde, 2011).

**LAND PRICES: Observed land rents**

The land price depends on the maps of land suitability, proximity to infrastructure and existing cultivation (Schmidt et al. 2015).

*Other relevant indicators for the ILUC assessment*

The estimates of ILUC effects can vary depending on many factors including (Mulligan et al., 2010):

- Higher yields of all crops;
- Different allocations of area changes to different natural lands;
- Different C stock & land use data;

- Accounting for co-products;
- Counting C recapture after production;
- Changes in the Albedo effect (e.g. snow on former boreal/temperate forest);
- Nitrogen cycle (where yield is increased from N fertilizer application);
- Time and warming effect;
- How forests and unmanaged land are modelled;
- Other greenhouse gases (e.g. cattle, rice methane);
- Production period (e.g. short rotation forestry or continued rotation);
- More conversion from lower-C land types (pasture) and not peat-lands;
- Increased cattle intensity/better practice.

## 3.3 Additional key drivers from bioeconomy sector

Beside economic related effects, there are other key drivers, well acknowledged in the literature, which can increase or decrease ILUC effects. These drivers are more difficult to measure and possibly they can be captured in some of the selected indicators presented above as change of price or related elasticities.

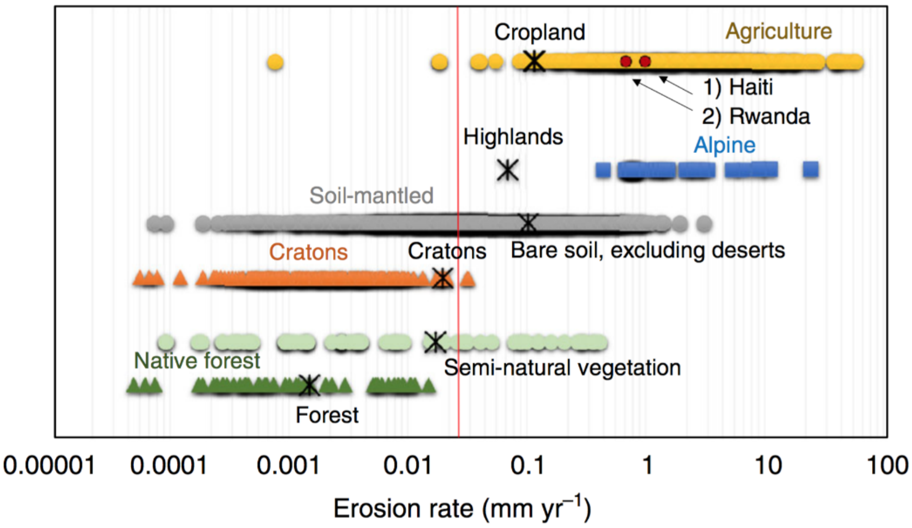
| Parameter | Description |
|---|---|
| **Land use policies**<br>(Wickle et al., 2014) | A very important aspect is the political framework for the protection of natural areas. Negative ILUC consequences such as deforestation or the loss of natural habitats can happen because there is a lack of an appropriate land use policy or appropriate protection and control measures. |
| **Agricultural policies**<br>(Mulligan et al., 2010) | Frameworks for agricultural production systems should include measures to maintain soil qualities and services. This includes, amongst others, requirements regarding the maintenance of soil organic carbon, protection from soil erosion, water management practices, *etc*. |
| **"Optimisation" in agricultural production systems**<br>(Wickle et al., 2014) | Increasing demands for dedicated crops for specific bioeconomy sectors may increase the attractiveness of double cropping systems. This could reduce the amount of additional land to be converted. |
| **Mega trends in the Bioeconomy** | Several additional parameters and trends might affect the future demand for single agricultural commodities. This includes aspects such as dietary patterns, the share of organic agricultural production systems compared to conventional agricultural production and/or the demographic development of a region. |

### 3.3.1 Soil Erosion and Crop-specific erosion factor as a risk factor

The results of the meta-analysis reported in the latest reference document of the United Nations (FAO&ITPS, 2015) on the status of global soil indicate that accelerated soil erosion is a major threat to soil. Land management and the related land use changes have an effect on the spatial patterns and magnitude of accelerated soil erosion which can affect land productivity and food security, biological diversity and carbon cycling. Borrelli at al. (2017) conducted a thorough estimates of soil erosion at the global scale by means of a high-resolution, spatially distributed, modelling approach based on the Revised Universal Soil Loss

In this study, published on Nature, the proposed new form of the global scale RUSLE- based assessment links to the key parameters required to assess the effects of global change.

