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Sustainability criteria for biofuels made from land and non-land based feedstocks

By:

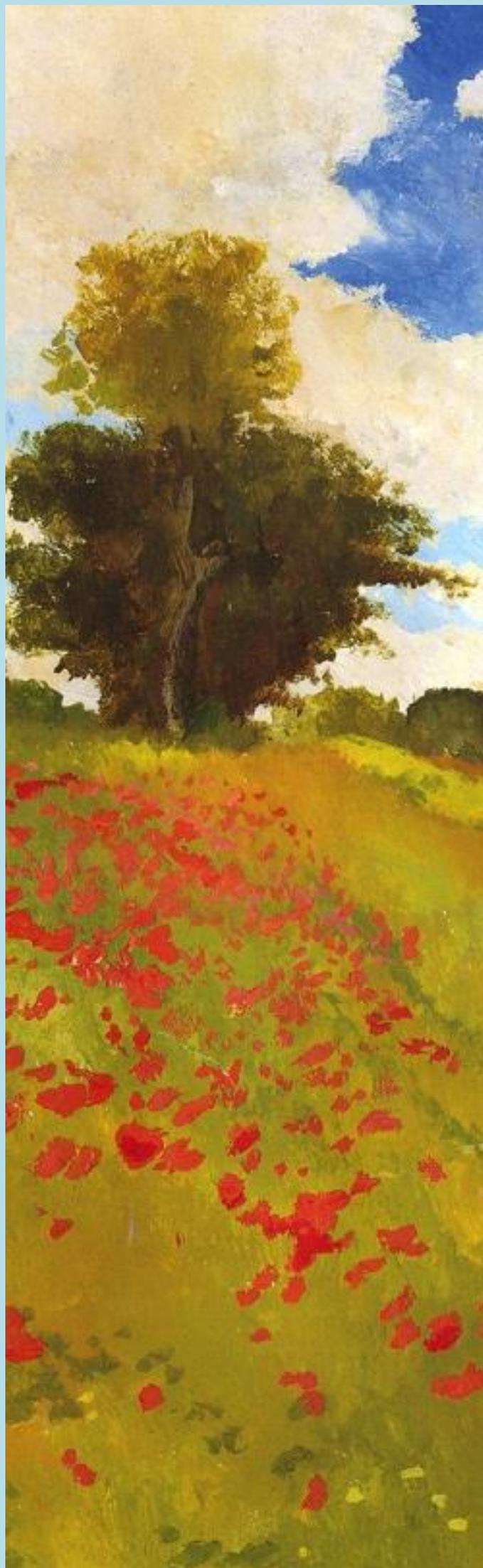
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Glossary of selected terms used in the report

Processing residue and by-products: A substance or object, resulting from a production process, the primary aim of which is not the production of that item. A substance that is not the end product(s) that a production process directly seeks to produce and the process has not been deliberately modified to produce it. (Directive (EU) 2015/1513; Directive 2008/98/EC)

Agricultural, aquaculture, fisheries and forestry residues: Residues that are directly generated by agriculture, aquaculture, fisheries and forestry; they do not include residues from related industries or processing.’ (Directive (EU) 2015/1513)

Feedstock: The input material used in the production of biofuels or bio-liquids

Cellulose: A carbohydrate polymer that acts as a structural component in plant cell walls. Higher proportions are found in fibrous plants such as wood or cotton.

Hemicellulose: A carbohydrate polymer that acts as a structural component in plant cell walls. The structure of hemicellulose allows it to be more easily broken down than cellulose.

Ligno-cellulose: A compound of carbohydrate polymers (cellulose and hemicellulose) bound to lignin.

Community: The European Union

Fallow land: All arable land either included in the crop rotation system or maintained in good agricultural and environmental condition (GAEC), whether worked or not, but with no intention to produce a harvest for the duration of a crop year. (Commission Regulation (EU) 2015/1391)

Waste: Any substance or object that the holder discards or intends or is required to discard. Substances that have been intentionally modified or contaminated to meet that definition are not covered by this definition. (Directive 2008/98/EC (Article 3(1)).

FSC: Forest Stewardship Council

PEFC: Programme for the Endorsement of Forest Certification

ILUC: Indirect Land Use Change

MJ: Megajoule (MJ) is equal to one million (10^6) joules

DBH: Diameter at Breast Height – a standard dendrometric measurement of tree size.

Preface by the European Climate Foundation

In December 2015, world leaders agreed a new deal for tackling the risks of climate change. Countries will now need to develop strategies for meeting their commitments under the Paris Agreement, largely via efforts to limit deforestation and to reduce the carbon intensity of their economies. In Europe, these climate protection strategies will be developed via the EU's 2030 climate and energy framework, with a view to ensuring an integrated single market for emissions reduction technologies.

Existing EU energy policy for 2020 foresees an important role for bioenergy as a means of reducing carbon emissions from heating, power and transport, and yet there are concerns that this has led to a number of negative consequences related to the intensification of resource-use. If bioenergy is to continue to play a role in EU energy strategies for 2030, it seems wise to learn from the past to ensure that this is done in a manner that is consistent with the EU's environmental goals, including the 2 degrees objective.

With this in mind, the European Climate Foundation has convened the *BioFrontiers* platform, bringing together stakeholders from industry and civil society to explore the conditions and boundaries under which supply-chains for advanced biofuels for transport might be developed in a sustainable manner. This builds on work developed in the ECF's *Wasted* platform in 2013-2014, which focused on waste- and residue-based feedstocks for advanced biofuels. This time around, there is an additional focus on considering land-using feedstocks and novel fuel technologies.

As the name *BioFrontiers* suggests, this discussion enters new territory and is faced with numerous gaps in knowledge. To facilitate a transparent and constructive debate between industry and civil society, the ECF has commissioned a number of studies to help fill such knowledge gaps. This is one such study. It does not represent the views of the members of the *BioFrontiers* platform, merely an input to their discussions. If this research also helps inform the wider debate on the sustainability of bioenergy, that is a bonus. I would like to thank the IEEP for using the resources provided by the ECF to improve our understanding of these important issues.



Pete Harrison
Programme Director, Transport
European Climate Foundation

Summary of proposed sustainability criteria

Defining effective and workable sustainability criteria is one of the critical steps in decarbonising Europe's energy sector. Such criteria must be effective in ensuring that bioresources are used in a sustainable manner, particularly for biofuels in Europe when contributing to long-term economic development; and operational in that they can be implemented within the current and proposed future policy framework. They should aim to provide the necessary safeguards for the use of bioresources in Europe requested by civil society, as well as the policy and investment certainty required by industry on the supply side. They should help to meet the EU's GHG emission reduction targets sustainably, whilst being applicable in a real-world situation, with due respect and acknowledgement of inevitable trade-offs. In developing these sustainability criteria we have aimed to ensure that the requirements on economic operators are proportionate to the risks posed by the feedstocks and are implementable in a practical way.

The criteria set out in this report fall into two specific types. There are *general criteria (GC)* that are applicable across all feedstocks and there are *specific criteria (SC)* that address explicit risks identified for individual or groups of feedstocks. ***To be effective, a coherent framework of sustainability criteria requires both general and specific criteria***, they are part of a set, are not substitutable and must be applied where they are relevant.

GC1 – The greenhouse gas emission intensity from the production and use of biofuels and bio-liquids shall be no more than [27g] CO₂ MJ¹. The calculation of the GHG emission intensity shall be done through the use of attributional LCA with the following factors taken into account: the production and harvesting methods used; the re-growth period of the biomass; collection and transportation emissions; and conversion emissions.

GC2 - The use of feedstocks should not cause the displacement of food, feed or timber production either directly or indirectly within a specific area or project¹. The specific area or project to which this criterion is applied shall be determined in advance of production so that an evaluation of the project or site can be made and act as a baseline against which to measure any displacement activities during production or after harvesting. This should take the form of a site or project management plan setting out the current production pattern (including areas of specific crops and their yields) and the intended siting of the biofuel feedstocks.

GC3 - The use of land-based biomass produced in an agricultural context for the express purpose of biofuel production should be limited to a sustainability ceiling set for the EU as a whole, with appropriate mechanisms for dividing it between Member States.

GC4 - The use, collection and harvesting of feedstocks, shall be in compliance with international, national, regional and local environmental legislation. This includes ensuring coherence with key EU legislation pertinent to the use, cultivation and collection of specific feedstocks and their potential impacts, such as ***compliance with the principles of the waste hierarchy (as set out in Council Directive 2008/98/EC), the Water Framework Directive (Directive 2000/60/EC) and the relevant Common Agricultural Policy (CAP) rules***, specifically those set out under the heading 'environment, climate change, good agricultural condition of land' in Annex II of Council Regulation 1306/2013.

¹ In this case, a 'specific area or project' refers to the collection or harvesting of feedstocks in relation to a specific biofuel plant or group of plants.

SC1 - Biofuels and bio-liquids should not be made from material obtained from land with high biodiversity value, except where the material can be harvested in compliance with conservation objectives. High biodiversity value land is defined as that which had one of the following statuses in or after January 2008, whether or not the land continues to have that status:

- a) primary forest and other wooded land, namely forest and other wooded land of native species, where there is no clearly visible indication of human activity and the ecological processes are not significantly disturbed;
- b) areas designated:
 - i) by law or by the relevant competent authority for nature protection purposes; or
 - ii) for the protection of rare, threatened or endangered eco- systems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the International Union for the Conservation of Nature, subject to their recognition in accordance with the second subparagraph of Article 18(4);

unless evidence is provided that the production of that raw material did not interfere with those nature protection purposes;

- c) highly biodiverse grassland that is:
 - i) natural, namely grassland that would remain grassland in the absence of human intervention and which maintains the natural species composition and ecological characteristics and processes; or
 - ii) non-natural, namely grassland that would cease to be grassland in the absence of human intervention and which is species-rich and not degraded, unless evidence is provided that the harvesting of the raw material is necessary to preserve its grassland status.

The Commission has established the criteria and geographic ranges to determine which grassland is covered by point (c) of the first subparagraph in Regulation (EU) No 1307/2014.

The status and completeness of conservation objectives may vary according to the particular designation and the Member State/Country involved. Advice should always be sought from the relevant competent national authority on the appropriate and permissible management of designate sites before undertaking production or vegetation harvesting.

SC2 - Biofuels and bio-liquids should not be made from material obtained from high carbon stock land except where the material can be harvested in compliance with conservation objectives. High carbon stock land is defined as land that had one of the following statuses in January 2008 whether or not it continues to have that status:

- a) wetlands, namely land that is covered with or saturated by water permanently or for a significant part of the year;
- b) continuously forested areas, namely land spanning more than one hectare with trees higher than five metres and a canopy cover of more than 30 %, or trees able to reach those thresholds in situ;
- c) land spanning more than one hectare with trees higher than five metres and a canopy cover of between 10 % and 30 %, or trees able to reach those thresholds in situ, unless evidence is provided that the carbon stock of the area before and after conversion is such that, when the

methodology laid down in (Annex [xx]² of the regulation) is applied, the conditions laid down in relation to GC1 [GHG emission saving requirement] are fulfilled.

The status and completeness of conservation objectives may vary according to the particular designation and the Member State/Country involved. Advice should always be sought from the relevant competent national authority on the appropriate and permissible management of designate sites before undertaking production or vegetation harvesting.

SC3 - Biofuel and bio-liquids should not be made from material where its extraction or cultivation will result in significant negative impacts on biodiversity or ecosystem function. In particular extraction or cultivation should not:

- result in a decrease in the diversity or abundance of species and habitats of conservation importance or concern;
- contravene existing management plans or conservation objectives;
- result in a reduction of soil organic matter or soil organic carbon to levels that are critical for soil fertility;
- result in risk of soil erosion;
- lead to a decrease in water availability in catchments where this is a concern; or
- lead to a critical decrease in water quality within a catchment.

Each area of risk is highly geographically variable. Guidance should be sought from the relevant competent national or regional authority to identify areas or issues of importance and relevance within the area or project concerned. Conservation objectives are described under SC1

SC4 - Where biofuels and bio-liquids are produced from novel non-native or invasive alien species (e.g. certain species of algae, tropical plants, etc.), their cultivation should be subject to an initial risk assessment and on-going monitoring in order to ensure that sufficient safeguards are in place to prevent escape to the environment.

SC5 - Biofuels and bio-liquids shall not be made exclusively from whole trees above a stem diameter of [x] cm at breast height. The diameter of the tree, measured conventionally at breast height (DBH), should be determined within the context of regional sustainable forest harvesting strategies and in relation to the tree species and forest from which they are harvested.

² Appropriate reference would be made to the annex describing the calculation methodology applying to this point.

