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Summary for policy makers

In October 2012 the European Commission published a legislative proposal to amend the RED and FQD aimed at addressing indirect land use change (ILUC). One of the proposed measures is a further incentive for biofuels produced from wastes, residues and (ligno) cellulose material. The Commission proposes to count these biofuels two or four times towards national biofuel mandates. While biofuels produced from wastes and residues can be very sustainable and achieve high direct GHG savings compared to fossil fuels, they are not necessarily ILUC-free. If, for example, a quantity of straw was used for animal feed and is now being used for ethanol production, more animal feed production is needed to compensate the loss of animal feed. This study examines a number of waste and residue material and assesses to what extent a 'surplus' of the materials exists which can be used to produce biofuels without causing ILUC; the rules laid down in the LIIB certification module[1] are used for this purpose. The materials assessed in this study are cereal straw, woody residues, used cooking oil (UCO) and corn cobs.

In order to assess the low ILUC potential for each of the materials this study first identifies the available *theoretical potential* of each of the materials. This is the quantity of the material which is available and could in theory be harvested or collected. Subsequently the *sustainable potential* is estimated. This is the quantity which can be harvested or collected in a sustainable way, taking into account the need to protect, for example, soil quality. Finally the *low indirect impact or low ILUC potential* is estimated. This potential takes into account the current non-bioenergy uses of the material. Displacing these uses could lead to ILUC and therefore these existing uses are deducted from the sustainable potential. Because UCO is traded globally its potential was assessed also outside the EU while the other materials were analysed at EU and Member State level.

This report shows that the assessed waste and residue materials assessed here all have considerable theoretical potentials, smaller but still substantial sustainable potentials and varying low ILUC potentials. For corn cobs the low ILUC potential could not be established, while straw, woody residues and used cooking oil all have a substantial low ILUC potential. Results can differ significantly from Member State to Member State. Germany, France and some other Member State for example have a large surplus of straw available while the Netherlands and Poland currently have a straw deficit. Using straw to produce ethanol in the latter two Member State poses a serious risk of negative indirect impacts. UCO is widely used as a biofuel already and this study shows that on the one hand ample ILUC-free potential is available, whilst on the other hand that UCO collection can be a dodgy business in certain regions, which makes quality control challenging. The use of UCO as cooking oil or for human consumption in China, Indonesia and possibly Argentina and dumping of UCO in rivers in some regions poses particular problems for public health and the environment. Using UCO which would otherwise be dumped to produce biodiesel can be highly beneficial beyond it being low ILUC.

[1] Low Indirect Impact Biofuels certification module, developed by WWF International, Ecofys and EPFL, www.liib.org

From low ILUC EU woody residues, low ILUC EU cereal straw and globally available UCO a total quantity of 17Mtoe of low ILUC biofuels could be produced: 11.2Mtoe from woody residues, 3MTOE from cereal straw and 2.8Mtoe from UCO. This estimated total would equal almost 60% of the total forecasted quantity of biofuels in the EU in 2020 when single counted and around 120% with double counting in place. The challenge is not the availability of ILUC-free feedstocks but in the willingness to invest in sufficient biofuel production plants which can reap this potential.

This study shows that a substantial quantity of cereal straw and forestry residues could be harvested and used for biofuels, but that an even greater quantity *cannot* be harvested without risking serious negative sustainability impacts. The current proposed positive lists for multiple counting do not limit the quantitative use of specific materials, in theory allowing both straw and 'bark, branches, leaves, saw dust and cutter shavings' (woody residues) to be completely harvested and used for biofuels. In order to reconcile the need for truly sustainable biofuels and the need to avoid negative sustainability impacts it would be necessary to introduce a maximum removal rate for primary land-using agricultural and forestry wastes and residues before these materials are included in the positive lists. It would be good to specify the removal rates at Member State level and if feasible an even more detailed regional specification. More research is needed to determine appropriate maximum removal rates.

When creating effective incentives for the use of wastes and residues as sustainable biofuel feedstocks it is advisable to take into account current uses of the feedstock. This study shows that this can require great efforts and results are often estimates, but in order to promote truly sustainable biofuels it is worth the effort.

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1 Introduction

1.1 Direct and indirect sustainability of biofuels

Increasing volumes of biofuels are blended in fossil petrol and diesel in many regions of the world. In the European Union, biofuels are mainly blended in order to mitigate climate change. The use of biofuels is promoted in two EU directives, the Renewable Energy Directive (RED)[2], which requires 10% renewable energy in transport in 2020 and the Fuel Quality Directive (FQD)[3], which requires fuel suppliers to reduce greenhouse gas emissions by 6% in 2020 throughout the supply chain from oil well to car wheel. Both the RED and FQD targets will be mainly met by the blending of biofuels.[4]

When the European Union agreed upon the RED and FQD targets in 2008, concerns over the sustainability of biofuels and competition with food led to the inclusion of mandatory sustainability criteria for biofuels in both directives. These criteria were the first mandatory requirements for biofuel sustainability worldwide. Biomass produced for biofuels consumed in the EU now has to meet more stringent sustainability requirements (most notably land-use and GHG related) compared to biomass for food, animal feed or other purposes.

The focus on biofuel sustainability and the emerging discussion on Indirect Land Use Change (ILUC) also led to the inclusion of the 'double counting provision' in the RED[5], which aims to increase the use of biofuels produced from wastes, residues and (ligno)cellulose materials by counting these biofuels twice towards national targets. This means that if for example a national biofuel mandate of 4% is in place, the target could be met by the supply of 2% biofuels produced from waste or residues. The reason for this incentive for biofuels from wastes and residues is the notion that no agricultural land is required to generate waste and residue materials. The double counting provision has led to a large increase in the consumption of biofuels from used cooking oils and animal fats in recent years. The FQD does not include a double counting provision but also in this directive biofuels produced from wastes and residues have the advantage that they have a relatively high GHG saving and are thus attractive compared to biofuels with a lower GHG saving because fewer litres of residue-based biofuels are needed to meet the FQD target. Wastes and residues as a feedstock for the production of biofuels will be the focus of this study.

The sustainability criteria for biofuels in the RED and FQD only address aspects *directly* related to the production of biofuel feedstocks. Since 2008, increasing attention has been raised to *indirect*

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[2] 2009/28/EC
[3] 2009/30/EC
[4] While the RED target is a volume target on an energy basis, meaning that it can be met by blending 10 per cent of biofuel on an energy basis in the total quantity of fossil petrol and diesel supplied to the EU market the FQD target is a GHG based target, meaning that the higher the GHG saving of biofuels compared to fossil fuels, the fewer litres of biofuels are required to meet the 6% target.
[5] Article 21(2), the provision allows double counting of biofuels produced from wastes, residues, lignocellulose and non-food cellulose materials.

sustainability aspects of biofuel feedstock production. ILUC currently dominates the EU debate on biofuels; it is the effect that when existing cropland is used for biofuel feedstock production, the previous land use is displaced and as a result there is an increased risk that non-agricultural land is converted into cropland elsewhere. ILUC can therefore lead to higher GHG emissions and loss of biodiversity. ILUC, its quantification and possible policy measures have been debated in the EU since 2008. In October 2012 the European Commission published a legislative proposal[6] to amend the RED and FQD aimed to address ILUC. This would mean that the use of biofuels will be subjected to a more stringent sustainability regime which also aims to address negative indirect sustainability aspects. Members of the European Parliament and Council are currently discussing the proposal. One of the measures which the Commission proposes as a solution against ILUC is a further incentive for biofuels produced from wastes and residues. The Commission considers these biofuels to cause little or no ILUC and proposes to introduce quadruple counting of certain wastes and residues (as well as lignocellulose and non-food cellulose materials) in addition to the existing double counting provision. In its proposal, the Commission has included lists of specific feedstocks which would be eligible for double or quadruple counting towards national renewable energy targets.

1.2 Wastes and residues should be part of the solution, not the problem

While biofuels produced from wastes and residues can be very sustainable and achieve high direct GHG savings compared to fossil fuels, they are not necessarily ILUC-free. If, for example, a quantity of straw was used for animal feed and is now being used for ethanol production, more animal feed production is needed to compensate the loss of animal feed. This additional feed production could come from additional harvest of straw but if in situations where straw is scarce, more agricultural crops are needed to produce additional animal feed. This could lead to an increased demand for agricultural land which could lead to the conversion of land into agricultural land elsewhere in the world and associated negative impacts on biodiversity and carbon stocks. Another example is the use of animal fats, which has been used for decades by the oleochemical industry. In recent years, increasing quantities of animal fats have been diverted towards biodiesel production, leading to increased competition between the oleochemical and biodiesel industries for raw materials. Because animal fats are not available in limitless quantities, their increased use as a biodiesel feedstock could cause the oleochemical industry to use palm oil as a feedstock instead of animal fats. Using animal fats for biodiesel could have the indirect impact of increased palm oil use by the oleochemical industry, which could indirectly cause the conversion of forests to palm oil plantations in Southeast Asia.[7] The above is not meant to discredit biofuels from wastes and residues which could be a highly sustainable biofuel feedstock, but to raise the point that incentives for wastes and residues should be smart and tailored.

[6] COM(2012)595.

[7] The indirect GHG impact of waste and residue feedstocks has not been quantified in modelling studies to date. Ecofys, IIASA and E4Tech aim to undertake this in the coming period.

This could for example be done by limiting incentives to those wastes and residues which do not cause ILUC or by tailoring them in such way that only the available surplus of waste and residue materials is steered towards biofuels.

The question - what role can waste and residue materials play to mitigate ILUC as a low ILUC biofuel feedstock? - deserves further analysis and is the central question of this report. If it can be demonstrated that a certain material has no or low ILUC impacts, it would be credible to incentivise its use as part of an effort to reduce ILUC, for example by including the material in the positive lists for double or quadruple counting or to allow its use under a specific sub-target for ILUC-free biofuels.

1.3 The LIIB methodology

Ecofys, WWF International and EPFL[8] have developed a certification module for low ILUC biofuels. This Methodology for **Low Indirect Impacts Biofuels (LIIB)**[9], which was published in 2012, enables the certification of several categories of biofuels which do not cause ILUC. The certification module comprises of four ILUC mitigation solutions:

1. "Unused" land;
2. Yield increases above business-as-usual scenario (BAU);
3. Integration in existing plantations;
4. Wastes and residues.

LIIB is not a stand-alone voluntary certification scheme but designed to be combined with existing voluntary schemes. While LIIB ensures no negative indirect impact takes place, the existing voluntary scheme ensures the direct sustainability requirements for biofuel production are complied with.

The latter solution type can be used to assess to what extent a waste or residue material is ILUC free. This is done by first assessing whether the material is a waste or residue (and not a by-product or a product) and subsequently assessing the available quantity of the material which is not already used for other purposes (food, animal feed, oleochemicals etc.) in a certain region. It has to be carefully assessed whether the use of the residue for biofuel production leads to unwanted indirect impacts. In case a residue is already used for other purposes, e.g. straw for animal feed as in the example in the previous section, steering the residue towards biofuels may lead to an increase in use of agricultural crop to compensate for the loss of animal feed. In this case, the residue could not or not entirely be certified as ILUC free. The current version 0 of the module states that only the share of wastes and residues which is not used for non-bioenergy uses in a certain region[10] is eligible for certification as a low ILUC biofuel. When updating the LIIB certification module to version 1 it could the exclusion of current bioenergy uses can be discussed.

[8] École Polytechnique Fédérale de Lausanne

[9] www.liib.org

[10] A region can either be a country, part of a country or a group of countries. In this report the region is either a country or group of countries.

If 20% of a residue is already used for other purposes only the remaining 80% of the residue in a region can claim LIIB compliance. This rule could be amended in a future updated version of the module.

If the current uses of the material have been assessed and it can be concluded that a clear surplus of the material exists beyond its current non-bioenergy uses, the material can be classified as low ILUC and be placed on a positive list by the scheme owner. Feedstocks placed on the positive list are eligible for LIIB certification. Biofuel producers using a feedstock that is included on the positive list only have to prove through verification that they actually use the material in order to obtain LIIB certification for their product.

Whether or not a waste or residue is ILUC-free can vary from region to region. A material can have many existing non-bioenergy uses, leaving little scope for biofuel use without displacing current uses in region A, while the same material may have hardly any existing non-bioenergy uses in region B, meaning the material would be low ILUC here. LIIB aims to take these potential differences into account and allows for diversification of positive lists for LIIB certification. The extent to which wastes and residues are ILUC free is thus determined per region from which a certain biofuel feedstock is typically sourced. In the LIIB certification module this is called the **feedstock-region combination**. If the inclusion of a waste or residue onto the LIIB positive list is assessed, the feedstock region combination has to be determined. In the case of cereal straw for example, the feedstock region combination can be cereal straw from Germany, because straw is usually not traded over large distances. For used cooking oils, the feedstock-region combination can be 'UCO from the US' or 'UCO from the EU', because the material is traded internationally meaning that focusing on smaller regions, such as individual Member State level, would make little sense.

In short, the LIIB analysis of a biomass material will follow these steps:

1. Determine whether a material is a waste or residue rather than a by-product or product;
2. Choose the most relevant feedstock-region combination;
3. Analyse the size of the excess potential for the relevant feedstock-region combination;
4. Determine whether the waste or residue is eligible for inclusion in the positive list by the scheme owner, thereby eligible for LIIB certification.

The requirements included in the LIIB certification module will be used in this study to assess the ILUC effects of the selected waste and residue materials.