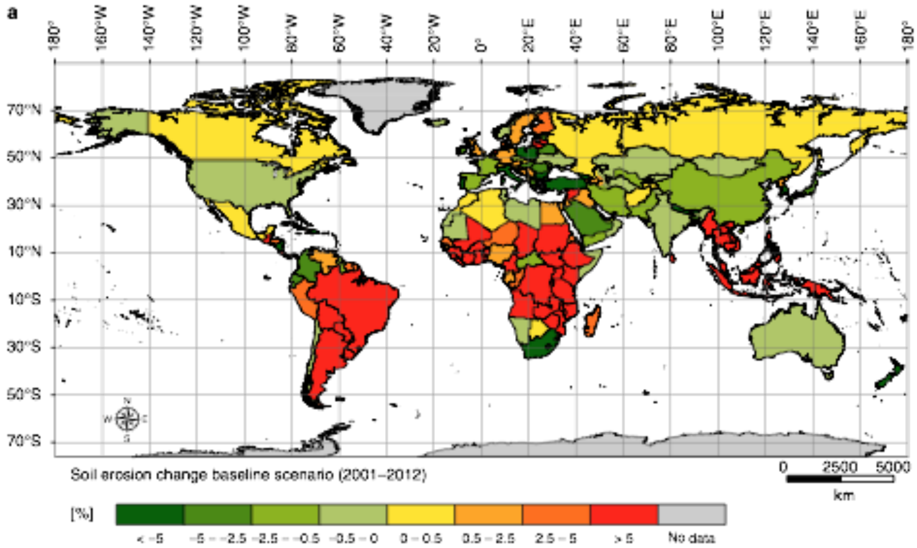
*Figure 4: Comparison of measured and modelled erosion rates. Representation of soil erosion rates measured on agricultural fields under conventional agriculture and other areas. The asterisk indicates the average. From Borrelli et al. 2017.*




In this work the authors came to the conclusion that the land changes related to cropland are responsible for about 80% of the increase in soil erosion. Therefore soil erosion can be used as a tracer for land use change.

A relevant aspect of soil erosion is the socio-economic one. In this work it was shown that the wealthy countries in temperate latitudes have the least erosion, while the poorest tropical countries are the most susceptible to high levels of soil erosion. The countries that can least afford soil protection measures are the most vulnerable. These countries are more often the same countries where ILUC effect has been observed in the review of existing models and related studies. In fact, soil erosion is a LUC tracer.

*Figure 5. Country-specific changes of the annual average soil erosion: Soil erosion change between 2001 and 2012 according to the baseline scenario. The chromatic scale represents the percentages of increase or decrease of the annual average soil erosion rates obtained by comparing the pixel-based values in each of the 202 countries under observation. The delta between the two observed periods solely depends on the land use and land cover change outlined combining satellite-derived land use land cover information with agricultural inventory data (Borrelli et al. 2017)*




The importance of which crops are selected for the manufacture of bio-based products is clear when considering that the countries most affected by soil erosion are the same countries were ILUC effects have been reported. Since specific crops have a different effect on soil erosion, the choice of source crop/biomass can constitute a risk factor as for ILUC.

In the RUSLE, the most commonly used equation to model soil erosion, the C-Factor measures the combined effect of the interrelated cover and management variable on the soil erosion process. More precisely, the C-factor is the ratio of the long-term soil loss from a vegetated area to the long-term soil loss from a reference area: a bare fallow area on the same soil cultivated up and down a 22 m long slope with a gradient of 9%.

Crop specific C-factors and land use specific C-factors have been computed by the JRC and Environmental Geosciences - University of Basel. As an example, annual crops associated with permanent crops display a C-factor ranging 0.07-0.35, vineyards 0.15–0.45, pastures 0.05–0.15. The higher the C-factor the higher the soil erosion.

Hence the choice of the crops used to make bio-based product can ultimately have an effect on soil erosion and therefore on the need for additional land through a cause-effect chain which can be represented as:

(+)LUC—>(+)C-factor—>(+)erosion—>(+)LUC

Which means that an increased LUC might specifically increase the C-factor, depending on the selected crop leading to more erosion and to a later stage to further LUC.

According to the team of the University of Basel and JRC and in many other works the causal link between soil erosion and loss of fertility and productivity is ascertained and well documented. The link between loss of fertility and further ILUC remains unexplained, just as the effect of soil erosion on ILUC. One possible reason for this could be the market re-equilibration: it is recognised that the effect of soil erosion is often internalised in the market by changes in the price of crop production, or that externalities are paid because of local effects of soil erosion such as eutrophication and water bodies siltation. In these cases erosion did not lead to further land expansion, leading to a mismatch between erosion and ILUC. Another possible explanation to the lack of a causal nexus between erosion and ILUC is that the increase in production rates for the most common crops, due to technological improvements, more rigorous land management and an increased use of fertilizers, might have masked the ongoing degradation of soils and their ecosystem service delivery capacity.

Quantis, a WP7 participant, reports that in common statistical LUC models, there are some countries that have large amounts of unallocated forest loss: this refers to forest losses that are not attributed to any specific activity and cause, namely agricultural activity and related land increase. Nonetheless it was clear that some crops have not increased their total area; rather, they were just relocated. The only plausible explanation to this forest loss and unchanged total used surface was loss of fertility on arable lands on one side and erosion at the expenses of forest on the other. In these cases forest loss was attributed to "inevitable erosion". Despite the fact the one cannot prove the contrary, it's legitimate to think that LUC was provoked by soil erosion.