1 Introduction

The principal aim of this study is to define and articulate effective and workable sustainability criteria for the use of biomass in the production of energy, primarily in biofuels, in the post 2020 period. The main focus is on renewable transport fuel, and thus on biofuels and bio-liquids, but many of the criteria are applicable to the wider use of biomass for energy purposes. Certain criteria already apply for this purpose but they have not been re-examined to take account an increasing range of feedstocks and competing applications as well as evolving sustainability concerns. The report aims to increase understanding in this area as well as to propose potential ways forward.

EU biofuels policy and the wider climate and energy policy framework are at a turning point. In 2020 many of the current targets for renewable energy deployment and Greenhouse Gas (GHG) emissions saving targets, including those in the transport sector, come to an end. The debate about how to reach these targets sustainably continues to be diverse and often polarised between a range of different sectoral and Member State interests. At the same time decision makers are starting to think about the policy framework to decarbonise the EU economy beyond 2020 and particularly to 2030 triggering discussions on the most sustainable and effective routes forwards. There is therefore a pressing need to develop sustainable and realistic solutions to meeting the EU's targets to 2020 and to ensure that these developments contribute to a longer-term sustainable decarbonisation trajectory to 2030.

Defining effective and workable sustainability criteria is one of the critical steps in this trajectory. Such criteria must be effective in ensuring that bioresources are used in a sustainable manner, particularly for biofuels in Europe when contributing to long-term economic development; and operational in that they can be implemented within the current and proposed future policy framework. They should aim to provide the necessary safeguards for the use of bioresources in Europe requested by civil society, as well as the policy and investment certainty required by industry on the supply side. They should help to meet the EU's GHG emission reduction targets sustainably, whilst being applicable in a real-world situation, with due respect and acknowledgement of inevitable trade-offs.

1.1 Rationale for sustainability criteria for renewable energy policy

Why are legislative sustainability criteria necessary for the use of biomass feedstocks driven by renewable energy policy, not least for biofuels when criteria are not currently required for all other uses of the same material? There are two primary reasons for this. First that public policy and public money is being used to promote the deployment of renewable energy of a kind that reduces emissions; therefore it must be ensured that these objectives are being met. Second, there is relatively limited sustainable supply of these resources when balanced against existing and future needs and the best means of deploying them needs to be identified and pursued.

The ***policy driven promotion of biofuels and other bioenergy*** in Europe through direct and indirect incentives (in some cases giving it a competitive advantage over other markets such as paper or board (Vis et al. 2016)) has been justified on the basis that it provides specific public benefits, particularly a reduction in GHG emissions. This is justified only if these

benefits are achieved and that deployment does not impact unduly negatively on other environmental priorities³. There is a real risk that, without checks and balances, public support for bioenergy could lead to over exploitation of resources. These risks need to be minimised/mitigated to ensure coherence in Community policy and prevent perverse outcomes arising. The production of conventional food, feed or timber (material) products with specifically sustainable characteristics are not promoted through policy in the same way. Hence, there is an additional responsibility on those producing or harvesting biomass for energy purposes to demonstrate sustainability, through compliance with criteria, beyond that incumbent on users of the same biomass intended for other markets. Whilst the requirement to meet higher standards can feel frustrating for bioenergy operators, and split supply chains can raise practical issues, it is perfectly logical in the context of using public money (including through mandates that must be paid for by energy consumers) for public benefit. Legislative sustainability criteria are a necessary mechanism to achieve this in the current context.

There is a **limited quantity of land and biomass** available in the EU, which is already heavily utilised to meet European and some global food, feed, and timber demands as well as some existing energy requirements (Hart et al. 2012; Allen et al. 2014). These demands and requirements are generally expected to grow over the next few years, with an expanding and richer world population. Whilst there may be more availability of biomass when considered at the global level (e.g. Souza et al. 2015), limits remain and the areas into which biofuel feedstock production expands generally has been existing productive agricultural land, or other suitable areas (e.g. Valin et al. 2015). There is already a well-established tension between these primary economic calls on the land and other existing or potential uses including the protection of biodiversity (Hart et al. 2012; Poláková et al. 2011), which is in decline in much of the world. Biodiversity and the functioning of natural ecosystems underpin the production of bioresources (TEEB 2010; Haines-Young & Potschin 2009). In the EU there is a policy goal to stop the decline of biodiversity and ecosystems by 2020 (European Commission 2011), which is itself a demanding goal.

Consequently, there is a *prima facie* concern about the extent to which a substantive new sector can be accommodated within the existing resource base without putting excessive further pressure on biodiversity, ecosystems and the services they support. Legislative sustainability criteria are a mechanism for steering the pattern and scale of resource use in a direction that recognises this context; and protects the key environmental parameters while involving stakeholders in a structured way.

³ In some situations the management and removal of vegetation can help to contribute towards conservation goals, providing that it is carried out sensitively in conjunction with site management objectives.

2 Identifying potential feedstocks

This chapter describes the types of feedstock that potentially could be used to produce advanced biofuels.

2.1 Expanding biofuel feedstocks

The EU is in a process of a transition away from conventional biofuel production to more advanced technologies that are able to utilise a wider range of materials. Due to the increasing availability of an expanding range of chemical, thermal and enzymatic conversion technologies, biofuel producers are no longer confined to extracting oils and sugars from a relatively limited pool of crop-based feedstocks. More advanced technologies can now utilise materials such as cellulose or hemi-cellulose, expanding the potential resource base for biofuels and bio-liquids considerably.

In this study the process of identifying feedstocks that potentially could be deployed over the next two decades or so started with the existing list of (implicitly “advanced”) feedstocks set out as part of a recent legislative change to the EU Renewable Energy Directive (2009/28/EC). This new legislation (Directive (EU) 2015/1513) aims to mitigate the impacts of Indirect Land Use Change (ILUC) and makes explicit reference to a set of feedstocks that would be eligible to receive support through public policy in order to encourage their use. This list, set out in Annex IX of the Directive, identifies the different feedstocks, mainly wastes and residues, whose energy content can be counted twice when calculating the share of energy from renewable sources in transport in 2020⁴. Under the agreed amendments to Article 3 of the RED⁵, the Commission is empowered to adopt delegated acts to amend the list of feedstocks in part A⁶ of Annex IX in order to add feedstocks, but not to remove them. This recognises the non-exhaustive nature of the list proposed. Helpfully, the amendments set out the requirements and criteria that would allow an addition to the list, where each delegated act put forward by the Commission “... shall be based on an analysis of the latest scientific and technical progress, taking due account of the principles of the waste hierarchy established in Directive 2008/98/EC, and supporting the conclusion that the feedstock in question does not create an additional demand for land or cause significant distortive effects on markets for (by-)products, wastes or residues, that it delivers substantial greenhouse gas emission savings compared to fossil fuels, and that it does not risk creating negative impacts on the environment and biodiversity.”

Annex IX includes 22 biomass feedstocks or groups of feedstocks, including certain agriculture and forestry crops and products, residues/by-products and wastes (see Annex 1). Although Annex IX provides short definitions for some feedstocks or feedstock groups, many definitions are still missing and in some cases are not straightforward. In considering

⁴ Referred to as the 10 per cent target as set out in Article 3(4) of Directive 2009/28/EC

⁵ The addition of a 5th paragraph to the article

⁶ Part A includes feedstocks and fuels whose energy content shall count double towards the renewable transport fuels target set out in Article 3(4) of the policy. Part A explicitly excludes the following feedstocks - (a) Used cooking oil and; (b) Animal fats classified as categories 1 and 2 in accordance with Regulation (EC) No 1069/2009 of the European Parliament and of the Council.

definitions it also should be noted that there is a range of existing EU legislation that categorises some of these materials in different ways, for different purposes such as the European Waste Framework Directive (EWFD - Directive 2008/98/EC) (Kretschmer et al. 2013). Such legislation arises from different policy concerns, such as whether material is potentially hazardous to human health or how far it falls within EU level competence to address. This leads to a certain amount of uncertainty about the most transparent and robust categorisation of feedstocks.

The origin of Annex IX warrants further consideration, particularly as this helps to explain why certain feedstocks and feedstock groups appear on the list and why others do not. Box 1 provides a brief summary of the origins of Annex IX as set out by the ARUP URS consortium (2014). Importantly the authors of this text note *“no single body of scientific work or assessment framework lies behind the establishment of this Annex IX list, the level of multiple counting, or the rationale for inclusion/exclusion of different feedstocks”*.

Box 1: Origins of Annex IX of Directive (EU) 2015/1513

Following Communication 2010/C160/02⁷ on the practical implementation of the EU biofuels and bio-liquids sustainability scheme, a working group consisting of Austrian, Danish, Dutch, French, Swedish and UK participants to REFUREC (Renewable Fuels Regulators Club) prepared a working document with the aim of helping Member States to implement a harmonised classification of wastes, residues and co-products. A distinction was made between agricultural and forestry residues (from cultivation, harvest and thinning etc.) and industrial processing residues (from food or timber processing, for example). REFUREC made a further distinction for co-products, based on the proportion of revenue derived from the co-product in relation to the main crop, but this was not taken forwards into the RED or FQD.

The Commission’s proposal for amending the RED and FQD (COM(2012)0288), introduces in the form of Annex IX, a list of feedstocks, whose biofuels should be counted double or quadruple their energy content towards national (RED) transport targets of member states, and gives the Commission delegated powers to change this list as indicated by scientific and technical progress. This list contains all the materials that were classified by the REFUREC working group as “wastes”, but also other feedstocks that were considered by the Commission to have low ILUC risk. As the original RED did not provide a definition of wastes and residues, individual interpretations have led to significant differences arising between Member States. This irregular implementation and potential for continued misunderstanding was the reason why the Commission decided to move from generic wording to an inclusive list approach. Introducing the Annex IX list was therefore intended to harmonise those feedstocks that received support once the proposed amendments were implemented by each Member State, provide greater market clarity and uniformity, and encourage diversification of the feedstock base.

List based approaches are seen as a useful policy tool, but do require transparent ownership, regular updating with an efficient process for including additions and sub-categories, along with clear definitions at the appropriate levels. Many of the Annex IX feedstocks were proposed to receive additional support, with their use for biofuels quadruple counting, since the biofuel conversion technologies required were still to be commercialised, and the current biofuel production costs likely to be high – these feedstocks were also seen as having the lowest ILUC risks. Non-food cellulosic material (e.g. Miscanthus) and Lignocellulosic materials except saw logs and veneer logs (e.g. Short Rotation Coppice, Small round- wood) were seen by Commission individuals as being higher risk due to their use of land, hence these feedstocks were only proposed as double counting – despite them being expensive and relying on more novel conversion technologies.

Source: Following a 2014 report covering the sustainability of Annex IX feedstocks by ARUP URS (2014)

⁷ Communication from the Commission on the practical implementation of the EU biofuels and bio-liquids sustainability scheme and on counting rules for biofuels (2010/C 160/02)

For this study we have taken a step back from the political process in order to produce a list of possible feedstocks for advanced biofuels using Annex IX as a guide. This has involved a categorisation of current and potential feedstocks into meaningful groups, from a conventional supply chain perspective but as closely aligned to existing policy definitions as possible. We have expanded the list of potential feedstocks in Annex IX to provide a more comprehensive picture, including those that could produce other forms of bioenergy⁸.

In total 48 different feedstocks (described in Annex 2) have been identified with collated information relating to their geographical distribution, transportability, existing uses, availability and supply, environmental considerations, and whether identified sustainability issues are covered by existing RED or other EU legislation. The information collected is based on a systematic review of a number of publications (Allen et al. 2014; Harrison 2014; ARUP URS 2014; Elbersen et al. 2012).

2.2 Identifying feedstock groups

Many of the feedstocks identified in this study share similar characteristics and as such warrant similar if not identical considerations about their overall sustainability. In order to provide a coherent framework for identifying feedstocks that share similar characteristics and sustainability requirements the 48 different feedstocks can be broadly described under three headings (Table 1). These related to the way feedstocks are produced and the sectors from which they originate; and how the different feedstocks are treated in European law.

Some forms of biomass share similar origins and characteristics in the way they are produced. For example, both agriculture and forestry biomass crops require land for their production. Which types of land are used and how that land is managed can affect the sustainability of production and of the whole supply chain. Other feedstocks may arise from specific waste streams that have existing uses or are subject to specified disposal routes⁹. In addition, the different feedstocks and feedstock groups are subject to different thematic and sectoral policies, such as EU waste law or agriculture sector policy that guide the use and management of these different resources. For example, certain types of material are considered to be 'waste' under EU law and are therefore subject to the requirements of the waste framework directive (WFD)¹⁰, landfill directive, sewage sludge directive and recycling targets.

⁸ Additional feedstocks that have been reviewed include: bio-waste, bacteria and waste bio-liquids and gasses.

⁹ Such as the management of harmful or mixed waste fractions.

¹⁰ For example, Article 2(1)(f) of the WFD explicitly excludes from the scope of the directive 'faecal matter, straw and other natural non-hazardous agricultural or forestry material...'.

