Assessing the land use change effects of using EU grassland for biofuel production

Task 4b of tender ENER/C1/2013-412

- Confidential –

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Date: 20 June 2016

Project number: BIENL15199

Reviewers: Matthias Spöttle and Daan Peters (Ecofys)

This study has been commissioned and funded by the European Commission

A cooperation of Ecofys, IIASA, AGRA CEAS and E4tech

Executive Summary

This study aims at providing estimates of indirect land use change emissions related to the use of grass in the EU for biofuel production. This document presents an overview of the situation of grassland resources in the European Union, and explores the impact of future scenarios of grass biomass conversion to biofuels using the GLOBIOM land use model. This study can be seen as an addition to the recent ILUC quantification study performed by Ecofys, IIASA and E4tech, which included a number of feedstock-specific scenarios, but did only include a scenario for perennial grass as a biofuel feedstock.

The analysis of the literature and recent dataset suggests that:

- The recent decrease in meat consumption and livestock grazing needs in the EU have lowered the level of pressure on the EU grassland. As a consequence, grassland has been observed to decrease in a few EU countries. Although there is no clear evidence on the exact level of grass underutilization, the downward pressure on the resource is likely to continue.
- A potential for increased grassland biomass production exists and grass productivity gaps could be reached with the right incentives. But this would also generate negative impacts on water quality, soil erosion and level of biodiversity. Future prospect on grassland productivity in the EU remains therefore unclear, and indirect land use change associated to competition with the use of grassland biomass for livestock needs to be explored.
- Various technological pathways can be envisaged to convert grass biomass to biofuels. They differ by their conversion efficiency and thus by their grass biomass requirements for a given target. Therefore, the potential impacts of grass biofuel use depend on the technological route adopted.

In light of these aspects, we explore the impacts of different scenarios of grass demand with the GLOBIOM model. These scenarios look at different levels of incorporation of grass-based biofuels in EU transportation at the horizon 2030. The following dimensions are tested:

- Level of incorporation (i.e. the shock in the model): we look at targets of incorporation of grass-based biofuels into EU transportation fuels of 0.5%, 1% and 2% (corresponding with 62, 123 and 246 PJ).
- Conversion pathway: three technologies are considered: biogas, cellulosic ethanol and green bio-refineries.
- Biodiversity protection: sensitivity analyses are conducted with alternative implementations of the sustainability criteria based on information on high natural value farmland presence likelihood.

Our results show that:

- Providing 1% of EU transport fuel from grass would require an equivalent of 8% (biogas pathway) to 17% (bio-refinery pathway) of current EU grassland biomass use.
- Below a level of 10% of EU grassland biomass use (16 Mt dry matter grass), ILUC values remain low (from 0 to 0.15 tCO_2/t dry matter grass) and moderate impact on the agricultural sector is expected. Most adjustment would take place through grassland intensification and expansion, complemented by some marginal substitution with forage crops. Impacts on prices and consumption of livestock products would remain limited.
- For an incorporation level of 0.5%, the ILUC values obtained for biogas and cellulosic ethanol remain close to zero. At a level of 1%, only biogas technology keeps a low ILUC value (12 gCO_2/MJ), which is comparable to the most efficient ethanol crops (14 gCO_2/MJ for maize in the previous GLOBIOM ILUC quantification study).
- For higher levels of incorporation or less efficient technologies, stronger impacts on feed use lead to larger expansion of fodder crops. This generates higher ILUC values through soil organic carbon emissions and foregone sequestration in natural vegetation biomass (from 33 to 79 gCO_2/MJ).
- Bio-refineries can produce feed products in addition to biofuels. However, the feedback effect of grass protein meals does not compensate fully in our results the effect of the forage crop expansion. This activity shows the highest ILUC values, also because all the emissions are in our case allocated to the biofuel product.
- Our results also illustrate the trade-offs between grassland resource availability and biodiversity protection. A part of the most productive biomass is made inaccessible as the level of biodiversity protection increases. A more stringent implementation of sustainability criteria would not increase the overall costs of biofuel production from grassland, but would increase the indirect effects on land use and GHG emissions.

Overall, the performance of the grass feedstocks appears to be primarily depending on the size of the shock. All pathways were more efficient for low shocks, with biogas showing better results in terms of emissions per unit of energy than cellulosic ethanol, and bio-refineries performed the worse if all their emissions are allocated to bioenergy.

Our findings suggest that, considering the non-linearity of the agricultural sector response to an additional grass demand, incentives to use the biomass resource should be designed with caution. Use of grassland biomass for biofuels could contribute to the EU biofuel policy mix, but should remain limited to be sustainable. Too strong incentives to convert grass biomass could jeopardize the expected GHG emission savings and pose challenges similar to that of the lowest yielded 1^{st} generation biofuel crops.

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Glossary

Grassland area: permanent vs temporary grassland. Grasslands are defined by EUROSTAT as permanent if they are not re-seeded for at least 5 years in row. Temporary grasslands are generally managed in rotation with crops over arable land.

Grassland area: Pasture and meadows: sub-category of permanent grassland, corresponding to relatively favorable biophysical environment (soil, altitude and slope) and generally subject to intensive management (introduction of non-native species, application of fertilizer and chemicals, high off-take rate). It is also often referred to as 'agriculturally improved grassland'.

Grassland area: Semi-natural grassland: sub-category of permanent grassland, corresponding to relatively unfavorable biophysical environment (soil, altitude and slope) and generally not subject to intensive management (native species, no amendment, low off-take rate). It also corresponds to the 'rough grazing areas' in the EUROSTAT definition.

Grassland productivity: yield vs NPP vs off-take rate. The **net primary productivity** is the yearly biomass productivity of grassland, while yield correspond to its harvested part. The **off-take rate** is the ratio of yield over NPP.

Grassland productivity: potential vs actual yield (or NPP). While **potential productivity** denotes the maximum achievable yield in a location for an optimal management, **actual productivity** denotes the productivity as further constrained by the management, and actually observed.

HNV farmland: High Nature Value farmland, an indicator of biodiversity-rich areas within agricultural land, as defined by the European Commission (see section I.B.2 for the full definition).

Livestock feed: Fodder. Fodder denotes in general feed material given to livestock, and is differentiated in this study from grains or feed concentrates. It comprises both grassland biomass (hay) grazed or mowed, and forage crops.

Livestock feed: Forage crops. Denotes the annual crops grown and harvested for the purpose of feeding livestock (stems and leaves are used as fodder), such as corn silage or oats.

t DM: tons of dry matter. Mass unit referring to the dry weight of plants or agricultural products, in contrary to tons of fresh matter (including the water content).

TLU: Topical Livestock Unit. A standardized metric measuring animal population used by the Food and Agriculture Organization. It weights the contribution of various animal species (e.g., swine, poultry, cattle, sheep, etc.) by their average grazing needs (1 TLU = 1 animal of about 250kg).

1 Introduction and concepts

1.1 Introduction

Grassland, according to EUROSTAT statistics, occupied 70.5 million ha within the EU28 in the year 2013. This area represents 13% and 33% of total land area and total utilized agricultural area, respectively. Grassland sustains many vital ecosystems services: it is a major source of biomass feedstock for livestock production in the EU, contributing to roughly one quarter of livestock protein needs. But it also provides large environmental benefits: these areas are usually richer in biodiversity than other agricultural lands, they reduce erosion by stabilizing soil in sloppy areas, regulate and purify water flows from fertilizers and pesticides, and can store large amounts of carbon in the soil (Smit *et al* 2008, Peeters 2009, 2012, Prochnow *et al* 2009). Grassland long-lasting contribution to the EU landscapes is also associated with a strong cultural heritage and recreational values. All these aspects have been since decades recognized by public policies, and grasslands are targeted by a large body of European, national and local legislation, such as agricultural sector policies, biodiversity protection policies or water regulations.

In the recent years, a number of studies highlighted a decrease in livestock grazing needs, due to shifts in the demand for meat and dairy products as well as strong structural adjustments in the livestock sector, relying more intensively on forage crops and feed (Peeters 2009, 2012, Prochnow *et al* 2009, Thraen *et a*l 2005). At the same time, climate change concerns have led to new perspectives for biomass that can be used as a substitute to fossil fuels in order to reduce greenhouse gas emissions. Grassland-based feedstock (hay) can be used in a solid form to generate heat and electricity, but also as an advanced biofuel feedstock, through transformation of its lignocellulose, or as biogas through anaerobic fermentation. Several processes are currently envisaged for advanced biofuels: gasification followed by Fischer-Tropsch process to produce biodiesel; enzymatic or thermochemical hydrolysis followed by fermentation to produce cellulosic ethanol (Schubert 2006). As reviewed by (Peeters 2009), advanced biofuel would provide a better valorization of grassland feedstock as compared to heat and electricity from solid biomass, but the biogas fermentation pathway remains the most cost efficient.

However, the development of biofuel production can have indirect land use change effects leading to additional GHG emissions. The later can jeopardize the net GHG emissions savings of substituting fossil fuels by biofuels. As highlighted by a report to the EC (Valin *et al* 2015), the various types of pathways considered for biofuel production are contrasted with respect to such undesirable effects. It is thus important to evaluate such effects for the specific case of grass-based biofuels. In this study, we evaluate the potential indirect land use change effects of hypothetical scenarios in which grass in the EU is used to produce biofuel, with the same modeling framework as in Valin *et al* (2015).

1.2 Concepts and definitions

1.2.1 Grassland as an agricultural land cover & land use

UNESCO defines *grassland* as "land covered with herbaceous plants with less than 10 percent tree and shrub cover" (FAO 2005). At the EU level, more precise definitions has been adopted to better depict its various types of land covers and uses: it allows for distinction of the type of land management, and its permanence. We focus here on definitions related to grassland as an agricultural land use, while biodiversity questions will be discussed in the following section.

The Farm Structure Survey (FSS) of EUROSTAT provides the most detailed description of grassland areas within agricultural holdings. *Permanent grassland* is the area used for more than five consecutive years for herbaceous forage crops cultivation, irrespective of its management (i.e., sown or self-seeded, cut or grazed, cut frequency, nutrient and plant protection application, etc.). On the contrary, *temporary grassland* is part of the rotation scheme of arable land and replaced by some arable crops more frequently than every five years.

Permanent grassland is further split into two categories, based on criteria for soil quality, biophysical conditions (altitude, slope), and management (possibility of intensive mowing/high animal density grazing or not). The *pasture and meadow* class, also frequently referred to as *agriculturally improved grassland*, are areas with medium to good soil quality and can be used for intensive grazing. They are often subject to application of nutrients/crop protection chemicals. The *rough grazing* class, also frequently referred to as *semi-natural grassland*, are low-yielding permanent grassland areas (e.g., in hilly and high altitude areas) usually not improved by agricultural practices such as fertilizer application, improved species cultivation, reseeding or drainage. They cannot support intensive grazing or mowing. After a change in legislation in 2003, permanent grassland '*not used for production, eligible for subsidies*' was split as a third sub-category, and must be maintained in good agricultural and environmental condition. The above definitions is fully consistent with those of

1.2.2 Grassland and biodiversity preservation

EU grasslands host a large number of biodiversity rich areas, often more biodiverse than natural areas. Terrestrial biodiversity is declining world-wide (Steffen *et al* 2015), but also within EU, mainly through the intensification of agriculture and the fragmentation of natural areas under the sprawling of urban areas (EEA 2010). During recent decades, EU policies aimed to protect EU biodiversity, for example by the EU Birds and Habitats directives, Natura2000 network and integration of biodiversity protection in other pieces of legislation. The introduction at EU-level of the concept of High Nature Value (HNV) farmland (see definition below) highlighted the importance of permanent grassland for biodiversity. It also pointed to the urgent need to revise the EU Common Agricultural Policy (CAP) to prevent further biodiversity loss as only 20% of HNV farmland falls within Natura2000 protected areas. Requirements for biodiversity protection were also included in the Renewable Energy Directive (2009/28/EC). It states that biofuel obtained from '*highly-biodiverse grassland*' will neither be counted in the targets nor eligible for public support. Non-natural areas (such as agricultural grasslands) are however eligible if harvesting of the raw material is demonstrated to be required to maintain biodiversity.

In practice, these different definitions addressing the biodiversity aspect of grassland are not well quantified:

- HNV farmland areas designate 'those areas in Europe where agriculture is a major (usually the dominant) land use and where that agriculture supports, or is associated with, either a high species and habitat diversity or the presence of species of European conservation concern, or both'. Although spatially explicit indicators exist (Overmars et al 2014, Andersen et al 2003, Paracchini et al 2008), the definitions provide significant challenges (Lomba et al 2014), and have not yet been integrated with the above definitions of grasslands.
- EU agricultural grasslands can also fall under the 'highly-biodiverse non-natural areas', precisely defined in the Commission Regulation (EU) No 1307/2014 of 8 December 2014. However, no dataset yet depicts such areas in a spatially explicit manner, and no direct link to the notion of HNV farmland has yet been established.

1.2.3 Biomass productivity of grassland

A few definitions should also be clarified with respect to the biomass productivity of grassland. Definitions found in literature range from estimates of the yearly biomass growth (e.g., the *net primary productivity* NPP) to estimates of yearly biomass use for livestock feeding in various forms (*grass yield*, in analogy to annual crops). Grass yield differs from NPP by the assumption on the share of biomass withdrawn from grassland, often referred to as *off-take rate*.

These three parameters are interdependent and tightly linked to the way grassland is managed. If mowed, grassland NPP is influenced by the frequency of cuts, while the share of cut biomass over NPP defines the off-take rate. If grazed, the density of animals affects the NPP, and their withdrawal defines the off-take rate. In both cases, the NPP varies with the off-take rate: NPP usually declines with too high off-take rates, but can also be higher for a medium value than for a zero off-take rate. Highest yields can thus be achieved through management conditions that are often specific to species and biophysical conditions.

In a particular location, the current productivity deviates from the productivity under optimal management under the same biophysical conditions. It is thus important to differentiate between *actual* and *potential productivity*, for both NPP and yield.

Finally, they productivity and management of grassland is linked to its biodiversity. Grassland total productivity (including roots and litter) and plant species diversity follow a 'hump-shaped' relationship, meaning that species diversity is higher for a medium level of productivity than for a low or high productivity level (Fraser *et al* 2015). However, this provides little operational guidance when considering i) the type of criteria adopted by European institutions in various regulations (much wider that a species diversity index), ii) the difference between grass yield and grassland total productivity, and iii) the fact that grassland management is not a neutral factor in such matter (Aguiar 2005, Manning *et al* 2014). Overall, there is room for optimizing management of grassland in a direction that balances biodiversity and grass yield, but such ideal management options are not yet identified over all EU.

1.2.4 Bioenergy and liquid biofuels from grassland biomass

Using grassland to produce biofuels is a potential advanced biofuel pathway. To the difference of crops, grasses allows a better conservation of soil and maintains biodiversity within arable land (Tilman *et al* 2006, Blank *et al* 2014). However, the grassland yield depends on the type of grasses and the management intensity. Because cultivated perennial grasses have already been covered in previous studies (see GLOBIOM ILUC quantification study), we only focus here on biomass produced from natural grassland (typically ryegrass).

Several possible pathways are considered. The first pathway is the production of **lignocellulosic ethanol** through hydrolysis and fermentation. This method is the most direct approach to transform grasses into a gasoline substitute. For diesel, a Fischer-Tropsch gasification process can be used to transform lignocellulose into biodiesel. These two processes aim at maximizing the use of the biomass to produce the liquid fuel, but their conversion efficiency depends on the content of lignocellulose in the grass.

The second pathway consists in the production of **biogas**, to be used for gas-to-liquid technologies or biomethane uses in transport. Biogas is produced by using the full biomass fermentation in a biodigester, which leads to slightly higher transformation yields.

The third pathway considered here corresponds to the treatment into a **bio-refinery** that separates the different chemical components of the grasses to maximize their economic uses (e.g., Kamm *et al* 2010). At the beginning of the process, the biomass is separated into a press juice and a press cake. The press juice contains most of the protein and sugars to be separated, whereas the press cake keeps the fiber content and can be burnt or converted into biofuel. Such an approach is more costly and has lower conversion efficiency for biofuel, but it maximizes the added value of the different amino-acids from the plant.