On this basis it can be concluded that specific crops used in the bioeconomy, and specifically to manufacture bio-based products, are not all equal. A specific emphasis and warning should be put on those crops responsible for higher soil erosion.

### 3.3.2 Trade liberalisation

Trade liberalization is the removal or reduction of restrictions or barriers on the free exchange of goods between nations. This includes the removal or reduction of tariff obstacles, such as duties and surcharges, and nontariff obstacles, such as licensing rules, quotas and other requirements. The easing or eradication of these restrictions is often referred to as promoting "free trade".

These measures affect trade elasticities in accordance to Armington theory because bilateral trade relationships influence trade (De Rosa al., 2016). Economists conducted a sensitivity analysis over alternate parameterizations of Armington substitution elasticities in an assessment of the likely impacts of trade liberalization in the Doha round. They found that doubling the Armington elasticities roughly doubles both the trade response and the welfare gains in the GTAP model (Hilberry and Hummels, 2013).

Trade agreements plays a relevant role in determining those sectors which will thrive and those who will contract and shifts among the final commodities. Laborde (2011), for example, predicted that under trade liberalization, EU ethanol production would decline, with sugar beet and wheat-based ethanol most affected. As a result, local production capacity and feedstock production are dominated by biodiesel production. With trade liberalization, biodiesels would absorb almost the total share of EU biofuel production. Therefore trade agreements should be regarded as a relevant variable, whose changes affect short term trade elasticities.

# 4. Limitations of the current ILUC approaches

The literature review clearly shows that there are several limitations of the ILUC approaches. According to Finkbeiner (2013) the limitation of the considered ILUC models are:

- CGE approach doesn't capture the agricultural sector in the same detail as PE models;
- PE models do represent the agricultural sector in greater details, but they are not linked to other sectors;
- Both partial and general equilibrium models display low level of traceability and transparency;
- in economic modelling, dLUC and ILUC cannot be differentiated (Delzeit et al., 2011) – this has to be done through the interpretation of the results;
- deterministic models mainly use statistical data on LUC from the previous years - the extent and type of forecasted LUC depends on the chosen reference years;
- most of the existing models (economic and deterministic) only partially consider regional specific characteristics (although PE models generally allow a greater degree of regionalisation, for example Lahl, 2010);
- explicitly aim to consider regional data and information while Fritsche et al. (2010) chose to provide easily implementable and universally applicable methodology without regional differences;
- the current approaches to quantify ILUC factors are fundamentally different with regard to methods and scope;
- the current ILUC estimations are highly uncertain (Al-Riffai et al. 2010; Laborde, 2011; Edwards et al. 2010; Sanchez et al. 2012; Bauen et al. 2010; IPCC, 2011);
- ILUC data suffer from epistemological limitations, because it is empirically difficult to observe or detect them physically, by distinguishing from other causes;
- none of the examined articles address political, cultural and economic aspects – except trade incentives and barriers (De Rosa et al., 2016).

Moreover, crucial for the assessment of dLUC and ILUC is the effect of increasing demand and associated increasing feedstock prices. Although equilibrium models can capture how much of the increased demand will be met by agricultural land expansion, agricultural intensification and decreased demand for food, it is unclear how more complex changes in the production chain (such as switching to second-generation crops/fuels) will contribute to ILUC (Wicke et al, 2014).

# 5. Adaptation of existing methods to a risk approach model for bio-based products

The present literature review shows that there is, in the biofuel sector, an *impasse* between experts advocating for the inclusion of ILUC in LCA and carbon footprint and experts denying the scientific reproducibility of that. This *impasse* precludes the application of ILUC figures to environmental considerations about the biofuel sector. To overcome this *impasse*, WP7 partners decided to adopt a risk-based approach.

The analysis of existing approaches and related key drivers and parameters also showed that bio-based products have not been considered yet. Here below the main differences between biofuels and bio-based products have been listed.

| | **Biofuel** | **Bio-based products** |
|---|---|---|
| **1** | Demand for food and feed, based on dynamics of population, economy and diet. | No difference. |
| **2** | Price of crude oil. | Price of substitutive goods of the petrochemical counterparts of bio-based products which are manifold and non-homogenous: petrochemicals-derived plastics and lubricants, fossil fuel derived surfactants and chemical specialities, etc. |
| **3** | Developments in the types of passenger vehicles used, which in turn determine the demand for bio-ethanol or biodiesel. | Applications of bio-based products which are manifold and non-homogenous |
| **4** | Developments in agricultural technology due to current and future research and innovation, particularly regarding new breeds and varieties, which result in yield increases or changes in the ratio between feed product and biofuel product. | No difference. |
| **5** | Developments in technologies to convert biomass into bio-based products, including the refining of biomass into specific products. | No difference. |
| **6** | Developments in policies, especially on trade, agriculture and spatial planning. | No difference. |
| **7** | End of life. Lifetime is usually short (less than 1 year). Combustion. | Some commodities, such as durable plastics may have a lifetime of 10 years or more. End of life is more varied and includes material recycling. |

Distinctions made, the *impasse*, and its possible solution, mentioned above about the ILUC for the biofuel sector applies to the bio-based sector as well.