Table 1: Categorisation of biomass feedstocks

Biomass category and description	Feedstock types*	Definition
Primary biomass that has been grown purposefully as such or constitutes the primary output from production, whether intended initially for energy purposes or not.	Land-based biomass	Those feedstocks that rely on land for their production. Such as energy crops, forest timber or short rotation coppice**.
	Aquatic vegetation based biomass	Those feedstocks that rely on primary biomass in the form of microorganisms. Such as micro-algae and bacteria, or macro-algae such as seaweed.
Residual biomass that is generated as an artefact of production and/or management but is not the primary output.	Agricultural residues	Those feedstocks that rely on agricultural crops for their production, indirectly requiring land but not driving land use. Such as straw, cobs and husks.
	Forest-based residues	Those feedstocks that rely on forestry for their production, indirectly requiring land but not driving land use. Such as bark, branches and leaves.
	Other vegetation based residues	Those feedstocks that result from the management of vegetation other than agricultural or forestry crops. Such as reedbed management or other semi-natural vegetation.
	Processing residues	Those feedstock that result solely from the food, wood and paper processing sectors. Such as sawdust and cutter shavings.
Waste biomass that is generated as an artefact of consumption, i.e. its use is not driving biomass production from land or land management decisions.	Animal-based wastes	Those feedstocks that become available due to the maintenance of livestock in an agricultural context. Such as manure
	Mixed wastes	Those feedstocks that would otherwise be discarded or are generated as waste from the use of products and consumption of biological material by society. Such as food waste or municipal solid waste
	Waste gases	Gaseous feedstocks that would otherwise be discarded or are generated as waste from industrial production process, such as steel mill flue gas

Source: IEEP. **Note:** * The different sub-categories of feedstocks are detailed in the annex to this report. ** Conventional food and feed crops would also be covered by this category

With any grouping there are grey areas. The distinction between waste biomass and residual biomass presents a particular challenge, with these terms sometimes used interchangeably. Existing legislative and statistical definitions are unhelpful in making a

further separation in this context. They range from the brief, such as that in the EWFD¹¹, to the more detailed, such as the definition of wastes provided by the United Nations¹². It could be argued that the majority of feedstocks considered here could be defined as ‘wastes’ as they are often intended to be discarded. However, residues and by-products do find distinction under EU law and often have established markets or uses beyond that of explicit waste management. It is important to identify these feedstocks and as such we have defined an intermediate category, *residual biomass*, based on the definition of by-products as set out in Article 5 of the EWFD (Box 2).

Box 2: Definition of ‘by-products’ according to Article 5 of Directive 2008/98/EC

- 1) A substance or object, resulting from a production process, the primary aim of which is not the production of that item, may be regarded as not being waste referred to in point (1) of Article 3 but as being a by-product only if the following conditions are met:
 - a) further use of the substance or object is certain;
 - b) the substance or object can be used directly without any further processing other than normal industrial practice;
 - c) the substance or object is produced as an integral part of a production process; and
 - d) further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.

Source: Directive 2008/98/EC

Some biomass fractions have the potential to move between categories over time as a result of production, economic or market factors. For example, whilst it is unlikely that a residue would become more profitable than the primary biomass from which it originates, and therefore drive production decisions, it may become a significant factor in overall profitability and thus influence production or utilisation decisions (see Box 1). Recital 6 at the beginning of the ILUC Directive makes explicit reference to this situation and how certain ‘residues’ that are produced deliberately should be considered differently by the policy: *‘With a view to avoiding the incentivisation of the deliberate increase in production of processing residues at the expense of the main product, the definition of processing residue should exclude residues resulting from a production process which has been deliberately modified for that purpose.’* (Directive (EU) 2015/1513).

In addition to feedstocks that can move between groups or be defined in different ways, there are other processes that utilise more than one feedstock from different groups. An example of this are the novel fuel production process using bacterial biomass and the fermentation of waste gas (such as those produced by steel manufacturing) rather than sugar fermentation. The process of feedstock production is similar to some of the more conventional waste biomass streams, as it arises as an unavoidable consequence of a

¹¹ *Any substances or objects, which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law.* Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

¹² *“Wastes are materials that are not prime products (that is products produced for the market) for which the initial user has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose. Wastes may be generated during the extraction of raw materials, the processing of raw materials into intermediate and final products, the consumption of final products, and other human activities. Residuals recycled or reused at the place of generation are excluded”.* (UNSD 1997)

manufacturing or consumptive process, yet the process itself combines waste and primary biomass (bacteria) in the production of fuels (Box 9).

Grouping is a useful step in understanding particular and common sustainability issues shared between feedstocks and in understanding how to address those issues through sustainability criteria. However, the potential for feedstocks to move between categories, or indeed the ambiguity around which feedstock fits within which group does not necessarily affect the considerations relevant to defining their sustainability. Robust sustainability criteria need to reflect the impact of using an individual feedstock or group of feedstocks irrespective of how they are categorised (Kretschmer et al. 2012; Searle & Malins 2016; Searle & Malins 2013).

3 Rationale for sustainability criteria

This chapter sets out the function of sustainability criteria, the rationale for new criteria and a brief review of current sustainability criteria.

3.1 The function of sustainability criteria

Ensuring the sustainability of biofuels and bio-liquids in practice is likely to require a broad suite of measures. Certification schemes, guidance and advice, support, industry standards, and trading bodies all can be expected to play a role in guiding the sustainable use of biomass (Bowyer et al. 2015). This study focuses on one element of this mix, legislative sustainability criteria.

The role of sustainability criteria set out in legislation is to ensure, in this case, that the policy driven production of biofuels and bio-liquids does not lead to unsustainable or perverse outcomes. Sustainability, as a concept, does not pre-define the use or function of specific biomass streams. As one trend develops there may come a shift from one technology to another or the diversion of resources from an existing to a new supply chain or technology. The criteria, and the framework that surround them therefore help to safeguard the achievement of the goals of the policy and to control unintended, perverse outcomes. These can arise easily where a system of incentives is introduced.

The development of sustainability criteria needs to provide some certainty for investors and other interested parties but at the same time it can be helpful if they are, in parts, iterative and flexible, accounting for new and emerging technologies, approaches and issues. The framework in which sustainability criteria operate should allow for reviews to take place, ensuring that on-going sustainability issues are addressed and that there is a clear vision for long-term sustainability that helps support investment in the sector.

3.2 The rationale for new sustainability criteria

The need for new sustainability criteria for biofuels and bio-liquids arises primarily as a result of a significant change in the number and type of feedstocks that can now be utilised for biofuel production¹³ and that are being incentivised through public policy (see Chapter 2). Two aspects become critical. The sustainability criteria within the RED focus primarily on land-based feedstocks¹⁴, and do not currently provide sufficiently robust criteria to address some of the issues that might arise in relation to the use of feedstocks that do not rely on land for their production or only partly so. The revisions to the RED set out in the ILUC Directive have attempted to broaden the list of potential feedstocks that could be incentivised for biofuel and bio-liquids production, but have not addressed their sustainability with equal measure. In addition, the current mandatory sustainability criteria focus only on carbon stock levels and biodiversity, with non-mandatory criteria having relatively limited power to address to land, soil and water impacts outside of these areas.

¹³ Through advanced conversion technologies

¹⁴ Primarily food and feed crops

The scale at which these new feedstocks may be deployed is as yet unclear. It will likely vary between Member States, depending on the technological and resource availability and related costs, and the precise mix of renewable energy deployment to 2030 is yet to be determined, particularly with the removal of binding targets on Member States. However, biofuels and bio-liquids are only one segment of the overall bioenergy system, which is itself only part of the broader bio-economy. The same feedstocks that are used to produce advanced biofuels can also be used to produce bioenergy¹⁵ for electricity and heat or form the basis of other bio-based chemicals, materials and products¹⁶. The policies and sustainability requirements surrounding these different areas vary considerably and have different political agendas and timescales. Dealing with this sort of uncertainty requires an effective policy that stimulates markets for sustainable feedstock use whilst providing necessary safeguards. As the feedstock base has become more complex, encompassing a wider variety of materials from spatially disparate and diverse locations, regulatory clarity, including sustainability criteria, will become ever more important to help guide investment and ensure the sustainable development of this sector.

Introducing relevant sustainability criteria for this broader suite of feedstocks could therefore help to shape the development of a more resource efficient and sustainable approach to the bioenergy, biofuels, and wider bio-based sectors, helping to underpin a more sustainable reinvigoration of the bio-economy. The political sensitivities around this are high, however. A robust, clear and operational set of sustainability standards is important for the industries involved, either directly in the biofuels and biomass production pathways or in sectors competing for the same resources. All face considerable uncertainties that changes in European policy could aggravate unless sensitive issues are anticipated and addressed. A stable set of standards that meet the requirement of the next few decades is overdue (IEEP 2014).

3.3 Existing legislative sustainability criteria - the *status quo* (November 2015)

The approach to developing sustainability criteria for the energetic use of feedstocks to produce biofuels and energy biomass has developed iteratively over a number of years. It has taken a variety of different paths, following technological developments and civil society concerns amongst other factors.

Sustainability criteria for those biofuels and bio-liquids that count towards the achievement of renewable energy targets are set out under Article 17 of the RED (see below). Whilst these criteria provide specific cases for exclusion, i.e. areas and situations in which biofuels are considered to be unsustainable, they do not form the whole of the approach to sustainability set out in the policy. A number of related articles in the RED form the legislative framework for sustainability and include approaches to define sustainability standards from the perspective of land use (Art.17 RED; Art. 7b FQD); implementing procedures for those standards (Art.7c RED); verification procedures and non-mandatory criteria (Art.18 RED); requirements for the level of GHG savings that should be achieved from renewable transport fuels (Art.17 (2) RED, Art.7a and 7b FQD); calculation

¹⁶ Such as bio-plastics, composite materials and chemicals.

methodologies (Art.19 RED; Art.7d FQD); and reporting requirements and approaches (Arts.22 – 24 RED, Art.9 FQD).

For the purposes of this study, the most important elements of the sustainability approach in the RED and FQD are the sustainability criteria (Art.17 RED; Art. 7b FQD), the required greenhouse gas (GHG) emission savings from biofuels and bio-liquids (Art.7a FQD), and the non-mandatory criteria (Art.18 RED). Together these provide the broad framework that helps guide the choice of feedstocks and identifies the fuel pathways available to Member States. Both are necessary and require adaptation to account for the expanded feedstocks considered in this study.

3.3.1 Sustainability criteria for biofuels and bio-liquids

Article 17 of the RED, and Article 7b of the FQD, set out the sustainability requirements for biofuels and bio-liquids that can be used to contribute towards national targets required under the two Directives, and that can receive public financial support. These requirements are made irrespective of whether the raw materials are cultivated inside or outside of the EU territory. The criteria relate to three key areas¹⁷ paraphrased as set out in Box 2.

Box 3: Sustainability criteria as set out in Article 17 of Directive 2009/28/EC*

- **Biodiversity (Art. 17[3] RED)** where biofuels and bio-liquids cannot be produced from raw material obtained from land with high biodiversity value that had one of the following statuses in or after January 2008, whether or not the land continues to have that status:
 - . These include:
 - Primary forest and other wooded land where there is no visible indication of human activity;
 - Areas designated by law for nature protection purposes by either competent authorities or international agreements; and
 - Highly biodiversity grassland, described in Commission Regulation (EU) No 1307/2014
- **High carbon stock land (Art. 17[4] RED)** where feedstocks should not be obtained from land with high carbon stock value in January 2008 and no longer has that status¹⁸. These lands include:
 - Wetlands;
 - Continuously forested areas
 - Other tree dominated areas with high carbon stocks
- **Peatlands (Art 17[5] RED)** where feedstocks should not originate from land that was peatland in January 2008, unless evidence is provided that the cultivation and harvesting of that raw material does not involve drainage of previously un-drained soil.

In addition to these criteria, special reference is made to materials cultivated in the Community being used for biofuels and bio-liquids needing to adhere to rules set out under the common agricultural policy (CAP)¹⁹.

¹⁷ Note that the GHG emissions saving criteria for the RED is discussed in the next section alongside that of the FQD requirement.

¹⁸ The provisions of this paragraph shall not apply if, at the time the raw material was obtained, the land had the same status as it had in January 2008.

¹⁹ Specifically the requirements and standards under the provisions referred to under the heading 'Environment' in part A and in point 9 of Annex II to Council Regulation (EC) No 73/2009 of 19 January 2009 establishing common rules for direct support schemes for farmers under the CAP and establishing certain support schemes for farmers and in accordance with the minimum requirements for good agricultural and environmental condition defined pursuant to Article 6(1) of that Regulation.

Source: Directive 2009/28/EC **Notes:** * The text here refers to the legal wording set out in the current Directive. This could be refined for the purpose of a more easily communicated set of criteria.