2 Grassland availability in the EU, its production potential and biodiversity levels

2.1 Data sources for grassland resource in EU

In this section we describe the different datasets available to quantify in a spatially explicit manner the extent, productivity and biodiversity richness of EU grasslands.

2.1.1 Extent of grassland areas

The various sources that quantify grassland coverage in EU are summarized in Table 1 below.[1] The EUROSTAT FSS dataset estimates the grassland area of more than 75 land cover and use classes under agricultural holdings in the EU28. Classes include temporary grassland, permanent pasture & meadow, permanent rough grazing (i.e., semi-natural areas), permanent grassland not used for production but eligible to subsidies. It provides country level estimates updated every two to five years based upon sample surveys, except for years 2000 and 2010 for which the entire farm population is surveyed (census data). However, the legislation underpinning land cover & use classification changed in 2003: the data under the first legislation (estimates up to 2007) are available at NUTS2, but in some EU28 countries large jumps can be found between years 2005, 2007 & 2010.

A second EUROSTAT dataset (regional agricultural statistics RAS), provides yearly time series of land cover and use area extent from 1974 to 2014 at the NUTS2 level. However, the level of detail in land cover and use categories is much lower than for EUROSTAT FSS, and the NUTS2-level information is neither complete nor always consistent with the national level aggregate.

FAOSTAT also provides yearly estimates of the area extent of land cover and uses classes over total land (i.e., not only under agricultural holdings) from 1961 to 2012 at national level. However, the number of classes varies over time: until 1990, only three classes are available for EU (permanent grassland, permanent crops and agricultural area); from 1990 to 2000 two additional classes are available (Forest area and other area); after 2000 three more classes are progressively added (temporary fallow land, temporary grassland, temporary crops) but they are not available for all countries.

[1] The LUCAS dataset provides a unified description of all land cover types & uses, but we excluded it since it has only two years (2009 & 2012) and only one overall grassland land cover class is available via the EUROSTAT database (LAN_LCV_OVW database).

In the end, great care should be taken when exploiting time series of the two above mentioned EUROSTAT datasets: significant jumps exist over time for some countries, due to changes in legislation but also changes in the strategy dealing with methodologically problematic types of land (see, for instance, the issue of common land in EUROSTAT). This can be illustrated, for example, by diverging trends in terms of total area (see next section). FAOSTAT seems more stable over time, but it is difficult to understand how this was achieved.

Two additional datasets based upon a consolidated compilation of the above statistics are available:

- The dataset described in (Smit et al 2008) provides for all EU28 Member States (and more countries) the area of permanent grassland, total area and utilized agricultural area up to the NUTS2 spatial resolution (yearly over the 1974-2006 time span), and the area of temporary grassland at national level (around year 2000).
- The long-established CAPRI economic model of the EU agricultural sector (Britz and Witzke 2014) also contains a consolidated database of land cover and use available yearly at NUTS2 level from 1984 to 2010, among which permanent and temporary grasslands are considered as two separate classes.

Box 1 - Grassland extent in the EU: choices for datasets use within this study

- With respect to *static description of main grassland categories*, two datasets are retained:
    - EUROSTAT FSS (Member-States level), because it provides the most complete and detailed description of the resource at EU level, from EUROSTAT.
    - The Smit2008 & CAPRI datasets, because it provides consolidated statistics over EU at higher resolution, and a joint estimate of grassland productivity (see next sub-section)
    - CLC2000, because it provides a complete and high resolution description of the resource over EU using a different methodology (remote-sensing), and is used as the land use dataset basis for the GLOBIOM model.
- With respect to analysis of time trends in grassland extent and use, the most consistent dataset is most probably country-specific, and we use the most appropriate source on a per country basis.

Finally, a last source of information, the Corine Land Cover dataset, is based upon remote-sensing methods. It provides a very high-resolution (100 or 250 meters) an estimate of the actual land cover & use over EU28 (and more) countries. It is available for years 2000 and 2006. Also, 1990 is available but with limited country coverage. Finally, we also used data for the year 2000, hereafter referred to as the CLC2000 dataset. It provides three nested levels of land cover and use classifications, with respectively 5, 15 and 44 classes. The GLOBIOM model used in this study builds upon the CLC2000 dataset at the second level of classification: it distinguishes three classes potentially containing grassland: one 'pasture' class and one 'heterogeneous agricultural areas' class within agricultural areas, and one 'shrub and/or herbaceous vegetation' class within forest and semi-natural areas.

Table 1 - Summary of data sources available for quantifying grassland extent

Name	Source	Reference	Content	Spatial resolution	Spatial domain	Temporal resolution	Temporal domain
ES- FSS	EUROSTAT FSS (ef_oluft)	http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Farm_structure_survey_(FSS)	large detail (more than 75 classes) on the area of agricultural holdings, including temporary grassland, permanent grassland (rough grazing, pasture & meadow, unused, total)	MS, NUTS2 for some years	EU28	(1990, 1995, 1997, 2000, 2003, 2005, 2007, 2010, 2013)	1990-2013
ES-RAS	EUROSTAT Regional Agricultural statistics (agr_r_landuse)	http://ec.europa.eu/eurostat/statistics-explained/index.php/Agriculture_statistics_at_regional_level#Data_sources_and_availability	small detail on the area of agricultural holdings (total area, utilized agricultural area, permanent grassland area are the most robust))	NUTS2	EU28	yearly	1974-2014
CLC2000	CLC2000 land cover & use data	http://www.eea.europa.eu/publications/COR0-landcover	Area per land cover (3 levels of classification - with resp . 5, 15 & 44 levels -)	100 or 250m	EU28+	(1990, 2000, 2006)	1990-2006
FAOSTAT	Various	http://faostat3.fao.org/mes/methodology_list/E	Area per land cover & use for 10 classes (including temporary and permanent grassland)	MS	EU28++	yearly	1961-2012
Smit2008	Various (EUROSTAT/FAO) sources compiled by Smit et al. 2008	Smit et al. 2008	permanent grassland, temporary grassland (country only), utilized agricultural area, productivity of permanent grassland	varying (NUTS2 to Country)	EU28 ++	yearly	1973-2006
CAPRI	Various sources (EUROSTAT mainly)	Tech. documentation of 2014	Permanent & temporary grassland area	NUTS2	EU28	yearly	1984-2010

2.1.2 Biomass production from grassland

Three sources of grassland production data were compiled for this study (see Table 2). In general, there are only few estimates of grassland biomass productivity with complete coverage of the EU28 Member States, for various reasons. Firstly, data collection and reporting of such data from statistical agencies did not start until very recently. Secondly, there is limited possibility (compared to crops) to rely on production and area statistics since they do not easily relate, and iii) such data in itself is much less monitored by farmers (in particular for grazed areas) and are not subject to commercial exchange under monitored markets. Finally, the estimates available rarely report the nature of the productivity reported (e.g, NPP vs. grass yields).

Three main types of methods are used:

- **Remote sensing.** Such a method is based upon indices of reflectance (NDVI index), generally combined to a map delineating grassland areas. As analyzed by Smit *et al* (2008), remote sensing-based estimates are largely departing from literature values due to classification and calibration difficulties.
- **Statistics and expert opinions**. EUROSTAT provides grass yield values at country level (APRO_CPP_CROP database) including permanent meadows, pastures as well as temporary grazing, but data are unavailable for most Member States, which means the picture is incomplete. However, some more complete datasets have built upon EUROSTAT data:
    - Smit and colleagues completed EUROSTAT information with national statistics and literature values. They report actual productivities at various spatial resolutions over EU28 MS (from NUTS2 to country level) around the year 2000. However, the authors do not indicate whether they report NPP or grass yield.
    - The CAPRI dataset reports a productivity value yearly at NUTS2 level over 1984-2010, estimated from the harmonization of many data sources within EUROSTAT database, and additional expert estimates. While it is not clear whether the productivity reported is NPP or grass yield, it seems likely that it is closer to NPP, since the database also reports feed, which is systematically lower. The difference in productivity and the feed requirements per hectare could thus be interpreted as the off-take rate.

Biophysical model. This method can differentiate actual from potential productivities and NPP from off-take rate and grass yield. It also accounts for climatic, biophysical (soil, altitude & slope) and management factors. Estimates can however significantly differ from literature values, in particular due to the lack of information on actual management, and to the lack of calibration on all possible management, climatic and biophysical conditions. The IIASA dataset (upon which the GLOBIOM model relies) contains a suite of several spatially explicit estimates of NPP, grass yield and off-take rates generated with EPIC, DAYCENT and CENTURY models. This dataset is available at the NUTS2 level, and incorporates estimates of switch grass productivities for varying levels of fertilizer intensity, as well as of productivities under semi-natural type of grasslands. In-depth description of the data can be found in (Havlík *et al* 2014).

Table 2 - Sources of data for quantified grassland productivity estimates

	Source	Reference	Variable	Spatial resolution	Spatial domain	Temporal resolution	Temporal domain
CAPRI	Various (EUROSTAT/expert estimate)	(Britz and Witzke 2014)	productivity (tDM/ha) of grassland (unspecific type of grassland, unspecified type of variable), total feed (i.e., used grass yield)	NUTS2	EU28	yearly	1984-2010
Smit2008	Various (National statistics/literature) sources compiled by Smit et al. 2008	(Smit *et al* 2008)	productivity (tDM/ha) of grassland (unspecific type of grassland, unspecified type of variable)	Various (MS to NUTS2)	EU28 ++	1 point	year 2000
IIASA	Various biophysical models	(Havlík *et al* 2014)	NPP (tDM/ha), off-take rate, grass yield (various management)	NUTS2 Name	EU28	1 point	around year 2000

2.1.3 Biodiversity within agricultural grassland

As explained in section 1.2.2, the concept of High Nature Value farmland is the most complete description of biodiversity over EU agricultural areas. Although not directly corresponding to the 'highly-biodiverse non-natural areas' as referred to in the EU RED, it is the closest related concept for which data is available at EU level. We rely on the dataset developed jointly by the European Environmental Agency and the Joint Research Center (Paracchini *et al* 2008), a geographical overlay at high spatial resolution of biodiversity measures on the one hand, and land cover and land use information on the other hand. Biodiversity indicators combine various datasets available at EU level (Natura 2000 network, Important bird areas, Prime Butterfly Areas) and national level, depicting locations hosting a large population of (or providing a key function for) endangered species, and covered by the Birds and Habitats European Directives. The land cover and use information relies on the CLC2000 dataset, in particular land CLC2000 classes related to agricultural activities. The geographical overlay is done at a resolution of 100 meters, and the results are aggregated in the form of a likelihood of HNV farmland at the resolution of 1 km.

As recognized by the authors, the methodology should not be considered accurate enough so that it would provide official estimates of HNV farmland area. They instead advise to use it as an indicator, and provide at the level of NUTS2 regions the share of agricultural land that can be considered as likely of High nature Value farmland.

2.2 Past and current use of grassland resource

2.2.1 Current geography of EU grasslands

Area extent. According to EUROSTAT FSS, and as illustrated in Figure 1, grassland covered in 2013 about 70.5 million ha within EU agricultural holdings. It is decomposed as follows: temporary grasses (16%), permanent pasture & meadow (54%), semi-natural permanent area (28%), and unused permanent grassland (2%). Except for Scandinavian countries where temporary grassland dominates, in most EU28 countries more than two-thirds of grassland is permanent. Within these countries, semi-natural permanent grassland forms more than 50% of permanent grassland in most Mediterranean countries (Spain, Greece, Portugal, Cyprus, Croatia) and in countries like Hungary, Bulgaria, and Latvia.

Actual & potential productivity. There is a general agreement that grassland potential productivity is mostly driven by a combination of biophysical and rainfall conditions. As illustrated by the Smit et al., (2008) dataset in Figure 2, highest productivities can be found in North Western countries of EU28 (Ireland, the Netherlands, UK, etc.), which correspond to humid areas where most of the good soils and improved grassland are located. Many countries from the Mediterranean basin are having the lowest productivity values, where water is the most limiting factor. Figure 2 only displays what is likely actual yield: as noticed by the Smit and colleagues, actual yield could remain at present largely below its potential in the Baltic countries, and could be improved on pastures by fertilizer application and improved grass species.

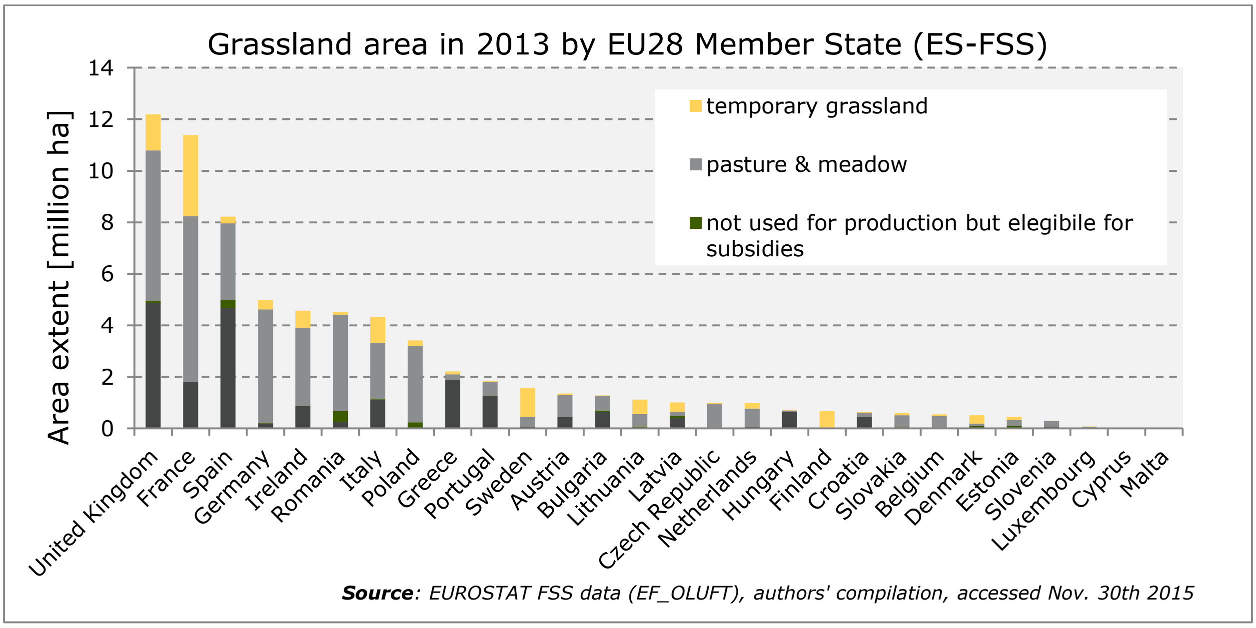

Figure 1 - Grassland area extent by type of grassland and EU28 Member State in 2013, according to EUROSTAT Farm Structure Survey.

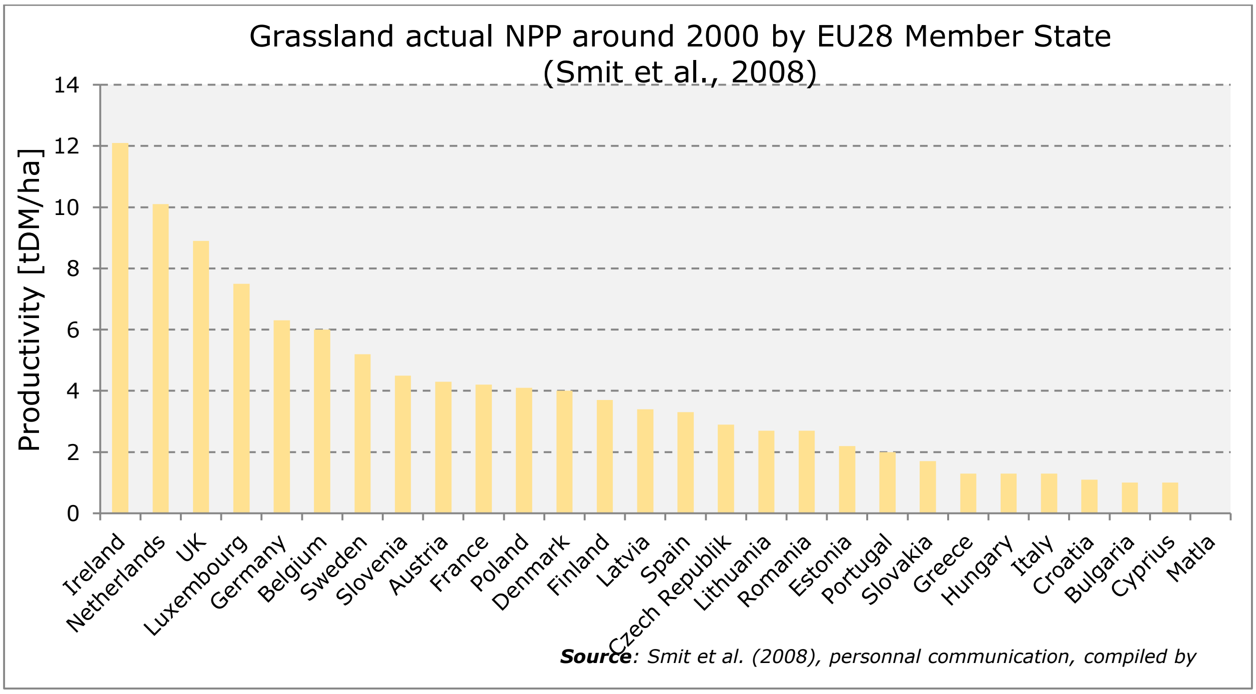

Figure 2 - Grassland productivity by EU28 Member State around year 2000, according to Smit et al 2008.