In order to derive an assessment method for ILUC risk light of the above highlighted limitations, to overcome it was decided to adopt a risk-based approach. This approach can be classified as a hybrid causal-descriptive approach. The essential motivations, objectives and ambition of this proposal are hereby described.

Economic models synthetically represent reality, and economic information convey many complex elements which compose cause-effect relationships. Despite the underlying complexity, however, economic models should be clear and easy to understand also for non-practitioners. Also, looking at the analysis of the key drivers and parameters made in section 3 one can easily understand that there are recurring factors which should be universally considered when studying ILUC effects; for example, a high domestic elasticity drives reduction in domestic uses. All cause-effects relationships should be isolated and their effect combined one-factor-at-a-time and globally. Furthermore, the complexity of the models should be reduced or increased gradually in order to be able to obtain at least some gross indication rather than highly disputed numbers.

Therefore, in order to make a risk approach operational, the following steps have been implemented:

- Economic models simplification and system representation by mean of conventional symbols and operators.
- Key drivers and parameters isolated and represented into the model as risk factors. These arrangements should be able to show the cause-effects as a narrative, in order to be understandable to both domain specialists and to stakeholders.
- All relationships depending on risk factors are qualified in terms of the sign of the effects and quantified.
- Emphasis is put not on the absolute quantity that each factor is able to modify rather than on the relative importance of the factors and their interaction. The goal is to establish which conditions are risky and/or prohibitive rather than quantify the exact amount of displaced land or environmental effects.

It was selected to adopt a tier approach in order to make the model operative stepwise and to allow its application to diversified objectives.

Thanks to its great data availability and abundance of literature, the **Global Trade Analysis Project (GTAP)** has been selected. The GTAP is a static computable global equilibrium (CGE) model adopting a specific approach reflecting imperfect substitutability of products across regions (Scarlat et al., 2015). Using this model Hertel (2010) modelled the effects on land conversion caused by the expansion of US maize ethanol use from 2001 levels to the 2015 mandated level of 56.7 giga-liters (GL) per year by forcing 50.1 GL of additional ethanol production. Hertel considered a target land harvested area of 15Mha to reach the mandated level of 50.1 GL and showed how market forces acted to reduce this initial requirement. In table I expected results are illustrated in the form of net land cover changes.

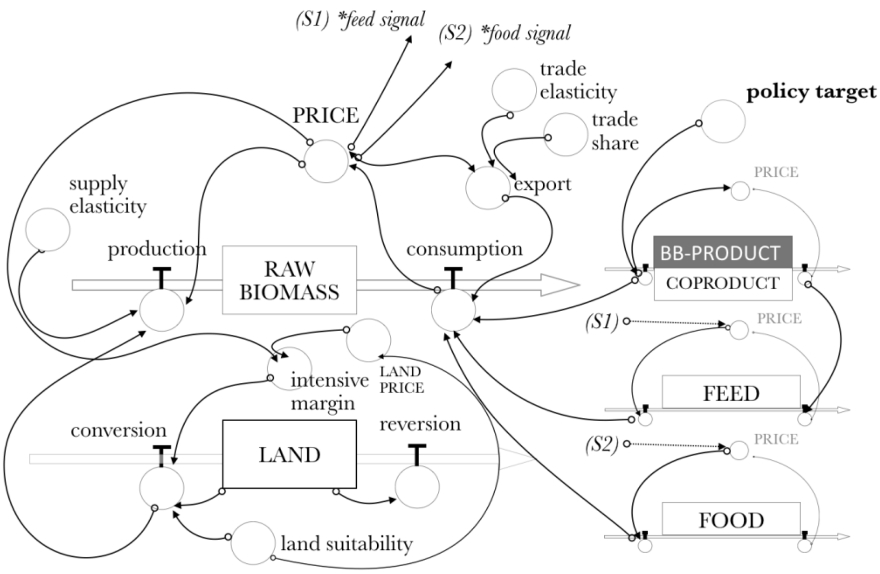
The cause-effects described in the model are represented through stock and flow diagrams through the **system dynamics methodology**, as shown in Figure 1. This methodology was developed by Jay Forrester in 1961 (Fuchs, 2006) and has its roots in control engineering, cybernetics, and general systems science—which, in turn, have their roots in early systems science for biology and physics. As explained by Fuchs (2006) system dynamics fit very well the purpose of representing economic systems.

The output of bio-based products is connected to land transformation and to the related econometric and biophysical factors. All stocks are represented by difference form (Euler form) of the differential equation that results from formulating a law of balance in instantaneous form, augmented by the initial value of the accumulating quantity. The model can be compared to the state of the art of models used to assess the trade of agricultural commodities to verify that all relevant cause-effect links are caught.