3.3.2 GHG emission savings criteria

Both the RED and FQD include GHG emissions saving criteria that require a certain percentage reduction in GHG emissions through the use of biofuels and bio-liquids, when compared to fossil fuels. These reductions can be summarised as requiring the GHG emissions savings from biofuels and bio-liquids counting towards renewable transport fuel targets to be at least 35% when compared to fossil fuels. Following the ILUC amendments the required emissions savings have changed. For existing installations a transitional period is set whereby biofuels shall achieve a greenhouse gas emission saving of at least 35% until 31 December 2017 and at least 50% from 1 January 2018. For new installations the requirement is more stringent, requiring at least 60% emission reductions ‘for installations starting operation after 5 October 2015’ (Directive (EU) 2015/1513).

3.3.3 Non-mandatory criteria

Article 18 of the RED outlines the verification procedure for complying with sustainability criteria under Article 17. Article 18(4) includes reference to other non-mandatory criteria that are of relevance to the overall sustainability of the policy. In particular “... *due consideration shall be given to measures taken for the conservation of areas that provide, in critical situations, basic ecosystem services (such as watershed protection and erosion control), for soil, water and air protection, indirect land-use changes, the restoration of degraded land, the avoidance of excessive water consumption in areas where water is scarce and to the issues referred to in the second subparagraph of Article 17(7).*” Whilst not part of the mandatory criteria, this inclusion recognises the potential risks to ecosystem function from the over exploitation or unsustainable production of biofuel feedstocks.

3.4 Other sustainability criteria and approaches

In addition to legislative sustainability criteria, there is a range of other types and approaches to sustainability criteria that exist outside of EU policy. These include the development of public and private sector sustainability criteria, principles and indicators through specific projects; international standards, such as ISO 13065; and industry initiatives, such as the Roundtable on Sustainable Biomaterials (RSB); as well as a growing tendency to require sustainability criteria in non-energy markets for food crops (through a range of quality and sustainability schemes) and for forest projects (e.g. FSC and PEFC).

These criteria and principles are not usually legally binding and apply to operators or individuals that opt into specific schemes or choose to abide by particular standards or approaches to satisfy other mandatory criteria²⁰. As such their existence helps to support the application of EU or national law (or international agreements) and provides guidance and certification support to operators and individuals. A summary of some of the existing approaches to sustainability standards for biofuels and bioenergy is provided by Fritsche and Iriarte (2014) and is not repeated here. Two types of approaches are worth mentioning in the context of this study.

²⁰ Such as voluntary schemes designed to demonstrate compliance with RED sustainability criteria

The first is the way Member States have approached sustainability of biofuels and biomass for energy. Member State sustainability standards for biofuels and bioenergy, where they exist separately from the EU framework, vary considerably. As required, Member States are implementing the sustainability standards set out in accordance with the RED and FQD where biofuels are used to count towards renewable transport targets. However, the approach they apply to the sustainability of solid biomass (and thus some of the feedstocks considered in this study) is more varied given the lack of standards set out in EU law. In 2010, the European Commission recommended sustainability criteria similar to those applying to biofuels and bio-liquids, for biomass installations of 1 MW electric or thermal capacity and above. The Commission also proposed to design national support schemes with the objective of stimulating higher efficiency of bioenergy plants and invited Member States to keep records of the origin of primary biomass used in electricity and heating/cooling installations of 1 MW or above.

A review of Member States' implementation of the 2010 recommendations (Pelkmans et al. 2012)²¹ found that relatively few Member States (BE, HU, UK) had introduced specific sustainable forest management (SFM) criteria for forest biomass and land criteria for agricultural biomass (UK). Some countries (BE, PL) had introduced regulations aimed at addressing potential competition with existing biomass uses or to limit stemwood from being eligible for renewables incentives. In the UK Renewables Obligation, the requirements for solid biomass sustainability in the form of land criteria are taken from the EU requirements on biofuels and thus provide a greater level of parity between the two end energy uses than in most cases (OFGEM 2016).

The second approach is the International Standards Organisation (ISO) standard 13065 (Sustainability criteria for bioenergy) designed to help assess the sustainability of bioenergy products and processes. It is intended to apply to all forms of bioenergy, regardless of raw material, geographical location, technology or end use. The standard sets a framework for considering the environmental, social and economic impacts of bioenergy production and products, supply chains and applications. It can be applied to a part or the whole of supply chains, or a single process.

Of most interest to this study is the treatment of waste in the standard. The standard (ISO 13065:2015(E)) includes specific reference to the way in which waste should be considered in relation to the GHG balance of any bioenergy resulting from it (Box 4). Importantly the standard recognises explicitly the potential alternative fate of the wastes considered and the associated GHG emissions.

²¹ **Belgium** - Adopted 2007 - Financial incentives linked to GHG savings, SFM requirements for forest biomass; **Hungary** - Adopted 2010 - SFM requirements for forest biomass; **Italy** - Adopted 2012 - Minimum GHG saving threshold for forest biomass; **UK** - Adopted 2013 - Minimum GHG saving threshold for solid and gaseous biomass, land use criteria for agricultural biomass, timber standard for wood fuel for heat and electricity.

Box 4: ISO Standard 13065 and the treatment of waste biomass for energy

Section 6.7 - *If waste is used as a feedstock, the GHGs associated with its handling and processing shall be included, and any exclusion of up-stream emissions shall be documented and justified. If a waste is used as a feedstock for bioenergy production, the alternative fate of that material shall be described (e.g. landfill, waste incineration, or decomposition on a field). If the alternative fate is included in the analysis it shall be included in the system boundaries of the reference system. The change in GHG emissions and change in carbon stock (e.g. in landfill) associated with the diversion of waste for use as bioenergy feedstock should be included in the calculation. If the inclusion of the avoided GHG emission results in a negative value, the final result for the calculation in 5.2.1.1.1 bullet c) should be assumed to be zero.*

This procedure constitutes system expansion.

The treatment of waste in the GHG analysis shall be documented and justified.

Source: ISO sustainability criteria for bioenergy (ISO 13065:2015(E))

Ensuring compliance, through auditing or compliance monitoring is another aspect of sustainability that warrants consideration when developing new sustainability criteria. At present, many biofuel suppliers provide such assurance through voluntary schemes that set out specific requirements that must be satisfied to comply with the sustainability criteria of the RED. Voluntary schemes certification standards include the International Sustainability and Carbon Certification (ISCC)²², Round table on Sustainable Biomaterials (RSB)²³ or the global standards developed through initiatives like the ISEAL Alliance²⁴ amongst others. In some cases the standards go beyond these requirements and address other aspects of sustainability not covered by the RED. A review of voluntary sustainability schemes can be found in (WWF 2013).

²² <http://www.iscc-system.org/en/>

²³ <http://rsb.org>

²⁴ <http://www.isealalliance.org>

4 Sustainability issues associated with expanded feedstock use

This chapter identifies the potential sustainability issues that could arise as a result of significantly increased or over use of certain feedstocks. Some issues are common to multiple feedstocks some are more specific in nature. Here we focus on identifying the risks, as this is a key step in developing sustainability criteria, the purpose of which is to avoid unacceptable impacts. Clarity about risks and the circumstances in which they arise is helpful to ensure a sustainable trajectory of development, but it does not mean that the scale or significance of the opportunities should be over looked.

4.1 Primary biomass

Primary biomass in this study refers to two specific types of feedstocks: land-based biomass such as agricultural crops that rely on land for their production; and micro-organism based biomass that is grown for the purposes of energy production in a variety of forms and contexts, such as micro-algae or bacteria.

4.1.1 Land-based biomass

For land-based biomass the risks to the environment are well documented (e.g. Allen et al. 2014; Malins et al. 2014; Winrock et al. 2013; Poláková et al. 2011), and relate to the expansion of cultivated area and/or the management practices adopted. The impact of expanded production will depend to some extent on the areas into which cultivation is expanded²⁵, the local conditions in and around those areas, and the management adopted, including methods used to improve crop yields (Winrock et al. 2013).

In natural, semi-natural or previously uncultivated areas, or areas of current low intensity cultivation²⁶, the commercial production of biomass is likely to be associated with more environmentally intrusive management changes²⁷ than if the land were left to develop naturally or cultivation remained at low intensities. Intensification of production, whereby a greater yield per unit area is the desired goal, is a logical response to optimising yields, with the ability and choice to do so often a function of both agronomic and market conditions. Intensification is not implicitly detrimental to the environment in areas of current cultivation, particularly where 'sustainable intensification' can be achieved within environmental limits (Buckwell et al. 2014). However, the predominant trend in intensification of European agricultural land has tended to favour more unsustainable pathways as a result of relatively cheap and accessible inputs (fertilisers and pesticides) and because negative externalities are not necessarily accounted for in economic decision making (Buckwell et al. 2014; Hart et al. 2012; Cooper et al. 2009).

Defining the specific site based impacts likely to arise from cultivation is far from straightforward and is often described in relative terms, such as the comparison of perennial crops to annual crops²⁸ rather than in relation to the vegetation growth on semi-

²⁵ Whether this is cultivated land, or expansion into previously uncultivated land of varying types.

²⁶ Referred to more commonly as 'extensive management'.

²⁷ Including the use of inputs such as fertilisers, pesticides and water, ploughing, cultivation and harvesting etc.

²⁸ i.e. in relation to replacing annual food and feed crops with energy varieties

natural or other land. In most cases, for previously uncultivated land, cultivation will bring with it changes to environmental conditions relating to soil, water, GHG emissions and biodiversity (amongst others) some of which are likely to be negative (Winrock et al. 2013). However, this will not be the case always, with low level and extensive management in some areas bringing about environmental benefits, or at least no further negative impacts (Box 8, p18). The scale of cultivation and the management approaches adopted will be a key factor in determining the level of impacts that result (Searle et al. 2016; Allen et al. 2014).

One type of cultivated land has received a lot of attention in the debate around energy biomass cultivation is that of fallow agricultural land. Fallow land is described in Commission Regulation (EU) 2015/1391 as “*All arable land either included in the crop rotation system or maintained in good agricultural and environmental condition (GAEC), whether worked or not, but with no intention to produce a harvest for the duration of a crop year*”. In many cases, the fallowing of agricultural land is a fundamental part of an arable rotation, allowing the soil to rest, recover nutrients, allow diseases and pests to disappear, and reduce the need for external inputs, such as water. In some areas there is fallow land that may be surplus to current agronomic or environmental requirements. However, careful consideration and evaluation of those areas is necessary to avoid any unnecessary impacts. For example, cultivation of fallow (i.e. taking it out of an arable rotation) could lead to significant biodiversity impacts, as such areas can provide valuable breeding and feeding habitats for a variety of birds, small mammals and invertebrates, as shown by studies of set-aside (IEEP 2008; Silcock & Lovegrove 2007; Hodge et al. 2006)²⁹.

Abandoned agricultural land is another category that has received considerable attention and one that offers both opportunities and risks to cultivation. More discussion on the risks of using abandoned agricultural land for energy crop production can be found in Allen *et al* (2014). In summary the risk depends on how long land has been abandoned, the vegetation state on the land and the modifications necessary to bring the land back into cultivation. For relatively recently abandoned land, the environmental impacts may be marginal and in line with existing cultivated areas. For longer term abandoned land, the change in vegetation composition to a more natural state, may result in increased risks to biodiversity and ecosystem services. Whether or not abandoned land is cultivated as a response to energy incentives remains a separate question. Land is often abandoned for good reason and such areas often operate on the margins of economic productivity. Subtle changes in commodity prices can make the difference between cultivation and abandonment, as can variations in weather patterns (from year to year), ownership and tenancy changes etc. (Hart et al. 2012; Poláková et al. 2011; Keenleyside & Tucker 2010). Recent work to model the potential land use change impacts from EU biofuel production shows that despite the existence of abandoned land available to biofuel feedstock production³⁰ only a proportion of this is utilised for expanded cultivation, with a general preference for existing cropland areas or ‘other natural vegetation’³¹ (see Valin et al. 2015). Estimating the areas of abandoned land in the EU is also notoriously challenging (e.g. Allen et al. 2015; Estel et al. 2015; Allen et al. 2014; Hart et al. 2012).

²⁹ For additional supporting evidence, see Allen et al. 2014

³⁰ As foreseen within the GLOBIOM model.

³¹ Again, as defined in the GLOBIOM model.

Both within and outside the Community, there are sites designated for their importance for nature conservation³² that should not be subject to cultivation activities where these would contravene conservation objectives. These areas are subject to a variety of risks, including cultivation. Beyond designated sites, there are other areas that are important for nature conservation, such as high nature value farmland and forestry (HNVFF) areas (Keenleyside et al. 2014), as well as natural and semi-natural habitats where the biodiversity value is closely connected to the low input production system. As these areas do not have specific designations or protection under EU law, they are vulnerable to changes in land use or management as a result of changed land use, cropping or management practices (Box 5).