Biodiversity content. As it can be seen in Figure 3, the Mediterranean, Carpathian and Alpine environments, parts of UK and Eastern and Central EU have a high density of HNV farmland, while regions of Mid-Western EU have a lower density of HNV farmland.

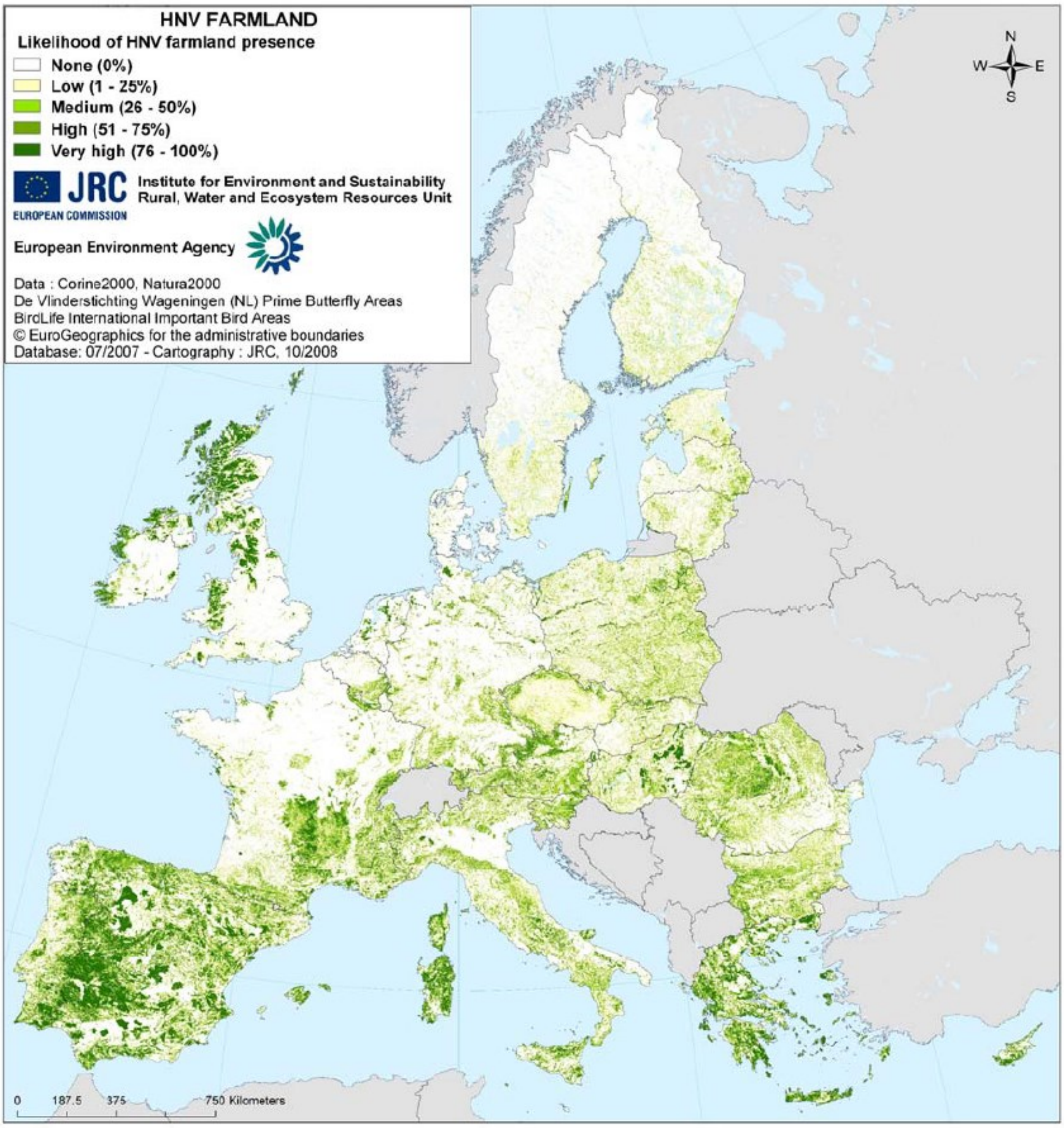

Figure 3 - Map of HNV farmland presence likelihood over EU (source: Paracchini et al 2008).

2.2.2 Agricultural and pasture area trends in the EU

Table 3 provides an overview of agricultural land use changes in the different EU countries since 1993. Agricultural areas in the EU have decreased over the past decades, as a consequence of changes in agricultural policies and production levels, of productivity increases and of land uptake for other uses. According to EUROSTAT FSS, utilized agricultural area dropped by 453,000 ha per year in the EU15, and by 216,000 ha per year in the EU25[2]. New Member States report increases in their utilized agricultural area over the past decade, but these do not compensate for the decrease observed in the EU15.

In parallel, permanent pasture and meadows in the EU have reduced on the same period. About 111,000 ha of pasture were lost per year between 2003 and 2013 in the EU15. However, the overall decrease in the EU28 amounts to -59,000 ha per year only, a large part of the difference driven by Bulgaria and Croatia. The decrease is larger according to the EUROSTAT RAS with 370,000 ha of pasture lost per year for the EU28 in the last decade[3]. Over the same period of time, forage area also increased significantly which suggests further use of cropland for animal feeding purpose.

Table 3 - Annual variation in utilized agricultural area and grassland area in the different EU Member States on the period 1993-2013 according to EUROSTAT (1000 ha per year)

	Utilized agricultural area		Permanent pasture and meadows		Forage crop area	
[1000 ha per year]	**1993-2003[a]**	**2003-2013[b]**	**1993-2003[a]**	**2003-2013 [b]**	**1993-2003[a]**	**2003-2013**
Belgium	5	-9	1	-5	0	0
Bulgaria		89		31		0
Czech Republic		-14		7		-4
Denmark	-8	-4	-2	1	9	12
Germany	NA	-28	NA	-32	NA	117
Estonia		16		7		-2
Ireland	2	24	-32	35	32	-9
Greece	43	-81	32	-42	1	6
Spain	46	-188	35	-56	-7	7
France	NA	-81	NA	-81	NA	19
Croatia		157		62		12
Italy	-162	-102	-58	-2	-30	25
Cyprus		-5		0		1
Latvia		39		13		10
Lithuania		37		-41		38

[2] This does not account for 'common land' for countries having added this land use category to their farm survey in 2010, namely Bulgaria, France, Greece and Ireland. See http://ec.europa.eu/eurostat/statistics-explained/index.php/Common_land_statistics_-_background

[3] The discrepancies between the annual crop statistics and the farm structural surveys are not possible to reconcile with the current information provided through EUROSTAT, because many differences, coming from variation in methodologies, are not fully documented by national agencies. See section 17 in http://ec.europa.eu/eurostat/cache/metadata/en/ef_esms.htm

	Utilized agricultural area		Permanent pasture and meadows		Forage crop area	
Luxembourg	0	0	0	0	0	0
Hungary		30		17		1
Malta		0		0		0
Netherlands	-1	-16	-18	-10	16	2
Austria	NA	-53	NA	-51	NA	2
Poland		-2		7		41
Portugal	-22	-8	61	32	-2	-1
Romania		-87		-25		14
Slovenia		0		0		1
Slovakia		-24		-26		2
Finland		1		0		2
Sweden	NA	-9	NA	-3	NA	18
United Kingdom	-28	99	18	103	-31	30
TOTAL EU15	-125	-453	36	-111	-12	231
TOTAL EU25		-375		-127		319
TOTAL EU28		-216		-59		344

[a] Only EU15 Member States available, except Germany, France, Austria, and Sweden.

[b] After analysis of FSS statistics and common land accounting, FSS data were corrected for common land in 2010 and 2013 for Bulgaria, France, Greece and Ireland. Source: EUROSTAT Farm Structural Survey

When looking at country level, dynamics of utilized agricultural area, pasture and forage crop area are more contrasted. In Spain, about 56,000 ha per year of permanent grassland were lost between 2003 and 2013, while utilized agricultural area decreased by 188,000 ha per year. In France and Germany, permanent pasture areas decreased by respectively 88,000 and 32,000 ha/year during the last decade. This is closer to their agricultural area decrease. Some other regions such as the UK even reported strong increases in pasture area over the last decade (by about 103,000 ha/year). Interestingly however, areas of forage crops have increased in all these countries in the same period, and the trend has been particularly strong in Germany (117,000 additional ha/year).

2.2.3 Livestock grazing needs

The patterns on land use change above need to be put in comparison with the dynamics in the livestock population and the corresponding grazing needs in the EU.

A decrease in ruminant population. The ruminant herd size in the EU decreased over the past decades. Cattle herd has been decreased by 13% between 1993 and 2003, and by an extra further 5% between 2003 and 2013. The decrease is stronger for sheep and goats (-16% and -12% over the same periods). Figure 4 and Figure 5 illustrate the situations at the level of the different Member States: the cattle decrease can be seen in all countries except for Ireland, Spain and Portugal. The population decrease in head has been observed in all countries without exception for sheep and goats.

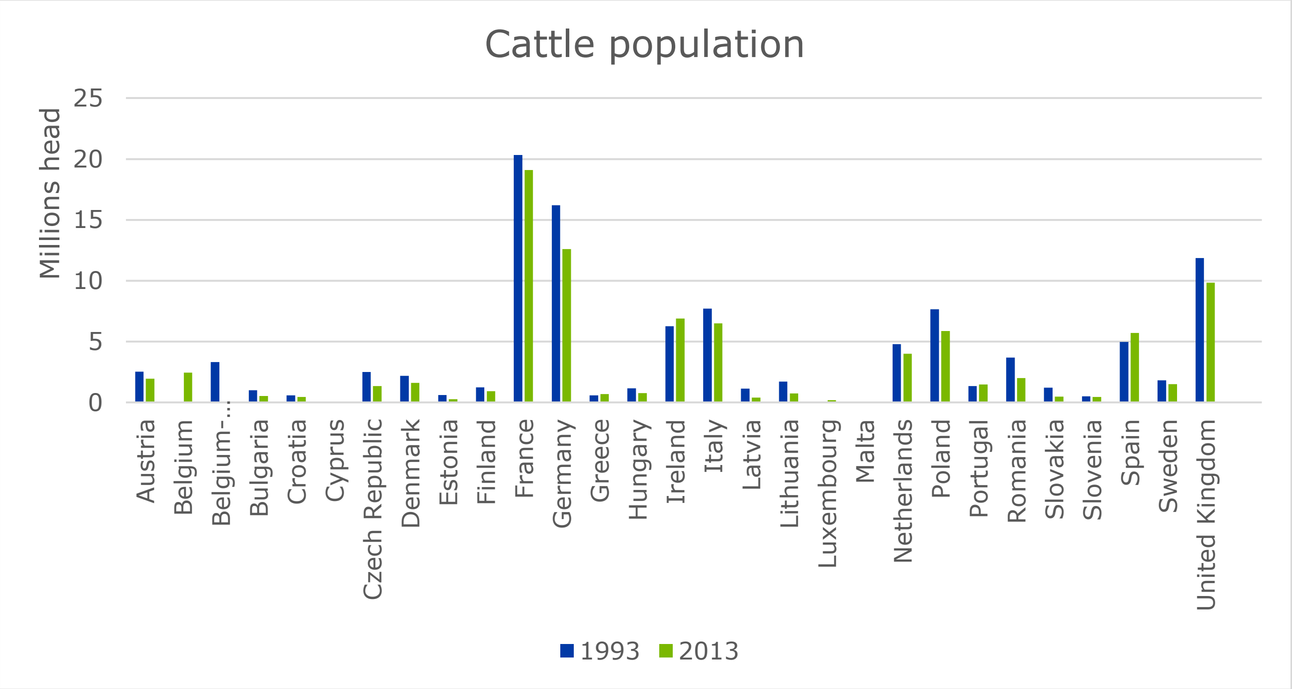

Figure 4 - Number of cattle head in the different EU Member States in 1993 and 2013 (million heads).

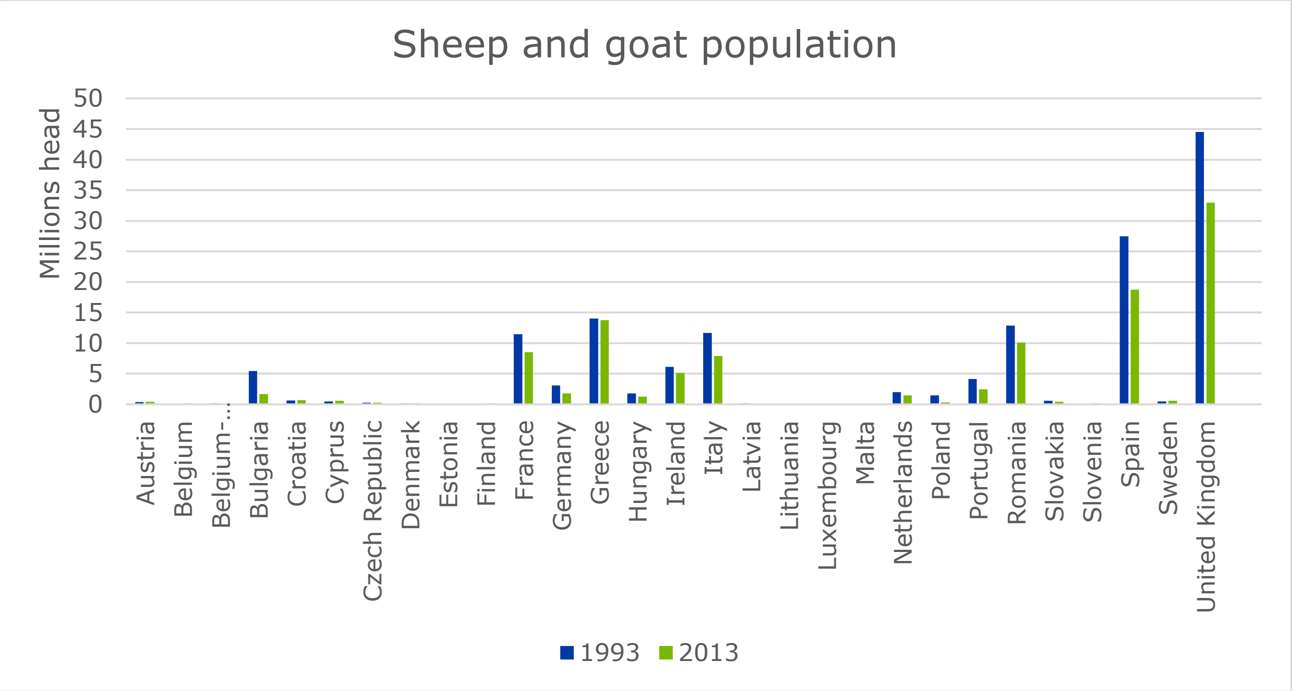

Figure 5 - Number of sheep and goat heads in the different EU Member States in 1993 and 2013 (million heads).