The conceptual model is represented by Figure 6. A system dynamic representation of the interactions has been adopted consisting of stocks or levels (boxes), flows (large arrows), variables (circles) and information controlling or mediating levels or other variables (thin arrows). Different forces are acting to reinforce negative and positive feedbacks.

The conceptual model consists of 5 main flows and related stocks: 1) bio-based products and optionally co-products; 2) feed; 3) food; 4) raw biomass; and 5) land (transformed land). These are controlled by variables ultimately affecting land consumption and can be related to a specific policy target and varying conditions such as employing co-products, cascading processing and/or growing novel crops over abandoned or non-productive agricultural lands.

*Figure 6: ILUC risk evaluation conceptual model of bio-based products (bb-products), consisting of stocks (rectangles), variables (circles) and causal links (connections)*




Moving from right-top side to left-bottom side, the following sequences are identified:

1) A policy target (including subsidies measures) is boosting the production of bio-based products in a specific area – in this case, production is a linear function of the policy target.
2) As bio-based production is based on raw biomass consumption, raw biomass consumption increases as well; a larger consumption (demand) implies a higher price.
3) A higher price affects raw biomass production, export and food and feed consumption. Export is diminished by a factor called trade elasticity, defining the response of traded quantities to changes in prices of tradable goods. Increases in food and feed prices will result in a contraction of consumption; this affects the demand for additional land, decreasing it (and, therefore, decreasing ILUC).
4) If bio-based production results in the manufacture of co-products which can substitute some feedstock-derived commodities (such as feed, textile, food) then raw biomass consumption is reduced by a substitution yield factor.

5) Supply response is induced by a higher price and leads to additional raw biomass production from land: effects here goes in two opposite directions: a) an intensive margin response resulting in higher yields, meaning less land is required with respect to the baseline; and b) additional land is required to meet an increased demand at the expenses of other croplands and land covers. Generally, this expansion results in a decline in average yields as the feedstock production expands into lands less suited for the target crop; this means a larger extent of land is required to meet increased production levels.
6) A fraction of the converted land reverts again to other productive/unproductive lands.

From the analysis of the economic models, different constitutive parts can be identified:

I. a proper economic part predicting changes in demanded quantities of additional land;
II. an economic-agronomic part explaining LUC from one type to another, i.e. specific land use changes successions such as the land transition matrix adopted in GLOBIOM;
III. a geographic-economic part accounting for the distribution of effects at a planetary scale, depending on the specific crop used as feedstock and trade routes;
IV. an environmental part explaining impacts according to soil organic carbon levels, biodiversity and other land use or land cover original characteristics in the affected areas.

These layers can be thought as tiers used by IPCC. The tier approach is functional to get a stabilised model and to provide future users with growing levels of complexity.

This articulation in tiers can be used to define the extent of the modelling effort. In order to achieve a risk-based evaluation one need to determine the probability of causing additional land consumption (**tier I**). At a higher level of precision different land types can be defined (**tier II**). At **tier II** level it is possible to restrict loose assumptions and introduce land specifications, where specific types of land are defined (RISK = risk factor ° additional land of specific type).
**Tier III** defines the specific geographic impact at regional (e.g. Europe) or country levels. At this point other factors might be introduced, such as the soil erosion factor and specific erosion effects (C-factor) as a sub-risk factor affecting yields and, in particular, the intensive margin. At **tier IV** environmental consequences are analysed, taking into account that factors such as soil erosion can amplify them. In this way, the scope of the work will proceed by degree of complexity. WP7 will focus on **tier I** and possibly attain **tier II** due to the fact that the latest two tiers will need a considerable modelling effort to include all the mathematic relationships relating the cover factor to soil depletion, to loss of yield and, finally, to the need of extra land.

The Sys-dyn-ILUC model aims at defining a RISK index for using additional feedstock to make bio-based products, implying that RISK is a function of a risk factors and additional land (AL).
At **tier I**, the model shows the extra-land useful to produce that specific type of feedstock (e.g. if a given product requires maize, the model determines the need for extra land to be converted by including market mediated responses). This means that extra land to be grown for corn is computed based on: i) price constraints, ii) the substitution of possible co-products, and iii) margin intensity effects. This is not dLUC, because market mediated responses are taken into account; it in not ILUC as conventionally intended either, however, since specific crop substitutions are not considered. The term "additional land" (AL) is comprehensive of all kind of lands subjected to cropland changes; hence, it does not distinguish among legacy conditions (forests, pastures, other croplands, i.e. land cover and land management).
When considering risk of bio-based product =risk factor ° additional land, each additional incremental volume of bio-based product is assigned to an additional - incremental - land surface depending on "risk factors": elasticities, yields and use of co-products. This is a monotone function: the more the additional land, the more the risk.
The expected output can be thought as in this representation: 1 additional t of product P1 ILUC bears a risk 3 on a 1-5 scale; P1 being a specific product having specific manufacturing area and cropping area.

# 6. Conclusions

Tapping from a copious literature, the project team isolated the specific factors which control land expansion as shown in Table 3.