Box 5: Biodiversity impacts associated with changes in land use and management

Biodiversity impacts vary significantly depending on the counterfactual; with the location of crop plantations, previous land use and crop type and management (e.g. cultivations, levels of pesticide and fertiliser inputs used)³³ are amongst the key drivers in the biodiversity impacts observed. Specific impacts are uncertain given that research into the impacts of bioenergy crops on biodiversity has been very limited, and most of it has focused on growing energy crops on existing arable land and replacing annual crops, rather than cultivation on abandoned or fallow land areas. Some generalisations can be made and some likely environmental impacts can be inferred from studies investigating the environmental implications of set-aside or fallow land and land abandonment. Poláková *et al* (2011) present a rather comprehensive compilation of literature focusing on the biodiversity implications of land under different forms of agricultural management, including no-management.

Most importantly, the replacement of any semi-natural habitat (especially those listed under Annex I of the Habitats Directive) by a dedicated bioenergy crop would result in significant biodiversity losses. However, the use of biomass harvested from semi-natural vegetation in such habitats (e.g. hay meadows or scrub / heathland habitats) might be environmentally acceptable, or even beneficial in some circumstances (BOX 8). Such uses would need to be carefully regulated to ensure they are sustainable and with appropriate management (e.g. no increase in the use of fertilisers and cutting carried out at suitable times and using appropriate machinery etc.). Where semi-natural habitats have been subject to, or are at risk of, abandonment then the harvesting of biomass could help to reduce or even reverse the impacts of land abandonment. As noted in several studies, abandonment of semi-natural habitats, particularly in Natura sites but also in other HNV areas, is a major threat to biodiversity in the EU, as the semi-natural vegetation and associated specialist fauna tends to be replaced by lower value dense rank grassland and scrub and generalist species (Poláková et al. 2011).

Source: Quoted directly from (Allen et al. 2014)

Beyond nature conservation concerns, changes in land management can bring with them risks to GHG balances, soils and water. These risks are described in detail in Winrock *et al* (2013) and Allen *et al* (2014) and are summarised in Box 6. Critically *“much of the actual risk will be determined at a highly localised level for specific agricultural systems. This will be based on small scale variation in natural risk (linked to soil type, slope, climatic conditions) but critically on management practices, given the important role of management techniques in mitigating or aggravating risks”* (Winrock et al. 2013).

³² Such as Natura 2000 sites, RAMSAR and other designations.

³³ Annual versus perennial

Box 6: Summary of risks to soils and water from the cultivation of bioenergy feedstocks

Greenhouse gas emissions - In terms of net greenhouse gas (GHG) emissions, changes in land use have a particular influence. The impacts vary in relation to the carbon contained in below and above ground biomass and soils, and the cultivation practices used, including tillage and fertiliser requirements. Increased cultivation, harvesting of vegetation, or extraction of residues, can lead to changes to natural processes that allow the increased build up of above and below ground carbon stocks.

Soil - Changes in soil carbon and soil structure have a further impact on GHG emissions from cultivation, generally with increased emissions that need to be offset against the sequestration achieved. Both the decline of organic carbon and increasing erosion rates are the key risks for European soils associated with agricultural activity (JRC 2009). Risks to soil from water erosion are particularly severe in southern Europe, whereas risks are usually more moderate in northern Europe with more variability found in central and Eastern Europe (Winrock et al. 2013).

Water - Crop cultivation will result in increased demand for water, either from irrigation or natural sources. The extent to which this is a problem will be determined by the local climatic and environmental conditions. For example, in more arid regions of the EU (Mediterranean and certain parts of Eastern Europe), impacts of any new cropping there are expected to be significant (EEA, 2013). Through a series of scenarios, Winrock *et al* (2013) note “a shift to bioenergy from existing average cultivation would result in a net increase in total water consumption, but a net decrease in irrigation demand for a given hectare”. The scale and extent of the impacts varies considerably in different climatic and biogeographic zones.

Source: Summarised and in-parts quoted from Allen et al. (2014) and Winrock et al. (2013)

The choice of crops to cultivate can also bring with it risks to biodiversity, particularly where they are non-native and invasive. These crops, selected for their growth traits and characteristics, may leak into the environment, displace native flora and fauna, or simply support lower levels of biodiversity than their native counterparts (Allen et al. 2014; Forsyth et al. 2004; Searle & Malins 2016).

For forests, a specific issue can arise as a result of the gap appearing between the time taken to accumulate carbon in above ground biomass, for example through forest growth, and the speed at which that carbon is released to the atmosphere. This phenomena known as ‘carbon debt’ or ‘carbon lag time’ is described in (Bowyer et al. 2012). Whilst this is primarily an issue for heat and power generation (Chatham House 2015)³⁴, the assumption of the carbon neutrality of solid biomass in key accounting legislation does affect biofuels and bio-liquids produced from forest biomass and should be taken into account when assessing sustainability, both in terms of scale and type of biomass used. More detail on this aspect of sustainability can be found in (Chatham House 2015; Matthews et al. 2015; Bowyer et al. 2012).

A separate, but not unrelated issue for land-based biomass concerns the dedicated use of whole trees for the production of biofuels. The questions of whether whole tree use for biofuel production is sustainable, remains, as with many other aspects of biofuels sustainability, one of context and scale. Defining what constitutes a ‘whole tree’ and the size at which using a whole tree becomes problematic from a carbon perspective is also challenging. Three scenarios can be envisaged. The first is one in which the whole tree is part of a coppice rotation, using short rotation (<5-8 years) poplar, willow or other relatively

³⁴ Due to the greater volumes of forest biomass consumed in this sector

fast growing coppice species. These ‘trees’ are effectively treated as perennial energy crops and could be sustainable if they are grown on land that does not displace other timber, food or feed production, or have negative impacts on biodiversity and carbon stocks. The second is a situation where whole trees are extracted from managed forest stands as part of operations to ‘thin’ the stand. The extraction of whole trees in this way (often called low grade timber) is a common practice in commercial forestry (and in some woodland management operations) to create space within the forest allowing the remaining trees to increase in size and quality for use in the sawmill industry. The sustainability of using these trees becomes a question of competing uses in relation to existing industries (such as the pulpwood and paper industry), low-grade fuel wood, or pellet manufacturing for bioenergy production. The final scenario is one in which whole stands of long-rotation (>5-8 years) trees become utilised to produce chips or pellets for biofuel use. Here the question of sustainability relates both to competing uses, i.e. the displacement of timber, pulp, paper or bioenergy production, and carbon debt (i.e. the regrowth period).

Each scenario brings with it different sustainability implications that are particularly challenging to define in a clear way to be addressed in policy. There are also other cases where the use of *part* of a whole tree through an integrated production process may represent a resource efficient use of woody biomass by using residual components to produce biofuels. This could be the use of forest harvesting residues (leaves, bark and branches), wood processing residues (sawdust and cutter shavings), or other parts of the round wood timber once it has been processed for another purpose, such as paper production.

4.1.2 Micro-organism-based biomass

Micro-organism-based biomass presents a separate suite of sustainability implications, mainly arising as a result of containment and leakage to watercourses. Relatively little work has been undertaken to ascertain the implications of algal or bacterial biomass cultivation and its impacts on the environment in the EU. A review by the National Academy of Sciences in America highlighted concerns over the use of water and requirements of nitrogen fertiliser to make algal biofuel production viable. In their review they summarise “...*that demand for transportation fuels would place unsustainable demands on energy, water, and nutrients with current technologies and knowledge*” (NAS 2012). It should be noted that this is in context of scale up to deliver 5% of transportation fuel needs, in the order of 39 billion litres of biofuel. The report also caveats the conclusion relative to this scale and the current technology available. More research in this area, particularly in relation to European biofuel production would be needed in order to provide a more robust assessment of the risks involved.

4.2 Residual biomass

Residual biomass in this study refers to biomass that is generated as an artefact of production and/or management but is not the primary output. This includes agriculture and forestry residues, other vegetation based residues (such as habitat management) and processing residues (such as sawdust, cobs, nutshells etc.).

The impact of expanded utilisation of processing residues relates mainly to displacement impacts from existing uses (which may also apply to agriculture and forestry residues). A

recent review of evidence on selected bioenergy schemes operating in the EU suggests that there is a link between the volume of processing residues consumed for energy generation and the incentives and support schemes in place, but that linking this to the displacement caused in other utilising sectors (e.g. the material sector) is more challenging given external factors³⁵ (Vis et al. 2016). Quantifying or predicting such impacts is challenging and requires lifecycle assessment (LCA) type approaches with assumptions made with regards the counterfactual situation. Depending on the degree to which the residues are already being utilised, diverting resources for use as biofuel feedstocks could cause displacement effects leading to indirect GHG emissions (Harrison 2014).

For agriculture and forestry residues, there is a wide range of existing uses that risk being displaced if they are utilised beyond certain levels for energy production. These can include composting and improving soil functionality in situ, through to animal bedding (see Kretschmer et al. 2012). The precise impact that diversion of these resources might have will depend on the particular residues, scale and the location from which they are sourced. In some cases there may be surpluses³⁶, in others there may already be shortfalls (Scarlat et al. 2010). Where there are surpluses there will be a level, often specific to individual fields or farm situations, below which the use of residues for biofuel production will be sustainable (Kretschmer et al. 2012; Searle & Malins 2013). However, under real-world conditions it is likely that a certain proportion of biofuel may be produced from those residues that have already been collected for other purposes (Harrison 2014), or where market demand increases the level of residue extraction from areas where they are providing a benefit. As a consequence there are potential impacts that may arise as a result of both displacement and extraction activities. To illustrate these potential risks, Box 7 summarises some of the potential environmental impacts of the over extraction of the agricultural residue cereal straw.

Another form of residual biomass is that arising following vegetation or habitat management, such as cutting of reed beds or roadside trees and verges. The use of such material, can, if harvested in line with conservation or management objectives, be genuinely sustainable and provide an additional source of income to promote beneficial management (Box 8). However, in some cases harvested vegetation will share the same sort of sustainability issues as the use of more conventional agriculture or forestry residue, in cases where leaving some biomass in situ is beneficial to the functioning of the ecosystem, or where the biomass already has an existing use, such as thatching from reed for example.

³⁵ Such as commodity market changes, oil prices, and economic trends.

³⁶ Quantities of excess straw tend to be more prevalent in Southern and Eastern Europe, where the risks of over-incorporation of straw into the soil to long-term soil fertility are generally higher (Edwards *et al*, 2005).

Box 7: Potential environmental impacts from the over-extraction of cereal straw

The main direct environmental impacts of extracting straw from agricultural areas are potential reduction in soil functionality* and potential impacts on fauna resulting from modifications to stubble heights and straw management *in-situ*. Indirect effects of straw removal are seen in respect to potential intensification or expansion of cereal cultivation, the use of alternative chemical soil improvers and indirect land use change due to expansion of production.

One of the most common uses of straw in the EU is the ploughing-in of cut straw following the cereal harvest to help maintain soil functionality. It is generally recognised that the maintenance of straw on or within the field is an important factor in maintaining soil organic matter (Gobin et al. 2011; Ericsson & Nilsson 2006; Börjesson 1996; DBFZ & Oeko Institut n.d.) and thus soil carbon levels (EEA Scientific Committee 2011)

There are other significant environmental benefits that result from leaving the cut residues on the surface of the soil. These include increased water infiltration and decreased evaporation; reduced soil erosion from wind and water; more stable soil temperatures and more humid soil surface conditions, all of which can help to maintain soil fauna and biological activity in the soil. Erosion and soil humidity considerations do not necessarily impose an additional constraint on straw extraction as long as SOM maintenance is ensured (DBFZ & Oeko Institut n.d.).

The reduction in stubble and the removal of residues could also have an impact on species that benefit from the sparse cover and availability of spilt grain and other plant seeds (such as many declining farmland birds).

Attempting to quantify an appropriate extraction rate at the EU or even national level is impractical as a result of varying bio-climatic and geophysical conditions from field to field. In some cases the level of extraction could be high, particularly where the incorporation of residues into soils is limited due to climatic conditions. In other cases it may be low. A generally accepted rule of thumb is that a third of the volume should remain *in situ*, but should ideally be based on more precise information at the farm or parcel level.

Source: Kretschmer et al. (2012) and references therein. **Notes:** * Soil functionality can be described in relation to a range of parameters that enable the continued ability of soil to function naturally. These include the proportion of organic matter, the level of susceptibility to erosion by wind and water, the soil's structure and capacity for infiltration, the health of its biota and its level of contamination (JRC 2009).

Box 8: Examples of beneficial semi-natural vegetation harvesting

"If carefully designed and regulated, the biomass from some non-crop habitats such as grassland buffer strips, seed-rich crops for birds and flower-rich crops for pollinators could be used to produce bioenergy. However, it would be important to ensure that this does not compromise agri-environment objectives and the basis for payment calculations."

"Carefully managed mowing of grassland and scrub clearance could help to mitigate the loss of livestock grazing and hay production where partial or complete abandonment occurs. However, it is important to note that the presence of livestock in such semi-natural habitats is beneficial for many ecological reasons, and therefore the harvesting of vegetation for bioenergy should only be carried out as last resort, where grazing is insufficient to maintain the ecological condition of the habitat."