Waste, residue, by-product or product?

The first step in the analysis is to define the material. No generally accepted definitions exist, except for waste. The European Commission proposes in its ILUC proposal to base the definition for waste on the definition included in the EU waste framework directive 2008/98/EC: 'any substance or object the holder discards or intends or is required to discard'.

The Commission adds that 'substances that have been intentionally modified or contaminated to meet that definition are not covered by this category'.[11] EU legislation does not clearly define the difference between residue materials and by-products. More certainty on this point would be desirable. In earlier work, Ecofys used the following considerations:

1. The primary aim of the process is the material(s) to which the process is normally optimised. Such materials should be regarded as main product or co-product, and the remaining materials are residues (or waste);
2. Primary technology choice for a process should not be determining. Instead the optimisation and management of the existing process should be determining;
3. If a material from a process constitutes an essential/considerable outcome of the process (amount and/or economic value) and this material has other uses than for energy applications, it should be regarded as a co-product, in spite of the fact that the process is normally not optimised to this material.

If the third aspect is taken into account, a material could be considered a residue if it has an economic value of around 15% or less compared to the total value of main products, co-products and residues.

1.4 Focus and general approach of this study

In this study, Ecofys assesses the potential in the EU of wastes and residues with a low ILUC risk which can be used for biofuel production, for the German, Dutch and Danish governments. The study is part of a larger project for the German government in which Ecofys also assesses the potential for biofuel production on unused land and from above trendline yield increases in the EU. In the present report, Ecofys assesses the potential for biofuel use of the following materials, without causing ILUC:

1. Cereal straw;
2. Bark, branches, leaves, sawdust and cutter shavings;
3. Used Cooking Oil;
4. Corn cobs *(quick scan only)*.

These materials were chosen because they are included in the proposed positive lists for double or quadruple counting in the European Commission ILUC proposal and because they currently are playing, or might in the future, play an important role as a feedstock of biofuels produced for the EU market. While it was not possible to investigate all materials included in the proposed positive lists in this study, it could be interesting to further investigate some of the other materials. In line with the four steps for an LIIB assessment of biomass materials, each chapter on each of the materials to be assessed starts with a brief assessment on whether the material is a waste or residue. Subsequently, the appropriate feedstock-region combination will be chosen.

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[11] European Commissions' ILUC proposal COM(2012)595, p. 13.

Theoretical, sustainable and low ILUC potential

In order to assess the low ILUC potential for each of the materials this study first identifies the available **theoretical potential** of each of the materials. This is the quantity of the material which is available and could in theory be harvested or collected. Subsequently the **sustainable potential** is estimated. This is the quantity which can be harvested or collected in a sustainable way, taking into account the need to protect, for example, soil quality. Finally the **low indirect impact or low ILUC** *potential* is estimated. This potential takes into account the current non-bioenergy uses of the material. Displacing these uses could lead to ILUC and therefore these existing uses are deducted from the sustainable potential. Because UCO is traded globally its potential was assessed also outside the EU while the other materials were analysed at EU and Member State level. Naturally the low ILUC potential is smaller than the sustainable potential which in turn is smaller than the theoretical potential. For UCO the theoretical potential and the sustainable potential are identical as all UCO which is technically available could be collected without leading to serious sustainability impacts.

Concerning the feedstock-region combination chosen in this report, cereal and rapeseed straw will be assessed at EU level, even looking specifically at the EU Member States with the largest straw availability. Corn cobs and ‘bark, branches, leaves, sawdust and cutter shavings’ will also be assessed at EU level. Used cooking oil (UCO) is traded internationally and imported into the EU from many destinations. UCO will therefore also not only be assessed at EU level but also for large relevant regions outside the EU (US, China, Indonesia, and Argentina).

Quantifying the available potential of waste and residue materials in a robust manner is difficult. Unlike agricultural crops or other main products, no statistics exist on the availability of wastes and residues. This study bases its quantification on available literature and on interviews with selected experts. In cases where little useful literature is available, as is the case for UCO, the interviews play a crucial role. The lack of statistics also means that the potentials quantified in this report are nothing more than estimates. We did our best to make the estimates as robust as possible but it remains important to note that all outcomes are estimates. Especially for UCO, the estimates are highly indicative. While taking note of this important limitation, this report could provide interesting insights into the assessed materials and the extent to which they can be part of truly sustainable biofuels production.

2 Cereal straw

This chapter aims to identify the quantity of straw which can be collected in a sustainable way and used to produce biofuel without causing ILUC. The research focuses on cereal straw, the most widely available type of straw. The cereal crops assessed are wheat, barley, oat, rye and triticale[12], which are considered to be the most representative in the EU-27 (in terms of production area and volume). After some descriptive sections first the *theoretical* potential of straw will be estimated, followed by the *sustainable* potential and finally the *low ILUC* potential of straw.

2.1 Defining cereal straw

2.1.1 Cereal straw production

Cereal crops are comprised of five main parts. These are the grain or seed, leaf material, chaff[13], stem and roots. In the case of rapeseed the seed is encased by the pod wall, rather than chaff.

Straw can be defined as any material that is left over in the field after the harvest of the main crop (i.e. grain or seed)[14]. In practise, this is predominantly the stem of the plant, but may also include some small amounts of leaf material and chaff. The crop roots, which comprise approximately 30% of the aerial biomass for cereal crops (see figure below), are not classified as straw.

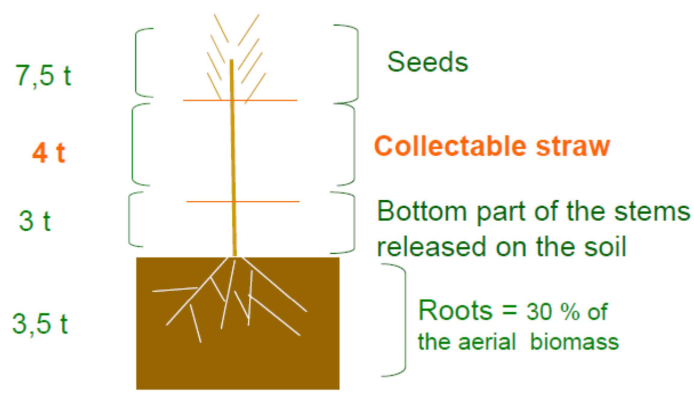

Figure 1: Diagrammatic representation of a cereal crop showing the collectable straw. Source: Panoutsou and Labalette (2006)[15]

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[12] Triticale is a hybrid of wheat and rye, which has become available in recent years.

[13] Outer casing of the grain which becomes separated during harvesting of the crop

[14] Straw is classified as an agricultural residue in the Renewable Energy Directive. However, the directive does not provide a definition of what straw is.

[15] Panoutsou and Labalette (2006), Cereals straw for bioenergy and competitive uses, JRC experts consultation – Pamplona, 18-19 October 2006

Harvesting of cereal crops and rapeseed typically takes place between June and August, the exact timing depending on the region, crop type and weather conditions in that year. Barley is usually harvested first, followed by rapeseed and then wheat (with some overlap between the harvest periods). Combine harvesters cut the crop stem approximately 10-15 cm above the ground for cereal crops and 15-20 cm for rapeseed. The grain is then "threshed" (shaken to separate the chaff) and collected, while the stem and leaf material falls to the ground. Some chaff may also be included, the proportion being determined by the configuration of the combine harvester.

Straw is left to dry in the field, known as "swathing", prior to baling. The typical moisture content achieved is around 16% moisture in northern Europe, but can be as low as 9% to 12% in southern Europe. The climate and weather conditions have a direct impact on the moisture content and overall quality of the straw, as well as the timing of the baling operations. Straw has to be harvested when dry, otherwise fungi will develop which will lead to very poor quality straw. This means that sometimes up to a week of dry weather is necessary before the straw in the fields is sufficiently dry to harvest. Chemicals desiccants can also be applied to speed up the drying process[16]. The straw is ideally harvested as soon as possible after harvest of the crop to enable preparation of the land.

The amount of the collectable material leftover after harvest of the straw is dependent on the height of the cutter bar used to harvest the crop. Increasing the blade height reduces the amount of straw that can be recovered at harvest.

Figure 2: Combine harvesting of oats. Straw is left to dry in the field (left hand side of picture). Source: UK Agriculture

An alternative to baling is to "chop" and "incorporate" the straw directly after harvest (i.e. plough it back into the soil).

[16] For example , this is practised in the UK for rapeseed straw and typically achieves a moisture content of 9-14%.

The choice of whether the straw is baled or incorporated can depend upon the relative economic value of the straw. In simple terms this is the value of straw to the farmer if it is baled and either used on-farm or sold on, versus the additional cost of applying fertiliser to compensate for the loss of nutrients. There are also other important considerations. For example, in a wet year the farmer may be less inclined to bale as this can delay the preparation of the next year's crop. The choice of whether to bale or to incorporate may vary on a year by year basis. See section 2.6.1.1 for further discussion on this.

The figures below illustrate how straw is harvested and baled.

Figure 3: Big baling of cereal straw. Source: UK Agriculture.

Figure 4: Collection of straw bales in the Uckermark, Germany. Source: Piorr (2007)

Following straw harvest the remaining straw that is leftover (referred to as “stubble”) is typically incorporated back into the soil. This has the benefit of burying weeds and creating a clean seedbed for drilling of the next year’s crop. In some cases the straw is simply left on the field.

Figure 5: Picture of a field being ploughed over in preparation for drilling (sowing) the next year’s crop. The left side of the field still contains the straw stubble. Source: UK Agriculture

2.1.2 On the choice of straw types

This chapter focuses on cereal straw. The cereal crops assessed are wheat, barley, oat, rye and triticale. Of these, wheat and barley are by far the most widely planted and make up around 80% of the cereal planting area in the EU-27.

It is noted that in some EU Member States other cereal crops may also be relevant. For example, corn (or maize) is widely planted across the EU-27, particularly in Romania, France, Hungary and Italy, however cob residues are covered separately in chapter 5. Similarly, rice is a major crop in Italy. Finally, sunflower production is significant in Romania, Spain, France and Hungary, however the collection of sunflower straw is not yet commercially feasible and was therefore not included in this study.

A considerable quantity of straw is generated from the production of rapeseed. Rapeseed straw can be more difficult to harvest compared to cereal straws as it is brittle in nature and therefore has a tendency to crumble during its harvesting[17].

[17] Modern combine harvesters employ a rotary system which tends to break the straw more making collection of the straw more problematic. This is also the case for cereal straw which can be shredded by modern combine harvesters.

It is this property, coupled with its high calorific value (due to the high oil content), that can make it an attractive fuel for energy generation. However, rapeseed straw is currently not harvested in significant quantities and this is not foreseen to change in the near future. For this reason a quantitative assessment of rapeseed straw is not included in this report, only a qualitative. A second reason for not including rapeseed straw is the fact that expert opinions on the sustainable removal rate vary considerably which makes it difficult to establish a credible estimate of its low ILUC potential.

2.2 Types and qualities of cereal straw and their use as biofuel feedstock

2.2.1 Types and qualities of straw

Baled straw typically has a bulk density of around 100-140 kg/m^3, which is relatively low compared to other biomass types, such as wood chips. The implication of this is that straw is an expensive raw material to transport. As such, a biofuel plant will need to be located close to the straw source (e.g. up to 50km away). Pelletising straw would increase the density, but also significantly add to the price and is therefore generally not considered a viable option[18].

As discussed in the previous section, the moisture content of straw can range from around 9% to 16% on average, depending on the region. When sourcing biofuel feedstock the straw should ideally be as dry as possible. The best quality straw is straw which has seen very little rain and is either yellow or white in colour. Straw which is dry when harvested, but which has seen lots of rain during its growing period is of lower quality and is darker in colour. The straw should also be clean and free from dirt and stones. Quality specifications would need to be clearly specified in supplier contracts, which would state the minimum and maximum acceptable ranges of the key parameters.

Effective storage conditions can play an important part in maintaining the quality of the straw. For example, by storing the straw on a hard standing and, if possible, under cover in wetter regions.

2.2.2 Cellulosic ethanol production installations using straw

There are a number of biofuel initiatives using straw globally, several of which are located in Europe[19]. Most of the operational projects are at the demonstration or pilot scales, although the plants now being built or in development are at the commercial scale. Wheat straw is the most widely used straw type, although a number of plants utilise wheat straw in combination with other agricultural residues, including corn stover. The more recent plants operate as “bio-refineries”.

[18] Drax Power in the UK own and operate a 100,000 tonne straw pelleting plant at Goole which is located 13 miles from the plant. The straw is sourced from farms in the local area.

[19] An overview of the initiatives is provided in the table below.

As well as cellulosic ethanol they also produce a number of secondary products such as lignin, renewable heat and power and bio-based chemicals. Companies that active in developing projects in Europe include Abengoa (Spain), BETA Renewables (Italy) and Inbicon (Denmark).

Abengoa[20]
Abengoa commissioned its first cellulosic ethanol plant in 2007, a 20,000 gallons per year (GPY) pilot plant in New England, USA. This was followed in 2009 by a 1.3 million gallons per year (MGY) demonstration plant in Salamanca, Spain which uses wheat and barley straw. During 2012 the company began construction of its first commercial scale cellulosic plant at Hugoton (Kansas, USA), which is due for completion at the end of 2013.

