Sustainable Liquid Biofuels from Biomass Biorefining (SUNLIBB)

Work Package 8: Sustainability Assessment

Task 8.3: Application to Maize Biorefineries

Deliverable D8.3: Supporting Sustainability Criteria: Maize

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Executive Summary

1. This report investigates relevant environmental sustainability criteria for whole maize, as a dedicated energy crop, and stover, as an agricultural residue from grain maize production, for the provision of biomass feedstock for biofuel and biochemical production in biorefineries within the context of the “Sustainable Liquid Biofuels from Biomass Refining” (SUNLIBB) Project. The SUNLIBB Project is funded by the European Commission (EC) under the 7th Framework Programme within the Energy Theme: Second Generation Biofuels and involves collaboration with the CeProBio Project in Brazil. The aims of the SUNLIBB Project are outlined and the role of Work Package 8 in addressing sustainability assessment is explained.

2. The current European Commission framework of sustainability criteria for biofuels and bioliquids in the European Union is introduced, particularly in terms of the Renewable Energy Directive. It is noted that the quantitative assessment of sustainability criteria is mainly restricted to the evaluation of the total greenhouse gas emissions associated with biofuel and bioliquid production. Currently, there is a distinction between biofuels and bioliquids derived from energy crops, such as whole maize that might be grown on existing agricultural land, and hence, might potentially displace food crops, and those obtained from agricultural residues, such as stover available after grain maize harvesting. If derived from whole maize, such biofuels could, in the future, be covered by the proposed addition of greenhouse gas emissions factors based on implied indirect land use change.

3. Other sustainability criteria are identified although these are addressed more broadly in the current regulatory framework for biofuels and bioliquids. They are evaluated in a necessarily qualitative manner using existing research, studies and published literature. These sustainability criteria for maize include land use, soil erosion, fertility and carbon, water use, emissions to water, emissions to air, biodiversity and other impacts such as traffic levels likely to be generated by large-scale, commercial biorefineries.

4. Conclusions are formulated and mitigation measures are described which might ensure or enhance the environmental sustainability of maize as a source of biomass feedstock for biorefineries. To avoid any future concerns over indirect land use change, a balance is required between the utilisation of lower yielding stover as an agricultural residue with limited alternative uses and higher yielding whole maize grown on existing agricultural land. Negative impacts from stover removal related to soil erosion, fertility and carbon can be addressed by limiting the amount of available above-ground biomass collected. Additionally, the adoption of minimum and no tillage cultivation with the use of ground cover crops after harvesting is important for avoiding soil problems with both grain and whole maize crops.

5. Although not widely researched, reductions in biodiversity by the cultivation of either grain maize or whole maize appear to be possible and this can be partly prevented by ensuring that these crops are not grown as monocultures. Suitable management plans for biorefineries are required to ensure that local concerns over traffic levels can be addressed by careful consideration of timing and routes.

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1. INTRODUCTION

The “Sustainable Liquid Biofuels from Biomass Refining” (SUNLIBB) Project is funded by the European Commission (EC) under the 7th Framework Programme within the Energy Theme: Second Generation Biofuels. Its support came about through the European Union (EU) – Brazil Co-ordinated Call and its activities involve collaboration with the CeProBio Project in Brazil. The aims of the SUNLIBB Project are:

- to use modern crop breeding approaches and cutting edge plant cell wall research to identify genes that will allow modification of cell wall composition so as to reduce costs associated with conversion processes,
- to upgrade residues and by-products, and to produce other value streams from biomass feedstocks so that the total energy output and profitability of second generation biofuels will be increased,
- to improve the process of converting sugars in biomass feedstocks into biofuels,
- to bring together improvements in biomass feedstocks and conversion processes in biorefineries so that the economic and environmental sustainability of second generation biofuels can be enhanced, and
- to review all pertinent guidelines, policies and regulatory frameworks for sustainable biofuels in both the EU and Brazil in order to take into account any influential developments that could affect the future potential for harnessing benefits from this work.

Within the SUNLIBB Project, Work Package (WP) 8 is concerned with “Sustainability Assessment”. Task 8.1 involves reviewing the policy and regulatory context at EU and Member State (MS) levels which have been reported in Deliverable D8.1 (Ref. 1). Specific environmental aspects of biorefineries supplied with sugar cane, maize and miscanthus feedstocks are addressed in Tasks 8.2 to 8.5. In particular, primary energy inputs, as indicators of energy resource depletion, and prominent greenhouse gas (GHG) emissions, in the form of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), as indicators of global climate change, are quantified by means of MS Excel workbooks for sugar cane biorefineries (Task 8.2), maize biorefineries (Task 8.3) and miscanthus biorefineries (Task 8.4). Sensitivity and comparative analysis are the main activities of Task 8.5. In addition to the quantification of specific environmental concerns, both Tasks 8.3 and 8.4 involve the qualitative assessment of other sustainability criteria for biofuels derived from biorefineries which process maize and miscanthus, respectively. This report covers the qualitative assessment of maize as a biorefinery feedstock.