No obvious trend in livestock grazing needs. The decrease in ruminant population did not necessarily lead to a decrease in grazing needs, since productivity per head has increased over the same period, for both meat and milk production. For instance, in 20 years, dairy herd size has decreased in the EU by 18%, whereas milk production has remained constant. Overall patterns of change can be observed on Figure 6.[4]

To identify where grassland resource might have been made available, we looked at joint variations of grassland area and meat and milk production by country (Figure 7):

- Ruminant meat production has decreased concomitantly to milk in France, Italy, Czech Republic or the United Kingdom (left panel). Grazing needs are therefore likely to have decreased in these countries, where grassland is more likely to be available. However, permanent pasture decreased in France (right panel) and remained stable in Italy and Czech Republic: except for the UK, it is not clear whether grassland has recently been made available.
- In Ireland the permanent pasture has increased while production remained stable: this also indicates potentially available grassland, similar to the case of UK.
- In Germany, the Netherlands or Romania, meat production decreased but milk production increased. The total increase in total ruminant protein production increased in Germany and Austria. Meanwhile, grassland decreased and therefore it is likely that little grassland has been made available in these countries.

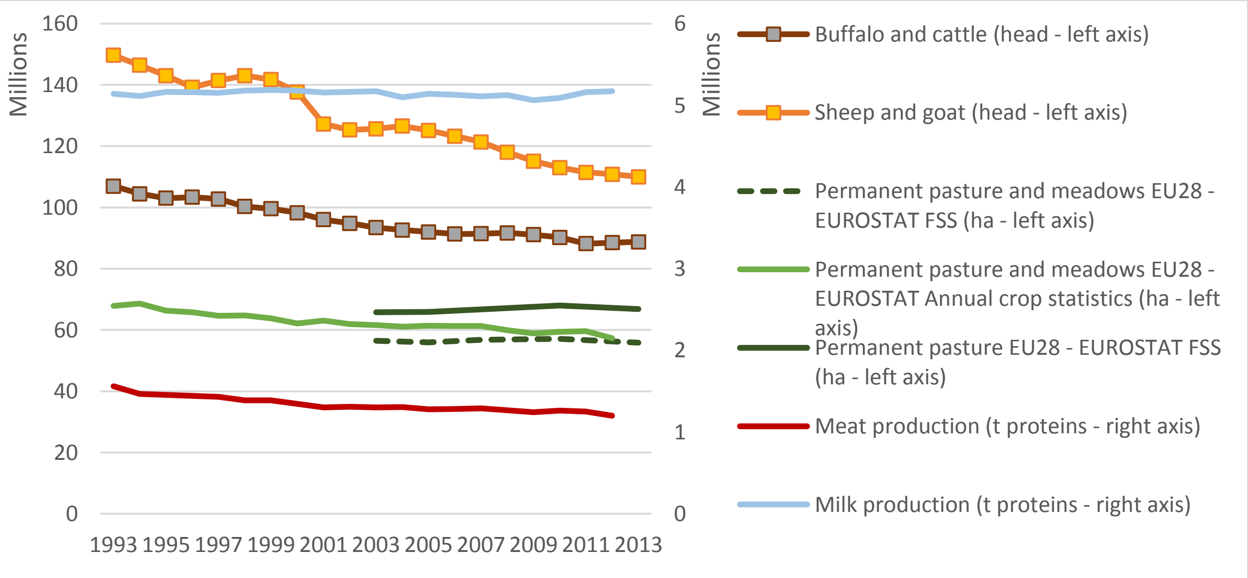

Figure 6 - Patterns for livestock herd size, production and pasture areas in the EU28 between 1993 and 2013

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[4] Note that this trend differs from time series from FAOSTAT, which report for the EU a decrease since 2000 of 5 million ha of grassland. The causes for these difference have not been identified, and EUROSTAT data have been kept as the reference.

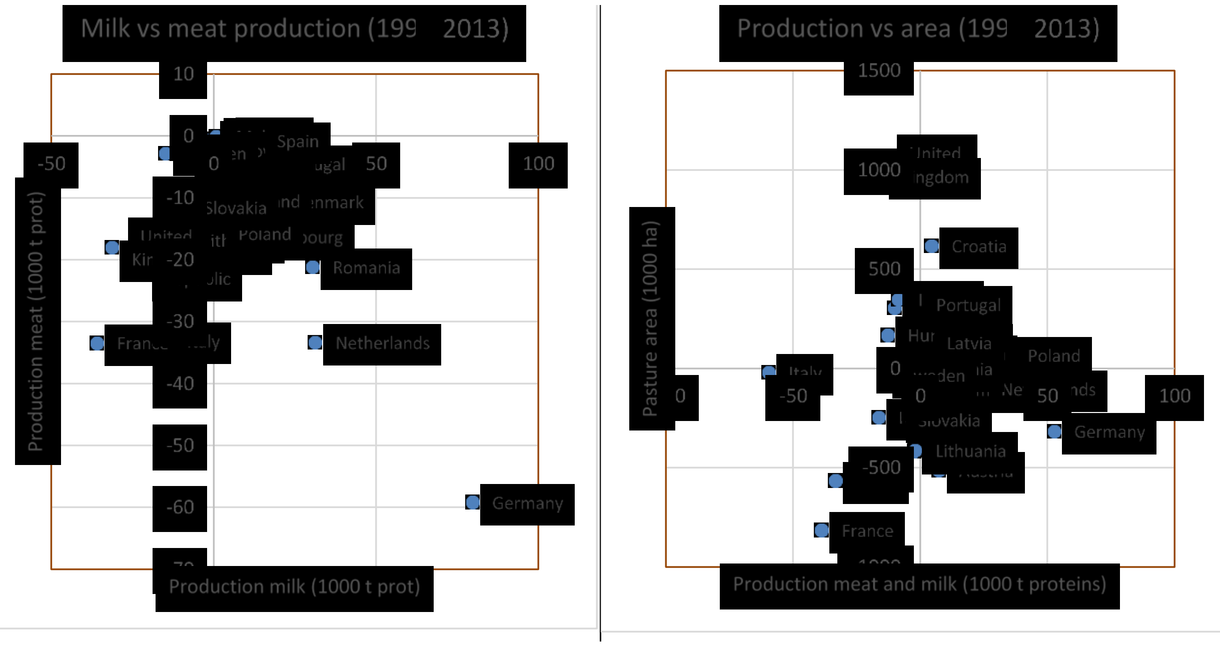


Figure 7 - Change in milk and ruminant meat production (left) and total ruminant production versus permanent pasture area (right) in EU28 countries between 1993 and 2013

2.3 The prospect for future grass biomass availability

The opportunity of using grassland in a close future for new uses such as bioenergy production remains subject to many uncertainties on the points investigated above.

To summarize, future potential will depend on:

- **Potentially available grassland area:** The exact amount of grassland area and the degree of its use does not allow delineating where grassland area has recently been made free on a spatial basis. The main uncertainty lies mostly in the potential for interaction with the livestock sector and its dynamic over various regions of EU.
- **Achievable grassland yields:** The actual and potential level of grassland productivity in EU is uncertain. However, a few studies highlighted potential gains in total grassland feedstock achievable in EU via an improved grassland management.
- **Stringency of environmental regulation:** While it seems there is room for increasing grassland productivity via changes in management practices, increasing attention is given in the EU to the role of agriculture on the environment (agri-environmental measures, ecosystem focus areas, sustainability criteria for biofuels).
- **Technological pathways:** Depending on the processing pathway used for biofuels, the amount of grass needed will vary. The grass conversion efficiency is also depending on the chemical composition, in particular the lignocellulose content.

- **Interaction with the livestock sector:** Grassland biomass is an important part of the feed basis of EU livestock production, which could be impacted by the alternative economic valorization provided by a biofuel pathway. This competition can have large economic and environmental implications.
- **Livestock sector future development:** Future prospect on red meat and dairy product demand in the EU is an important source of uncertainty for the sector. If current trend of meat demand were to continue, the grassland biomass available would be much higher than at present day. However, land management restrictions, biodiversity conservation and common agricultural policy development can also drive grassland availability in different directions.

3 Model & Scenarios

3.1 The GLOBIOM model

For our analysis, we rely on the Global Biosphere Management Model (GLOBIOM, Havlík *et al* 2011). This model has already been used for the analysis of ILUC quantification of first and second generation biofuels and documented on the internet website of this project (www.globiom-iluc.eu).

GLOBIOM is a global partial equilibrium model integrating the agriculture and forestry sectors in a bottom-up setting based on detailed grid-cell information. It is used to analyze global issues concerning land use competition between the major land-based production sectors up to 2050. The model has been applied already to a large set of topics, the most relevant for this study being bioenergy policies (Havlík *et al* 2011, Valin *et al* 2015, Mosnier *et al* 2012b), deforestation (Mosnier *et al* 2012a), long-term development of the agricultural markets (Valin *et al* 2013, 2014), or mitigation in the livestock sector (Havlík *et al* 2014, 2015).

GLOBIOM is particularly well adapted to the study of the grass biomass and its use by the livestock sector. The model features a spatially explicit representation of the grassland cover with productivity estimates based on soil, slope, altitude and local climate. The dataset used for grassland in the EU has in addition been refined for the purpose of this project (see Appendix). The livestock production activities are defined in several alternative production systems adapted from Sere *et al* 1996: for ruminants, grass based systems (arid, humid, temperate/highlands), mixed crop-livestock systems (arid, humid, temperate/highlands), and others; for monogastrics, smallholders and industrial systems are distinguished. Animal outputs include four meat types, milk, and eggs, and environmental factors are also estimated (manure production, N-excretion, and GHG emissions).

For each species, production system, and region, input-output parameters are calculated based on a digestion model (RUMINANT). Feed rations consist of grass, stovers, feed crops aggregates, and other feedstuffs. The representation of the grass feed intake is an important component of the system representation as grassland productivity is explicitly represented in the model. Therefore, the model can represent a full interdependency between grassland and livestock. Sparing grassland can only be reached by change in total demand, animal productivity and spatial reallocation of the production to more productive grasslands. Switches between production systems define the feedstuff substitution and the intensification or extensification of livestock production. For more details on this feature, see Havlík *et al* (2014).

3.2 Scenario description

The analysis above has highlighted the different dimensions of uncertainty for future grassland resources. The feasibility of a scenario using grass as a feedstock will depend on the quantities required for biofuel production, the type of technology used, and the amount of grass that will be made available. Based on this diagnostic, we propose different scenarios articulated across three processing pathways, four different biodiversity settings and three different level of biomass extraction per technology (see Table 4).

Table 4 - Scenario design for analysis of the impact of using grass as a biofuel feedstock

Scenario name	Technological pathway	Incorporation level of grass-based biofuel in EU transportation fuel	Biodiversity protection
Biogas scenarios			
Gas05	Biogas	0.5%	RES sustainability criteria
Gas1	Biogas	1%	RES sustainability criteria
Gas2	Biogas	2%	RES sustainability criteria
Ethanol scenarios			
ETOL05	Cellulosic ethanol	0.5%	RES sustainability criteria
ETOL1	Cellulosic ethanol	1%	RES sustainability criteria
ETOL2	Cellulosic ethanol	2%	RES sustainability criteria
Biorefinery scenarios			
BioR05	Biorefinery	0.5%	RES sustainability criteria
BioR1	Biorefinery	1%	RES sustainability criteria
BioR2	Biorefinery	2%	RES sustainability criteria
Biodiversity scenarios			
Gas1_noHNV	Biogas	1%	RES sustainability criteria
Gas1_HNV30	Biogas	1%	*Exclusion of regions with HNV farmland likelihood > than 30%*
Gas1_HNV20	Biogas	1%	*Exclusion of regions with HNV farmland likelihood > than 20%*
ETOL1_HNV20	Cellulosic ethanol	1%	*Exclusion of regions with HNV farmland likelihood > than 20%*
BioR1_HNV20	Biorefinery	1%	*Exclusion of regions with HNV farmland likelihood > than 20%*

The *Baseline* scenario corresponds to an updated version of the reference scenario used on the GLOBIOM ILUC quantification study. It differs only through an updated livestock sector parameterization, with new data on grazing distribution and more precise estimates of meat and milk demand prospect in the EU by 2030, following the literature review of this report. In the *Baseline* scenario, no grassland is used for biofuel production.

A first group of scenarios considers the current prescription on biodiversity protection under the sustainability criteria (first nine scenarios in Table 4). These scenarios consider three different technological pathways:

i. biogas with three different levels of incorporation: 0.5% in *Gas05*, 1% in *Gas1* and 2% in *Gas2,*
ii. cellulosic ethanol with the same levels of incorporation than for biogas: 0.5% in *ETOL05*, 1% in *ETOL1*, and 2% in *ETOL2*,
iii. green bio-refinery with the same levels of incorporation compared to the previous scenarios: 0.5% in *BioR05,* 1% in *BioR1* and 2% in *BioR2*.

Conversion efficiencies and coproduct yield associated to these three pathways are provided in the technical appendix of this report. All the shocks considered are applied at the 2030 time horizon. Levels of biomass required to provide the 1% vary depending on the feedstock considered. A back on the envelop calculation suggests that a target of 1% would require approximately 8%, 11% and 16% of the current grazing resources in the EU, for biogas, cellulosic ethanol and green bio-refineries, respectively.

Varying the level of biodiversity protection is the second dimension of our analysis. By default, we consider that grass used for bioenergy cannot be sourced from areas under HNV farmland. These areas are estimated by taking the likelihood of HNV farmland in each region and multiplying it by the total area of grassland. The HNV farmland areas estimated that way are excluded in all the scenarios above from bioenergy production. However, we test the effect of two variants in biodiversity protection. These two variants are applied to the *Gas1* scenario (grass biogas for 1% incorporation). In the first scenario *Gas1_HNV30*, all NUTS2 regions where HNV farmland likelihood exceed 30% are excluded from bioenergy sourcing regions (in dark green on Figure 8). In the second scenario, *Gas1_HNV20*, the excluded regions are extended to NUTS2 regions with more than 20% likelihood of HNV farmland (two darker levels of green on Figure 8). As a counter-factual, we also consider the case where no sustainability is applied, i.e. no restriction are considered for HNV farmland. This corresponds to the scenario *Gas1_noHNV.* In order to compare the impact of the biodiversity variant across the pathway, the stricter biodiversity protection scenario is also considered for the cellulosic ethanol and the biorefinery pathways (*ETOL1_HNV20* and *BIOR1_HNV*).