Beta Renewables[21]
Beta Renewables, a joint venture between Chemtex (Gruppo Mossi & Ghisolfi), capital investment company TPG and Novozymes, commissioned the world's first commercial scale cellulosic ethanol plant in Q4 2012 at Crescentino, Italy. The planned production capacity is 20 MGY (initially 13 MGY). The main feedstocks are arundo donax (an energy crop) and wheat straw, although the relative proportions of each are not readily available. The company also operates a demonstration scale plant at Rivalta, also in Italy.

Inbicon[22]
Inbicon is a joint venture between Dong Energy and Novozymes. It commissioned its first cellulosic ethanol plant in 2009 at Kalundborg, Denmark and is in the process of developing two commercial scale plants. The 20 MGY plant at Maajberg, also in Denmark is due in early 2016, while the 10+ MGY Spiritwood plant in North Dakota, USA is due in the third quarter of 2015. The Kalundborg plant sources 30,000 tonnes of wheat straw per year. The other two plants will also use wheat straw.

[20] http://www.abengoabioenergy.com/web/en/
[21] http://www.betarenewables.com/index.html
[22] http://www.inbicon.com/pages/index.aspx

Table 1: Overview of operational and planned cellulosic ethanol biofuel initiatives using straw as a feedstock (demonstration and commercial scale projects only). Sources: Advanced Ethanol Council, 2013[23] and company websites.

Company	Country	Location	Feedstock(s)	Product(s)	Scale	Date of operation
Installations in Europe						
Abengoa	Spain	Salamanca	Wheat and barley straw	1.3 MGY cellulosic ethanol	Demonstration	2009
BETA Renewables	Italy	Crescentino	Wheat straw, rice straw, bagasse, arundo donax, corn stover, poplar	13 MGY (later 20 GPY) cellulosic ethanol	Commercial	Q4 2012
BETA Renewables	Italy	Rivalta	Variety of cellulosic non-food biomass	~365 TPY cellulosic ethanol and bio-based chemicals	Demonstration	2009
CEG Plant	Poland	Goswinowice	75% wheat straw and 25% corn stover (250,000 TPY)	13 MGY, 70,000 TPY lignin at 50-60% moisture content and 22.3 Mnm^3 biogas (75% methane)	Commercial	
Chempolis	Finland	Oulu	Wheat and bagasse (25,000 TPY)		Demonstration	2010
Clariant	Germany	Straubing	Wheat straw (4,500 TPY)	0.330 MGY cellulosic ethanol, cellulosic sugars and bio-based chemicals	Demonstration	2012
Inbicon	Denmark	Kalundborg	Wheat straw (30,000 TPY)	1.5 MGY cellulosic ethanol, 11,400 TPY lignin fuel pellets, 13,900 TPY sugar molasses	Demonstration	2009
Inbicon	Denmark	Maajberg	Wheat straw	20 MGY cellulosic ethanol, 1.7 BCF of biogas, renewable electricity for 25,000 households, 565,000 TPY of renewable fertiliser, 56,000 TPY of solid biofuel for power/heat	Commercial	Q1 2016
Installations outside Europe						
Abengoa	US	Hugoton (KS)	Agricultural residues, energy crops, prairie grasses	25 MGY (and 20MW power)	Commercial	Q4 2013
Iogen	Canada	Ottawa (ON)	Cereal straw, bagasse, corn stover, grasses	1 MGY cellulosic ethanol	Demonstration	2005
Inbicon	US	Spiritwood (ND)	Wheat straw (25 TPH)	10+ MGY cellulosic ethanol, 83,000 TPY lignin fuel pellets, 94,000 TPY sugar molasses	Commercial	Q3 2015
Zea Chem	US	Boardman (OR)	Wheat straw, poplar trees	0.250 MGY cellulosic ethanol and bio-based chemicals	Demonstration	2012
Zea Chem	US	Boardman (OR)	Wheat straw, poplar trees	25+ MGY cellulosic ethanol and bio-based chemicals	Commercial	Q1 2015

Key: GPY = Gallons per year, MGY = Million Gallons per year, TPY = Tonnes per year, TPH = Tonnes per hour, BCF = Billion Cubic Feet

[23] http://ethanolrfa.3cdn.net/d9d44cd750f32071c6_h2m6vaik3.pdf

2.2.3 Opportunities for nutrient recycling when using straw for bioenergy

When biomass is converted through combustion or gasification, all the nitrogen is lost. Combustion and high-temperature gasification will render the phosphorus unavailable to plants. Low-temperature gasification retains the phosphorus and potassium, but the nitrogen is lost in the process. Biological conversion of the biomass retains all the nutrients in a form that is available to plants and these can be returned to crop production[24].

If straw is used as a feedstock for biogas production then the digestate can be applied to the land following conversion. In the case of cellulosic ethanol production the nutrients would be almost exclusively in the liquid phase, and it may be feasible to separate them out[25]. The lignin does not contain any nutrient; only carbon, oxygen and hydrogen.

2.3 The most suitable feedstock-region combination

The LIIB methodology states that only the share of wastes or residues which is not used for non-bioenergy purposes within a certain region is eligible for certification as low ILUC biofuel. For example, if 20% of a residue is already used for other purposes, only the remaining 80% of the residue in a region can claim LIIB compliance.

The extent to which wastes and residues are ILUC free is thus determined per region from which a certain biofuel feedstock is typically sourced. This is called the **feedstock-region combination**. In the case of cereal straw it is usually not traded over large distances due to its low bulk density. International trade in straw does occur (see section 2.3.2), however the volumes traded are relatively small when compared to the domestic use. An exception to the latter is the Netherlands as will be described later in this chapter.

For this reason this study will assess the straw use and production at a country level (e.g. straw produced and used in Germany). This because the ILUC risk might be considerable in a certain country, but insignificant somewhere else, meaning that a larger region (i.e. the entire EU) would not be appropriate.

2.3.1 Domestic straw trade

When mixed farming (both cattle and crop production) was the predominant farming system in Europe, straw harvested from cereal production would have been utilised on-farm for livestock. However, following the specialisation of agricultural production there is often a geographical

[24] University of Copenhagen and Aarhus University (2013), The +10 Million tonnes study, Increasing the sustainable production of biomass for biorefineries
[25] Uffe Jørgensen, University of Aarhus, *pers comm*.

disconnection between where straw is produced and where the demand is. As a consequence, the source of straw for many agricultural uses is rarely on-farm[26].

Straw is sometimes traded over considerable distances within a country or region depending on the regional supply/demand dynamics. For example, in the United Kingdom (UK) significant volumes of straw are traded from the Eastern counties of England to the South West, Wales and Scotland to meet the market demands of the livestock sector[27]. Similarly, in Poland, straw deficits in the Malopolskie and Podlaskie regions require straw to be transported in from the neighbouring Śląskie and Mazowieckie regions[28].

2.3.2 International trade

Straw is also traded cross-border between European countries. This is primarily between the countries where large surpluses of straw exist (e.g. France, Germany, Poland, UK) and those countries which have large straw deficits (e.g. Netherlands, Belgium and Austria). France and Germany, in particular, export large amounts of straw. That said, the volume of straw traded between countries per year is highly variable, the main driver being the weather conditions in both the importing and exporting country and the resulting impact that this has on the straw price. For example, an estimated 500,000 tonnes of straw was exported from the UK to Europe in 2011/12. This was because the UK had more favourable weather conditions during the 2011 straw harvest than the other major straw producing countries of France, Germany and Poland. However, in 2012/13 this is likely to be significantly less as Dutch merchants are able to import straw from France at a lower price[29].

The Netherlands imports much straw, preliminary from neighbouring countries (north of France, western Germany), but also from further away including the UK, Germany (Berlin region) and southern Spain. Importing straw from the south of Spain is only viable because the trucks that are used for transport would otherwise be returning to the Netherlands from Spain empty loaded and can therefore be leased cheaply. Straw has even been imported to the Netherlands from outside of Europe, with a shipment arriving from Canada last year in empty containers which would otherwise be unused.[30] A Dutch trader we spoke to indicated that he sources straw predominantly from central Europe (Poland, Romania and Bulgaria) due to the abundance of straw in the region[31].

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[26] IEEP (2012), Mobilising cereal straw in the EU to feed advances biofuel production, Available at: http://www.ieep.eu/assets/938/IEEP_Agricultural_residues_for_advanced_biofuels_May_2012.pdf

[27] CSL (2008), National and regional supply/demand balance for agricultural straw in Great Britain, Report prepared for the NNFCC, November 2008, Available at: http://www.nnfcc.co.uk/tools/national-and-regional-supply-demand-balance-for-agricultural-straw-in-great-britain

[28] Jasiulewicz, M. (2010), Regional energy potential of biomass in Poland

[29] Graham Lawson, British Straw & Hay Merchants Association, *pers comm*.

[30] Gert-Jan Wielink, HISFPA, *pers comm*.

[31] Mr Verschoor, Dutch straw trader, *pers comm*.

Straw is exported from Spain from the Castilla y Leon region to Portugal and from the northern regions of Spain (Basque Country, Navarra, La Rioja) to France, Belgium, the Netherlands and even as far afield as Germany. The traded volumes vary per year.[32]

Denmark exports around 80-120,000 tonnes of straw per year, primarily to the Netherlands (80%), where it is used, for example, in the tulip industry (to protect the bulbs over winter) and also for animal bedding. The quality of straw exported depends on the end-use. Straw sold for animal bedding is often barley straw and has to be of high quality (i.e. clean, dust free and heat treated to kill pathogens), whereas straw sold on to the tulip industry can be of lower quality and is typically wheat straw. Denmark also exports straw to Germany. Finally, of note is that a few Danish straw producers are collecting straw from Poland for export to Germany and the Netherlands.[33]

2.3.3 Straw pricing

Customers in the Netherlands pay relatively high prices for their straw, as it is generally imported from abroad. Prices in 2012 were typically €110 to €120 per tonne, but were as high as €170 per tonne (assumed to be on a delivered basis). During the last five years prices have always been above €100, previously the price level was around €70 to €80 per tonne. Straw trade is mostly bilateral agreements between relatively small traders who buy straw from farmers and sell it to individual customers. The large trading firms are not involved in the trade. Weekly straw prices are published in the Netherlands (both in Emmeloord and Goes).[34]

The UK Department for Environment, Food & Rural Affairs (Defra) publishes monthly UK barley and wheat straw and hay spot prices (data is supplied by the British Hay & Straw Merchants Association)[35]. The figure below charts the straw pricing for wheat and barley straw between 2010 and May 2013 for two different bale sizes.

[32] Fredi López Mendiburu, Acciona Energiá, *pers comm*.
[33] Thomas Holst, Danish Agriculture and Food Council, *pers comm*.
[34] Gert-Jan Wielink, HISFPA, *pers comm*.
[35] https://www.gov.uk/government/statistical-data-sets/commodity-prices

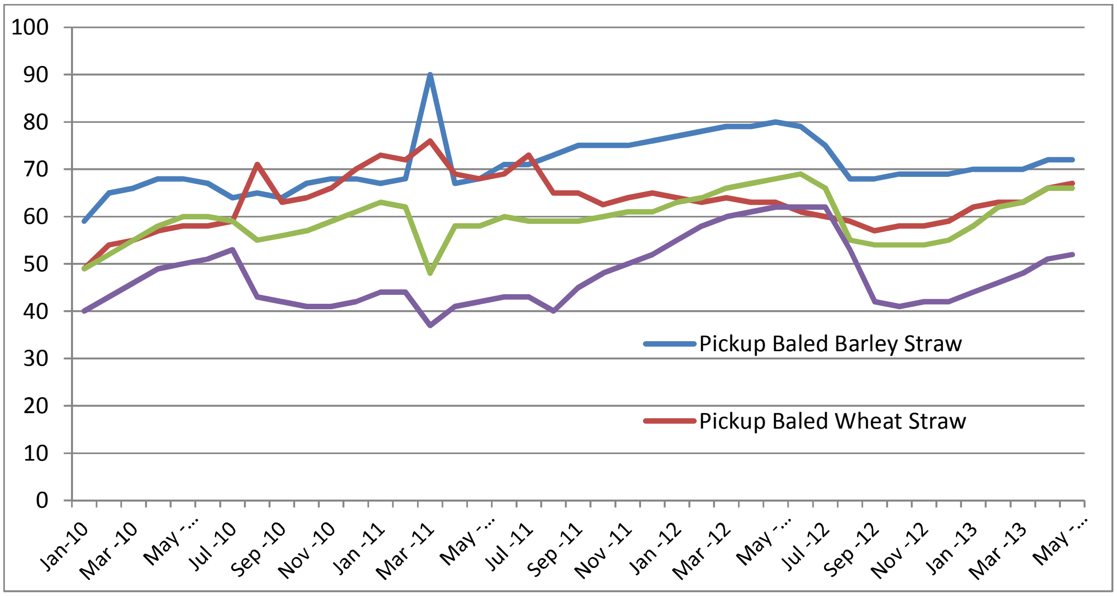

Figure 6: Average spot pricing for wheat and barley straw between 2010 and May 2013. Source: Defra, https://www.gov.uk/government/statistical-data-sets/commodity-prices

The average price of "Pickup Baled Barley" straw in 2013 May YTD is £71 (~€83) per tonne and £63 (~€73) per tonne for "Big Square Baled Barley" (ex-farm basis[36]). This compares to £64 and £48 per tonne for wheat, a premium of around 10 to 30%. The average prices in 2012 for both straw types were broadly similar. The straw spot price varies during the year, the general trend is that the price is lowest between July and December (i.e. when there is most straw available) and highest between January and June (i.e. when straw availability becomes scarcer).