2. SUSTAINABILITY CRITERIA

Sustainability criteria for biofuels and the biomass feedstocks from which they can be derived have evolved over a period of time in the EU. Officially, the initial consideration of sustainability criteria was set out in the EC’s Renewable Energy Directive or RED (Ref. 2). Within the RED, the main focus for biofuels is the evaluation of total GHG emissions within the context of target net savings relative to fossil fuel comparators. However, other aspects of environmental sustainability are related to the conversion of land to biomass feedstock cultivation and potential threats of carbon stock destruction (Ref.2; paras. 70 – 73); the protection of ground water and surface water quality (Ref. 2; para. 74); the avoidance of soil erosion (Ref. 2; para. 77); and the promotion of biodiversity (Ref. 2; para. 69). The specific sustainability criteria set out in the RED stated that biofuels should not be derived from land with highly biodiverse value (primary forests and other undisturbed wooded land, protected areas and highly diverse grassland) nor from wetlands and continuously forested areas (Ref. 2; Article 17, paras. 1 -6). Furthermore, a requirement was laid on the EC to report periodically on these aspects and soil, water and air protection associated with the provision of biomass feedstocks for biofuel production, and implementation of the Cartagena Protocol of Biosafety and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (Ref. 2; Article 17, para. 7). Additionally, the issue of social sustainability was addressed by emphasising compliance with Conventions of the International Labour Organisation regarding forced or compulsory labour; freedom of association and protection of the right to organise; application of the principles of the right to organise and to bargain collectively; equal remuneration of men and women workers for work of equal value; abolition of forced labour, discrimination with respect of employment and occupation; minimum age of admission to employment; and prohibition and immediate action for the elimination of the worst forms of child labour (Ref. 2; Article 17, para. 7).

The conversion of land for the cultivation of biomass feedstocks for biofuel production is generally covered by the term “direct land use change” (dLUC). This is now accommodated with GHG emissions calculations by the evaluation of carbon stock changes as specified by a standard approach established by the EC (Ref. 3). Broadly speaking, in order to meet required net GHG emissions savings by biofuels, the incorporation of the effects of dLUC into GHG emissions calculations discourages the cultivation of biomass feedstocks on land whose recent conversion has involved the destruction of high carbon stocks, such as forests, peatlands and grasslands. The RED also pointed to concern over the impact of biofuel production on food prices (Ref. 2; Article 17, para. 7). This, in turn, relates to the issue of “indirect land use change” (iLUC) in which the cultivation of biomass feedstocks displaces previous food production that results, eventually, in the destruction of carbon stocks as land is converted elsewhere to arable and livestock farming. This is a very controversial issue since estimation of the actual magnitude of carbon stock changes which can be attributed to the original biomass feedstock cultivation depends on the reliability and accuracy of global land use modelling. However, this has led the EC to propose additional iLUC factors for the cultivation of certain biomass feedstocks as part of amendments to the Fuel Quality Directive (FQD) and the RED (Ref. 4). Currently, these factors cover cereals and other starch-rich crops, sugars and oil crops. As such, this would affect biofuels derived from starch in maize and sugar in sugar cane. Conversely, measures are also proposed to encourage the production of biofuels from specific residues, including bagasse from sugar cane processing and stover from grain maize production, and “non-food cellulosic material”, such as that provided by whole maize and miscanthus[1]. The EC has also elaborated the interpretation of sustainability criteria for biofuels (Ref. 5). In addition to adding details to specific calculations of total GHG emissions, this seeks to clarify definitions of land with high carbon stocks and high biodiversity value.

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[1] The proposed mechanism for encouraging the use of such biomass feedstocks is to inflate the contribution of biofuels derived from them to the revised targets of the contributions for the proportion of biofuels and bioliquids to transport fuel supply.

3. MAIZE SUSTAINABILITY CRITERIA

There is a defined methodology for quantifying total GHG emissions associated with the production of biofuels and bioliquids in the EU in order to meet specified targets for net GHG emissions savings. Such quantification is addressed for biorefineries supplied by maize in a specially-developed MS Excel workbook which forms the other part of this Deliverable, the current version of this being SUNLIBB Maize Biorefinery v04.xlxs (Ref. 6). The current official approach to other sustainability criteria is more generalised. However, it is possible to identify broad categories of sustainability criteria that need to be considered for maize. In particular, these include land use; soil erosion, soil fertility and soil carbon; water use; emissions to water; emissions to air; biodiversity and other impacts such as traffic issues. In considering these impacts, it is necessary to take into account differences between obtaining biomass feedstock for biorefineries from whole maize or stover. Such differences, which are also accommodated within the MS Excel workbook, are important to the discussion of sustainability criteria. In both instances, these biomass feedstocks are regarded as potential sources of lignocellulosic material for biorefineries within the SUNLIBB Project. In the case of whole maize, the majority of the above-ground biomass, consisting mainly of stalks and leaves, is cultivated, effectively, as an energy crop. In contrast, stover is the agricultural residue, again mainly consisting of stalks and leaves, which remains after the harvesting of grain maize. Whilst the essential biomass material from these sources is the same, the implications of their provision are different in terms of sustainability criteria.