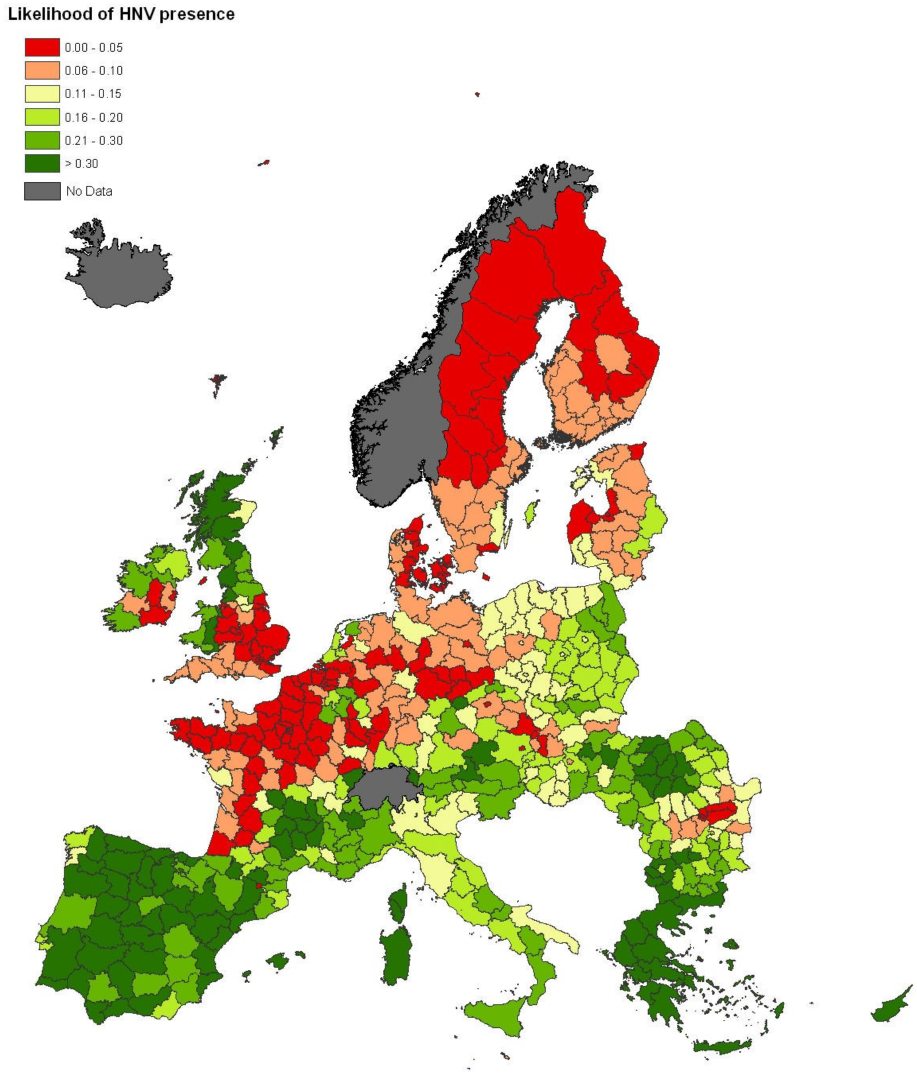


Figure 8 - Likelihood of High Nature Value farmland presence in EU NUTS region (source: Paracchini 2008)

4 Model results

4.1 Baseline results

Our baseline scenario considers that the demand for meat in the EU will follow the structural changes observed so far with substitution between ruminant meat and pig and poultry meat. Demand for beef and lamb meat in the EU is expected to continue to decrease over the next decades, which will increase the availability of grass. As illustrated in Figure 9, the consumption of beef meat decreases by 9% and lamb meat by 11% between 2000 and 2030. During the same period, pig and poultry meat and eggs, which already constitute the largest part of meat demand, increase by 17%. However, this substitution does not necessarily means that pressure on grassland decreases because consumption of milk remains strong with a slight increase by 4%.

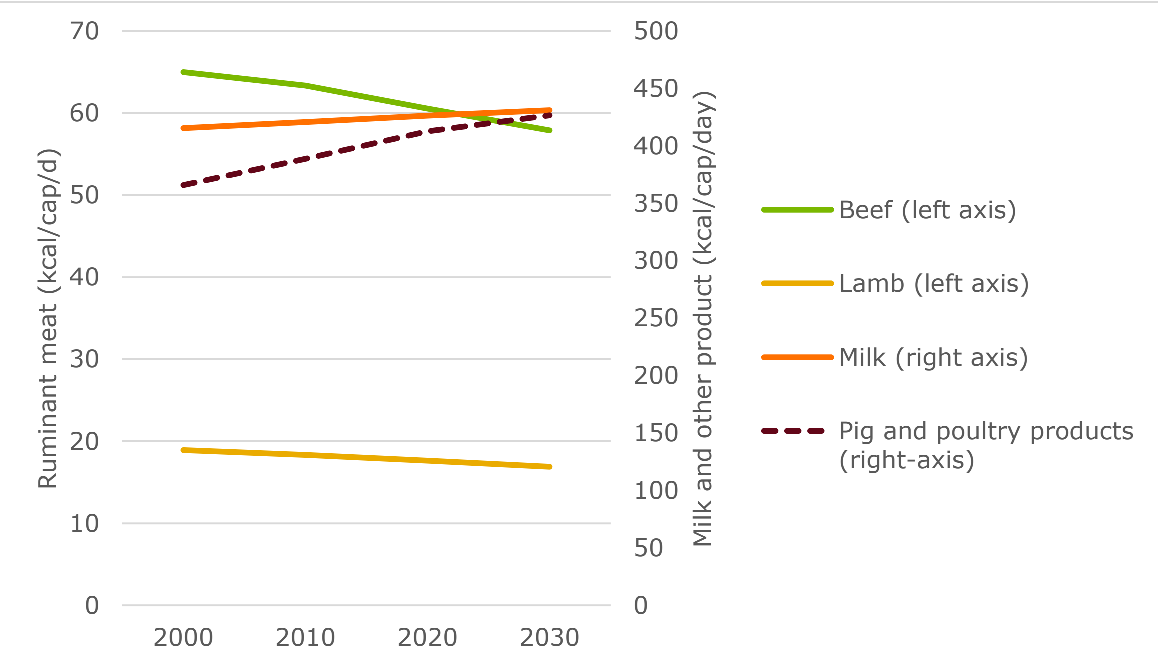


Figure 9 - Demand per capita for meat and milk products in the EU28 between 2000 and 2030.

These trends translate into changes for the livestock sector production levels and number of animals. Indeed, despite an increasing global demand, the EU28 does not increase its export due to its lack of competitiveness on the international markets. Production of beef and lamb meat decreases by 510 thousand tons between 2000 and 2030. The milk sector, in contrast, continues its production increase with 12.8 additional million tons in the same period. Herd sizes are adjusted accordingly (Figure 10), with a decrease in the number of ruminant in the EU, in particular in Western EU where the herd size is decreased by 8%, in particular through the non-dairy herd (-12%). Animal number is found to decrease in all regions, except in North of the EU where the production remains stable due to the increase in milk and dairy consumption.

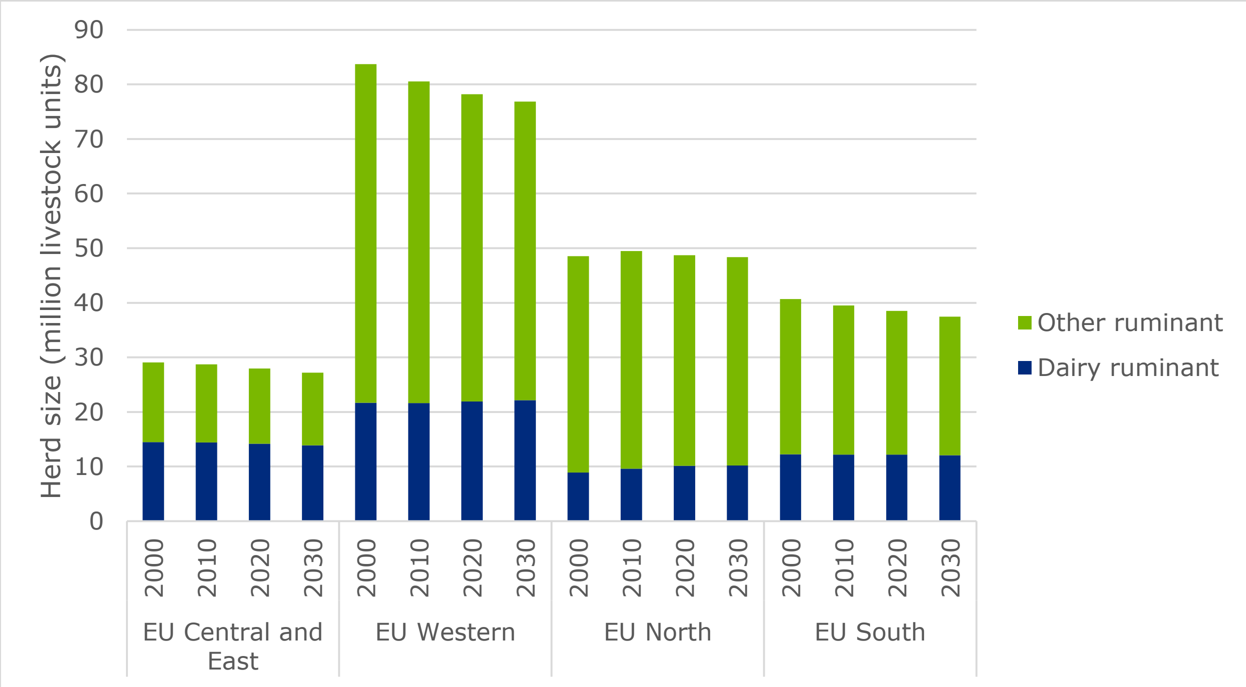
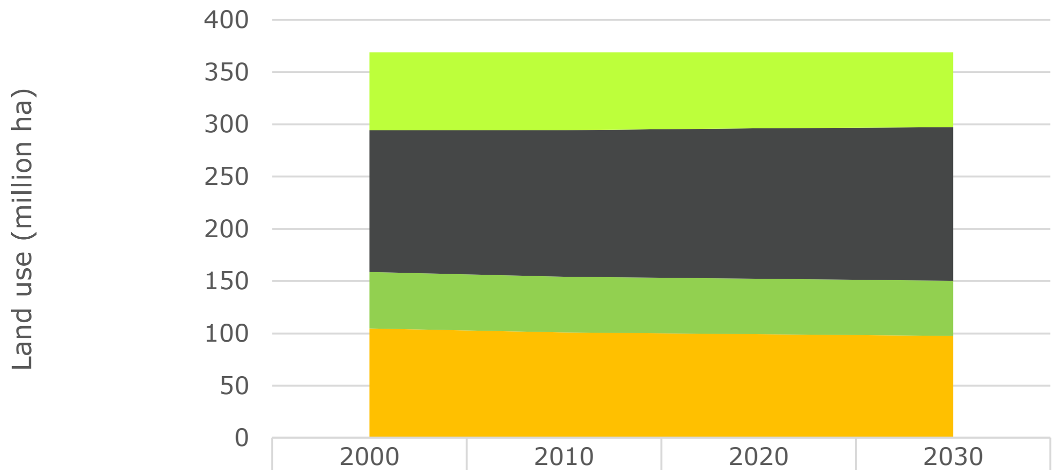


Figure 10 - Herd size in the different EU28 macro regions (in million livestock units, livestock unit here is used in the sense of FAO, i.e. 1 unit is equivalent to an animal of about 250 kg).

Changes in herd size affect the demand for grazing and decrease the use of grassland. Figure 11 shows the change in the different land use in the model baseline for the EU. Grassland is found to decrease by 1.2 Mha between 2000 and 2030. This decrease is however lower than the cropland decrease, which reaches 7 Mha on the same period. This decrease of cropland is also related to the livestock production decrease because animals require forage crops and concentrate rations made from cereals and oilseeds. Land use change occurs to the benefit of forests that increases by 11 Mha, and expands also at the expense of other natural vegetation, including previously abandoned cropland.



	2000	2010	2020	2030
Other natural land	74630	74510	72703	71613
Forest	135536	140164	143903	146893
Grassland	54005	53262	53034	52804
Cropland	104687	100922	99218	97547

Figure 11 - Land use in the EU on the 2000-2030 period in the baseline (million ha, and thousands ha in Table)

4.2 Effect of grassland biofuels scenarios

We apply the different grass biofuel shocks detailed above to the model to assess how the different indicators are departing from the baseline. For each scenario, the shock is applied at the horizon 2030 with an overall target for the whole EU (no country specific targets), while assuming all grassland biomass-based biofuel is produced with a single specific pathway (specific to each scenario). The shock translates in the model as an inelastic demand of additional grassland biomass to be supplied, at the EU28 level. This means that the model is free to determine which regions are the most cost-competitive to provide the feedstock.

4.2.1 Regional patterns of the grass biofuel production

The contribution of the various countries to the shock (in percentage of total biomass requirement) largely depends on the level of biomass required (see Figure 12). This is due to the fact that biomass availability and average opportunity costs largely vary across countries.

UK and Ireland (and to a lesser extent Poland and Romania) have significant grassland biomass reserves (up to 14 million tons of dry matter) that could be used for a relatively low cost. These countries are the first to source biomass for small shock (e.g *Gas05* or *Gas1* scenarios). When total biomass requirements further increases (e.g. *Gas2*, *ETOL1, ETOL2*), other countries start to contribute to the overall demand (Spain, France, Germany, Netherlands & Sweden). Beyond a total of 20 (respectively 30) million tons of dry matter, marginal grass demand is largely sourced from France (respectively Germany, see scenarios *ETOL2*, *BioR1, BioR2*).

Overall, the choice of the technological pathway makes a large difference in geographical patterns of production for a given target. This is directly driven by the differences in conversion efficiency (and hence total biomass requirements). For an incorporation target of 1%, biomass would be sourced mostly from the UK and Ireland if assuming a biogas pathway (requirements of 12 Mt DM). If assuming a bioethanol pathway for the same target (requirements of about 17 Mt DM), UK and Ireland would be contributing slightly more than the previous case. But this would represent only about two thirds of the contribution, and contribution of a larger number of countries would be needed. Under a bio-refinery pathway (requirements of 26 Mt DM), France would become significant producer.

These geographical patterns and their strong dependency on the total amount of biomass required result from to two main factors. On the one hand, grassland production costs vary spatially: the higher the total biomass requirement, the higher the market value associated to the use of grassland for biofuel production. While for a small shock it is economically interesting to produce biofuel-dedicated grassland biomass only in a limited amount of places, it becomes economically viable to produce over larger areas as the total biomass requirement increases.

On the other hand, the total grassland area, its productivity, and its use for producing various products differ widely across countries. This provides the basis of the geographical patterns in production costs. UK and Ireland are the first countries to contribute and are with the biggest producers. This is fully consistent with the literature, reporting that these countries have large grassland area and the highest grassland productivity in EU. It is also fully consistent with our analysis of recent trends in grassland that the livestock sector (see section II.B.3), highlighting the pressure on grassland in these area have recently declined. In addition, the livestock sector in UK and Ireland is specialized in sheep and goat products (comparatively to other countries) that have lower value than bovine milk and meat products. Therefore the opportunity cost of biofuel-dedicated grassland is lower compared to the rest of EU. On the contrary, the opportunity cost of using grassland for biofuel production is higher in France. This is consistent with France contributing only for larger shocks.

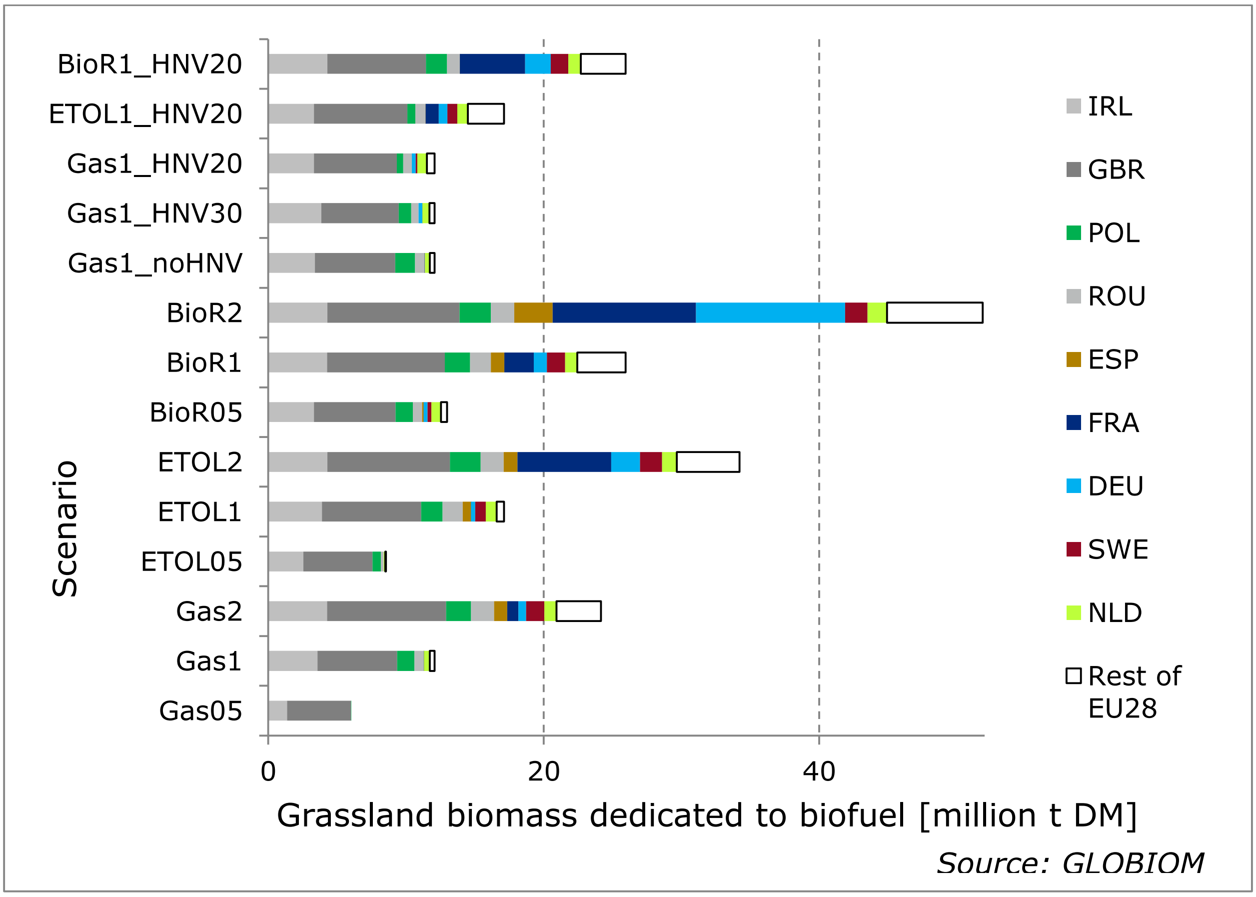


Figure 12 - Grassland biomass harvested for biofuel production in the EU countries in 2030, by scenario.