The UK power sector typically pays less for straw compared to other markets. This is because they can provide a definite market and make it easier to contract[37]. Straw that is sold on long-term contracts (e.g. ten or more years) for power generation sells for around £40 per tonne delivered, the price being linked to the moisture content. Supply contracts are typically based on a minimum moisture content of 16%, and the price is lowered accordingly for every 1% above the minimum, up to a maximum of 25%[38].

In Denmark, straw prices depend on the end-use market. The price of straw supplied for central heating and power is around 600 to 650 DKK (~€80 to €87) per tonne, while straw supplied for small local district heating is around 550 to 600 DKK (~€74 to €80) per tonne delivered. The lower price for local district heating reflects the fact that the transport distances are generally much shorter. Also, delivery schedules can be very demanding for the larger central heating and power projects.

[36] "Ex-farm" is the price at the farm gate. It does not include the cost of transport to the end-user.
[37] Harley Stoddard, Home Grown Cereals Association (HGCA), *pers comm*.
[38] http://www.farmersguardian.com/home/machinery/machinery-features/managing-sustainable-straw-supply-for-renewable-energy-generation/48317.article

Farmers will know in advance what the weekly straw requirement is, but may have only one hour's notice to prepare the straw for collection which can be disruptive for the farmer. Straw sold to the livestock sector is a similar price, but it is often sold on the field for baling and collection rather than delivered (the price is typically 200 to 250 DKK per tonne or ~€27 to €34).[39]

The price of straw in Hungary is reported to be significantly lower at around 7,000 HUF (~24 EUR) per tonne on average[40]. (It is not understood whether this is an ex-farm or delivered price.)

2.4 Methodology to estimate theoretical and sustainable potential

Straw production data is not officially recorded by EU Member States, or reported by Eurostat. However, an estimate can be made using the annual crop production volume as a basis. Similarly, data on the uses of straw is not widely recorded.

In the absence of available data, the following methodology was used to estimate the sustainable straw potential and existing uses. It follows the approach taken by the Joint Research Centre (JRC) of the European Commission, namely the work by Scarlat et al. (2010)[41].

1. Obtain crop production data per Member State
2. Estimate theoretical straw potential
3. Estimate sustainable straw potential

These are discussed separately below.

2.4.1 Obtain crop production data per Member State

Crop production data for wheat, barley, oat, rye and triticale was extracted from Eurostat[42] and summarised per Member State, crop type and year in MS Excel.

The crop production varies between years in line with the crop planting area and yield, and therefore an average was calculated. A ten year average of the most recently available data (i.e. for the period 2002-2011) was considered to be most representative.

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[39] Thomas Holst, Danish Agriculture and Food Council, *pers comm*.

[40] Katalin Mohr, Hungarian Agricultural Research Institute (AKI), *pers comm*.

[41] Scarlat et al. (2010), Assessment of the availability of agricultural crop residues in the European Union: Potential and limitations for bioenergy use, Waste Management, Number 30, pages 1889-1897

[42] http://epp.eurostat.ec.europa.eu/portal/page/portal/agriculture/data/database; The following database table was used: Agriculture, Agricultural production (apro), Crops products, Crops products: areas and production (apro_cpp), Crops products (excluding fruits and vegetables) – annual

Table 2: Average annual production of selected crops in the EU-27 between 2002 and 2011 in 1,000 tonnes. Source: Eurostat.

Member State	Wheat	Barley	Oat	Rye	Triticale	Total
Austria	1,511	880	140	183	215	2,929
Belgium	1,794	356	30	3	44	2,225
Bulgaria	3,642	782	48	15	23	4,510
Cyprus	12	68	1	0	0	81
Czech Republic	4,126	1,988	172	167	219	6.672
Denmark	4,880	3,468	283	188	168	8,987
Estonia	268	310	81	34	15	709
Finland	769	1,837	1,176	63	0	3,845
France	36,768	10,598	741	134	1,837	50,078
Germany	23,045	11,180	970	3,176	2,415	40,786
Greece	1,704	251	105	31	7	2,091
Hungary	4,425	1,102	145	92	448	6,212
Ireland	737	1,193	133	0	0	1,326
Italy	7,308	1,128	345	10	0	8,791
Latvia	751	285	132	116	31	1,316
Lithuania	1,483	847	147	141	254	2,873
Luxembourg	79	50	9	7	22	165
Malta	0	0	0	0	0	0
Netherlands	1,218	282	10	12	17	1,539
Poland	8,909	3,485	4,966	3,534	4,184	25,078
Portugal	176	50	61	23	27	337
Romania	5,579	1,052	339	33	102	7,104
Slovakia	1,480	691	41	65	40	2,318
Slovenia	146	65	5	3	12	230
Spain	6,037	8,724	1,025	254	120	16,158
Sweden	2,215	1,515	908	138	223	5,009
UK	15,004	5,783	706	35	65	21,593
EU-27	**134,068**	**57,968**	**12,220**	**8,455**	**8,395**	**221,105**

Ten Member States were selected to assess in detail. The basis of selection was the average annual production of the five straw generating crops under review. The Member States selected (in order of production) were: France, Germany, Poland, UK, Spain, Denmark, Italy, Romania and Hungary. In addition, the Netherlands was also selected.

2.4.2 Estimate Theoretical straw potential

Straw to Crop yield ratio

An estimate of the theoretical straw potential can be made by using the ratio of straw to crop yield on a dry basis[43]. This ratio is specific to the crop type and variety[44] and furthermore impacted by climate and soil conditions, as well as by farming practises.

The Straw to Crop yield ratios were estimated per Member State and crop type using correlations proposed by Scarlat et al. (2010). This study derived the correlations by plotting Straw to crop ratio data against data on Crop yield, and then determining the curve of best fit. These are indicated in the table below.

Table 3: Correlations proposed by Scarlat et al. (2010) for cereal crops (where y is the Straw to Crop ratio and x the Crop yield in tonnes per ha).

Crop type	Correlation	Coefficient of determination (R^2)[45]
Wheat	y = -0.3629 - Ln(x) + 1.6057	0.2795
Barley	y = -0.2751 - Ln(x) + 1.3796	0.3631
Oat	y = -0.1874 - Ln(x) + 1.3002	0.2121
Rye	y = -0.3007 - Ln(x) + 1.5142	0.2198

The crop yield data used in the above calculations was the ten year average between 2002-2011.

The table below summarises the Straw to Crop ratio estimates per Member State using these correlations.

[43] An alternative is to apply the Harvest Index (HI), which is the ratio between grain yield on a dry basis and the total crop dry weight at harvest.
[44] For example, the ratio for wheat will be different to barley, and similarly the ratio for spring barley will be different to winter barley.
[45] The R^2 value measures how much variation there is in the data. It is a fraction between 0.0 and 1.0 and has no units. Higher values indicate that the model fits the data better.

Table 4: Straw to Crop ratios as determined by the correlations proposed by Scarlat et al. (2010).

Member State	Wheat	Barley	Oat	Rye
Denmark	0.89	0.93	1.01	1.03
France	0.90	0.87	1.03	1.05
Germany	0.88	0.89	1.02	1.03
Hungary	1.10	1.04	1.14	1.28
Italy	1.15	1.03	1.14	1.21
Netherlands	0.83	0.88	0.99	1.07
Poland	1.11	1.06	1.12	1.24
Romania	1.25	1.14	1.21	1.28
Spain	1.22	1.10	1.17	1.34
UK	0.86	0.90	0.97	0.97

In the absence of a correlation to estimate the Straw to Crop residue ratio for triticale we used the ratios for wheat[46]. (An alternative could be to use the ratios for rye, however we decided to take a more conservative approach and use wheat as the ratios are lower.)

Estimate the theoretical and sustainable straw potential
The theoretical straw potential can be estimated as follows:
Theoretical straw potential [tonnes per year] = Straw to Crop ratio x Crop production [tonnes per year]

During straw harvesting it is not possible to collect all of the available straw. There are a number of factors that limit the amount of straw that can be recovered. These include the technical limitations of the harvesting equipment, the crop type and variety, the harvest/stubble height as well as losses from lodging (crops flattened by wind or rain). The amount of straw that can be realistically collected is termed the "*technical straw potential*".

However, when estimating how much straw can be collected the associated environmental impacts of straw removal also need to be considered. These impacts principally relate to the preservation of soil quality (see section 2.5.1 for further details).

[46] As noted previously, triticale is a hybrid of wheat and rye.

The term “Sustainable removal rate” is used to describe the total amount of straw that can be removed from the land without adversely affecting the soil quality, and the “*Sustainable straw potential*” describes the amount of straw that can be sustainably collected. By implication, the sustainable straw potential is lower than the technical straw potential.

Scarlat et al. (2010) assumed a sustainable removal rate of 40% for cereal crops. In other words, the straw can be sustainably removed from the field once every 2.5 years *on average*. The Sustainable straw potential was then estimated using this sustainable removal rate.

Sustainable straw potential [tonnes per year] = theoretical straw potential [tonnes per year] x sustainable removal rate [%]

2.4.3 Validation with experts

The sustainable straw production estimates, and underlying data (specifically the Straw to Crop ratios and Sustainable removal rates), were validated against available literature and also with Member State experts and other relevant experts and organisations, and amended where appropriate.

Straw to Crop ratios
The Straw to Crop ratios used are indicated in Table 5 below.

Sustainable removal rates
These are provided in section 2.5.2.

Table 5: Actual Straw to Crop ratios used to estimate the Total straw production (based on expert input or literature).

Member State	Wheat	Barley	Oat	Rye	Triticale	Comments
Denmark	0.55	0.55	0.8	0.8	0.8	As indicated in Danmarks Statistik[47]. (Note that this provides the straw to crop ratios after straw removal. We have assumed a removal rate of 60% to back-calculate the ratios prior to removal.)
France	-	-	-	-	-	We used the total straw production estimates indicated in France AgriMer, 2012[48]. This study did not state the Straw to Crop ratios.
Germany	0.8	0.7	0.9	1.1	0.9	As advised by Daniela Thrän, DBFZ.
Hungary	0.9	1.03	1.5	0.9	1.4	As advised by Norbert Kohlheb, Szent István University in Hungary.
Italy	1.15	1.03	1.14	1.21	1.15	JRC assumptions for all crops except for triticale, which was assumed to be the same as wheat.
Netherlands	0.83	0.88	0.99	1.07	0.83	JRC assumptions for all crops except for triticale, which was assumed to be the same as wheat.
Poland	0.91	0.86	1.45	1.05	1.13	As indicated in 4biomass, 2010[49].
Romania	1.0	1.25	2.0	1.5	1.0	As advised by Viorel Ion, University of Agronomic Sciences and Veterinary Medicine of Bucharest. Triticale assumed to be as per wheat.
Spain	1.2	1.3	1.3	1.34	1.2	For wheat, barley and oat we used estimates assumptions provided by CENER: Centro Nacional de Energías Renovables and CIEMAT: Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas. Ministerio de Educación y Ciencia[50]. Rye was as per JRC assumptions, while triticale was assumed to be as per wheat.
UK	0.84	0.84	0.97	1.0	0.84	Wheat, barley, oat as indicated in HGCA (2010)[51]. Oat as per JRC assumption. Triticale assumed to be as per wheat.

[47] http://statistikbanken.dk/statbank5a/default.asp?w=1920

[48] France AgriMer (2012), L'observatoire national des ressources en biomasse Évaluation des ressources disponibles en France, ÉDITION octobre 2012, Available at: http://www.franceagrimer.fr/content/download/15926/119849/file/DOC_FINAL_Obs_Biomasse_12-12.pdf

[49] 4biomass (2010), Study on biomass trade in Poland, WP 4.2.4, Available at: http://www.central2013.eu/fileadmin/user_upload/Downloads/outputlib/4biomass_Poland_trade_study_uploaded.pdf

[50] Junta de Analucia (2008), Potencial energético de la biomasa residual agrícola y ganadera en Andalucía, Available at: http://www.juntadeandalucia.es/agriculturaypesca/portal/export/sites/default/comun/galerias/galeriaDescargas/cap/servicio-estadisticas/Estudios-e-informes/historico/metodologia-y-documentos-de-apoyo/biomasa.pdf

[51] HGCA (2012), Energy potential from UK arable agriculture: Straw – what is it good for?!, Available at: http://publications.hgca.com/publications/documents/HGCA_straw_paper_2012.pdf

2.5 Sustainable straw potential in EU Member States

2.5.1 Straw removal and the impact on soil quality

Straw incorporation can provide several benefits relating to the soil quality, including:

- Maintaining and improving Soil Organic Matter (SOM)
- Maintaining and improving Soil Organic Carbon (SOC)
- Providing a source of organic nutrients (and micronutrients)
- Preventing soil erosion from wind and water
- Improving water retention

These are discussed in turn below.

Soil Organic Matter
The EC Soil Framework Directive[52] defines SOM as "*the organic fraction of the soil, excluding undecayed plant and animal residues, their partial decomposition products, and the soil biomass*". SOM consists of between 50 and 58% carbon (C) and hydrogen (H), oxygen (O), nitrogen (N), phosphorous (P) and sulphur (S).

The table below compares the different fractions of SOM[53].

Table 6: Size and breakdown rates of various soil organic matter fractions.