3.1 Land Use

Maize is grown in the EU for a variety of purposes which chiefly consist of grain for food and animal feed, and silage or forage for animal feed. An increasing amount of whole maize is being cultivated as a biomass feedstock for anaerobic digestion (AD). However, a comparatively small but growing amount of maize grain in the EU is used as a biomass feedstock for biofuel production involving fermentation to bioethanol. This contrasts with the United States of America (USA) where a substantial amount of maize grain is used for this purpose. In addition, there is also interest in using stover as a biomass feedstock for bioethanol production in the USA, although this has yet to emerge as a major consideration in the EU. It should be noted that a more prominent non-food/feed use of grain maize in the EU is for the manufacture of biomaterials, such as paper, cardboard, textiles and bioplastics, and biochemicals, such as pharmaceuticals and glue.

It is notoriously difficult to quantify this general picture of maize use by means of relevant and up-to-date statistics for the EU-27. There are two main reasons for this. Firstly, comprehensive and detailed statistics on maize production and use do not appear to be available regularly across the entire EU-27. Instead, suitable statistics are only prepared by certain MSs so that a complete overview is rarely possible. Secondly, those statistics that are available are often quoted in incompatible units given the different purposes for the products of maize cultivation. However, it is possible to assemble an approximate breakdown of maize cultivation in the EU-27 in terms of grown areas by product end use (Ref. 7). This breakdown is presented in Table 1 which shows that grain maize for animal feed at 53% was the main end product of land used for maize cultivation in the EU-27 in 2008. The second most important use of such land was silage grown specifically for animal feed at 34%.

Table 1 Approximate Breakdown of Areas of Maize Cultivation by End Use in the EU-27 in 2008

End Use	Area Cultivated		Notes
	(10^6 ha)	(%)	
Grain Maize for Animal Feed	7.228	52.5	(a)
Grain Maize for Human Food (as maize grain)	0.763	5.6	(b)
Grain Maize for Biomaterials and Biochemicals	0.486	3.5	(c)
Grain Maize for Seed	0.123	0.9	(Ref. 7)
Grain Maize for Bioethanol	0.106	0.8	(d)
Grain Maize for Human Food (as sweet corn cobs)	0.074	0.5	(Ref. 7)
Sub-Total for Grain Maize	*8.780*	*63.8*	(Ref. 7)
Silage Maize for Animal Feed	4.730	34.3	(e)
Silage Maize for Anaerobic Digestion	0.260	1.9	(Ref. 7)
Sub-Total for Silage Maize	*4.990*	*36.2*	(Ref. 7)
Totals	**13.770**	**100.0**	

Notes

(a) Based on total grain maize cultivation area of 8.780 x 10^6 ha and a ratio between grain maize animal feed production of 48.9 x 10^6 t and total grain maize production of 59.4 x 10^6 t (Ref. 7).

(b) Based on total grain maize cultivation are of 8.780 x 10^6 ha less estimated cultivation areas for biomaterials and biochemical of 0.486 x 10^6 ha, for seed of 0.123 x 10^6 ha, for bioethanol of 0.106 x 10^6 ha, and for sweet corn cobs of 0.074 x 10^6 ha (Ref. 7).

(c) Based on biomaterial and biochemical production from grain maize of 3.2 x 10^6 t and an assumed average grain maize yield of 8.78 t/ha based on EU-27 total grain maize production of 57.800 x 10^6 t and total grain maize cultivation area of 8.780 x 10^6 ha (Ref. 7).

(d) Based on bioethanol production from grain maize of 0.7 x 10^6 t and an assumed average grain maize yield of 8.78 t/ha based on EU-27 total grain maize production of 57.800 x 10^6 t and total grain maize cultivation area of 8.780 x 10^6 ha (Ref. 7).

(e) Based on total silage maize cultivation area of 4.990 x 10^6 ha less silage maize cultivation area for anaerobic digestion of 0.260 x 10^6 ha (Ref. 7).

By comparison, the breakdown of harvested maize area in the USA is approximately 92% for grain maize and 8% for silage maize (Ref. 8). Of the grain maize area harvested, it can be estimated that between about 31% and 42% has been used to provide feedstock for bioethanol production in recent years (Refs. 8 and 9). This suggests that between 29% and 38% of the maize area harvested in the USA is devoted to bioethanol production. As such, bioethanol production from grain maize is the major contributor to biofuel supply in the USA. Although this is clearly not the case in the EU, the amount of grain maize being used for bioethanol production in the EU-27 is increasing. However, bioethanol from EU grain maize only accounted for approximately 4% of total biofuel production in the EU-27 in 2008 (Ref. 10).