All risk factors depend on specific assumptions and conditions, such as crops and specific regional area and to baseline values. According to first results, the most relevant factors affecting land consumption depend on the sensitivity of domestic markets to price changes – i.e. demand elasticity - of the main raw biomass used in end-products. When demand elasticity is high, one should expect a strong reduction in the internal market, thus counteracting an increased consumption in the bio-based industry. The effect is opposite (O) to land consumption. The higher the supply elasticity the higher the production and consequently land expansion, therefore the effect is in the same direction (S) to land consumption.

*Table 3: Sample of risk factors and cause-effect link with respect to land consumption: opposite (O) and same (S) effect.*

| Risk factor | u.m. | Effect on the ILUC |
|---|---|---|
| **Intensive margin** | t/ha*y | O |
| **Land suitability** | t/ha*y | S |
| **co-products** | t/y | O |
| **Demand elasticity** | % | O |
| **Export - Trade elasticity, Trade share** | % | S |
| **Supply elasticity** | % | S |

Furthermore, other factors reduce the ILUC effects, such as co-products obtained in the processing of bio-based products which may be able to substitute agriculture commodities in the food and feed sectors.

In the conceptual framework, the bio-based products and co-products are referred to the geographical area of production.

As a next step, the team will improve the understanding on how all factors conjure to worsen or mitigate or oppose ILUC effects. If some specific factors and conditions are crucial, then we can define risk indicators: the higher the value of the indicator, the higher the ILUC risk. We will do so by working on selected case studies. Besides the specific indicators for ILUC risk reduction, recommendations will be issued for enabling national government policies and foreign direct investment, as well as policy at an international level.

# 7. Annex

## 7.1 Annex 1

The links between the key drivers of ILUC and standardisation work related to the sustainability of biofuels and biomaterials.

| | | Text | Analysis & Comments |
|---|---|---|---|
| **Body** | ISO | In developing this International Standard, issues concerning direct and indirect effects were carefully considered. The aim of this International Standard is to provide clear guidance to produce consistent and replicable results. The term 'indirect effects' can be understood in different ways due to various opinions and definitions. This International Standard considers the measurable environmental, social and economic effects that are under the direct control of the economic operator and caused by the process being assessed. For the purpose of this standard, these are defined as 'direct effects'. Other effects that do not meet these requirements are not included. | Although 'indirect land-use change' is not explicitly mentionned (neither in this clause nor in the rest of ISO 13065), ILUC is one of the main targets of this paragraph. This clause shows that ILUC was deliberatly not included in the scope of ISO 13065 (consistent with other ISO standards) |
| **Topic** | Bioenergy | | |
| **TC** | ISO/PC 248 | | |
| **Ref.** | ISO 13065 | | |
| **Title** | Sustainability Criteria for bioenergy | | |
| **Chapter** | 4. General Requirements | | |
| **Clause** | 4,12 | | |
| **Element** | Direct and indrect effects | | |
| **Body** | ISO | **6.1 General**<br>This clause establishes the requirements for quantifying GHG emissions to address the GHG principle (see 5.2.1). GHG quantification shall be undertaken in accordance with ISO/TS 14067 as supplemented by clause 6. ISO/TS 14067 specifies principles, requirements and guidelines for the quantification and communication of the carbon footprint of a product (CF°, based on International Standards on life cycle assessment (ISO 14040 and ISO 14044) and on environmental labels and declarations (ISO 14020, ISO 14024 and ISO 14025).<br>(...)<br>**6.8 System boundaries**<br>The system boundaries shall be treated according to the guidance in ISO/TS 14067 and shall be equivalent for compared bioenergy and reference systems. | Under ISO 13065, reduction of GHG emissions is one of the applicable sustainability principles. The measurement of GHG emissions requires the use of the method laid down in ISO/TS 14067 (NB: currently under revision).<br>ISO/TS 14067 does not propose a method to account for ILUC emissions (see row 15), hence neither does ISO 13065. |
| **Topic** | Bioenergy | | |
| **TC** | ISO/PC 248 | | |
| **Ref.** | ISO 13065 | | |
| **Title** | Sustainability Criteria for bioenergy | | |
| **Chapter** | 6. Greenhouse Gas methodologies, assessment and comparison | | |
| **Clause** | 6.1 & 6.8 | | |
| **Element** | General & System boundaries | | |
| **Body** | CEN | Land use has a direct impact on the amount of carbon stored both in the soil and aboveground. This clause deals with emissions caused by the change of use of the land where the biomass is grown. Emissions related to "indirect land use change" (ILUC) are not included in Annex V of the RED and therefore not considered in this standard | As shown by this paragraph, ILUC emisssions are deliberately not included in the EN standards on sustainabilty criteria for the production of biofuels and bioliquids for energy applications.<br>The EN 16412 series is currently being revised so as to intergrate Directive EU 2015/1513. Although often referred to |
| **Topic** | Bioenergy | | |
| **TC** | CEN/TC 383 | | |
| **Ref.** | EN 16214-4 | | |