Soil Organic Matter Fraction	Particle size (mm)	Turnover time (years)	Description
Plant residues	≥ 2.0	< 5	Recognisable plant shoots and roots
Particulate organic matter	0.06 – 2.0	< 100	Partially decomposed plant material, hyphae, seeds, etc
Soil microbial biomass	Variable	< 3	Living pool of soil organic matter, particularly bacteria and fungi
Humus	≤ 0.0053	< 100 – 5000	Ultimate stage of decomposition, dominated by stable compounds

SOM is a particularly important soil quality and influences physical, chemical and biological soil properties. These include the physical structure and stability, ease of cultivation, ease of root growth,

[52] COM(2006) 232
[53] http://soilquality.org/indicators/total_organic_carbon.html

water infiltration rate, erosion, nutrient uptake and biodiversity. Straw is one of the few management tools available for effectively maintaining SOM.

Decreases in SOM content, through cultivation or tillage intensification, are often related to the deterioration of soil structure. Effects include the loss of aggregate stability, increased crust formation, increased runoff and soil erosion, increased compaction, slower water infiltration and a slower exchange of water/gasses. With regard to the additional SOM, it can help soil retain moisture but it is mostly only of value to the heavier soil types.

A study for the EC[54] analysed the effect of different management systems on SOM. The study considered straw extraction rates of 30%, 50% and 100% compared to a business as usual (BAU) extraction rate of 10% and estimated the potential impact on humified organic carbon content. The results for cereal straw show that the humified organic carbon is, respectively, 7%, 21% and 38% lower than in the BAU scenario. In the case of rapeseed the reductions are 9%, 22% and 47% respectively. This highlights the importance of incorporating straw.

Soil Organic Carbon

SOC is one of the most important constituents of the soil due to its capacity to affect plant growth as both a source of energy for microorganisms and a trigger for nutrient availability through mineralization. A direct effect of poor SOC is reduced microbial biomass, activity, and nutrient mineralization due to a shortage of energy sources.

Powlson et al. (2011)[55] reviewed experimental data for twenty five long-term studies in Europe (and overseas) assessing the impact of straw incorporation versus removal. The study concluded that straw addition, or removal, has a relatively small effect on the total SOC in most situations. Despite this the study indicated that even small changes in SOC can have disproportionally larger impacts on soil physical properties, such as aggregate stability and water infiltration rate. The study recommends that local assessments are undertaken to determine the frequency of straw removal that is acceptable for soil functioning; and that it is unwise to remove straw every year as this is likely to lead to deterioration in soil physical properties.

A Danish agricultural expert[56] we consulted indicated that an assessment of the total management of the crop system is necessary and that the frequency of straw removal will depend on considerations such as the soil type and crop rotation. For example, grass is more effective at storing carbon than straw and consequently if the crop is rotated regularly with grass then it may be feasible to remove more straw.

[54] Gobin et al. (2011), Soil organic matter management across the EU best practices, constraints and trade-offs, , Available at: http://ec.europa.eu/environment/soil/som_en.htm

[55] Powlson et al. (2011), Implications for Soil Properties of Removing Cereal Straw: Results from Long-Term Studies, Agronomy Journal, Volume 103, Issue 1, pages 279-287

[56] Uffe Jørgensen, Senior Scientist, Department of Agroecology at Aarhus University, *pers comm.*

The historical land management is also an important factor. For example, if the land was used as pastureland then the SOC would increase over time, as the permanent grassland would store carbon. Conversely, continuous cereal crop production would reduce the SOC, especially if straw is regularly removed and minimal animal manure is applied to the land. Ultimately it is the farmer who will decide whether, or not, to incorporate and how to best manage the land.

The Aarhus University undertook long-term research into the variability of SOC in Denmark between 1986 and 2009[57]. They found that there was a clear tendency for increasing SOC on sandy soils and reductions on loamy soils. The research concluded that this effect may be linked to land use, since grasslands and dairy farms are more abundant in the western parts of Denmark, where most of the sandy soils are located. In practise, large quantities of straw have been extracted from loamy soils with little input from grass, or manure, which led to a loss of 20 tonnes of SOC per ha (in the 0-50 cm soil layer) and over 30 tonnes per ha (in the 0-100 cm soil layer) over the research timeframe.

Providing a source of organic nutrients

Straw has a significant benefit for the farmer as a fertiliser source. Incorporating straw returns potash (K_2O) and to a lesser extent phosphate (P_2O_5) to the soil, reducing the costs of buying inorganic sources of these key nutrients[58]. The Defra 2010 UK Fertiliser Manual recommends that an additional 40 kg K_2O per hectare is applied to the soil if cereal straw is removed to compensate for the nutrient loss (compared to when straw is incorporated)[59]. The value of incorporating straw as a fertiliser source will vary on a site by site basis depending upon the soil type and fertiliser prices.

The HGCA (a division of the UK Agriculture and Horticulture Board[60]) provide an interesting insight into perceived value of incorporating straw and claim that the nutrient value and benefit of the additional SOM is overstated. They estimate that the nutrient value of wheat straw, including nitrogen, phosphate and potash was about £18 per tonne in 2011, compared to a straw price of £40 per tonne if sold on for energy[61].

Another consideration is that when straw is decomposed in soil by microorganisms, a certain quantity of N is concurrently absorbed by the microorganisms. This is because cereal straw has a low N concentration (typically 0.5%) compared to about 4% or more in microbial cells. Thus N is taken up from the surrounding soil to meet the microbial demand. This can be beneficial, leading to slightly decreased nitrate leaching during the subsequent winter or spring. This temporary locking up of N may also lead to a short-term shortage of N for an emerging crop, shown by a slightly yellow appearance and this is sometimes used as justification for increased fertilizer N applications to crops. However, these effects are generally small. For example, in one experiment in the UK a decrease in

[57] Olesen et al. (2012), Verification of changes in soil C-balance: Soil samples in the national grid, Aarhus University, Department of Agroecology, Blichers Alle 20, 8830 Tjele

[58] As well as a reduction in environmental impacts, such as nutrient run-off and GHG emissions associated with fertiliser manufacture.

[59] Defra, Fertiliser Manual (RB209), 8th edition, June 2010, Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69469/rb209-fertiliser-manual-110412.pdf

[60] http://www.hgca.com

[61] HCGA (2012)

overwinter nitrate leaching of 10 kg N per ha was observed, but in other cases there was no detectable effect. The N initially absorbed by microbes will be built into the organic matter within the soil and in the longer-term would be expected to lead to an increased supply of N from the soil and a decreased requirement for fertilizer N. However, the evidence is that these effects are small; detected in some situations, but not in others. It is sometimes stated that N absorbed during straw decomposition will be released to the following crop[62], but there is little evidence that this mechanism exists to a significant degree. The release of N appears to be very slow and over many years, at least in temperate climates.[63]

Finally, although the loss of nitrogen, phosphate and potash can be calculated and restored, there are 102 mineral elements in soil and it can be difficult to know exactly how much of these are lost when straw is removed[64].

Preventing soil erosion
If straw is left on the soil surface, rather than incorporated, it acts as a surface mulch and is valuable in controlling soil erosion from both water and wind. Preventing soil erosion has the additional benefit of reducing nutrient run off.

Improving water retention
Straw cover can reduce evaporation from the soil surface, thereby conserving moisture and increasing the number of days a crop can survive in drought conditions. Improved soil physical properties related to crop residues, such as reduced bulk density and greater aggregate stability, also lead to better water infiltration and retention[65].

2.5.2 Sustainable removal rate for straw

It is not a straightforward task to estimate the sustainable removal rate. The amount of straw that should be left on the land to maintain soil quality is site specific and varies considerably according to local conditions. These include the[41]:

- farming practices: crop rotation, tillage[66], fertilisation
- site conditions: soil type, soil fertility, SOM, SOC, soil moisture, topography and slope, risk of erosion
- climate conditions: wind, precipitation patterns

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[62] Edwards et al, 2005, GIS-Based Assessment of Cereal Straw Energy Resource in the European Union. Proceedings of the 14th European Biomass Conference & Exhibition, Biomass for Energy, Industry and Climate Protection, 17-21 October 2005, Paris. , Available at: http://iet.jrc.ec.europa.eu/remea/sites/remea/files/gis-straw_assessment.pdf
[63] Professor Powlson, Rothamsted Research, *pers comm.*
[64] http://www.fwi.co.uk/articles/01/08/2012/134166/burning-demand-for-straw-power.htm#.UZ9U5JzjFGM
[65] USDA (2006), Crop Residue Removal for Biomass Energy Production: Effects on Soils and Recommendations, 22 February 2006, Available at: http://soils.usda.gov/sqi/management/files/agforum_residue_white_paper.pdf
[66] Studies have shown that more straw can be removed if reduced or no tillage farming is practiced.

The level of on-farm animal husbandry can also influence the sustainable removal rate, as animal manure (which typically also contains some straw) can be used as an alternative option to maintain SOM. However, in some Member States, such as Slovenia and the Czech Republic, this is not a viable option, due to the significant decrease in the livestock sector in those countries in recent years. Straw is therefore particularly valuable as a soil improver and up to 40% of the available straw is incorporated.[67]

When assessing the sustainable removal rate it should be noted that even when the straw is removed some residues will always be returned to the soil, principally the roots and stubble. Panoutsou and Labalette (2006)[15] estimated that even when straw is collected more than 50% of the organic matter is kept in the field. This is consistent with Powlson et al. (2011) which indicates that 50% of all above ground residues (stubble, chaff and uncollected straw) are returned to the soil under UK conditions even when straw is baled. In addition, roots and their associated exudates represent a significant input of organic carbon into soil, whether or not straw is returned.

As part of this study we conducted a literature review and consulted a number of experts to verify whether the sustainable removal rates of 40% were appropriate. On the whole, the feedback we received was that these assumptions were sufficiently conservative. In the UK, the HGCA consider that 60% of the available cereal straw can be removed[68], although this appears to a technical removal rate rather than a sustainable removal rate[69]. The experts we contacted in Denmark[70], Italy[71] and Romania[72] all considered that the JRC assumptions are reasonable, while a recent study in France proposes a removal rate of 50% for cereal straw[48]. In Hungary, the expert we consulted indicated that a removal rate of 33% is considered sustainable, although typically 50% of the straw is currently removed[73]. In Poland the removal rate is considerably higher, as only 10 to 15% of the straw is currently incorporated. Finally, in Germany, a recent study by DBFZ[74] proposed that between 27% and 44% of the cereal straw should be removed. However, it should be noted that these removal rates are not based on the Theoretical straw potential, but are instead based on an adjusted potential which assumes that 10% of the Theoretical straw potential is used for materials use.

We also contacted Professor Powlson[75], a soil science expert associated with the Rothamsted Research centre in England. In his view the sustainable removal rate is likely to vary across a wide range of between 25% to 50%, although he would propose a default removal rate of 33%.

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[67] IEEP (2012), Mobilising cereal straw in the EU to feed advances biofuel production, Available at: http://www.ieep.eu/assets/938/IEEP_Agricultural_residues_for_advanced_biofuels_May_2012.pdf

[68] Harley Stoddard, Home Grown Cereals Association (HGCA), *pers comm*.

[69] ADAS (2008), Addressing the land use issues for non-food crops, in response to increasing fuel and energy generation opportunities, NNFCC project 08-004, October 2008, Available at: http://www.nnfcc.co.uk/tools/addressing-the-land-use-issues-for-non-food-crops-in-response-to-increasing-fuel-and-energy-generation-opportunities-nnfcc-08-004

[70] Uffe Jørgensen, University of Aarhus, *pers comm*.

[71] Vincenzo Motola, ENEA/JRC, *pers comm*.

[72] Viorel Ion, University of Agronomic Sciences and Veterinary Medicine of Bucharest, *pers comm*.

[73] Norbert Kohlheb, Szent István University in Hungary, *pers comm*.

[74] DBFZ et al. (2012), Basisinformationen für eine nachhaltige Nutzung von landwirtschaftlichen Reststoffen zur Bioenergiebereitstellung, Endbericht FZK 03KB021, Available at: http://www.dbfz.de/web/fileadmin/user_upload/DBFZ_Reports/DBFZ_Report_13.pdf

[75] http://www.rothamsted.ac.uk/aen/CarbonCycling/Powlson.htm

The removal rate will be very site specific and depend on a number of factors, including the resilience of the soil. He recommends that local studies are undertaken to establish the necessary straw input to maintain appropriate soil properties before embarking on a straw-based bioenergy program. Ideally the studies would be conducted in contrasting environments to test the long-term impact on SOM content of different straw removal rates. However, according to Professor Powlson the evidence from existing experiments is that it would take many years (at least ten and probably longer) to obtain definitive results. A viable alternative would be to conduct modelling studies in relevant contrasting situations covering different climates and soil types. Several well-established models of soil carbon dynamics exist (including RothC, CENTURY, DNDC and others) that have been tested in a wide range of environments. Professor Powlson therefore considers that it should be entirely practicable to determine the rate of straw return necessary to maintain a given SOM level in different situations using modelling informed by local agronomic and soils knowledge.[76]

The experts we consulted had contrasting views regarding rapeseed straw removal. Several took the view that no rape straw should be removed as it all needed for humus production[77]. However, Professor Lewandowski at the University of Hohenheim suggests that a removal rate of 50% is possible under optimal conditions, depending on the soil and crop rotation[78], while Professor Powlson considers that there is no specific evidence to justify rapeseed straw being treated differently from other organic inputs, such as cereal straw or animal manure[79]. Also, as rapeseed is normally grown in a rotation with cereal crops with rapeseed grown no more frequently than one year in three, its return or removal would not be a dominant factor in determining an overall sustainable removal rate.