4.2.2 Impacts on the livestock sector

4.2.2.1 Adjustment across grass supply and utilization balances

The additional demand of grassland biomass for biofuel production impacts the livestock sector for all scenarios, with impacts increasing more than proportionally with the total grassland biomass requirements for biofuel.

As seen in Figure 13 (green and blue bars), the grassland biomass requirements for biofuel production lead to more grassland biomass being harvested (by up to 7.5 Mt DM). Net grassland area increase has a small contribution to this increase: less than 1 million additional hectares, i.e. less than 1.5% of the grassland area in 2013 according to EUROSTAT. Most of the additional grassland biomass comes instead from reallocation of grassland to areas of relatively higher yield.

However, biofuel-dedicated grassland biomass demand can also compete with use as a feed for livestock even for scenarios with low level of biofuel demand. For instance, in the *Gas05* scenario (6 Mt DM requirements), almost one third of biomass requirements comes from grassland biomass initially used as feed for livestock in the baseline (orange and red bars). This suggests that adjustment of the livestock grass demand occurs independently from the magnitude of the biomass requirements. This effect however strongly increases with the biomass requirements. As the total biomass requirements increases with the biofuel target (or with lower technological efficiency), the additional biomass is increasingly sourced from grassland biomass diverted from livestock feed (up to 40 Mt DM in scenario *BioR2*). This will lead to a strong increase of forage crops compared to the baseline.

4.2.2.2 Adjustment on livestock feed and production

The biofuel shocks impact the livestock sector via a substitution of grass fodder by forage crops. Most of the lost fodder feed (from grassland) is replaced by fodder from forage crops (orange bars in Figure 13 maize silage and other green fodder). This can represent up to a +57% increase in forage crop area compared to the baseline. This is a significant intensification process, requiring more intensive cropland.

However results do not suggest further intensification, such as adjustments in livestock management systems towards more concentrates and grains. The net livestock decrease in feed fodder demand (red bars) range between 1.5 and 5 Mt DM. Figure 14 shows the net changes in feed by category following the bioenergy demand shocks. In all scenarios (except the bio refinery scenarios), decrease use of fodder as feed is not replaced by other feed categories. At the same time, the efficiency of the livestock sector (in terms of protein production per dry matter ton of feed) is slightly improved (at maximum +1.3%, see

Table 5).

The bio-refinery pathway does not really alter the picture. Although this pathway generates grass cake by-products that can be used as feed for livestock, it does not counteract the intensification through increasing forage crop production. Instead, the main effect is mainly a substitution of other cakes in existing highly intensified livestock systems. Comparing the *BioR05* scenario with the *Gas1* scenario that require approximately the same amount of grass biofuel, we note almost no difference in the impact on the price and production level of livestock products.

Overall, our results suggest that due to the adjustment described above, final impacts on the production and price of livestock products remain limited. Production of livestock proteins decreases by up to -2% while the price of livestock products increases by up to +6%.

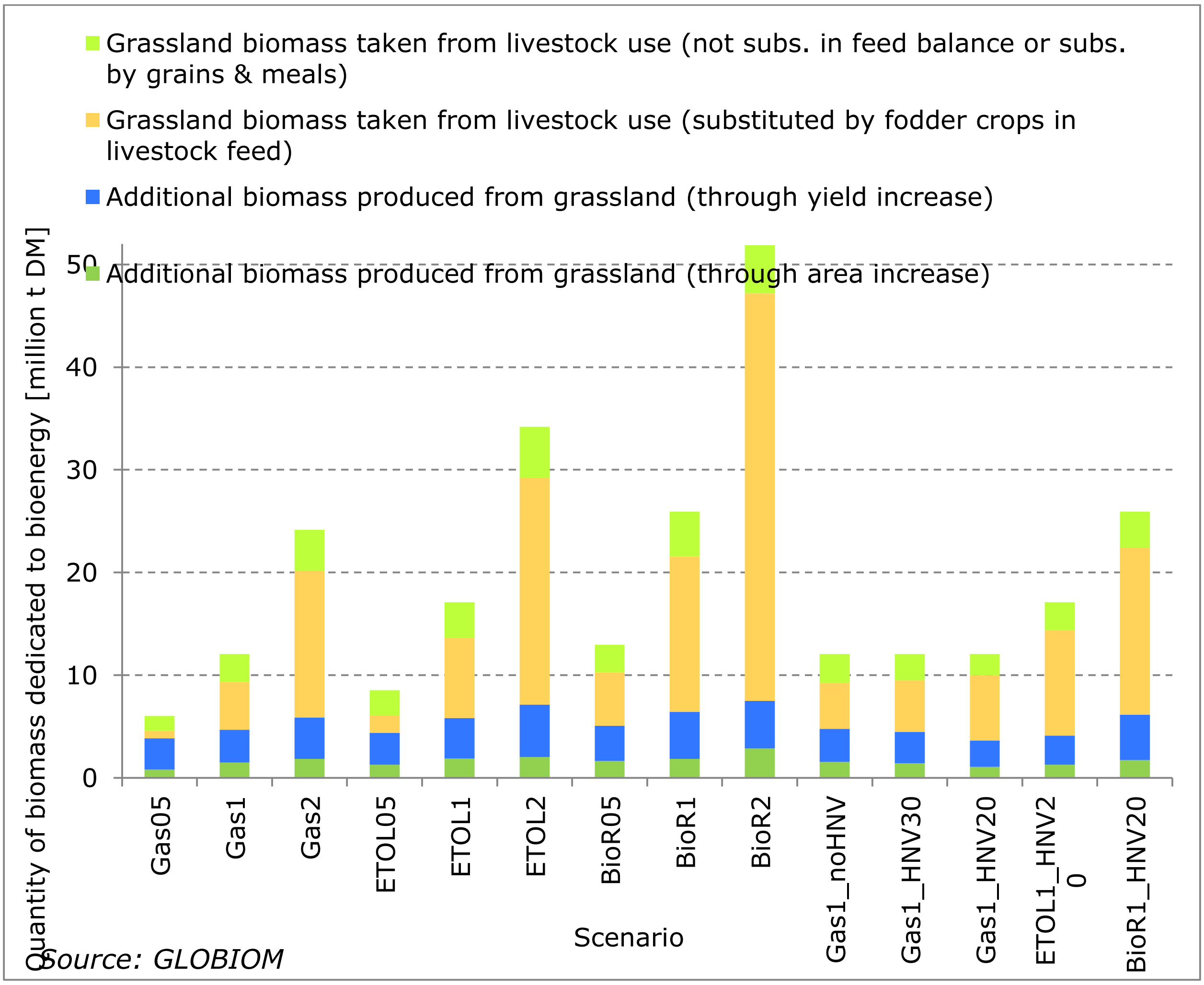


Figure 13 - Sources of grassland biomass dedicated to biofuel production in 2030, at EU28 level. Sources include: additional grassland production - increased area and increased yield - displacement of grass feed through substitution by forage crops and decrease in demand for grass from the livestock sector.

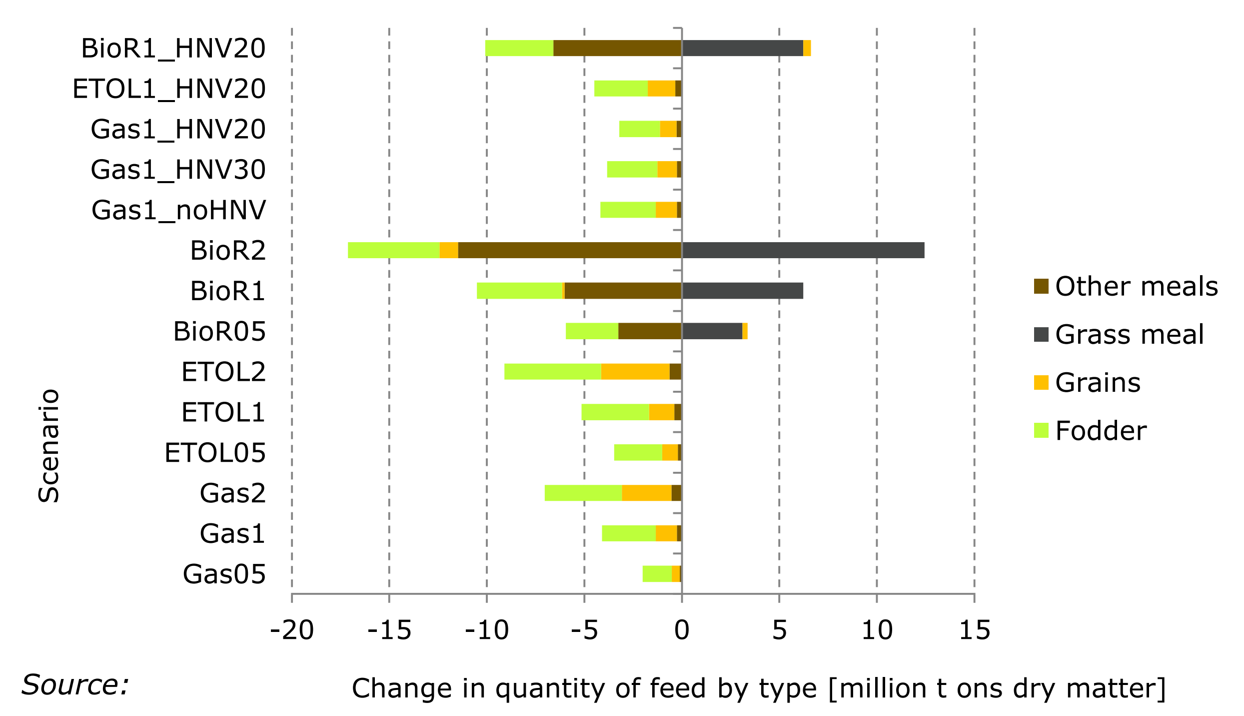


Figure 14 - Changes in livestock feed, by feed category in the EU28 by 2030 compared to the baseline. The fodder category covers grassland biomass and forage crop biomass. The grain category covers cereals and other crops commonly used as feed concentrate. 'Grass meal' is a product generated by green bio-refinery and only present in the bio-refinery scenarios. 'Other meals' correspond to protein meals sourced from oilseed crushing and ethanol co-products.

Table 5 - Simulated impact of the various scenarios (compared to the baseline in 2030, in %) at the EU28 level.

	Grassland area	Grassland Yield	Forage Crop area	Forage Crop yield	Feed conversion efficiency	Livestock production index	Livestock product price index
Gas05	0.5	1.8	0.5	0.4	0.3	-0.1	0.3
Gas1	0.9	1.9	4.5	1.3	0.5	-0.4	1.0
Gas2	1.1	2.4	25.7	-4.0	0.7	-1.3	3.2
ETOL05	0.7	1.9	1.6	0.5	0.4	-0.3	0.6
ETOL1	1.1	2.4	11.8	-0.8	0.6	-0.7	1.6
ETOL2	1.2	3.0	37.2	-4.8	0.9	-1.9	4.7
BioR025	0.9	2.1	5.0	1.3	0.5	-0.4	0.7
BioR1	1.1	2.7	25.7	-3.5	0.8	-1.2	2.7
BioR2	1.7	2.8	56.9	-3.7	1.3	-2.3	5.5
Gas1_noHNV	0.9	2.0	4.2	1.3	0.5	-0.4	1.0
Gas1_HNV30	0.8	1.8	5.1	1.3	0.5	-0.4	0.9
Gas1_HNV20	0.6	1.5	8.4	0.1	0.4	-0.2	0.8
ETOL1_HNV20	0.8	1.7	16.2	-1.5	0.5.	-0.4	1.3
BioR1_HNV20	1.0	2.6	25.7	-2.6	0.7	-0.8	1.9

4.2.2.3 Impact of the biodiversity constraints

There is a trade-off between cost-efficiency of biofuel production from grassland on the one hand, and biodiversity preservation on the other hand.

In our baseline assumption, we impose that biofuel-dedicated grass cannot be harvested from HNV farmland areas. This did not constrain the contribution of various countries, as illustrated by comparing the *Gas1* and *FGas1_noHNV* scenarios in Figure 12. We assumed that HNV farmland presence probability translates into a share of grassland that is biodiversity rich: this still leaves significant grassland area available for biofuel production.

However, this can be interpreted as a weak implementation of the biodiversity protection criteria for two main reasons. Firstly, grasslands are thought to host a higher level of biodiversity comparatively to other agricultural land: we expect the share of grassland area excluded from biofuel production to be higher than HNV farmland likelihood. Secondly, we also assume that livestock- and biofuel-dedicated uses of grassland can fully reorganize spatially so that livestock use could move the more biodiversity rich grasslands: this assumption is probably overoptimistic.

We therefore tested stronger implementation assumptions. Under these assumptions, NUTS2 regions for which HNV farmland presence probability is higher than a certain threshold (30% and 20% for respectively HNV30 and HNV20 scenarios) are excluded from biofuel-dedicated production. For both cases, the contributions of UK, Poland and Romania are reduced (scenario *Gas1_HNV30* and *Gas1_HNV20* in Figure 12) while the contribution of Spain fully disappears (e.g., ETHOL1_HNV20 compared to ETHOL1, or BioR1_HNV20 compared to BioR1).Instead, France, Germany and other countries start to produce. These results are consistent with the patterns of HNV farmland throughout EU (see Figure 8) and the results of other scenarios highlighting France and Germany could be significant producers, but at a higher cost.

On the one hand, it seems that part of grassland biomass that could be sourced at relatively lower cost is biodiversity rich, and implementation details matter for its protection. On the other hand, the impacts of a stronger implementation on the prices and level of production of livestock products is relatively modest, implying that the cost of biodiversity protection would not jeopardize biofuel production from grassland.

4.3 Impacts on land use and GHG emissions

4.3.1 Land use change

Impact of the different scenarios on land use change are illustrated in **Error! Reference source not found.**. The two main effects of the shocks on land use in the EU (left hand side) are: first, an increase in grassland aimed at increasing the harvestable area for the grass supply (green); and second, an increase in cropland to grow more forage crops, following the substitution with grass highlighted above. For low grass requirement scenarios (*Gas05*, *Gas1*, *ETOL05*, *BioR05*), grassland expansion appears mostly sufficient to provide the biomass for biofuels, and cropland is hardly affected. As the level of the shock increases, the contribution of cropland expansion becomes preponderant, due to the increased harvest of forage crops. The maximum land use change is reached for the BioR2 scenario, with about 3.2 Mha of cropland expansion and 0.9 Mha of grassland increase.

When looking at the rest of the world, impacts are relatively unnoticeable in the case of cropland for all scenarios except the bio-refinery ones. However, grassland expansion in the rest of the world reflects that some livestock production has been replaced by imports, following increase in price for domestic livestock products in the EU. For instance, in the case of the ETOL1 scenario, grassland increases by 0.28 Mha outside of the EU, versus 0.58 Mha within the EU.