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|---|---|---|---|
| **Title** | Sustainability criteria for the production of biofuels and bioliquids for energy applications (GHG caluclation using LCA) | | as the 'ILUC Directive', this piece of legislation does not lead to ILUC emissions being accounted for in the sustainabilty criteria applying to biofuels (Annex VIII laying down ILUC factor is only used by Member States for reporting purposes). This is reflected in the current revision of the EN 16412 series where ILUC emissions are still excluded. |
| **Chapter** | 5 Biofuels and bioliquids production and transport chain | | |
| **Clause** | 5,2 | | |
| **Element** | Land use and land use change | | |
| **Body** | CEN | No reference to ILUC | Land use change is addressed in Chapter 6, listing social criteria.<br>The section on land use change underlines the potential negative impacts of land use change on food security.<br>Nothing with relation to ILUC (emissions) is mentioned. |
| **Topic** | Bio-based products | | |
| **TC** | CEN/TC 411 | | |
| **Ref.** | EN 16751 | | |
| **Title** | Bio-based products - Sustainability Criteria | | |
| **Chapter** | - | | |
| **Clause** | - | | |
| **Element** | - | | |
| **Body** | ISO | No reference to ILUC | The LCA standards are dated 2006, that is, before the concept of ILUC started being debated. The ISO LCA standards give a framework and introduce all the basic concepts needed to carry out an LCA.<br>Since ISO 14040 and ISO 14044 were drafted, LCA techniques have also changed and while those two standards remain a undisputidly strong basis, major items are not addressed. For example, the existence of various methodologies - typically attributional vs. consequential LCA (ALCA vs. CLCA) - and their respective differences/advantages are not explained. This has an indirect effect on our ILUC discussion, as CLCAs is often depicted as more appropriate to model ILUC effects that ALCA. Work within ISO is currently taking place to determine what the future amendments to the two LCA standards should focus on. |
| **Topic** | LCA | | |
| **TC** | ISO/TC 207 | | |
| **Ref.** | ISO 14040 + ISO 14044 | | |
| **Title** | Life cycle assessment | | |
| **Chapter** | - | | |
| **Clause** | - | | |
| **Element** | - | | |
| **Body** | JRC (EC) | **Indirect land use changes in consequential modelling** | As shown by this paragraph, ILUC emisssions are deliberately |

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|---|---|---|---|
| **Topic** | LCA | As no widely accepted provisions exist for indirect land use, but such are still under development by several organisations, no specific provisions are made at this point. The appropriate way how to integrate indirect land use changes is hence to be developed for the specific case, in line with the general provisions o consequential modelling. This is unless specific provisions would be published under the ILCD. Such provisions might be part of a future supplement. | not included in the 2010 ILCD Handbook, although emissions arising from indirect land-use change are explicitly acknowledged as a reality.<br>Since the publication of this general guidance document, no further indication regarding a harmonised methodology to account for ILUC emissions has been developed. |
| **TC** | - | | |
| **Ref.** | ILCD Handbook (general guidance) | | |
| **Title** | General Guide for Life Cycle Assessment - Detailed Guidance | | |
| **Chapter** | 7 Life Cycle Inventory analysis - collecting data, modelling the system, calculating results | | |
| **Clause** | 7.2.4.5 | | |
| **Element** | Further aspects, recommendations, and observations | | |
| **Body** | ISO | change in the use or management of land which is a consequence of direct land use change (3.1.8.4), but which occurs outside the product system (3.1.4.2) being assessed | NB: ISO/TS 14067 was published in 2013 and is currently being revised.<br>Through the revision, the technical specification should be made an international standard instead (a standard has more authority than a technical specification). The revision process is already quite advanced (draft international standard stage).<br>In the current ISO DIS 14067:2017, the definition of ILUC is slightly different (more precise thanks to the note and example): 'change in the use of land which is a consequence of *direct land use change* (3.1.7.5), but which occurs outside the system under study'<br>Note 1 to entry: land use change happens when there is a change in the 'land-use catergory' as defined by IPCC (e.g. from forest land to cropland).<br>Example: If land use on a particular parcel of land changes from food production to biofuel production, land use change might occur elsewhere to meet the demand for food. This land use change elsewhere is indirect land use change. |
| **Topic** | Carbon Footprint | | |
| **TC** | ISO/TC 207 | | |
| **Ref.** | ISO/TS 14067 | | |
| **Title** | Carbon footprint of products | | |
| **Chapter** | 3. Terms and definition | | |
| **Clause** | 3.1.8.5 | | |
| **Element** | Indirect land use change | | |
| **Body** | ISO | Indirect land use change (ILUC) should be considered in CFP studies, once an internationally agreed procedure exists.<br>(…)<br>NOTE: There is on-going research to develop methodology and data for the inclusion of ILUC in GHG reporting. | Same in ISO DIS 14067:2017.<br>This reinforces the idea that ILUC emissions are relevant, but the methodology to account for them, still controversial. |
| **Topic** | Carbon Footprint | | |
| **TC** | ISO/TC 207 | | |
| **Ref.** | ISO/TS 14067 | | |
| **Title** | Carbon footprint of products | | |