The breakdown of maize cultivation areas within the EU-27 in 2008 is summarised in Table 2. This shows that 5 MSs dominate maize cultivation in the EU-27 accounting for 73% of the total maize area in 2008. Most of the prominent MSs concentrate on grain maize production although there is a fairly equal split between grain maize and silage maize in France, and a distinct emphasis on silage maize in Germany. The relatively large area used to grow grain maize offers opportunities to obtain substantial quantities of stover as a biomass feedstock for biorefineries. However, in 2008, only between 10,000 t and 20,000 t of stover were recovered for bioenergy production, mainly in the form of heat and/or power generation (Ref.7). Assuming an average stover yield of 8.2 t/ha at 68% moisture content (Refs. 7 and 11 to 13), or 3.1 t/a at 15% moisture content, then this suggests a total quantity of stover available in the EU-27 in 2008 of almost 27 x 10^6 t at 15% moisture content. Since existing recovery for bioenergy production only amounts to less than 0.1% of this total, there would appear to be considerable potential for use as a biomass feedstock in the EU. This is provided that there are no other current uses of stover such as animal feed for which there are no known comprehensive EU statistics. Obviously, any major existing use of stover would compromise the biomass feedstock prospects of this agricultural residue.

Table 2 Breakdown of EU-27 Maize Cultivation Areas in 2008 (Ref. 7)

Member State	Grain Maize Area (10^6 ha)	Silage Maize Area (10^6 ha)	Total Maize Area (10^6 ha)
France	1.595	1.385	2.980
Romania	2.465	0.030	2.495
Germany	0.520	1.565	2.085
Hungary	1.205	0.085	1.290
Italy	1.020	0.225	1.245
Others	1.975	1.700	3.675
Totals	**8.780**	**4.990**	**13.770**

The attraction of using stover, as with any other agricultural residue, as a biomass feedstock for biorefineries is that it does not require extra land, as would be the case for a specific energy crop such as whole maize. However, the fact that provision of stover is completely dependent on the production of grain maize means that, unlike an energy crop, its ultimate supply is constrained by considerations related primarily to the demand for grain maize. This limits the flexibility of the biomass feedstock to meet changes in demand for the end use products of the biorefinery, such as biofuels and biochemicals. It will be apparent that these different sources of maize biomass feedstock also have different implications for dLUC and iLUC. The use of stover as a biomass feedstock should not result in any dLUC and it might only cause iLUC if there were significant existing uses for this agricultural residue. For example, if its application as a biomass feedstock displaced its use as an animal feed, then alternatives would be required, which might have iLUC implications depending on the nature and sources of these substitutes. In contrast, the use of whole maize as a biomass feedstock can result in either dLUC or iLUC, unless it can be cultivated economically on previously unused land with little or no carbon stock.

In an attempt to avoid iLUC, it would be necessary to grow whole maize on land that is not currently used for food or feed production. The effective creation of new agricultural land for whole maize cultivation would normally imply the conversion of currently-unused land. For example, it is often suggested that unused grassland might be converted to the cultivation of energy crops, such as whole maize. Although the creation of such new agricultural land might provide relatively good quality soils that could support economic yields, it would be necessary to take dLUC into account. In particular, changes in carbon stock due to land conversion would have to be determined. As mentioned in Section 2, a standard approach has been established by the EC for assessing carbon stock changes resulting from dLUC (Ref. 3). Unfortunately, the carbon stock of grassland is relatively high, resulting in GHG emissions from dLUC that could be unfavourable in the assessment of any biofuels derived from whole maize grown on such converted land. Similar concerns would arise for the conversion of peatlands and forests, although this latter option would probably not be considered in practice. Hence, whole maize is likely to be grown on existing agricultural land, with potential consequences for iLUC unless other unused land can be identified for practical conversion.

As with perennial energy crops, such as miscanthus, it might be possible to grow annual whole maize as a biomass feedstock on marginal land, degraded land or contaminated land. Leaving aside uncertainties over the precise classification and identification of such land that might not be suitable for food production, the cultivation of whole maize on these types of land raises a number of important issues. Most significantly, there is the concern that cultivation of whole maize on land which is in any way less fertile or suitable might reduce its annual yield which is an economically attractive attribute of this particular biomass feedstock. If this is the case then yield reductions to uneconomical levels are likely to be counteracted by the application of suitable amounts of nitrogen (N) fertilisers. This would result in higher GHG emissions associated with whole maize cultivation, from both N fertiliser manufacture and subsequent soil N_2O emissions. Additionally, there would be the potential to increase nitrate pollution of local water supplies (see Section 3.4).