The cutting of vegetation for bioenergy purposes could help to mitigate the significant impacts of eutrophication (resulting in vegetation change and substantial biodiversity declines) of semi-natural grasslands in the EU as a result of atmospheric nitrogen deposition (Ellenberg et al. 1989; Bobbink & Lamers 2002; NEG-TAP 2001). This process is exacerbating the effects of under grazing (i.e. high increases in vegetation density and sward height), however the mitigation potential of vegetation requires further research.

Source: Quoted from Allen et al. (2014)

4.3 Waste biomass

Waste biomass is referred to in this study as biomass that is generated as an artefact of consumption, i.e. its use is not driving biomass production, land use or land management decisions. This includes animal-based wastes, such as manure, and other wastes, such as municipal solid waste, or food waste.

The potential biodiversity, soil and water impacts of expanding the use of waste resources for energy production are relatively modest compared to the other types of feedstocks considered in the study (Harrison 2014). Yet there are two specific aspects to consider when looking at utilising waste resources in new processes, such as biofuels. These are the EU's efforts to reduce waste generation and improve recycling and the potential competition with existing uses.

With the publication of the circular economy strategy COM(2015) 614/2 there has been a renewed commitment of the EU's efforts to improve resource efficiency and reduce waste. The circular economy package includes a series of legislative proposals on waste with a range of associated targets for waste management, including common EU targets for recycling 65% of municipal waste and 75% of packaging waste by 2030. Where waste cannot be prevented or recycled the Commission note the potential environmental and economic benefits of recovering its energy content with a proposed 'waste to energy' initiative (guided by the principles of the EU waste hierarchy) expected to be adopted in the framework of the Energy Union. Currently waste to energy refers to the incineration of residual waste streams and it is not wholly clear at this point whether this will include biofuel and bio-liquid production. If it does, the production of biofuels and bio-liquids could help the EU towards meeting its waste management targets overall and therefore improve resource efficiency.

The other main potential issue of utilising waste resources as a biofuel and bio-liquid feedstock is the possible competition for other end uses that could be in some cases associated with a better GHG emission profile, or other associated benefits, such as material recycling or composting. Understanding the precise nature of these impacts is particularly difficult to predict and will be influenced strongly by the substitution process³⁷. Wastes present one of the potentially more sustainable biomass feedstocks and the potential risks associated with diverting existing uses should be considered carefully and not unnecessarily limit the use of wastes in biofuel and bio-liquid production.

One category of waste feedstocks presents a particular challenge and a very different set of sustainability issues. These are the novel fuel production process using bacterial biomass and the fermentation of waste gas (such as those produced by steel manufacturing (Box 9) rather than sugar fermentation. The process of feedstock production is similar to some of the more conventional waste biomass streams, as it arises as an unavoidable consequence of a manufacturing or consumptive process, yet the process itself combines waste and primary biomass (bacteria) in the production of fuels. Although available commercially, such processes are relatively new and therefore potential impacts at scale are poorly understood,

³⁷ For example whether or not a digestate-based fertiliser is produced from the biofuel conversion process.

as are the potential alternative uses. Therefore the assessment of such fuels should be done holistically, taking the life cycle analysis of the process into account and ensuring it adheres to all sustainability criteria, including GHG savings.

Box 9: Combining bacteria and waste flue gases to produce liquid biofuels

Like all other routes to bioethanol, gas fermentation involves biological conversion of inorganic gaseous carbon to bioethanol that can be blended with gasoline. Photosynthesis is but one of the approaches to carbon fixation found in nature. Organisms exist in ecological niches where fully oxidized carbon and light are non-existent, for example hydrothermal vents. Acetogenic bacteria are examples of ancient organisms (predating algae or cyanobacteria) that can assimilate energy from inorganic carbon as the sole carbon source and are capable of growth and metabolism in the complete absence of sunlight. Ethanol is produced naturally as a part of this process. In addition, the bacterial biomass does not require the land, fertiliser or infrastructure for harvesting that plant based biomass requires, rather the biomass is contained in a bioreactor that is integrated onto an existing industrial site.³⁸

Waste industrial emissions, including those from steel manufacturing are very similar to the gases produced by hydrothermal vents that acetogens grow on in nature. They include carbon dioxide, carbon monoxide, and hydrogen. Acetogenic bacteria are able to consume hydrogen-free carbon monoxide rich gas streams because they perform an efficient biological water-gas shift reaction which catalyses the release of hydrogen from water by using the energy content of carbon monoxide. The technology can therefore be adjusted to a variety of gas mixtures available at industrial sites and other residue gas streams. In the steel industry, an essential use of carbon is as a chemical reactant to reduce iron oxide to metallic iron. This is an important distinction from the typical industrial use of carbon as a fuel.

The resulting steel-mill waste gases are unavoidable wastes of industrial production and the steel producer is required to discard them. A further use (other than energetic) of the waste gases is not certain. While a proportion of industrial off-gases are flared to the atmosphere, some are combusted for power. The efficiency of electricity production is low (typically 25-35% and sometimes less for older installations) because the dilute, low-calorific value gases, found in many industrial gas streams, combust very inefficiently.

Source: *Per comm Freya Burton and Willemijn Van der Werf, Lanzatech*

³⁸Note that today all biofuels require external inputs, including some amount of fossil energy for fuel production, but there are major differences among them. Plant based biomass would require, energy for fertilizer, cultivation, harvesting, processing and transportation. Bacteria require energy for processing and transport.

5 Sustainability criteria

This chapter sets out the sustainability criteria that, if implemented as part of an improved sustainability framework (see section 5.4), would mitigate the risks posed by increased use of biofuel feedstocks identified in this study. Some of these potential risks apply to all feedstocks, some apply to specific groups, and others are feedstock specific.

In developing these sustainability criteria we have aimed to ensure that the requirements on economic operators are proportionate to the risks posed by the feedstocks and are implementable in a practical way (see section 5.3). In addition, effort has been made to ensure that the sustainability criteria are articulated simply and, where possible, address multiple risks.

The criteria fall into two specific types. There are *general criteria* that are applicable across all feedstocks and there are *specific criteria* that address explicit risks identified for individual or groups of feedstocks. The general criteria reflect the aims of renewable energy policy e.g. to reduce emissions significantly and seek coherence with existing legislative requirements developed in other aspects of EU policy, such as waste legislation or biodiversity protection. The *specific criteria* provide a mechanism to help guide economic operators in their choice, location and scale of feedstock use so as to lead to more sustainable biofuel production than market forces or other driving factors may otherwise give rise to. **To be effective, a coherent framework of sustainability criteria requires both general and specific criteria**, they are part of a set, are not substitutable and must be applied where they are relevant.

The criteria can be summarised in Table 2.

Table 2: Summary of general and specific sustainability criteria

General criteria	Specific criteria
GC1 – Greenhouse gas emission intensity	SC1 – High biodiversity value
GC2 – Land use change and displacement effects	SC2 – High carbon stock
GC3 – Scale of deployment	SC3 – Ecosystem function
GC4 – Coherence with existing legislation	SC4 – Invasive species
	SC5 – Whole trees

General and specific criteria are set out in the two following sections. Blue text denotes the sustainability criteria wording, whereas black text is the explanation of the criteria.

5.1 General criteria for sustainable feedstock use

The four general criteria set out below aim to guide policy driven developments and operations in this sector towards the utilisation of resources for biofuel and bio-liquid production that: ensure the Carbon efficiency of the fuels produced; limit unwanted displacement effects; address scale issues; and ensure coherence with relevant Community and international policies and objectives.

GC1 – The greenhouse gas emission intensity from the production and use of biofuels and bio-liquids shall be no more than [27g] CO₂ MJ⁻¹. *The calculation of the GHG emission intensity shall be done through the use of attributional LCA with the following factors taken into account:*

- *the production and harvesting methods used;*
- *the re-growth period of the biomass;*
- *collection and transportation emissions; and*
- *conversion emissions.*

This criterion reflects the overall ambition to decarbonise transport fuels and is similar to the current Article 17(2) criteria in the RED. Yet, rather than setting the level of CO₂ emissions as a saving relative to a fossil fuel comparator, as is the case currently, the criterion here sets an absolute value for CO₂ emissions. The setting of an absolute value for a well defined analytical exercise (attributional LCA) instead of a carbon saving percentage reduces uncertainty for economic operators, as it ensures that support is not contingent on external factors (e.g. the carbon intensity of fossil fuels which can change over time). It would also make it clearer within the legislation that it is not analytically correct to conflate the carbon intensity calculated through attributional life cycle assessment (ALCA) with the emission reduction delivered by the policy as a whole (cf. Plevin et al. 2014).

The precise number that would be appropriate, shown here in square brackets, would need to be developed on the basis of more detailed assessment. The 27g CO₂ MJ⁻¹ is a translation of a 70 per cent GHG emission saving requirement which might be expected to follow from the standard in the current RED³⁹ but could be set at a different saving rate or a banded rate (providing a range of potentials) based on a suitable rationale.

It should be noted that indirect impacts are excluded from the GHG saving calculation here and are covered explicitly in GC2 below. This is in no way intended to diminish the importance of indirect impacts or to imply that they should not be addressed through policy. Accounting for indirect impacts has proved to be particularly challenging and they are difficult to measure in practice. Yet these challenges should not reduce the ambition of the policy or this criterion, but rather serve to bolster efforts to improve the monitoring and reporting of GHG emissions associated with biofuel production. Where and when indirect impacts can be suitably calculated and accounted for, they should form part of the overall GHG emission savings requirement in policy. *This criterion should therefore be subject to review based on updated information of available ILUC calculation approaches and evidence of ILUC impacts from EU biofuel deployment.* Until that point, a separate criterion has been developed to deal with indirect impacts.

³⁹ Article 17(2) of Directive 2009/28/EC as amended by Directive EU/2015/1513

GC2 - The use of feedstocks should not cause the displacement of food, feed or timber production either directly or indirectly within a specific area or project⁴⁰. *The specific area or project to which this criterion is applied shall be determined in advance of production so that an evaluation of the project or site can be made and act as a baseline against which to measure any displacement activities during production or after harvesting. This should take the form of a site or project management plan setting out the current production pattern (including areas of specific crops and their yields) and the intended siting of the biofuel feedstocks.*

This criterion addresses both the direct and indirect displacement impacts that may result from growing or harvesting a biofuel feedstock. Implementation of this criterion would mean that within a specific area or project the production of a biofuel feedstock does not lead to any displacement of existing production outside of that area. This has two effects.

- The first is that the system boundary for assessing displacement is contained within a specific area applicable to the project, and can thus be monitored more easily than dispersed impacts. Monitoring the location of production can be undertaken both *ex ante* through management plans and *ex post* through monitoring or checking the location of feedstock production.
- The second is that ILUC impacts are expressly avoided by ensuring production of feedstocks either takes place on land that would not cause the displacement of production, such as abandoned or degraded land, or that production volumes are maintained through increased yields within the existing project or area. Again this can be monitored both *ex ante* through management plans and *ex post* through yield assessments of any potentially displaced food, feed or timber production.

The question of what constitutes an ‘area’ or a ‘project’ requires further articulation under this criterion. The concept of production or sourcing areas is common to the assessment of feedstock sustainability assessments through voluntary schemes. Often the area considered is either that of the individual farm, field or plantation from which the biomass is being sourced, or, as in the case of group certification, it is the radius from which supply to the first gathering point is possible. For this criterion it is proposed that the area refers to the individual farm, field or plantation from which the biomass is sourced. These areas are within the control of an individual operator and for which a management plan could more easily be developed.

With this criterion there is still a risk that biofuel feedstocks would be grown on non-agricultural land with biodiversity, carbon stock or regulating ecosystem value. This is addressed through strict adherence to the specific criteria set out in section 5.2. These criteria shall also be applicable to any displacement of food, feed or timber production within the project or area, as a direct result of biofuel feedstock production (i.e. the policy). This is important to ensure that indirect impacts of intensified production processes, such as increased fertiliser or pesticide use, arising as a result of a need to maintain or increase yields, do not result in environmental impacts.

⁴⁰ In this case, a ‘specific area or project’ refers to the collection or harvesting of feedstocks in relation to a specific biofuel plant or group of plants.

GC3 - The use of land-based biomass produced in an agricultural context for the express purpose of biofuel production should be limited to a sustainability ceiling set for the EU as a whole, with appropriate mechanisms for dividing it between Member States.

The criterion refers to all land-based biomass grown in an agricultural context, thereby explicitly excluding forest biomass (covered by SC5) but including energy crops alongside conventional food and feed crops. It has been developed in the recognition that the deployment of land-based biomass for energy production can be sustainable at specific scales and in specific contexts. Where these scales and contexts are exceeded, there is a risk to sustainability.