The case of the bio-refinery scenarios is interesting, because some singular patterns appear in the rest of the world, in response to the production of grass cakes. Cropland decreases by up to 0.6 Mha in the case of *BioR2*, and grassland is increasing by 1.1 Mha. The same patterns are observed with lower magnitude for the two other scenarios. This effect is due to the replacement of soybean cakes imported from Latin America by the grass cakes produced in EU. Cropland in Latin America is replaced for a large part by grassland, as production is boosted by more abundant protein meals. At the same time, the oil deficit created by this substitution is also fostering some further deforestation related to palm oil expansion in Southeast Asia (-0.15 Mha in *BioR2*).

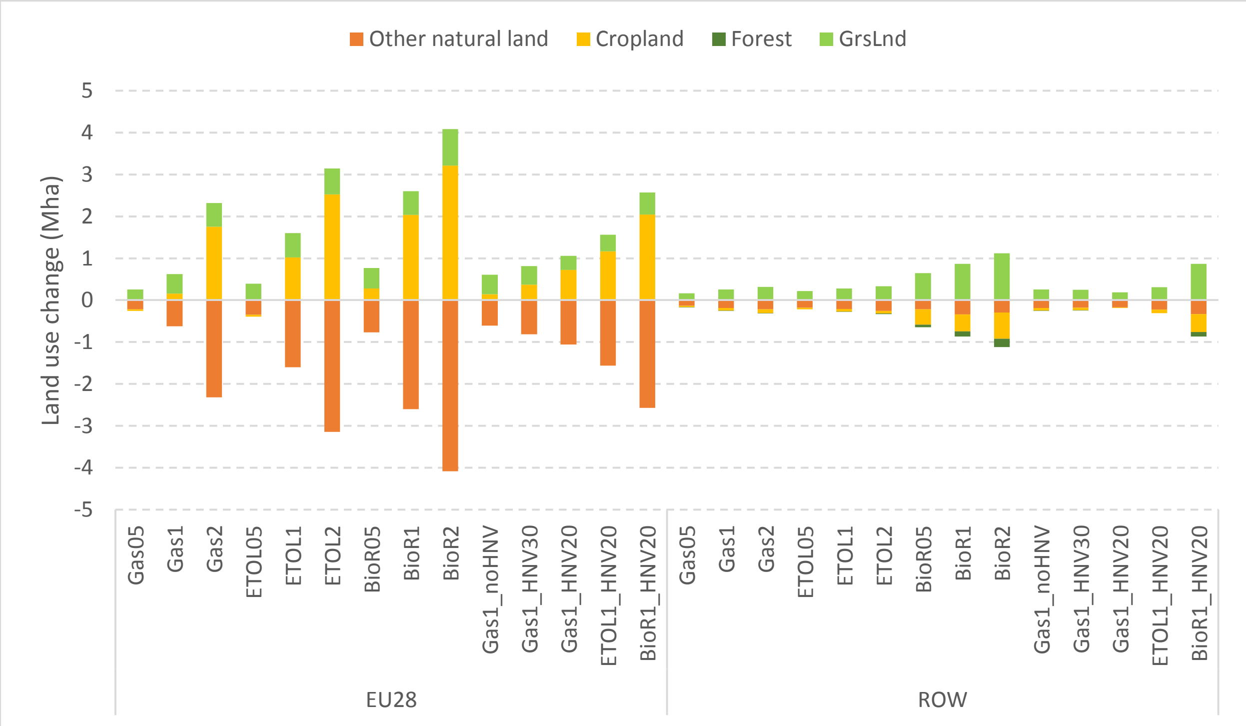


Figure 15 - Land use change in the EU28 for the different biofuel scenarios by 2030, compared to the baseline.

4.3.1.1 GHG emissions from land use change

The greenhouse gas emissions associated to land use change in the different scenarios are directly related to the findings above (Figure 16). Scenarios sourcing the largest amount of grass biomass are the ones leading to the highest levels of cumulated emissions. The biggest source of GHG emissions appears to be soil organic carbon released through the expansion of cropland into grassland or other natural land. The harvest of additional fodder crops (maize silage and other fodder crops) lead in our representation to increased tillage, which reduces the organic carbon content of the soil. In the ETOL2 scenario, the release reaches 156 $MtCO_2$ after 20 years. The second most important source is the foregone sequestration associated to agricultural land expansion. In the bio-refinery scenarios, this is even the highest source of emissions, because the largest source of land expansion in these cases is grassland. Peatland emissions and carbon sequestration in agricultural biomass (palm plantations) occurs only in the bio-refinery scenarios. Conversion of natural vegetation appears having a relatively minor role in the overall emission patterns.

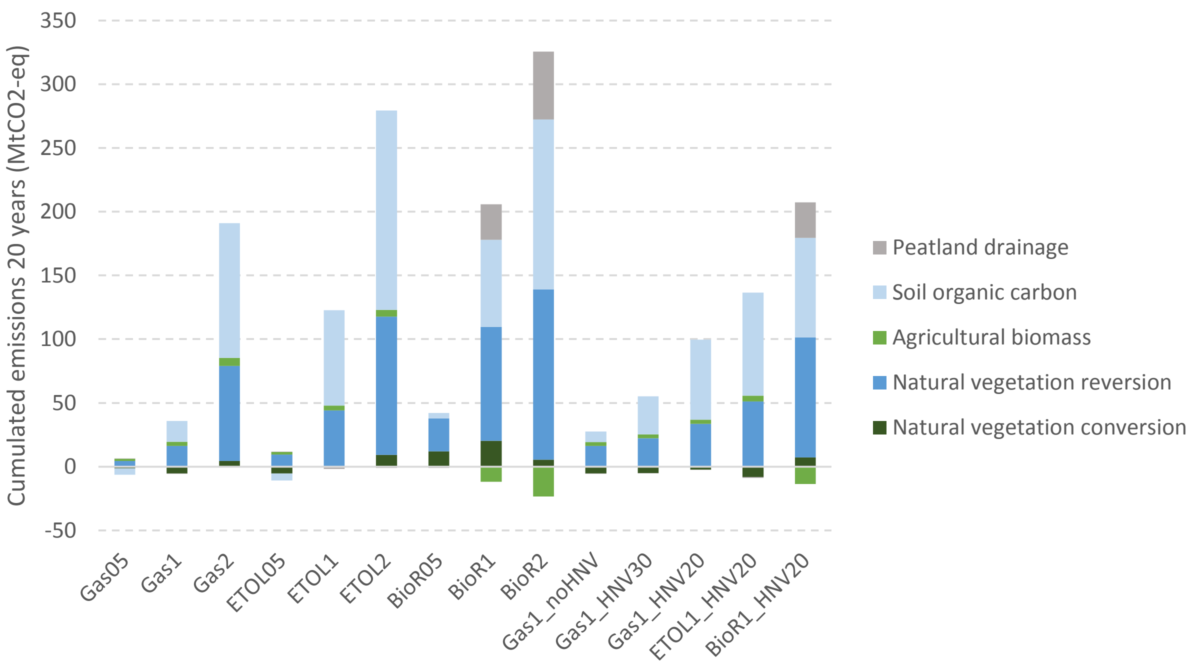


Figure 16 - Cumulated global emissions over 20 years for the different grass biofuel scenarios

The effects of biodiversity protection can be seen in the last scenarios of Figure 16. No sustainability criteria in the *Gas1_noHNV* scenario leads to slightly lower emission level by 27%. By opposition, increasing the sustainability criteria by excluding more production areas increases the total emissions by 65% and 220% in the scenarios *Gas1_HNV30* and *Gas1_HNV20*, respectively. In comparison, the same effect on the *ETOL1_HNV20* scenario is much lower, only 6% increase, whereas *BioR_HNV20* does not show any change. This is not surprising as we have seen before that with the higher levels of uptake, most effects are channeled through cropland expansion and no longer through grassland expansion.

In order to better separate the effect of the shock size, we can analyze the emission per unit of energy produced for the different technological pathways. The indirect land use change values in gCO_2/MJ are shown in Figure 17. The results respect the hierarchy of biofuel conversion efficiencies. Grass biogas has the lowest LUC values due to its high yield. The results however are strongly non-linear, due to the impact of large shocks on the resource and the associated substitution effects. When sourcing only 1% of biofuel from biogas, the LUC values remain below 15 gCO_2/MJ under the baseline sustainability criteria implementation. But if incorporation level is increased at 2%, the impacts are larger, at almost 40 gCO_2/MJ. The same effect is observed for cellulosic biomass beyond the incorporation level of 0.5%. The LUC values for the different ethanol scenarios vary between 40 and 60 gCO_2/MJ once the 1% threshold is passed. The most dramatic impacts are observed in the case of bio-refineries with 33 gCO_2/MJ for the 0.5% level already, and 79 and 61 gCO_2/MJ for the scenarios *BioR1* and *BioR2*, respectively. The high values are directly the consequence of the low feedstock conversion efficiency that required very large amounts of biomass, whereas the feedback effect of coproducts is not sufficient to mitigate the soil organic carbon emissions and foregone sequestration.

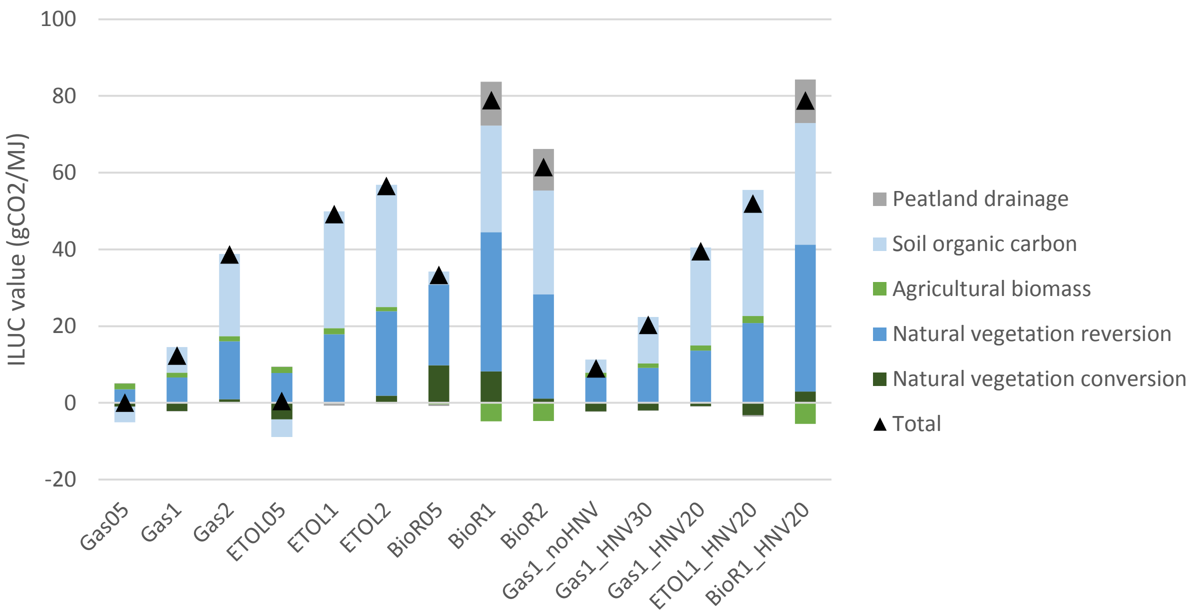


Figure 17 - ILUC value associated to the biofuel grass pathways in the EU for different levels of use

Additional calculations can be performed to express the results as emissions per unit of grass, which also removes the bias introduced by the conversion pathway (Table 6). The results show to groups of value: in the low to moderate biomass uptake cases (lower than 20 Mt DM), the values are in the range 0-0.15 tCO_2/t dm grass. But beyond this threshold, values increase at about 0.28-0.4 tCO_2/t dm grass. These latter values require efficient conversion pathways to maintain the overall land use change emissions are levels satisfying emissions reduction criteria.

These results can be compared with the ILUC values associated to the most important component of the grass, if valued by market prices. According to market data, protein prices is higher than fibre prices (about 710 EUR/t for proteins compared to 240 EUR/t for fibre[5]). Therefore, more land use effect would be allocated to the protein part than the biofuel part if an attributional approach was followed compared to a consequential analysis as presented here, based on structural modelling. Table 6 illustrates what the emissions would be per tonne of protein and tonne of fibre for grass across the scenarios. We here assume grass contains 54% fibre and 17% protein per dry matter weight. We therefore obtain a share of LUC value going for 39% to protein and 42% to fibre. ILUC values per ton of fibre are with such allocation found slightly lower than value for grass (max at 0.31 tCO_2/t) and protein are significantly larger (max at 0.92 tCO_2/t). This illustrates that following a consequential approach allocates more impact to bioenergy than the attributional does approach.

Table 6. - LUC value associated to grass in the different scenarios

Scenario	tCO_2 per t dm grass	tCO_2 per t fibre	tCO_2 per t protein
Gas05	0.000	0.000	0.001
Gas1	0.122	0.095	0.282
Gas2	0.383	0.299	0.885
ETOL05	0.003	0.003	0.008
ETOL1	0.344	0.269	0.794
ETOL2	0.395	0.309	0.913
BioR05	0.154	0.120	0.355
BioR1	0.364	0.284	0.840
BioR2	0.283	0.221	0.654
Gas1_noHNV	0.089	0.070	0.206
Gas1_HNV30	0.201	0.157	0.465
Gas1_HNV20	0.391	0.305	0.903
ETOL1_HNV20	0.363	0.283	0.838

[5] Ecofys (2016) Decomposing biofuel feedstock crops and estimating their ILUC effect. Report for the European Commission.

5 Conclusion

The recent reduction in ruminant meat consumption in the EU opens new perspectives on alternative uses of the grassland. In particular, using grass to produce biofuels could participate to the overall effort of substituting fossil fuel by renewable energy. We used in this report the GLOBIOM model to explore the extent to which different levels of grass demand could generate new biofuels while keeping emissions from land use change at low levels.

Our analysis shows a potential for producing bioenergy from grassland, but associated GHG emissions increases with the level of grassland use. Impacts are also contrasted across the three conversion pathways tested: biogas, cellulosic ethanol, and ethanol from green bio-refinery.

At low incorporation levels, grass used for biogas and cellulosic ethanol could be sourced without major impacts on land use and the agricultural sector. Higher levels of use increased the magnitude of impacts, as livestock feed from grassland is substituted by forage crops. Beyond 1% of incorporation at the EU level, the displacement of land induced high ILUC values, even when producing protein concentrate coproducts for livestock through bio-refineries. In order to keep ILUC impacts low, we find that total grassland biomass use for biofuel should remain below 10-15 Mt dm, which represents less than 10% of the grassland biomass in the EU. This estimate would however require further research to more precisely assess the current level of underutilization of the resource.

Our results also show that grassland biomass could be used with limited impacts on biodiversity. However, the most productive grasslands of the EU (Ireland and UK), which are among the most biodiversity rich, are the first to be mobilized for biofuel production. Therefore the implementation of the sustainability criteria is key to preserve these high biodiversity areas. Sufficient grassland biomass can be sourced from less sensitive areas such as in France or Germany, although this also increases indirect GHG emissions through an increased reliance on forage crops for livestock feeding.

The conclusion of this research have to be interpreted with caution considering the significant uncertainty remaining around grassland use. Future research is needed on key questions such as the precise state of grassland extent and productivity in the EU, the current livestock sector practices and the margins of intensification of the resource use, the uncertainties on the future of the common agricultural policy and the livestock sector in different regions, the evolving technologies for advanced biofuels.

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Appendix: grass ethanol conversion pathways

We consider for this report three different production pathways: biogas, cellulosic ethanol and green bio-refinery. Details of conversion efficiency coefficient are provided in this appendix.

I.1 Grass biogas

We assume for grass biogas the same conversion efficiency range as for maize silage. Grass biogas yield depends on lot on the management practice. Our assumption corresponds here to the average yield of ensiled grass (Smyth et al., 2009, Table 4).

Table I.1 - Conversion of grass to biogas

Product	Unit	Input	Output
Grass	tonne (0% mc)	**1**	
Biogas [a)]	GJ		**9.9**
	tonne (0% mc)		**0.198**

a) We assume 300 m3/t dm, with lower heating value methane at 33 MJ/m3.

I.2 Grass cellulosic ethanol

Grass cellulosic ethanol yield depends on the composition of species on the grassland. According to Adler et al. (2009), the yield is lower with highly biodiverse land but still potential yield remains higher than 300 l/t.