Another consideration for the cultivation of whole maize specifically on contaminated land would be the possible take-up of soil pollutants. Although there may be no immediate concerns about contamination by pollutants, such as heavy metals, of whole maize used for purposes which ensure that they do not enter the food chain, there are indirect considerations that would have to be addressed. For example, it would be necessary to establish that such contaminants do not interfere with the pre-treatment and/or subsequent processing of this biomass feedstock in proposed biorefineries. No significant effect on biogas yield from the anaerobic digestion of whole maize grown on land contaminated with cadmium, lead and zinc has been observed in field trials in Belgium (Ref. 14). However, it is not apparent whether similar research has been conducted on similarly-derived whole maize used in biorefineries. There might also be concerns that any contaminants taken up by the whole maize might ultimately reside in the waste products from these biorefineries. The ways in which such contamination might have to be addressed would depend on the subsequent treatment of these waste products. For example, if used in anaerobic digestion to generate biogas, the resulting digestate may become contaminated which could pose problems for its subsequent use as an organic fertiliser. Alternatively, if dried and burnt for energy recovery, flue gas controls might have to be imposed and ash disposal restricted. Clearly, careful evaluation of potential impact pathways would have to be investigated although the possibility of using contaminated land in such a productive manner could be extremely attractive in the future.

If these and similar concerns prove insignificant or if they can be overcome technically, there is another consideration for the possible cultivation of whole maize on contaminated land. This arises because, unlike perennial energy crops such as miscanthus, whole maize is an annual crop. Hence, it would form part of a rotation with other crops. To ensure that contaminants do not enter the food chain, it is unlikely that annual food crops would form part of this rotation. Consequently, other annual energy crops suitable for use in a rotation to maintain productivity would have to be grown following whole maize cultivation and harvesting. It would be necessary to identify such complementary energy or non-food/feed crops and, as with whole maize, address any issues of absorbed contaminants on their subsequent use as biomass feedstocks.

All these relatively complex considerations emerge whilst attempting to avoid iLUC due to the cultivation of whole maize as a biomass feedstock for biorefineries. If whole maize is grown on land previously used for food or feed production then, ideally, iLUC should be taken into account, especially in relation to the calculation of associated GHG emissions for the purposes of policy analysis. However, this is not a simple task since, currently, there is no universally-agreed approach to the assessment of iLUC and its impact on GHG emissions despite the existence of a number of relevant models (see, for example, Ref. 15). For the time being, it has been proposed that so-called iLUC factors should be incorporated into the RED for calculating GHG emissions associated with the production of biofuels from certain biomass feedstocks in the regulatory context (Ref. 4). However, the proposed iLUC factors only cover biomass feedstocks from cereals and other starch-rich crops, sugars and oil crops. In effect, the proposed iLUC factors relate to food crops which are commonly used in existing biofuel production and, as such, whole maize is not included in the current list. At the moment, the concept of iLUC factors and their proposed values are the subject of polarised debate and disagreement in the European Parliament with different voting outcomes from the Industry, Research and Energy (ITRE) Committee and Environment (ENVI) Committee. Hence, these iLUC factors have not been adopted officially so far. However, if this were to happen, it could be expected that the concept might be extended to other crops grown on agricultural land, resulting in possible application to whole maize used as a biomass feedstock for biorefineries. This future possibility poses a policy risk to the use of whole maize as a feedstock for biofuel production.

Overall, land use considerations appear to favour stover over whole maize as a biomass feedstock for biorefineries. However, it should be noted that the potential yield of whole maize, typically around 41 t/ha at 68% moisture content (Ref. 16), is considerably higher than that of stover, typically around 9 t/ha with an equivalent 68% moisture content (Refs. 7 and 11 to 13). Hence, on average, about 80% less land area would be required to obtain any given amount of biofuel or biochemical from whole maize than stover. Consequently, where there are similar sustainability concerns for both whole maize and stover, it could be that the former would be considered more favourably than the latter.

Beyond land use issues, there are other sustainability considerations that affect these biomass feedstocks differentially. In particular, the concerns for whole maize are similar to those for any annual crop which includes high levels of biomass removal. In contrast, the concerns for stover are more in common with those of most crop-derived agricultural residues. The concerns for stover mainly revolve around its removal as opposed to possible incorporation. This alternative does not apply to whole maize since the fundamental approach with such a crop is to remove as much above-ground biomass as possible for use as a feedstock. With either source of biomass feedstock, it is usually assumed that all below-ground biomass is incorporated along with a given proportion of above-ground biomass. In the case of whole maize, this above-ground biomass should mainly consist of near-surface stalks. Although such biomass will also be incorporated in the case of stover removal, more above-ground biomass might be unrecovered due to the nature of grain maize harvesting and the economics of residue collection. Typically, only between 30% and 40% of the stover available is currently collected (Ref. 11). It should be noted that most of the research on the effects of stover removal on soil erosion, soil fertility and soil carbon (see Section 3.2) has been conducted in the USA where this biomass source currently appears to be receiving more attention as a commercial feedstock for biofuel production than it is in the EU. In contrast, the effect of whole maize cultivation on biodiversity (Section 3.6) has attracted more attention in the EU.