There is space within the agricultural context, which includes abandoned land, for the production of crops, whether traditional or more novel, for biofuel feedstock purposes provided that they meet the other sustainability criteria enumerated here. In some cases they may bring opportunities, in others, risks. However, there are limits to the amount of land that could be devoted to such production without creating conflicts with food production on the one hand or biodiversity conservation on the other. Current evidence suggests that most such crops would be grown on existing agricultural land in order to secure sufficient yields to be commercially viable (Valin et al. 2015; Allen et al. 2014). Consequently there is a risk that conflicts with food production could occur in future under a strong development trajectory, although this is not the case at the moment. In parallel, while production could be increased in more marginal or abandoned areas there are further potential restrictions given Europe's limited area of semi-natural vegetation and the large distance to go before the current target of stopping the decline of biodiversity in the EU by 2020 is met. Whilst GC2 (no displacement), SC1 (high biodiversity) and SC3 (other biodiversity and ecosystems) would help to address the concerns listed here, they do not address fully the potential impacts of incremental deployment at scale, neither do they provide a clear direction of travel on which to make future investment decisions in this area. Creating a mechanism to recognise such limits would provide a clear signal of the acceptable dimension of development in the coming decade.

The precise scale over which the impacts may materialise are difficult to determine in advance. In particular, indirect impacts are difficult to quantify or determine specifically in relation to a given feedstock or deployment situation. Whilst there is undoubtedly variation between the impacts caused when different types of crops/biomass or production systems are adopted, the precise nature and quantification of those impacts cannot be determined *ex ante* with sufficient rigour to enable a differentiated approach. The overall cap on feedstocks under this criterion acts as a safeguard against this potential uncertainty but the ceiling on the overall supply should be established on the basis of more complete evidence and through sustainability impact assessments undertaken at the national level. This principle sets the overall scale of land-based biofuel deployment within the national context.

A precedent for these requirements is established in the current RED and ILUC Directives; these measures place a seven per cent cap on certain types of land-based biomass. In

addition an approach to implementing this type of criterion is in operation under the Common Agricultural Policy for restricting (to a ratio percentage⁴¹) the amount of permanent grassland that can be converted to arable land within a given time period (Regulation (EU) No 1307/2013).

GC4 - The use, collection and harvesting of feedstocks, shall be in compliance with international, national, regional and local environmental legislation. This includes ensuring coherence with key EU legislation pertinent to the use, cultivation and collection of specific feedstocks and their potential impacts, such as **compliance with the principles of the waste hierarchy (as set out in Council Directive 2008/98/EC), the Water Framework Directive (Directive 2000/60/EC) and the relevant Common Agricultural Policy (CAP) rules**, specifically those set out under the heading 'environment, climate change, good agricultural condition of land' in Annex II of Council Regulation 1306/2013.

This principle makes reference to existing legislation and legal requirements with the protection of the natural environment, soil and water resources in different Member States, and seeks to ensure coherence in Community policy. Precedence for these requirements is established in the current RED as revised by the ILUC Directive.

5.2 Specific criteria

Five sustainability criteria address specific issues that may arise from using certain feedstocks or groups of feedstocks.

SC1 - Biofuels and bio-liquids should not be made from material obtained from land with high biodiversity value, except where the material can be harvested in compliance with conservation objectives. High biodiversity value land is defined as that which had one of the following statuses in or after January 2008, whether or not the land continues to have that status:

- a) primary forest and other wooded land, namely forest and other wooded land of native species, where there is no clearly visible indication of human activity and the ecological processes are not significantly disturbed;
- b) areas designated:
 - i) by law or by the relevant competent authority for nature protection purposes; or
 - ii) for the protection of rare, threatened or endangered eco- systems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the International Union for the Conservation of Nature, subject to their recognition in accordance with the second subparagraph of Article 18(4);

unless evidence is provided that the production of that raw material did not interfere with those nature protection purposes;

- c) highly biodiverse grassland that is:

⁴¹ Member States shall ensure that the ratio of areas of permanent grassland to the total agricultural area declared by the farmers in accordance with point (a) of the first subparagraph of Article 72(1) of Regulation (EU) No 1306/2013 does not decrease by more than 5 % compared to a reference ratio to be established by Member States in 2015 by dividing areas of permanent grassland referred to in point (a) of the second subparagraph of this paragraph by the total agricultural area referred to in point (b) of that subparagraph. (Article 45 of Regulation (EU) No 1307/2013)

- i) *natural, namely grassland that would remain grassland in the absence of human intervention and which maintains the natural species composition and ecological characteristics and processes; or*
- ii) *non-natural, namely grassland that would cease to be grassland in the absence of human intervention and which is species-rich and not degraded, unless evidence is provided that the harvesting of the raw material is necessary to preserve its grassland status.*

The Commission has established the criteria and geographic ranges to determine which grassland is covered by point (c) of the first subparagraph in Regulation (EU) No 1307/2014.

The status and completeness of conservation objectives may vary according to the particular designation and the Member State/Country involved. Advice should always be sought from the relevant competent national authority on the appropriate and permissible management of designate sites before undertaking production or vegetation harvesting.

This criterion is an adaptation of the current sustainability criteria set out in Article 17(3) of the RED. It aims to address the potential risks that might arise from the harvesting of existing vegetation, or the cultivation of crops, from land that has recognised and high biodiversity value. The clause added to the criteria recognises that in some cases it may be beneficial to harvest vegetation in an acceptable way from certain sites where active management is required for their conservation, or that conservation management will result in surplus vegetative material. It is important to note that there are areas that are important for biodiversity and nature conservation that fall outside of designated sites. These are addressed through **SC3**.

Conservation objectives may be more or less defined depending on the designation and the countries involved. The concept of conservation objectives for designated sites stems from the Birds (Directive 2009/147/EC) and Habitats (Directive 92/43/EEC) Directives. For example Natura 2000 sites, comprising Special Protection Areas (SPA) under the Birds Directive and Special Areas of Conservation⁴² (SAC) set out under the Habitats Directive include conservation objectives and in many cases require appropriate management plans or assessments. Implementing the requirements of the designation vary between SPAs and SACs. SACs may require management plans or other appropriate measures that correspond to the ecological requirements of the natural habitat types and the species of Community interest. For SPAs, the conservation objectives should be met while taking account of economic, social, cultural, regional and recreational requirements. It is for Member States to establish the most appropriate methods and instruments for implementing the Directives and for achieving the conservation objectives of Natura 2000 sites. Other designated sites, whether they are EU, national, regional or local may have variations on conservation objectives or other forms of guidance that helps to determine the management of the site.

⁴² Designated by Member States following adoption of the site as a Site of Community Importance at the EU level.

SC2 - Biofuels and bio-liquids should not be made from material obtained from high carbon stock land except where the material can be harvested in compliance with conservation objectives. High carbon stock land is defined as land that had one of the following statuses in January 2008 whether or not it continues to have that status:

- d) wetlands, namely land that is covered with or saturated by water permanently or for a significant part of the year;
- e) continuously forested areas, namely land spanning more than one hectare with trees higher than five metres and a canopy cover of more than 30 %, or trees able to reach those thresholds in situ;
- f) land spanning more than one hectare with trees higher than five metres and a canopy cover of between 10 % and 30 %, or trees able to reach those thresholds in situ, unless evidence is provided that the carbon stock of the area before and after conversion is such that, when the methodology laid down in (Annex [xx])⁴³ of the regulation) is applied, the conditions laid down in relation to GC1 [GHG emission saving requirement] are fulfilled.

The status and completeness of conservation objectives may vary according to the particular designation and the Member State/Country involved. Advice should always be sought from the relevant competent national authority on the appropriate and permissible management of designate sites before undertaking production or vegetation harvesting.

This criterion is an adaptation of the current sustainability criteria set out in Article 17(4) of the RED. It aims to address the potential risks that might arise from the harvesting of existing vegetation, or the cultivation of crops, from land that has carbon stock value. The clause added to the criteria recognises that in some cases it may be beneficial to harvest vegetation in an acceptable way from certain high carbon stock sites where active management is required for their conservation. For the extraction of materials on land with high carbon stocks, but not covered by this list, refer to **SC3**

SC3 - Biofuel and bio-liquids should not be made from material where its extraction or cultivation will result in significant negative impacts on biodiversity or ecosystem function.

In particular extraction or cultivation should not:

- result in a decrease in the diversity or abundance of species and habitats of conservation importance or concern;
- contravene existing management plans or conservation objectives;
- result in a reduction of soil organic matter or soil organic carbon to levels that are critical for soil fertility;
- result in risk of soil erosion;
- lead to a decrease in water availability in catchments where this is a concern; or
- lead to a critical decrease in water quality within a catchment.

Each area of risk is highly geographically variable. Guidance should be sought from the relevant competent national or regional authority to identify areas or issues of importance and relevance within the area or project concerned. Conservation objectives are described under SC1

⁴³ Appropriate reference would be made to the annex describing the calculation methodology applying to this point.

This criterion is an extension of the current non-mandatory sustainability criteria referred to in Article 18 of the RED. It addresses the risks posed by the extraction or cultivation of material both within and outside of designated sites (see SC1 & 2) that would result in soil, water or biodiversity impacts, and affect the functioning of ecosystems on which the production of biomass (whether primary or residual) relies. No specific threshold is identified in this criterion, as there can be considerable variation between each site and production system. In practice a site-based assessment would be necessary to determine the current situation, determine an appropriate management regime and on which to monitor progress.

SC4 - Where biofuels and bio-liquids are produced from novel non-native or invasive alien species (e.g. certain species of algae, tropical plants, etc.), their cultivation should be subject to an initial risk assessment and on-going monitoring in order to ensure that sufficient safeguards are in place to prevent escape to the environment.

This criterion recognises that many “energy” crops are selected on the basis of their ability to grow rapidly and often in poor (usually agronomic) conditions. Many of these species are not native to the EU and pose an environmental risk if they were to escape into the environment. A site-based assessment would be necessary for implementation, depending on the chosen feedstocks, but other more general approaches may be suitable, based on existing guidance in this area.

Within the EU, Regulation 1143/2014/EU sets out the requirements for preventing and managing the introduction and spread of invasive alien species (IAS) in Europe, including the criteria by which invasive or alien status is defined. The list of IAS of Union concern will be adopted and updated by way of implementing acts. The first implementing act⁴⁴ was submitted by the European Commission towards the end of 2015 for the consideration of the Committee of Member State representatives. Whilst the committee gave a favourable option, the act is yet to be implemented in practice and thus is not included here.

Similar governing rules may exist in third countries that produce biofuel feedstocks, or fuels imported to the EU as a result of the RED. Compliance with such rules shall be ensured.

SC5 - Biofuels and bio-liquids shall not be made exclusively from whole trees above a stem diameter of [x] cm at breast height. The diameter of the tree, measured conventionally at breast height (DBH), should be determined within the context of regional sustainable forest harvesting strategies and in relation to the tree species and forest from which they are harvested.

This criterion seeks to address issues that remain unresolved through the above-described criteria. Mainly in relation to the carbon implications of utilising whole trees for the production of biofuels not covered by GC1, as well as competition aspects not covered specifically by GC2 (see section 4.1.1). While the direct harvesting of whole trees for the express purposes of biofuel or bio-liquid production is rare in Europe, the use of imported

⁴⁴ Containing 37 IAS

woody biomass or the processing of trees into pellets or chips for use in bioenergy generation is more common. Should there be a change in markets, particularly those driven by policy, this criterion would provide a safeguard to prevent unsustainable practices from developing, primarily within the EU, but also outside.

This point is further elaborated in the preamble to the ILUC Directive in *'order to ensure the long-term competitiveness of bio-based industrial sectors, and in line with the Commission Communication of 13 February 2012 entitled 'Innovating for Sustainable growth: A Bioeconomy for Europe' and the Commission Communication of 20 September 2011 entitled 'Roadmap to a Resource Efficient Europe', promoting integrated and diversified biorefineries across Europe, enhanced incentives under Directive 2009/28/EC should be set in a way that gives preference to the use of biomass feedstocks that do not have a high economic value for uses other than biofuels'* (Directive (EU) 2015/1513).

It should be noted that forest and wood processing sectors in Europe often utilise a variety of biomass fractions from whole trees as part of an integrated production process. In some cases this includes producing process energy or generating biofuels or bio-liquids from fractions of the original source timber. Maximising the use of biomass in this way is important to deliver resource efficiency aims and should not be prevented by this criterion. Where this criterion would act is if a facility that was dedicated to the production of biofuels and bio-liquids were to harvest or source (from within or outside the EU) whole trees 'exclusively' for this purpose⁴⁵.

Identifying the specific size of trees subject to this criterion would need to be done in context and it is unlikely to be possible to set a single figure at the EU level. More reasonably it would be possible to define tree diameters in relation to a set of defined criteria, such as sustainable forest management (SFM) practices⁴⁶, country production practices, established industry standards, etc.