In summary, we understand that the optimal removal rate can vary from region to region. However, we see that the JRC's overall estimates are considered to be acceptable by several experts. For this reason, we have proposed to use the estimates as our default position. We have then tailored the removal rates in the investigated EU Member States, where possible, through consulting with the experts.

The table below summarises the Sustainable removal rates we have used in the selected Member States. It should be stressed that although we include a single figure for the sustainable removal rate at Member State level, in reality the removal rate is likely to vary quite significantly and in some cases may even be zero.

[76] Professor Powlson, Rothamsted Research, *pers comm.*
[77] Professor Daniela Thrän, DBFZ , *pers comm.;* Dieter Bockey, UFOP, *pers comm*.
[78] Iris Lewandowski, University of Hohenheim, *pers comm*.
[79] Professor Powlson, Rothamsted Research, *pers comm.*

Table 7: Sustainable removal rate assumptions for cereal crops per Member State.

Member State	Sustainable removal rate	Comments/rationale
Denmark	40%	Uffe Jørgensen, University of Aarhus, confirmed that the JRC defaults are reasonable for Denmark.
France	50%	As indicated in France AgriMer, 2012[48], based on research by GIE Arvalis/ONIDOL[80]. This is based on a number of studies and considers the following parameters: 1. Soil type; 2. Crop rotation; 3 'Original and Historical organic states' (i.e. considering SOM and SOC).
Germany	34%	Based on DBFZ, 2012 which indicates that a sustainable removal rate of 27% to 44% is relevant for cereal crops. We have used the lower value and uplifted this to 34% (i.e. 27x0.9+10) to adjust for the materials use – as discussed above.
Hungary	33%	As advised by Norbert Kohlheb, Szent István University in Hungary.
Italy	40%	JRC default. No information provided.
Netherlands	40%	JRC default. No information provided.
Poland	40%	JRC default. No information provided.
Romania	40%	Viorel Ion, University of Agronomic Sciences and Veterinary Medicine of Bucharest, confirmed that the JRC defaults are representative for Romania.
Spain	40%	JRC default. No information provided.
UK	40%	HGCA assumes a removal rate of 60%, based on ADAS (2008), although this appears to be a Technical removal rate, rather than a Sustainable removal rate. We have therefore assumed a more conservative removal rate of 40% in-line with the JRC default.

2.5.3 Estimate of Sustainable straw potential

As a recap, an estimate of the sustainable straw potential was made by applying the Sustainable removal rate by the Theoretical straw potential. The estimates per Member State and crop type are presented in the figure below.

[80] GIE ARVALIS/ONIDOL, Maintien du taux de matière organique des sols : une contrainte pour la mobilisation de la biomasse ?

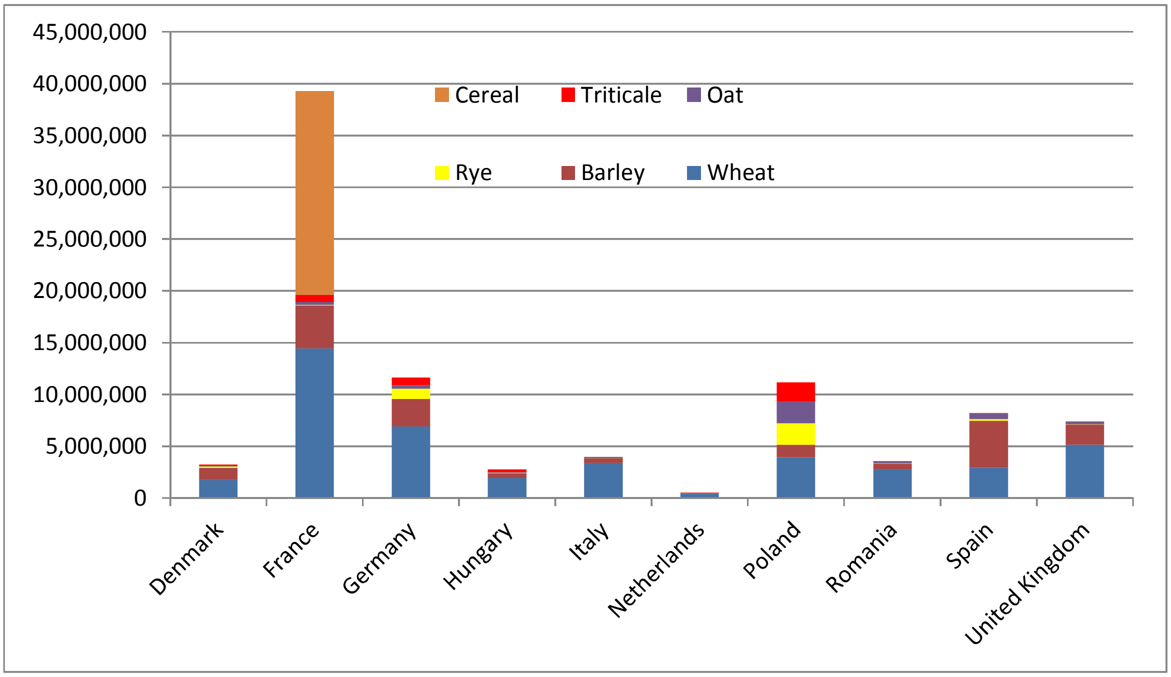

Figure 7: Estimate of straw potential in the selected Member States. Units: tonnes (wet matter). Note that the data source used for France did not provide a breakdown per cereal crop type.

The total estimate of Sustainable straw potential in the ten selected countries is 72.2 million tonnes (wet matter). As expected, the Member States with the largest sustainable straw potential are those which also have the largest crop production. The largest potential is in France at 19.6 million tonnes, with Germany next at 11.7 million tonnes, closely followed by Poland at 11.2 million tonnes. The lowest straw potential is in the Netherlands with just over 0.5 million tonnes.

Table 8: Estimate of sustainable straw potential per Member State. Units: tonnes (wet matter).

Member State	Sustainable potential (tonnes)	Share of total (%)
Denmark	3,242,787	4.5
France	19,647,059	27.2
Germany	11,646,537	16.1
Hungary	2,761,137	3.8
Italy	3,987,705	5.5
Netherlands	517,629	0.7
Poland	11,186,491	15.5

Member State	Sustainable potential (tonnes)	Share of total (%)
Romania	3,589,068	5.0
Spain	8,196,081	11.4
UK	7,417,777	10.3
Total	**72,192,271**	**100%**

Wheat straw is by the dominant straw type in the vast majority of the Member States, typically comprising over 60% of the total, with barley up to 20% in most Member States. Spain is the only country where the potential of straw barley is higher than wheat at 55% of the total. Rye and oat straw typically make up 5% or less of the total, with the exception of Poland where these two crops make up around 18% each. Triticale also makes up around 17% of the straw potential in Poland, by far the highest share in any country for this crop (Hungary is next highest at 9%).

The total estimate of Sustainable straw potential is broken down as follows. Note that for France, we estimated the split as 73% wheat straw, 21% barley straw, 4% triticale and the remainder oat and rye (based on the average crop production data 2002-2011):

Table 9: Estimate of Sustainable straw potential in the selected Member States. Units: tonnes (wet matter).

Straw type	Sustainable potential (tonnes)	Share of total (%)
Wheat	43,631,139	60%
Barley	17,259,940	24%
Oat	4,078,227	6%
Rye	3,409,710	5%
Triticale	3,813,255	5%
Total	**72,192,271**	**100%**

2.6 Current uses and their relative importance

In this section, we describe the uses for straw in the EU and indicate their relative importance. We also explain the methodology we have employed to estimate the existing straw demand for each of these uses.

2.6.1 Current uses of straw

2.6.1.1 Incorporation

Incorporation of straw is currently the most common use following harvest, although the degree to which straw is incorporated varies in different parts of the EU, between farm type and size. The option to incorporate is more prevalent in regions where there is a high level of technical capacity. In some cases, for example small traditional farms in Spain, the lack of machinery, or the cost to contract in machinery can prevent the ploughing-in of straw. In Italy, where there are good networks/cooperatives for machinery use the ploughing-in of straw is more common, even on smaller farms[81]. Similarly, a high level of technical capacity exists in northern European countries, such as France, Germany and the UK.

Further factors which affect the level of incorporation within an annual rotation are the soil moisture level, nitrogen content and temperature. As a consequence of these limitations, it is common for farmers, particularly in southern and Eastern Europe to incorporate straw into the soil in only two out of three years[82].

Incorporation versus baling
Although there are several potential benefits of incorporating straw into the soil there are also potential negative impacts. Chopping the straw prior to incorporation slows the combine harvester and can result in increased harvest fuel costs. Incorporated straw may also impede root growth in the next year's crop for clay soils, depending on how the straw is ploughed in. Finally, incorporation may also result in increased weed, slug and disease problems. (See also section 2.5.1 for a discussion on the impact of straw removal on soil nitrogen.)

Similarly, baling the straw can also have both positive and negative implications. There is an economic benefit of selling the straw, although this is (partly) offset against the cost of baling and storing the straw, particularly if contractors are involved. Removal of the straw also results in the loss of nutrients (and micronutrients) as well as organic matter, which may result in the need to apply additional artificial fertiliser at a cost. There are also practical reasons why some farmers are very reluctant to bale. For example, wet weather following the harvest delays the baling of straw, which can potentially lead to delays in the establishment of the following year's crop[83]. Baling also brings the risk of soil compaction, and subsequent yield loss, if the weather has been wet (particularly for heavier clay soils).

The table below summarises the main considerations between incorporating and baling straw from a farmer's perspective.

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[81] IEEP (2012)
[82] IEEP (2012)
[83] Although cereal grain can be dried if harvested at 25% moisture content, quality straw cannot and needs to be at least 15% moisture content.

Table 10: Summary of the pros and cons of straw incorporation versus straw baling – from a farmer's perspective. Adapted from HGCA (2009).[84]

Incorporating straw	Baling straw
Advantages	**Advantages**
• Maintains and improves soil quality	• Income from straw sale
• Returns nutrients (and micronutrients) to soil, which may lead to reduced artificial fertiliser usage and cost	• Cleaner stubble and so potentially easier and faster establishment of next year's crop
• Potential to reduce nitrate loss (and associated reduction in GHG emissions)	• No diesel requirement to chop the straw
• No compaction of soil from baling and carting in wet conditions	• Potentially reduced weed, slug and disease problems
• No delay in establishing next year's crop from baling and carting	
Disadvantages	**Disadvantages**
• Slower harvest time and extra combine harvester diesel usage required to chop the straw	• Possible deterioration in soil quality
• Possible difficulty in establishing next year's crop due to root penetration difficulty if straw incorporated on clay soils	• Loss of nutrients (and micronutrients) from the field, which may lead to increased artificial fertiliser usage and cost
• No income from straw sale	• Delays in baling and carting may delay establishment of next year's crop
• Potential increase in weed, slug and disease problems	• Diesel usage for straw baling and carting (although this activity may be undertaken by a contractor)
	• Possible compaction of soil due if baling and carting is undertaken in wet conditions
	• Income of straw may not cover costs of operation and nutrient removal

[84] HGCA (2009), Assessing the nutrient content of cereal straw, Information sheet 05/Spring 2009, Available at: http://www.hgca.com/document.aspx?fn=load&media_id=5162&publicationId=5704

Straw burning
The burning of straw and straw stubbles was previously a very common method of dealing with straw after harvest. It has been banned in the vast majority of Member States[85] under compulsory Good Agricultural and Environmental Condition (GAEC) standards as applied under the CAP. Some Member States, including Denmark and the UK, also ban straw and stubble burning under national legislation[86].

Nonetheless, some farmers consider straw a burden and burn it rather than incorporate it. Ironically, this is more typical in southern and eastern Europe, where the risks to long term soil fertility are generally higher[87]. Although straw burning is forbidden in Italy it is still practised in some regions if there is no market for the straw (northern Puglia is an example). This situation is more typical in very dry regions where annual straw incorporation is not a viable option due to the slow rate of biodegradation of the straw (this may take two to three years). Farmers may instead prefer to burn the straw to get rid of it and prepare the land for the next year's planting[88]. Similarly, we understand that straw burning still occurs in parts of Spain, despite it being forbidden. In Romania, straw used to be commonly burned on the fields until two to three years ago when this practice was banned by law[89]. Farmers risk paying penalties and losing Common Agricultural Policy (CAP) subsidies if they are caught burning straw, and are also becoming more aware of the role that straw can play as a soil improver[90].

2.6.1.2 Livestock sector

Aside from incorporation, one of the most common uses of straw is within the livestock sector, for animal bedding and feed. It is in practise difficult to separate the two uses as some of the straw sold for bedding will invariably also be used for feed. This is particularly so for oat and barley straw which are more palatable to livestock than other straw types. Wheat straw is the least palatable of all the cereal straws.

Animal bedding
Chopped cereal straw is the most commonly used bedding material for livestock and a significant proportion of the available straw is used for this purpose. It is readily available and has good thermal properties and a moderate absorption capacity. Wheat straw is most widely used given its widespread availability. Barley straw is also used and has the benefit of being more robust, lasting longer than wheat straw which is quite brittle and breaks down easily. It is, however, the least absorbent of all the straws, and is around 33% less absorbent than oat straw which is the most absorbent straw type

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85 Only four Member States do not impose a ban on the burning of arable stubbles under cross compliance GAEC standards - Cyprus, France, Ireland, and Slovenia
86 IEEP (2012)
87 Edwards et al (2005)
88 Vincenzo Motola, ENEA/JRC, *pers comm*.
89 Mr Verschoor, Dutch straw trader, *pers comm*.
90 Viorel Ion, University of Agronomic Sciences and Veterinary Medicine of Bucharest, *pers comm*.