3.2 Soil Erosion, Fertility and Carbon

In general, the supply of whole maize and stover as feedstocks for biorefineries present similar issues for effects on soil since both sources involve the removal of potentially large amounts of above-ground biomass. However, most attention has been directed towards the removal of stover as this is material which can be incorporated into the soil. The impact of the collection of stover on various sustainability criteria, including soil quality, has been modelled at a State level in the USA and this suggested that there should be a maximum limit removal (Ref. 17). Further research (Ref. 18) has supported the proposal for a maximum limit to stover removal in order to prevent wind and water erosion of soils and to maintain soil organic carbon (SOC). The protection of soils from erosion and maintenance of their fertility for following crops has been linked to the level of soil organic matter (SOM) which obviously decreases when stover is removed (Ref. 19). In addition to increases in erosion and decreases in SOC, soil nitrogen and phosphorus loss have been observed with stover removal (Ref. 20). Field trails with varying levels of stover removal, ranging from complete removal at 7.8 t/ha through intermediate removal at 3.8 t/ha to low removal at 1.5 t/ha, has suggested that there are subtle soil changes which would result in negative consequences, especially for subsequent crop productivity, from repeated harvesting (Ref. 21). As well as limiting removal, impacts on soil erosion and fertility can be mitigated by adopting minimum tillage and no tillage methods of cultivation (Refs. 20, and 22 to 25). The value of winter cover crops for both grain and whole maize has been noted as another means of reducing possible soil erosion (Refs. 24 and 26).

3.3 Water Use

Both grain and whole maize have relatively high water requirements and this must be supplied artificially in areas that are prone to long dry periods during the growing season (Ref. 27). Hence, irrigation might be required in more southerly parts of the EU. However, these areas are more commonly used for grain maize cultivation in which stover utilisation is a secondary consideration. In other words, any irrigation is to ensure good yields for the grain crop rather than stover harvesting. In the case of whole maize, the purpose is to achieve high yields of above-ground biomass and, hence, adequate water supply to this crop might be regarded as a priority. However, whole maize cultivation for biorefinery feedstock production is likely to be focused on areas that already grow silage maize. These areas usually have sufficient rainfall to avoid significant or frequent irrigation.

3.4 Emissions to Water

Artificial and organic N fertilisers are applied to both grain and whole maize to achieve commercially acceptable yields. Consequently, problems can occur with nitrate leaching and eutrophication in neighbouring water courses and underground aquifers (Ref. 27). In particular, nitrate leaching, as well as soil enrichment with phosphates, has been observed with whole maize grown in North West Germany (Ref. 26). It is thought that this might be due to the over-supply of readily available semi-liquid manure, to which maize is tolerant. It might also be expected that nitrate leaching into local ground water might be a concern when growing whole maize on marginal, degraded or contaminated land as a result of higher N fertiliser application rates that might be required to achieve commercial yields. Herbicide and pesticide spraying can be necessary for both grain and whole maize cultivation so that subsequent leaching can also be a potential consideration for both crops (Ref. 26).

3.5 Emissions to Air

The main emissions to air associated with whole maize cultivation and stover harvesting relate to diesel combustion by agricultural machinery. Apart from prominent GHG emissions, diesel combustion is chiefly responsible for the release of oxides of nitrogen (NOx), particulates, sulphur dioxide, carbon dioxide and non-methane volatile compounds. Many of these emissions are related to air quality problems although these are usually an issue in urban areas where diesel combustion is concentrated principally due to high levels of traffic. These emissions to air are of less concern in rural areas where most if not all operations for whole maize and stover production would take place ensuring that such pollutants are dispersed over comparatively large areas. In general, the provision of both these sources of biorefinery feedstock poses no special problems with emissions to air other than those associated with other annual crop production.

3.6 Biodiversity

In so far as both grain and whole maize can be cultivated as monocultures, these crops can reduce biodiversity (Ref. 27). The removal of stover decreases the amount of SOM and this can have negative impacts on plants, insects, birds and animals, especially during the winter period after harvesting. However, it has been proposed that this can be counteracted by the cultivation of catch crops and green manures that provide ground cover that can foster biodiversity (Ref. 26). Where crops such as silage maize have replaced cereal crops, a decline in biodiversity, mainly affecting plants, invertebrates and birds has been observed in the UK (Ref. 28). Apart from isolated studies such as this, there appears to have been little research into the effects of whole maize cultivation and stover removal on biodiversity.