Table I.2 - Conversion of grass to cellulosic ethanol via hydrolysis fermentation

Product	Unit	Input	Output
Grass	tonne (0% mc)	**1**	
Cellulosic ethanol [a)]	GJ		**6.99**
	tonne (0% mc)		**0.261**

a) IRENA (2013) Table 42.provides for lignocellulosic biomass an average yield of 440 liters of ethanol per tonne (0% mc) wood. However the same report explains yield beyond 330 liters of ethanol per tonne are not economically profitable, therefore we assume here a yield of 330 liters per tonne. Assume LHV ethanol at 26.81 MJ/kg at 0% mc as in other tables above, and a density of 0.79 kg/litre.

I.3 Biorefinery

Green biorefineries transforms grass input into different subcomponents. First the grass is pressed which creates two products: the press juice, which contains most of the plant nutrients, and the press cake mainly composed of fibers. The press juice is then treated to separate the different constituents. Proteins can be isolated into protein pellets that are later used as feed for the livestock sector. The juice residues can be transformed through fermentation into biogas. The grass press cake can be valued through combustion, feed or transformed into lignocellulosic biofuel.

For the representation used in this report, we consider that biofuels are sourced both from the lignocellulosic ethanol from the press cake and the biogas from the press juice.

Table I.3 - Conversion of grass to cellulosic ethanol via green bio-refinery

Product	Unit	Input	Output
Grass	tonne (0% mc)	**1**	
Cellulosic ethanol [a)]	GJ		**3.52**
	tonne (0% mc)		**0.132**
Grass protein meal (58% protein)	tonne (0% mc)		**0.240**
Biogas	GJ		**1.09**
	tonne (0% mc)		**0.022**

a) 1 t dm grass yields 65% fibre product with 58% fibre content, 24% protein concentrate with 58% protein content and 11% of juice residues. Cellulosic ethanol for woody biomass at 6.99 GJ/t dm and biogas at 9.9 GJ/t (see methods above). Source: Central scenario from Ambye-Jensen M.and Adamsen A.P.S. (2015).

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Appendix: Improving the grassland resource description in GLOBIOM

In general, the GLOBIOM model uses the following sources of data and procedure for initializing the grassland resource description:

- The grass yield is determined by selecting a spatially explicit estimate from the IIASA dataset of grassland productivities, as a realistic combination of assumptions with respect to off-take rate and management/grassland type.
- The area of grassland is estimated from the 'pasture' class of the CLC2000 dataset at the NUTS2 level, and the implied grassland feedstock estimated.
- In some cases, the grassland area derived with the sole 'pasture' CLC2000 class (as stated above) multiplied by the grassland productivity value is lower than our estimates of livestock grassland feedstock needs (see (Havlík *et al* 2014) for further details). In such cases, we assume that it relates to uncertainties in land cover classification and we take the missing 'grassland' area from the 'heterogeneous agricultural areas' and 'herbaceous vegetation cover' CLC2000 classes, potentially containing grassland by definition.

For this study, we evaluated the current GLOBIOM dataset for grassland data against other data sources, and then decided to re-compute the grassland yield data to better represent spatial variations across NUTS2 regions, following the data of Smit *et al* (2008).

I.5 Improving the grassland productivity estimates

In the current EU version of GLOBIOM the sources of grassland yield are selected between estimates of the CENTURY, DAYCENT and EPIC models for various types of grassland species and management at the scale of Member States. However, in the EU28 two sources of data allow our data to be refined: first, EUROSTAT provides at the scale of NUTS2 regions the share of permanent grassland area under pasture meadow & semi-natural grassland, allowing refining the type of vegetation and management that should be used to represent grasslands. Second, Smit et al. 2008 provide at the same spatial resolution (NUTS2) an estimate of grassland yields: this allows refining the type of management and the source used. We thus compiled from our sources two sets of layers, providing at NUTS2 level the yield values under four management assumptions (of increasing intensity) for respectively pastures (EPIC simulations, management varies by fertilizer application level and off-take rate), and semi-natural grassland (CENTURY simulations for natural vegetation, management varies by off-take rate). For each management intensity level, the averaged productivity is calculated by weighting contributions from pastures and semi-natural grasslands (i.e. extensive grassland), using EUROSTAT information on the area share of these two types of grassland. Finally, we select among these four management intensities at NUTS2-level the one being closest to yield levels estimated by Smit *et al* (2008). As stated above, the grassland area is defined in GLOBIOM by the area necessary to satisfy current livestock grazing needs (for a given value of productivity). Thus, the improvement of productivity estimates will lead to different grassland area estimates: we evaluated both variables before and after harmonization with Smit *et al* (2008).

I.6 Data comparison.

We compared the GLOBIOM values (before and after improving the grassland productivity values) for the year 2000, in terms of grassland extent and productivities to other sources available (Figures A1 to A3). As the data on the area extent and productivity of grassland is rather uncertain and in part determined by livestock grazing requirements we compared this variable for GLOBIOM to that of the CAPRI model, the most comparable and widely accepted dataset over the EU28. The two estimates are in relatively good agreement (Figure A3**Error! Reference source not found.**), given that they rely on two very different approaches. The differences for some countries owe thus most probably to assumptions about the feed ratio of different livestock categories.

As displayed on Figure A1**Error! Reference source not found.**, the permanent grassland area (before grassland yield improvement) is also in relatively good agreement between the GLOBIOM, CAPRI and Smit2008 datasets. However, GLOBIOM departs from CAPRI and Smit2008 estimates for a few countries like France, UK, Germany, Italy, and Romania. Given our procedure to initialize the grassland resource data, the area depends directly on assumptions about livestock feed requirements and grassland productivity (both NPP and off-take rate). As it appears on Figure A3**Error! Reference source not found.**, differences in grass yield (dark and blue bars) might explain area deviations between GLOBIOM and CAPRI for example for Germany (GLOBIOM grass yield estimate is lower than in CAPRI, and this largely explains the area extent overestimation). However, if looking at what we interpret as NPP in Germany, CAPRI values seem extremely high as compared to Smit2008.

Since our definition of grassland area is tightly linked to livestock grazing needs, we estimated it was better to improve the grassland data by first adjusting yield values to best data available at high resolution (Smit et al 2008). As displayed in **Error! Reference source not found.**, this step brought up closer to the yield values Smit et al in countries where previously discrepancies have been identified (e.g., Germany, UK, France). As displayed in Figure A4**Error! Reference source not found.** (maps at NUTS2 level of difference to Smit et al 2008), we also significantly improved the match at higher spatial resolution (NUTS2 level), which is critical when starting to look at spatially more heterogeneous questions, such as biodiversity. This also mechanically led us to larger deviations in terms of grassland area (Figure A2**Error! Reference source not found.**) to both Smit et al 2008 and CAPRI. This is however expected, and should not affect our results much, since the remaining land remains available for grassland expansion.

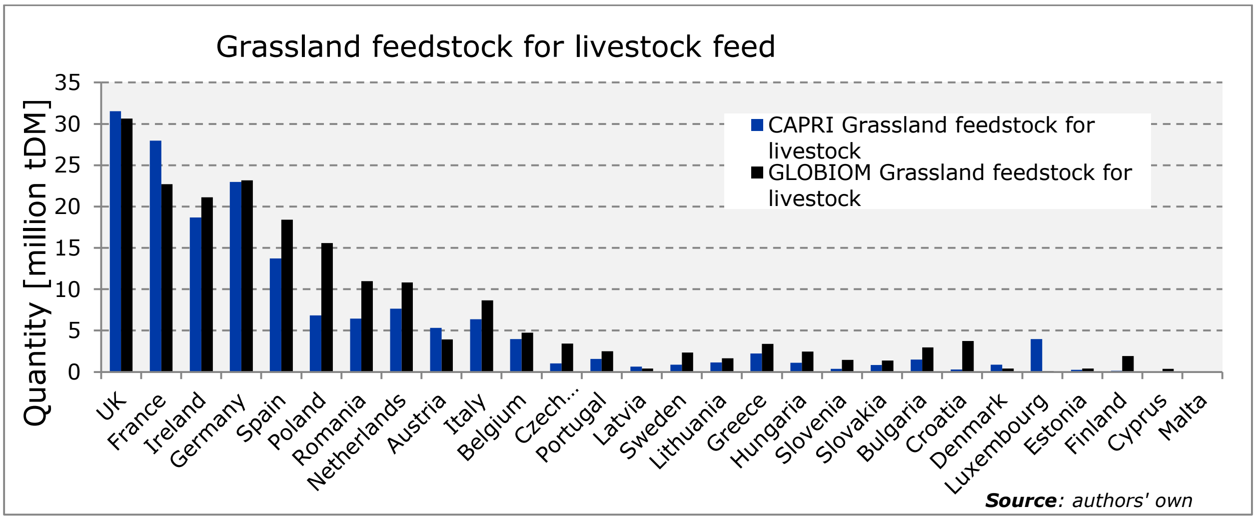

Figure I.1 - Comparison of grassland feedstock requirements for livestock around year 2000 (GLOBIOM vs. CAPRI)

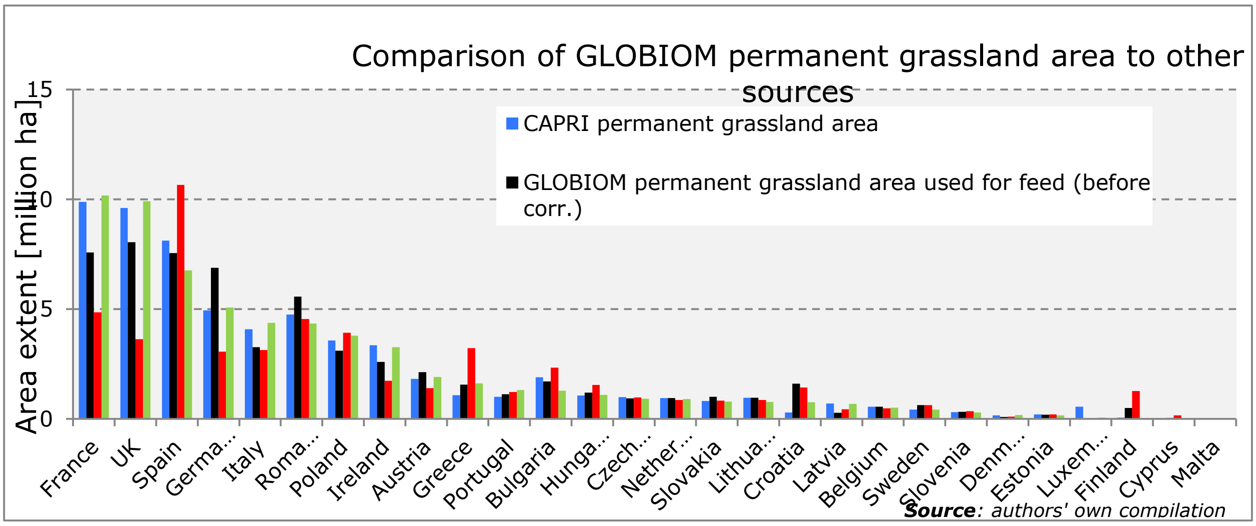

Figure I.2 - Comparison grassland permanent area around year 2000 (GLOBIOM vs. CAPRI & Smit2008)

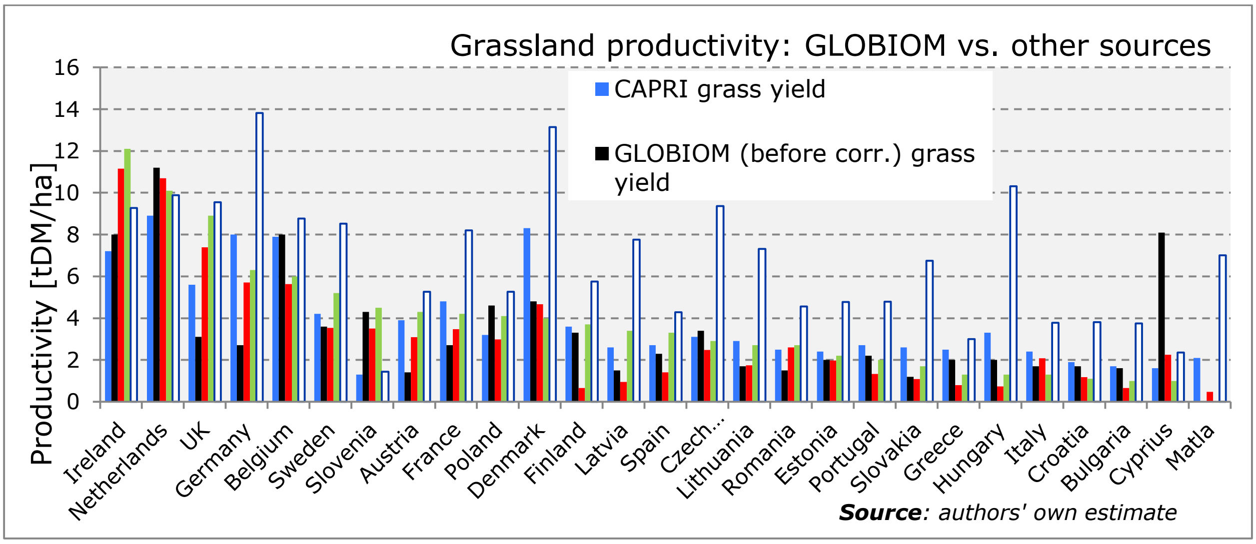

Figure I.3 - Comparison of grassland productivity estimates (NPP & grass yield) around year 2000 (GLOBIOM vs. CAPRI & Smit2008)

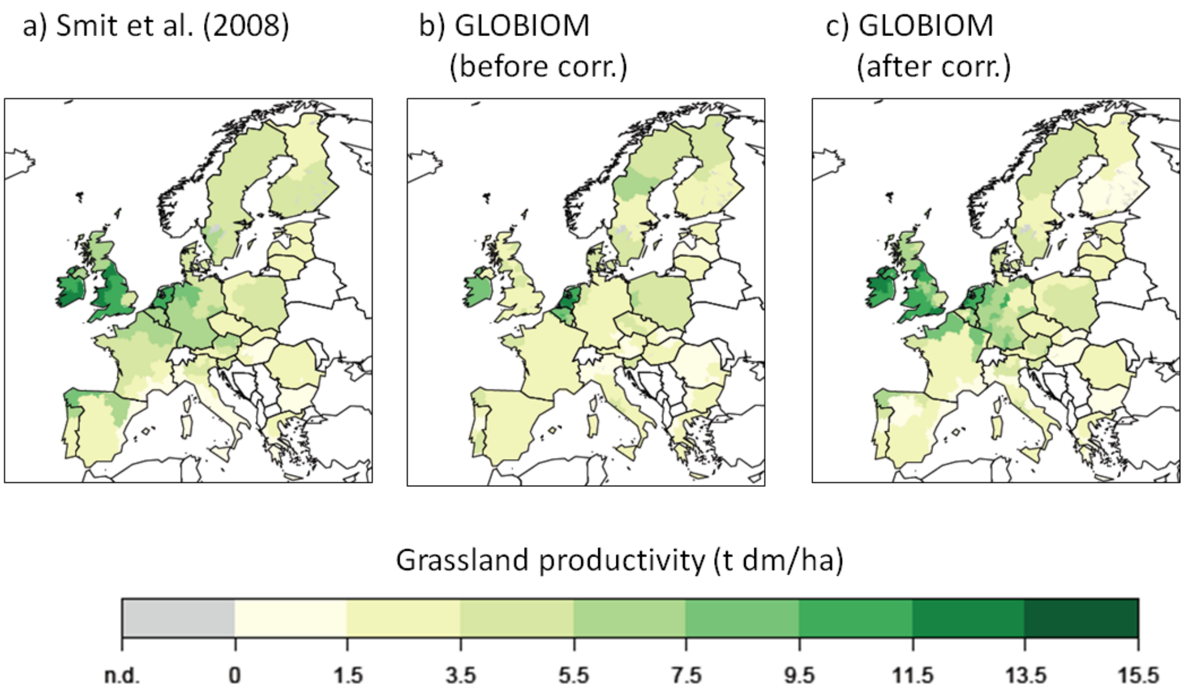

Figure I.4 - Comparison at NUTS2-level of grassland biomass productivity in EU28 (circa year 2000) between Smit et al. (2008) and GLOBIOM values (before and after correction).

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