5.3 Implementation

One of the main questions that arise in relation to the development of sustainability criteria is how they could be implemented and where the burden of implementation or compliance checking would reside.

In order to ensure that advanced biofuels are developed and deployed, the burden on operators must be limited to the level necessary to ensure sustainability of supply. This requires the clear articulation of the sustainability criteria as well as a range of other tools,

⁴⁵ An exception could be considered on a project by project basis if the timber was grown as dedicated biofuel feedstock on land not used for agricultural or forestry purposes, i.e. an energy crop context, providing all other criteria were observed. Further consideration of this and other exceptions are needed.

⁴⁶ Forty seven European countries and the European Union are signatories to the Ministerial Conference on the Protection of Forests in Europe (MCPFE) have adopted SFM. MCPFE includes SFM guidelines, criteria and indicators, monitoring and reporting and assessments. The term SFM was defined in 1993 in the Helsinki resolution (MCPFE 1993) as "the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems".

such as clear and timely guidance from the European Commission on the implementation of the criteria; effective and efficient voluntary schemes and certification standards; and data on which to make assessments.

5.3.1 Criteria as part of a package

The general and specific criteria set out above form a set, all of which are necessary to ensure the sustainable production and use of biofuels and bio-liquids promoted through policy.

One specific issue continues to present a challenge to the effective operation of sustainability schemes in this context, that of indirect effects, particularly ILUC. In particular an agreed and robust method to calculate or assess the precise nature of the ILUC impacts has not yet been developed and has restricted progress and investment certainty for advanced biofuels, despite recent work (e.g. Valin et al. 2015). Respecting the needs to develop proportional and implementable criteria, this study offers an approach to circumvent the agreement of a specific measurement of ILUC or agreement on specific ILUC numbers (or factors) that can be attributed to individual crops or situations. **For this to work, it is essentially that *all* criteria identified in this study are implemented in practice.**

Table 3 sets out the general and specific criteria defined in Chapter 5 and the issues covered or not covered by the different criteria. These criteria are non-hierarchical in that they are equally important, and they are non-substitutable in that no one criterion could substitute another.

Table 3: Issues addressed by sustainability criteria posed in this study

Criteria	Issues covered	Issues not covered by this or previous criteria
General criteria		
GC1 (GHG intensity)	The carbon efficiency of feedstock production and harvesting and biofuel production, irrespective of fossil fuel comparator	Indirect land use change impacts – recognising the challenges of calculation and monitoring (GC2); Scale of deployment (GC3).
GC2 (land use change and displacement)	Indirect land use change impacts by calculating and mitigating displacement impacts at the project or site level	Competing uses of feedstock (GC4)
GC3 (Scale of deployment)	Indirect land use change impacts through significant scale up of land-based biofuel feedstock deployment	-
GC4 (Coherence in legislation)	Coherence with EU and international policy governing the protection of the environment. Competing uses.	-
Specific criteria		
SC1 (High biodiversity value)	Impacts of cultivation or material extraction on areas of high biodiversity land. Allows extraction on areas where harvesting vegetation would be beneficial to conservation objectives.	Areas of high carbon stock or biodiversity importance outside of designated sites (SC2); Ecosystem function (soils, water, biodiversity) outside of designated sites (SC3); Invasive or alien species (SC4)
SC2 (High carbon stock)	Impacts of cultivation or material extraction on areas of high carbon stock land. Allows extraction on areas where harvesting vegetation would be beneficial to conservation objectives.	Carbon impacts outside of high carbon stock land (GC1, SC3)
SC3 (Ecosystem function)	Impacts of cultivation or material extraction on biodiversity and ecosystems outside of designated sites.	Invasive species (SC4)
SC4 (Invasive species)	Impacts of the release or escape of invasive or alien species	-
SC5 (Whole trees)	Carbon and displacement impacts not covered explicitly in GC1 and GC2)	-

5.3.2 Verifying compliance

The criteria set out in this report would be put into practice by: an obligation on operators to follow certain general principles; and a site based assessment or audit that would be needed for certain issues. It is not within the scope of this study to provide a full description of how the general and specific criteria set out above should be addressed. However, it is helpful to consider in general terms how such an approach might work.

The general and specific criteria set out fall into three broad categories:

- Those that require compliance with existing EU legislation or policies, which have existing and well-developed implementation guidance and procedures associated with them (GC4);
- Those that require a threshold to be established in advance of implementation, (GC1 - 3); and
- Those that are, or can be more site or feedstock specific in nature and cannot be pre-determined in advance of their implementation and require the determination of specific areas and then a demonstration of compliance either by a competent authority or by the economic operators involved (GC2; SC1 - 4).

Whilst the first two categories are similar in formulation to the current RED sustainability criteria, and therefore reasonably well developed, the last category represents a new approach, one that reflects a more diverse potential feedstock base. The sustainability implications for material harvesting and extraction rates and invasive species relate to specific site based conditions for the species and feedstocks concerned (Kretschmer et al. 2012; Scarlet et al. 2010). This is essential as general rule would be impractical. For example, to try to develop residue extraction rates for all possible residue forms in all locations in the EU would be unworkable, moreover the data and information on which to make such assessments does not exist (Kretschmer et al. 2012; Searle & Malins 2013; Allen et al. 2015). Setting a reduced set of generic restrictions (or a single maximum rate for all cases) would be arbitrary and lead to a rate that would be too high in some cases and overly restrictive in others. Such criteria require more detailed, on-site assessments to determine the potential risk and therefore the specific scale of cultivation or rate of extraction related to a given project or plant location.

To effectively implement such an approach in practice would often require a site based assessment and usually the development of a management plan that would ensure the sustainability of feedstock harvesting or collection, and, if implemented well, could lead to the improvement of conditions on site. The use of site-based assessments and the development of management plans could allow economic operators greater freedom to develop practices and feedstock utilisation approaches that work best for them in a given location or under certain conditions. Of course, a form of compliance audit or checking procedure would be necessary in line with current requirements for assessing sustainability compliance of operators.

The development of site based assessments and management plans is not without precedent and is already being used in many voluntary schemes demonstrating compliance with the current RED criteria. Also management plans for some agri-environment schemes operating under the CAP follow just such an approach, including a site assessment,

development of (in this case conservation) objectives, identification of appropriate management activities, and regular checking and follow up to ensure activities are being implemented effectively.

Further work would be needed in order to make more specific recommendations on what would be the best approach to implement the general and specific sustainability criteria listed here in an effective, transparent way, avoiding unnecessary cost. What can be stated is that the approach to implementation should ensure biofuels developed on the basis of the new feedstock sources are sustainable; that economic operators have the flexibility to develop supply chains that meet their requirements, whilst being sustainable; and that compliance checking and auditing presents as limited a burden on competent authorities as possible.

5.4 An improved framework for sustainability

A durable and effective approach to ensuring the sustainable use of biomass as a whole for energy purposes requires more than the development and application of criteria alone. The criteria need to fit within a wider EU framework which could include a clear climate and energy policy regime for 2030 and beyond; the identification of the scale of ambition (target or limit setting); improved information and data gathering; clear and specific objectives for specific sectors or technologies where appropriate; clear terminology and definitions; the governance framework to implement the criteria and shape the development of the sector; and guidance and advice, relating to the sustainability criteria. The elaboration of an improved governance framework to better implement a sustainable renewable energy policy is beyond the scope of this report but such issues are being explored actively at the moment in the lead in to anticipated EU proposals on bioenergy in 2016 (Bowyer et al. 2015).

Coherence at the EU level is clearly a priority and helpful in the creation of a stable investment climate and so has been the main focus of this report. However, it must also be acknowledged that the ***policy framework for renewables needs to be elaborated at other levels as well, with many decisions taken at the regional or local level.***

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The following text was added to Directive 2009/29/EC as a result of the amending legislation under Directive (EU) 2015/1513

'ANNEX IX

Part A. Feedstocks and fuels, the contribution of which towards the target referred to in the first subparagraph of Article 3(4) shall be considered to be twice their energy content:

- (a) Algae if cultivated on land in ponds or photobioreactors.
- (b) Biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under point (a) of Article 11(2) of Directive 2008/98/EC.
- (c) Bio-waste as defined in Article 3(4) of Directive 2008/98/EC from private households subject to separate collection as defined in Article 3(11) of that Directive.
- (d) Biomass fraction of industrial waste not fit for use in the food or feed chain, including material from retail and wholesale and the agro-food and fish and aquaculture industry, and excluding feedstocks listed in part B of this Annex.
- (e) Straw.
- (f) Animal manure and sewage sludge.
- (g) Palm oil mill effluent and empty palm fruit bunches.
- (h) Tall oil pitch.
- (i) Crude glycerine.
- (j) Bagasse.
- (k) Grape marcs and wine lees.
- (l) Nut shells.
- (m) Husks.
- (n) Cobs cleaned of kernels of corn;
- (o) Biomass fraction of wastes and residues from forestry and forest-based industries, i.e. bark, branches, pre-commercial thinnings, leaves, needles, tree tops, saw dust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin and tall oil.
- (p) Other non-food cellulosic material as defined in point (s) of the second paragraph of Article 2.
- (q) Other ligno-cellulosic material as defined in point (r) of the second paragraph of Article 2 except saw logs and veneer logs.
- (r) Renewable liquid and gaseous transport fuels of non-biological origin.
- (s) Carbon capture and utilisation for transport purposes, if the energy source is renewable in accordance with point (a) of the second paragraph of Article 2.
- (t) Bacteria, if the energy source is renewable in accordance with point (a) of the second paragraph of Article 2.

Part B. Feedstocks, the contribution of which towards the target referred to in the first subparagraph of Article 3(4) shall be considered to be twice their energy content:

- (a) Used cooking oil.
- (b) Animal fats classified as categories 1 and 2 in accordance with Regulation (EC) No 1069/2009 of the European Parliament and of the Council

Annex 2 Feedstocks identified in this study

- **Agricultural (non-food) and forestry crops** are dedicated grassy and woody crops that are unsuitable for human or animal consumption and are grown primarily for the purpose of producing biomass for energy in agricultural context.⁴⁷ These crops include three main sub-groups: annual and perennial agricultural crops (e.g. Miscanthus, Switchgrass, Reed canary grass, Giant reed; Perennial rye grass; Sorghum); short rotation coppice (SRC) (e.g. Willow, Poplar or Eucalyptus); and short rotation forestry (SRF) (Sycamore, Ash, Beech).



- **Arable and horticultural crop harvesting and management** feedstocks are those residues that remain following crop harvesting and management processes. These include straw and stover.



- **By-products from livestock industry** are those residues that become available due to the maintenance of livestock in an agricultural context. This group includes animal manure, in the form of liquid manure or slurry, as well as solid manure and dung.



- **Agricultural processing residues** are residues that result from industrial processing of agricultural products. These residues include bagasse, cobs, nut shells, husks, grape marcs and wine lees, empty palm fruit bunches and palm oil mill effluents.



⁴⁷ Based on the categorisation adopted in Allen et al. (2014) Space for energy crops – assessing the potential contribution to Europe's energy future, pp. 6-7.

- **Forestry or forest biomass** is biomass resulting from forest management and harvesting operations.⁴⁸ Forestry includes three main feedstocks: early thinnings⁴⁹, small round wood (or thinnings)⁵⁰ and round wood.



- **Forest-based crop harvesting and management** feedstocks are those residues that remain following crop harvesting and management operations have taken place. These are primarily woody residues, mainly forest biomass as well as woody biomass on non-forest land, and include stem tops, bark, branches and foliage, stumps and roots.



- **Woody and wood industry processing residues** are residues that result from the processing of wood, paper and pulp materials. These residues include sawmill co-products (sawdust and cutter shavings), tall oil and black/brown liquor.



- **Harvested semi-natural biomass** result from management and harvesting operations of vegetation in semi-natural areas. These residues include reed cuttings, coppice and stand clearance and grass cuttings.



⁴⁸ Management and harvesting activities include early thinning, thinning and final harvest.

⁴⁹ According to IINAS et al. (2014), early thinnings are defined as 'very young stands which were formerly considered as pre-commercial'.

⁵⁰ According to IINAS et al. (2014), small round wood or thinnings are referred to as an assortments of wood of different quality, for either energy or material uses.

- **Landscape care biomass** results from maintenance operations of artificial vegetation in public spaces, i.e. parks, gardens, roadsides, hedgerows, boundary ridges and rail- and waterways. This includes leaves, branches and grass cuttings.



- **Organic / biological waste streams** result from the discard of organic and biological material by households and industrial processes. These include two main feedstock sub-groups: municipal biological waste and industrial biological waste.



- **Micro-organism based biomass** encompasses single- or multi-cellular organisms (i.e. micro and macro algae) and bacteria.



- **Non-biobased materials** include those feedstocks that are not produced from substances of biological origin. These include industrial non-biobased gas and liquid streams from renewable and non-renewable energy sources, i.e. steel mill gases and hydrogen.