3.7 Other Impacts

An issue which affects most biomass feedstocks is the generation of traffic levels, especially during the harvesting period, around the biorefinery. As a biomass feedstock, stover and whole maize are relatively low bulk density materials. For example, in baled form, stover has a bulk density of between 100 kg/m^3 and 200 kg/m^3 (Ref. 29). Some increase in bulk density can be achieved by pelletising although this is unlikely in terms of supplying a biorefinery which might be expected to be located near the sources of stover and whole maize supply. Transportation from farms to a biorefinery by bulk road freight lorries would be favoured from an economic perspective, thereby reducing vehicle movement relative to the use of tractors and trailers. Transportation is likely to be spread out over a period of time if storage at the biorefinery is limited. If access routes and schedules are carefully organised to minimise nuisance to local inhabitants, traffic levels would not be expected to create major problems.

4. CONCLUSIONS

A number of sustainability criteria have been established for biofuels and bioliquids within the EU under the RED from the EC. In particular, quantitative regulations exist for the production of biofuels from stover, as an agricultural residue, and whole maize, as an annual energy crop, in terms of associated total GHG emissions and net GHG emissions savings relative to conventional diesel and petrol used as transport fuels. However, other sustainability criteria are broader and can only be addressed in a qualitative manner. In general, these sustainability criteria depend on contrasting characteristics of stover removal and whole maize cultivation. The supply of biorefinery feedstocks from these sources appears to present no impacts on water use and emissions to air greater than other existing agricultural activities. Other environmental aspects present more specific challenges, especially in terms of iLUC, soil erosion, fertility and carbon, and biodiversity. However, these impacts can be minimised through suitable mitigation measures:

- to reduce iLUC, a balance is required between the amount of feedstock obtained from stover, which has a relatively lower yield but can avoid iLUC provided that it has no existing productive use, and whole maize, which has a markedly higher yield but can generate iLUC if grown on existing agricultural land,

- to avoid significant iLUC with whole maize used as a biorefinery feedstock, this annual crop should be grown on marginal, degraded or contaminated land provided that it forms part of a rotation with other energy crops that do not enter the food/feed chain and that it can achieve commercially-acceptable yields without excessive application of N fertilisers, herbicides and pesticides that could cause significant emissions to local water sources,

- to limit problems with soil erosion, fertility and carbon, and biodiversity, stover removal should be limited to a pre-determined percentage of the above-ground biomass available, and it should be derived from grain maize cultivation based on minimum or no tillage with following catch crops or green manures to provide ground cover in winter,

- to prevent appreciable loss of biodiversity, large-scale monocultures of grain and whole maize should be avoided, with careful planning of rotations including ground-covering winter catch crops and green manures, and restrictions on artificial and organic N fertiliser, herbicide and pesticide applications, and

- to address any potential concerns over traffic levels, especially in the vicinity of biorefineries, harvesting and transportation plans for stover and whole maize should be devised to prevent congestion and minimise vehicle movements through careful consideration of timing and routes.

REFERENCES

1. “Sustainability Policy and Regulatory Review Report” by L. C. Stringer and S. Afionis, SUNLIBB Deliverable D8.1, University of Leeds, Leeds, United Kingdom, March 2012.

2. “Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC” European Commission, Brussels, Belgium, 5 June 2009, http://ec.europa.eu/energy.

3. “Commission Decision on the Guidelines for the Calculation of Land Carbon Stocks for the Purposes of Annex V of Directive 2009/28/EC” Official Journal of the European Union, L151, p. 19 - 41, European Commission, Brussels, Belgium, 17 June 2010, http://ec.europa.eu/energy.

4. “A Proposal for a Directive of the European Parliament and of the Council Amending Directive 98/70/EC Relating to the Quality of Petrol and Diesel Fuels and Amending Directive 2009/28/EC the Promotion of the Use of Energy from Renewable Sources” COM(2012) 595 Final, European Commission, Brussels, Belgium, 17 October 2012, http://ec.europa.eu/energy.

5. “Communication from the Commission on the Practical Implementation of the EU Biofuels and Bioliquids Sustainability Scheme and on Counting Rules for Biofuels” 2010/C 160/02, European Commission, Brussels, Belgium, 19 June 2010, http://ec.europa.eu/energy.

6. “Maize Supply Chain Workbook” by O. Mwabonje, C. Hatto and N. D. Mortimer, SUNLIBB Maize Biorefinery v04.xlxs, Deliverable D8.3, North Energy Associates Ltd., Sheffield, United Kingdom, August 2013.

7 “European Confederation of Maize Production: Annual Report 2007-2008” Journées Mais, No. 16, CEPM, Paris, France, 17 September 2008.

8. “Corn Production Statistics” National Agricultural Statistics Service, United States Department of Agriculture, www.nass.usda.gov, accessed 2 August 2013.

9. “Statistics on Ethanol Production from Corn” Alternative Fuels Data Center, United States Department of Energy, www.afd.energy.gov, accessed 2 August 2013.