(it is 10% more absorbent than sawdust)[91]. Oat straw is very light and fluffy and so is best used indoors, otherwise it can blow away. Rye raw can be a suitable source of bedding, however, it is particularly susceptible to ergot fungus infestation. Finally, chopped rape straw is also used, typically in combination with cereal straw; the rape straw forms the bottom layer with the cereal straw added on top. Rape straw can also be used as a bedding material for horses, although the quality has to be very good (e.g. dry and clean with very low dust levels). It is not suitable for calves or lambs though, due to its very stalky structure.[92]

The best quality straw is straw which has seen very little rain and is either yellow or white in colour. Straw which is dry when harvested, but which has seen lots of rain during its growing period is of lower quality and is darker in colour. Straw that is clean, dust free and heat treated to kill pathogens is more attractive to the livestock sector, particularly for use as animal bedding for horses.

Straw use also plays an important role in animal welfare, and particularly for pigs. EU Directive 91/630/EEC[93] states that '*pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as **straw**, hay, wood, sawdust…*'[94].

It is not feasible to calculate the exact quantities used for animal bedding as its use is dependent on the livestock type and age, the livestock management system, intensity of production and weather conditions. Furthermore, in some countries (such as the UK) straw can be swapped under '*straw for muck*' deals, whereby a cereal farmer gives straw to a livestock farmer for animal bedding, who later gives back the 'muck' (i.e. manure and soiled straw) to apply to the land. These deals are not reported.

Animal feed

Straw is fed to livestock as a source of long fibre, which is an essential part of a ruminant's diet. It is estimated that such roughage (which could be straw, hay or silage) should comprise a minimum of 10% of the feed ration[95]. There is a limit, however, on how much straw can be applied as straw does not provide sufficient energy and protein on its own. A US study estimates that the limit may be up to a maximum of 50% of the feed in mature beef cows, but only up to 25% for heifers (young cows), depending on the exact combination of the feed[96].

It is not feasible to calculate the exact quantities used due to the different feeding systems and feed rations adopted by individual farmers.

[91] Wheat straw is around 25% less absorbent than oat straw

[92] http://www.bpex.org.uk/downloads/301431/299588/Bedding%20options%20for%20the%20English%20pig%20industry%20.pdf; http://hccmpw.org.uk/publications/farming_industry_development/alternative_bedding_for_livestock/;

[93] COUNCIL DIRECTIVE of 19 November 1991 laying down minimum standards for the protection of pigs as amended

[94] IEEP (2012)

[95] CSL, 2008, National and regional supply/demand balance for agricultural straw in Great Britain, Report prepared for the NNFCC, November 2008

[96] http://www.ag.ndsu.edu/drought/forages-and-grazing/feeding-straw

2.6.1.3 Horticulture

Straw has a number of uses within the horticultural sector and of these, mushroom production is the most significant.

Mushroom production
Straw is used as a key ingredient to produce growth substrate for mushroom production. It is mixed with manure, typically from horse stables (the manure will also have some straw already integrated into it). Blood and ground chalk are also added. The exact quantity of straw used depends on the composting technique. Wheat straw is preferred, although barley straw can also be used (e.g. in the Netherlands poorer quality wheat or barley straw is used, similarly in Denmark barley straw is also used). The ideal moisture content is 15%, although a range of 12 to 20% can be accepted.

There are at present no viable alternatives to using straw and as such straw is a very valuable commodity for the mushroom production industry. Experiments have been undertaken to test alternatives, such as sawdust and conventional compost, but they have as yet not been able to demonstrate that they could effectively replace straw[97].

In some countries the substrate (also known as Spent Mushroom Compost or "Champost" in the Netherlands) is spread on to arable fields as a fertiliser following use, or used to make compost (but not for mushroom growing). However, in other countries regulations require its disposal.

The Netherlands and Poland are the key markets in terms of mushroom production in the EU-27, with France and Spain also producing significant volumes.

Frost protection
Straw is used as mulch for vegetable production, particularly root vegetables like carrots and also parsnips to a lesser extent. The straw protects the crops against frost damage during the winter. Modern machinery can separate out the straw at harvest and a small portion (10%) of the collected straw can be recycled if it of sufficient quality. Otherwise it is chopped and incorporated as this tends to be the easiest method of dealing with the straw[98].

A significant amount of straw is also used in the flower industry in the Netherlands to protect tulip bulbs from frost damage.

Strawberry production
Straw was widely used as mulch for strawberry production, both to prevent moisture loss and to keep the ripening fruit free from soil contamination. Its use is now more limited as production has moved away from field grown cultivation. Strawberries are now commonly cultivated under cover in

[97] Elodie Deckert, GEPC (European Mushroom Growers Group), *pers comm*.
[98] Harley Stoddard, Home Grown Cereals Association (HGCA), *pers comm*.

polytunnels and either planted in polythene 'grow bags' inserted into the soil, or even in soil less "table tops" suspended in the air. Limited amounts of straw are still used as a mulch inter-row, or where the production is on trays to stop water ingress into the crop. Straw can also be used to suppress growth in order to stagger crop production, but this is no longer widely practised.

Straw is not widely used for the production of other soft fruits.

2.6.1.4 Industrial uses

There are also a number of industrial uses of straw, however these are currently not significant.

Building materials
Straw can be used as a building material, either as straw bales or as pre-fabricated straw panels[99]. Straw bale walls are usually lime rendered inside and out to form a breathable and weatherproof finish. A key advantage of straw is that it has excellent thermal insulating properties compared to conventional building materials, such as brick. Straw walls also exhibit good fire resistance.

Another straw based product is "straw board" which is made by compressing straw (usually wheat) under heat and pressure until the straw bonds. Straw board panels are primarily used as an internal walling solution, and provide an alternative to stud and plasterboard walls, chipboard and fibreboard[100].

Thatching
Thatched roofs were once commonplace across Europe, but are now present in a small minority of dwellings. The preferred cereal straw type used is wheat. Barley and oat straw are considered as having poor durability on the roof. Rye straw is sometimes used, but is not considered to have the durability of wheat[101]. The types of wheat suitable for thatching are older varieties with long stems and low grain yields, whereas modern varieties (i.e. dwarf or semi-dwarf) are bred to have shorter stems and high grain yields.

Paper and pulp
Straw can be used for the manufacture of paper and pulp as an alternative raw material to wood fibre. In Hungary the Dunaújvárosi Cellulózgyár Kft. (Cellulose factory of Dunaújváros Ltd.) has been producing cellulose from straw fibre since 1962. The plant was processing around 50,000 tonnes of wheat straw per year in 2002 (part of which was also used for food production)[102].

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99 http://www.modcell.com/
100 http://www.nnfcc.co.uk/publications/nnfcc-renewable-building-materials-factsheet-walls-and-panels; http://www.nomadeis.com/dl/2013/05/Rapport-final-NOMADEIS-MEDDE-phase-1.pdf
101 Stephen Letch, UK National Thatching Straw Growers Association, *pers comm*.
102 http://www.ienica.net/reports/Hungary.pdf

In France, CIMV Marne is planning to produce cellulose pulp for paper manufacture from straw and other cellulosic raw materials as part of a biorefinery concept that will also produce cellulosic ethanol and bio-based chemicals[103].

2.6.1.5 Energy generation

Straw can be used as a fuel for heat and power generation in either dedicated plants or co-fired with coal in conventional power stations. Denmark is the market leader in using straw for energy generation in both Europe and globally, with a history dating back to the early 1990s. Around 1.8 million tonnes per year are currently burned, of which around 57% is wheat straw and 30% barley straw with the remainder made up of rape, rye, triticale and oat straw. Dong ENERGY and Vattenfall are the key market players.

The UK has one operational straw fired power plant, at Ely in Cambridgeshire, which was commissioned in 2000. The plant has a requirement of around 210,000 tonnes per year of wheat straw. Ely prefers not to source barley straw because of its value as animal feed[104]. Drax Power also burns upwards of 60,000 tonnes of pelletised straw (typically wheat and rape straw)[105]. In late 2013 a 40MW plant at Sleaford in Lincolnshire is due to be commissioned, which will source up to 250,000 tonnes per year of straw. A second 40MWe plant is due to open at Brigg, also in Lincolnshire, in 2016[106]. A third 40MWe plant is planned for Mendlesham in Suffolk.

In Hungary, a 35MW plant located at Pécs (south Hungary) became fully operational this year, with a straw requirement of 300,000 tonnes of straw per year. The plant also provides 100% of the district heat demand of the town[107]. Other projects have been under discussion, including a 50MW plant at Szerencs (265,000 tonnes per year of wheat straw, maize stalk and energy grass) and a 25MW plant at Szolnok. Cement companies had also expressed an interest in using straw, but are instead using wood chips due to relatively high price of straw in the local region.[108]

In Spain, ACCIONA Energia, operates three straw fired biomass plants. These are the 25MW power plant at Sangüesa (Navarra province, northern Spain) commissioned in 2002, which has a fuel requirement of 160,000 tonnes (composed of 60% wheat straw, 20% oat straw, 5% barley straw and 15% corn stover). Two plants were commissioned in 2010, both of 16MW capacity. The first is located at Briviesca (province of Burgos in Castilla y León), which has a straw requirement of 102,000 tonnes (composed of 55% wheat straw, 30% oat straw and 15% barley straw. The second is located at Miajadas (Cáceres), which has a fuel requirement of 55,000 tonnes (composed of 5% each wheat, oat and barley straws, 15% corn stover and 70% energy crops (sorghum and triticale).[109]

[103] http://www.cimv.fr/cimv/20-.html
[104] Harley Stoddard, Home Grown Cereals Association (HGCA), *pers comm*.
[105] Robert Woods, Drax Power, *pers comm*.
[106] http://www.businessgreen.com/bg/news/2288856/pensiondanmark-venture-snaps-up-strawpowered-biomass-plant
[107] http://www.pannonpower.hu/en/member-companies/pannon-ho-kft/our-activities
[108] Csaba Vaszkó, WWF Central Eastern Europe/Hungary, *pers comm*.
[109] Fredi López Mendiburu, Acciona Energiá, *pers comm*.

In Poland, a 30MW biomass plant is under construction in Winsko, southwest Poland and is expected to be commissioned in 2014. The fuel requirement is 220-240,000 tonnes per year (straw, forest biomass and energy crops)[110].

Finally, a 49.8MW straw fired heat and power plant is under construction in Elmsland, Germany and will be the first such plant in the country[111].

2.6.1.6 Summary of straw uses and alternatives

The table below summarises the current uses for straw and their alternatives.

Table 11: Uses of straw and alternative materials. Adapted from IEEP (2012).

Straw use	Straw type use / preference	Alternative material(s)
Uses within the agricultural sector		
Incorporation	Any straw	Mineral fertiliser, manure, cover/catch crops, green manure
Animal bedding	Cereal straw	Sawdust, wood chips, wooden slats, other plant material (e.g. bracken, miscanthus, reed grass)
Animal feed	Cereal straw - barley and oat straw are preferred	Commercial feed, hay, silage, outdoor grazing
Mushroom production	Wheat straw preferred – can also be barley straw	No commercially available alternatives
Frost protection	Cereal straw	Vegetable production: Plastic sheeting - but straw is still often applied as a top layer, synthetic fleece Flower production: Compost, paper mulch[112]
Strawberry production	Cereal straw – barley straw is preferred	Matting or polythene sheeting
Uses outside the agricultural sector		
Building materials (straw bales, straw panels, straw board)	Wheat straw	Conventional building materials, hempcrete
Thatching	Wheat straw	Water reed, combed wheat reed, heather
Paper and pulp	Cereal straw	Wood fibre
Energy (heat, power, biofuel)	Any straw	Conventional fuels, other biomass feedstocks

[110] http://pepsa.com.pl/sites/default/files/press/9.03.2012_prezentacja_winsko_-_wersja_angielska.pdf
[111] http://www.bioenergie-emsland.de/
[112] Dutch Royal General Bulb Growers' Association (KAVB), *pers comm*.

2.6.2 Estimating straw use

Methodology for estimating straw use
Scarlat et al. (2010) identified three main uses for straw across the EU, namely for use as animal bedding and feed in livestock production, in mushroom production and for industrial uses. (As discussed above in section 2.6.1, there are in fact a number of other uses for straw, although none of these represent significant amounts.)

The table below provides an overview of the assumptions used by Scarlat et al (2010) in estimating the straw use per Member State.

Table 12: Assumptions used in Scarlat et al. (2010) in estimating the straw use across the EU. The assumptions for the livestock sector and mushroom production were based on JRC stakeholder/expert feedback.

Straw use	Assumptions
1. Livestock sector (animal bedding and animal feed)	
Cattle	1.5 kg per head per day, for 25% of the population
Equines (horses, mules)	1.5 kg per head per day, for 25% of the population
Sheep	0.1 kg per head per day
Pigs	0.5 kg per head per day, for 12.5% of the population
2. Mushroom production	Average annual consumption is 1.6 million ton per year (note: no breakdown per Member State or average straw usage per ton of mushroom production is provided)
3. Industrial uses (e.g. pulp and paper, insulating material for buildings)	1% of total straw production (note: this assumption is based on an estimate for Ireland in 2004)

Livestock data per Member State for 2002-2011 was obtained from Eurostat for cattle, sheep and pigs[113]. As Eurostat only contains data up to 1997 for equines more recent data (for 2004) from the CAPRI model[114] was used instead. Note that straw use for other livestock, such as goats to chickens, was not considered by Scarlat et al. (2010).