| | | | |
|---|---|---|---|
| **Chapter** | 6. Methodology for CFP quantification | | |
| **Clause** | 6.4.9.4 | | |
| **Element** | Land use change | | |
| **Body** | ISO | GHG emissions and removals occuring as a result of ILUC:<br>- should be considered for inclusion;<br>- shall be documentes separately in the CFP study report, if calculated | Same in ISO DIS 14067.<br>Also interesting to note that the standard not only refers toILUC emissions, but also GHG removals as a result of ILUC. |
| **Topic** | Carbon Footprint | | |
| **TC** | ISO/TC 207 | | |
| **Ref.** | ISO/TS 14067 | | |
| **Title** | Carbon footprint of products -- Requirements and guidelines for quantification and communication | | |
| **Chapter** | 6. Methodology for CFP quantification | | |
| **Clause** | Table 1 | | |
| **Element** | Specific GHG emissions and removals documented separately in the CFP | | |
| **Body** | BSI | **Note 3** While GHG emissions also arise from indirect land use change, the methods and data requirements for calculating these emissions are not fully developed. Therefore, the assessment of emissions arising from indirect land use change is not included in this PAS. The inclusion of indirect land use change will be considered in future revisions of this PAS. | As shown by this paragraph, ILUC emisssions are deliberately not included in this 2011 Publicly Available Specification, although emissions arising from indirect land-use change are explicitly acknowledged as a reality.<br>The 2011 PAS has not yet been revised. |
| **Topic** | Carbon footprint | | |
| **TC** | - | | |
| **Ref.** | PAS 2050 | | |
| **Title** | Specification for the assessment of the Life Cycle GHG of Goods and Services | | |
| **Chapter** | 5 Emissions and Removals | | |
| **Clause** | 5,6 | | |
| **Element** | Inclusion and treatment of land use change | | |

| | | | |
|---|---|---|---|
| **Body** | Greenhouse Gas Protocol (WRI & WBSCD) | Indirect land-use change is defined as land-use change that occurs when the demand for a specific land use (e.g., an increased demand for crops as a bioenergy feedstock in the United States) induces a carbon stock change on other land (e.g., increased need for cropland in Brazil causing deforestation). This displacement is a result of market factors and calculated using data consistent with a consequential approach. Therefore, the inclusion of indirect land-use change is not a requirement of this standard. However, if indirect land-use impacts can be calculated and are determined to be significant for a given product, the magnitude of the impacts should be reported separately from the inventory results. | The requirements and guidance in the Greenhouse Gas Protocol follow<br>the attributional approach to life cycle accounting (GHG emissions and removals are attributed to the unit of analysis of the studied product by linking together attributable processes along its life cycle); while accounting for ILUC emissions is only relevant if you consider a hybrid or consequential approach.<br>This is the reason given by the Greenhouse Gas Protocol guidance document to not take into account ILUC emissions (and to require a seperate reporting if such emissions are quantified). |
| **Topic** | Carbon footprint | | |
| **TC** | - | | |
| **Ref.** | Product Life Cycle Accounting and Reporting Standard | | |
| **Title** | - | | |
| **Chapter** | 7 Boundary Setting | | |
| **Clause** | 7,2 | | |
| **Element** | Requirements | | |

## 7.2 Annex 2

The template for the literature review.

| **Item** | |
|---|---|
| ***Reference (full citation – please use the "European Union Inter institutional Style Guide")***[2] | |
| ***Crop or product (or waste) used as bio-based feedstock*** | |
| ***Co-products (by-products) obtained in the processing of bio-based products which may be able to substitute agriculture commodities in the food and feed sectors.*** | |
| ***Geographic location, if defined*** | |
| ***Limitations of the study as acknowledged by the authors*** | |
| ***Other information or comments*** | |

| ***Indicators/Relevant variables*** | ***Considered (Y) or not (N)*** | ***Description*** | ***Effect on the ILUC (opposite (O) or same (S) effect)*** | ***Relevance / Priority (Risk Factors) (if indicated)*** |
|---|---|---|---|---|
| **Intensive margin** | | | | |
| **Land suitability** | | | | |
| **Price changes – demand elasticity** | | | | |
| **Export - Trade elasticity, Trade share** | | | | |
| **Supply elasticity** | | | | |
| **Land price** | | | | |

**Please indicate other variables/indicators/criteria or factors that can be relevant for the ILUC analysis, adding all lines needed**

| ***Indicators/Relevant variables*** | ***Description*** | ***Effect on the ILUC (opposite (O) or same (S) effect)*** | ***Relevance / Priority (Risk Factors) (if indicated)*** |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

[2] The "European Union Interinstitutional Style Guide" is available in most bibliographic management tools and compatible with http://citationstyles.org/. See also www.citationmachine.net/european-union-interinstitutional-style-guide/cite-a-other (for instance) for automated citation formatting.

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