10. “Biofuels Baseline 2008” by C.Hamelinck, M. Koper, G. Berndes, O. Englund, R. Diaz-Chavez, E. Kunen and D. Walden, Project No. PECPNL084543, Ecofys Consultancy, Utrecht, the Netherlands, 18 October 2011.

11. "Economics of Crop Residues: Corn Stover" by D. R. Petrolia, Transition to Bioeconomy Conference, Little Rock, Arkansas, United States of America, June 2009.

12 "Harvest Index: A Predictor of Corn Stover Yield" by D. Pennington, Michigan State University Extension, 28 January 2013; http://msue.anr.msu.edu, accessed 31 July 2013.

13. "Buying and Selling Corn Silage or Other High Moisture Feeds" by D. Feuz, C. Israelsen, A. Young and L. Holmgren, Utah State University Co-operative Extension, Logan, Utah, United States of America, July 2012.

14. “Safe Use of Metal-Contaminated Agricultural Land by Cultivation of Energy Maize (Zea mays)” by S. van Slyckens, N. Witters, E. Meers, A. Peerse, E. Michels, K. Adriaensen, A. Ruttens, J. Vangransveld, G. Du Laing, I. Wierinck, M. Van Dael, S. Van Passel and F. M. Tach, Environmental Pollution, No. 178, pp. 375 – 380, June 2013.

15. “Indirect Land Use Change from Increased Biofuels Demand: Comparison of Models and Results for Marginal Biofuels Production from Different Feedstocks” by R. Edwards, D. Mulligan and L. Marelli, EUR 24485 EN, European Commission Joint Research Centre, Institute for Energy, Ispra, Italy, 2010.

16. "Maize - A Growers Guide" 2011, Limagrain UK Ltd, http://www.limagrain.co.uk/products/maize.html, accessed 29 November 2012.

17. “Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol” by J. Sheehan, A. Aden, K. Paustian, K. Killian, J. Brenner, M. Walsh and R. Nelson, Journal of Industrial Ecology, Vol. 7, Nos. 3 – 4, pp. 117 – 146, 2004.

18. “Corn Stover Soil Organic Carbon Further Constrains Biomass Supply” by W. W. Wilhelm, J. M. F. Johnson, D. L. Karlen and D. T. Lightle, Agronomy Journal, Vol. 99, pp. 1665 – 1667, 2007.

19. “Environmental Implications of Biomass Removal” by J. L. Hatfield, Fluid Journal, pp. 8 – 11, Winter 2008.

20. “Corn Stover Cost, Availability and Sustainability” by D. Archer, United States Department of Agriculture, Mandan, North Dakota, United States of America, 2008.

21. “Crop and Soil Responses to Using Corn Stover as a Bioenergy Feedstock: observations from the Northern US corn belt” by J. M. F. Johnson, V. Acosta-Martinez, C. A. Cambardella and N. W. Barbour, Agriculture, Vol. 3, pp. 72 – 89, 2013.

22. “Harvesting Corn Stover for Bioenergy: does it have long-term effects on soil health?” by B. Moebius, H. van Es, J. Idowu, R. Schidelbeck, D. Clune, D. Wolfe, G. Abawi, J. Thies and B. Gugino, Cornell University, Ithaca, New York State, United States of America, 2007.

23. “Corn Stover as a Bioenergy Feedstock: identifying and overcoming barriers to corn stover harvest, storage and transport” by D. Klingenfeld, Master’s Report, Harvard Kennedy School, Cambridge, Massachusetts, United States of America, 2008.

24. “Corn Stover for Ethanol Production: potential and pitfalls” by E. Marshall and Z. Sugg, WRI Policy Note No. 4, World Resources Institute, Washington D.C., United States of America, January 2009.

25. “Feasibility of Corn Stover in Missouri” by R. Milhollin, J. Hoehne, J. Horner, S. Weber and C. George, University of Missouri Extension, Missouri, United States of America, January 2011.

26. “The Environmental Impact of Maize Cultivation in the European Union: practical options for the improvement of the environmental impacts – case study Germany” by C. Finke, K. Möller, S. Schlink, B. Gerowitt and J. Isselstein, Research Centre for Agriculture and Environment, Georg-August-University of Göttingen, Germany, November 1999.

27. “Global Maize Production, Environmental Impacts and Sustainable Production Opportunities; a scoping paper” UNDP Green Commodities Facility, United Nations Development Programme, www.greencommodities.org, June 2010.

28. “Cereal-based Whole Crop Silages: potential biodiversity benefits of cereal production in pastoral landscapes” by S. R. Mortimer, Aspects of Applied Biology, Vo. 81, pp. 77 – 86, 2007.

29. “Densification Characteristics of Corn Stover and Switchgrass” by N. Kaliyan and M. V. Morey, Transactions of the American Society of Agricultural and Biological Engineers, Vol. 52, No. 3, pp. 907 – 920, 2009.