To calculate the straw used for mushroom production per Member State the total EU-27 estimate of 1.6 million tonne was pro-rated according to the Member State's average mushroom production between 2002-2011 as reported by Eurostat[115].

[113] http://epp.eurostat.ec.europa.eu/portal/page/portal/agriculture/data/database; Database: Agriculture, Agricultural production (apro), Livestock and meat (apro_mt), Livestock, (apro_mt_ls)
[114] Common Agricultural Policy Regionalised Impact model (CAPRI) as used in the Biomass Futures, Atlas of EU biomass potentials, 2012 study
[115] http://epp.eurostat.ec.europa.eu/portal/page/portal/agriculture/data/database; Database: Agriculture, Agricultural production, Crops products, Crops products: areas and production (appro_cpp), Fruits and vegetables - annual data (apro_cpp_fruveg)

The Total straw use can be estimated as follows:

Total straw use [tonnes per year] = Livestock heads x straw use per day [tonnes per year] + (MS Mushroom production / Total Mushroom production) x 1,600,000 [tonnes per year] + Total straw production x 1% [tonnes per year]

Validation with experts

The straw use estimates were validated against available literature and also with Member State experts and other relevant organisations and amended where appropriate. For straw use in mushroom production we contacted the GEPC (European Mushroom Growers Group), who provided estimates per Member State.

2.6.3 Analysis of straw use

The figure below provides an overview of the estimated straw use in the ten selected Member States, outside of incorporation. On the whole, it was possible to obtain detailed data for most of the countries, with the exception of Italy, the Netherlands and Spain. For these countries we used the JRC assumptions for straw use in the livestock sector and estimates provided by the GEPC (European Mushroom Growers Group).

It is clear that by far the most common use of non-incorporated straw is in the livestock sector with around 88.2% of straw being used for this purpose. Straw use for energy generation is the next biggest use at 5.5%, while horticulture is marginally lower at 4.8%. Industrial uses make up around 1.5%.

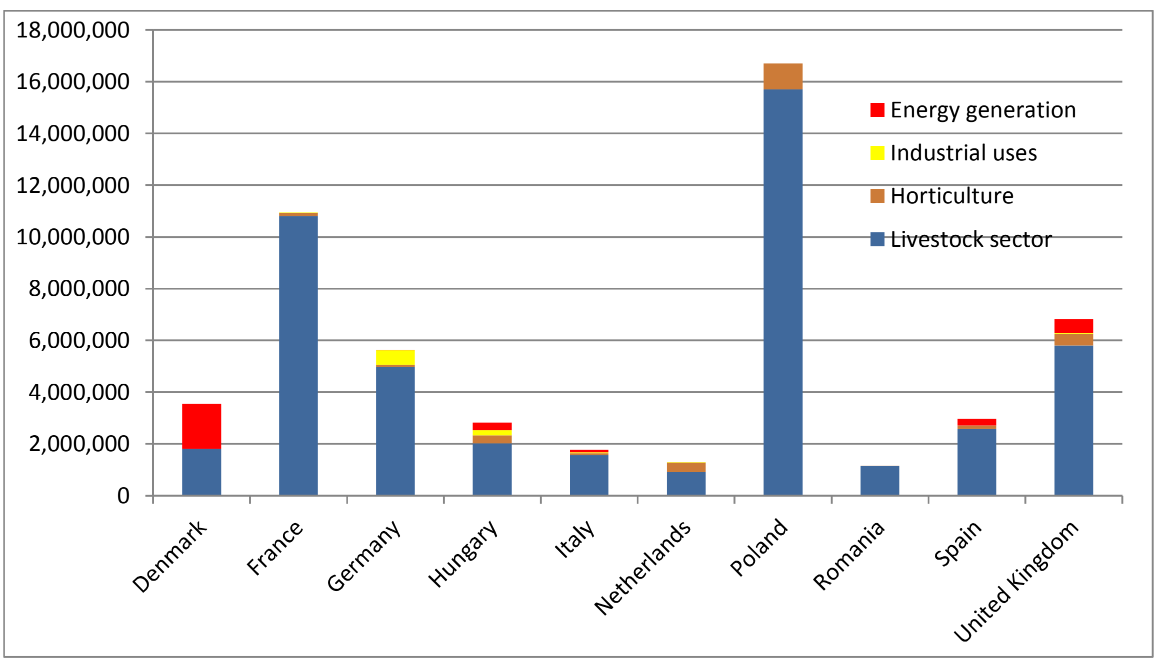

Figure 8: Estimate of the current straw used in the selected Member States. Units: tonnes (wet matter)

When analysing the ten Member States in detail some interesting insights emerge. For the majority of countries straw use in the livestock sector represents over 85% of the total (around 85% in the UK, 87% in Spain, 89% in Germany, 94% in Poland and close to 100% in France and Romania). Denmark is a major exception in that the straw use is evenly distributed between the livestock sector and energy generation.

Over 70% of the straw used for horticulture is for mushroom production, with Poland and the Netherlands two of the main markets. Straw use in the horticultural sector is extensive in the Netherlands (around 29%), and furthermore this is likely to be a conservative estimate as the use of straw in the flower industry is not currently included due to the lack of available data.

Other than Denmark, straw use for energy generation is relatively high in Hungary (11%), Spain (9%) and the UK (8%).

Based on the information available it would be appear that the use of straw for industrial uses is extremely limited in all Member States with the exception of Hungary and Germany, where this makes up around 7% and 10% of the totals respectively.

Poland has the largest estimated straw use at 16.7 million tonnes, of which 15.7 million tonnes is for the livestock sector. This estimate is significantly higher than the estimated for the other Member States, particularly when a comparison of the livestock numbers is made. The next highest straw use is in France (10.9 million tonnes), the UK (6.8 million tonnes), followed by Germany (5.6 million tonnes).

A more detailed summary of the straw use by Member State, including the data source, is provided in the table below.

Table 13: Estimate of cereal (wheat, barley, oat, rye, triticale) straw use per Member State in 2013.

	Denmark[1]	France	Germany	Hungary	Italy	Netherlands	Poland	Romania	Spain	UK
Livestock sector										
Animal bedding	1,143,400	10,805,882[3]	4,980,000[6]	2,031,644[9]	1,563,937[11]	915,033[11]	12,200,000[13]	1,151,295[11]	2,582,995[11]	5,800,000[16]
Animal fodder	660,500						3,500,000[13]			
Horticulture										
Mushroom production	Included in above totals (but likely to be negligible)	135,450[4]	78,120[4]	300,000[10] (of which mushroom production around 25,000[4])	75,600[4]	372,960[4]	1,000,000[13]	Negligible[14] (mushroom production around 7,700[4])	126,000[4]	56,700[4]
Frost protection		No information	Negligible[7]		No information	No information	Negligible		No information (but likely to be negligible)	405,000[16]
Strawberry production					No information					Negligible (estimated to be around 10,000)[17]
Industrial uses										
Building materials	Negligible	8,500[5]	553,333[6]	200,000[10]	39,877	5,176	Negligible[13]	Negligible[14]	Negligible	Negligible (estimated to be around 20,000)[18]
Thatching		No information								
Paper and pulp	0	0					0[13]	0	0	0
Energy generation										
Heat and Power	1,723,100	No information	0	300,000[10]	No information	No information	No information	Negligible[14]	265,500[15]	520,000[19]
Biofuels	30,000[2]	0	4,500[8]	0	90,000[12]	0	0	0	0	0
Total	**3,557,000**	**10,949,832**	**5,615,953**	**2,831,644**	**1,769,414**	**1,293,169**	**16,700,000**	**1,158,995**	**2,955,245**	**6,811,700**

Table 13 is primarily based on expert interviews and publically available information, or otherwise using JRC assumptions (as indicated in red). Units: tonnes (wet matter). Table data sources and assumptions:

1. Data on straw use in Denmark was accessed from Danmarks Statistik. Straw use data is estimated for energy generation, animal feed, animal bedding and incorporation. See: http://statistikbanken.dk/statbank5a/default.asp?w=1920. Note that we not include data on corn for grain or rape seed as these crops were not in the scope of this study.
2. This relates to the straw requirement for the Inbicon plant at Kalundborg. We have assumed that the straw use for Energy generation also includes biofuels.
3. Data was taken from France AgriMer (2010) and includes straw use for sheep, pigs, goats[116], cattle and chickens. The report indicated that straw use for building materials is marginal. Note that the estimate is provided on a dry matter basis. We have assumed a moisture content of 15% to convert to a wet matter basis.
4. Estimates of straw use for mushroom production were provided by Elodie Deckert at the GEPC (European Mushroom Growers Group) and relate to button mushrooms (oyster and shiitake mushrooms make up <1% of the market). Note that the estimate provided was the total straw requirement (i.e. includes both fresh straw and straw contained in manure). We have assumed that 70% of the straw is fresh straw.
5. Data was taken from Nomadéis (2012). This study estimates the straw use in the construction sector as 7,500 to 8,500 tonnes in 2012.
6. Estimates provided by Professor Daniela Thrän, DBFZ.
7. As advised by Dieter Bockey, UFOP
8. This relates to the straw requirement for the Clariant plant at Staubing.
9. Estimate provided by Norbert Kohlheb, Department for Environmental Economics, Institute for Environmental and Landscape Management, Szent István University in Hungary. This is based on the requirement for animal bedding only (and were advised that this is likely to be a conservative estimate). A lower estimate of 1.5 million tonnes for animal bedding and animal feed was provided by Csaba Vaszkó, WWF Central Eastern Europe/Hungary. We therefore decided to use the higher estimate of 2m tonnes.
10. Estimate provided by Csaba Vaszkó, WWF Central Eastern Europe/Hungary.
11. Estimates based on the assumptions provided in Scarlat et al. (2010) (see section 2.6.2). In the case of Romania the estimate also includes straw use for goats[64] (assumed to have the same straw as sheep), as provided by Viorel Ion, University of Agronomic Sciences and Veterinary Medicine of Bucharest. The same assumption was used for Spain.
12. This relates to the straw requirement for the BETA Renewables plant at Crestino and assumes that 50% of the total fuel requirement is cereal straw.
13. Estimates provided by Mariusz Matyka at the Institute of Soil Science and Plant Cultivation - State Research Institute in Puławy, Poland.
14. Estimate provided by Dr Viorel Ion, Associate Professor, Vice-Dean of the Faculty of Agriculture, University of Agronomic Sciences and Veterinary Medicine of Bucharest, Romania
15. Estimate provided by Fredi López Mendiburu, Acciona Energiá. Based on Sangüesa (136,000 tonnes), Briviesca (102,000 tonnes) and Miajadas (27,500 tonnes). For the Miajadas plant we have assumed that 50% of the straw usage for energy crops (triticale and sorghum) relates to triticale, equivalent to 19,250 tonnes.

[116] Spain, France and Romania all have significant goat populations. Average livestock heads between 2002-2011 were 2.9 million, 1.3 million and 0.8 million respectively.

16. Estimate provided by Harley Stoddart, Research Manager for Industrial Uses, HGCA.
17. Estimate based on discussions with British Summer Fruits strawberry and a selection of strawberry growers in the UK.
18. Estimate based on discussions with Stephen Letch, UK National Thatching Straw Growers Association, ModCell and John Williams, Head of Materials for Energy & Industry, NNFCC.
19. Estimate based on straw requirement for Ely (210,000 tonnes), Drax (60,000 tonnes) and Sleaford (250,000 tonnes).

2.7 Conclusions: low ILUC potential for straw in EU Member States

According to the LIIB methodology, a waste or residue is low ILUC if no current uses of the material are displaced, other than current bio-energy uses or forms of disposal such as land-filling and burning. This means that the low ILUC potential of straw is quantified by taking the total sustainable potential of straw and deducting all current uses except bioenergy, burning and incorporation.

2.7.1 Estimate of low ILUC potential for straw

The table below summarises the low ILUC potential estimates for straw.

Table 14: Estimates for the Low ILUC potential. Units: million tonnes (wet matter).

Member State	Sustainable potential	Straw uses (excluding energy generation, incorporation and burning)	Low ILUC potential
Denmark	3.2	1.8	1.4
France	19.6	10.9	8.7
Germany	11.6	5.6	6.0
Hungary	2.8	2.5	0.2
Italy	4.0	1.7	2.3
Netherlands	0.5	1.3	-0.8
Poland	11.2	16.7	-5.5
Romania	3.6	1.2	2.4
Spain	8.2	2.7	5.5
UK	7.4	6.3	1.1
Total	**72.2**	**50.7**	**21.4**

An estimated total of 21.4 million tonnes of low ILUC straw is available in the EU. While this is a best estimate it should be clear that in reality the number can be different based on a number of parameters including the quantity of straw which can be sustainably removed in a certain region in a certain year.

Of the overall estimated low ILUC potential, France has the largest share of 8.7 million tonnes, followed by Germany at 6.0 million tonnes and Spain at 5.5 million tonnes. Romania and Italy have estimated potentials of around 2.4 million tonnes each, while Denmark and the UK have estimated potentials of 1.4 and 1.1 million tonnes respectively.

A straw deficit occurs in both the Netherlands and Poland. In the case of the Netherlands this is expected as straw production is very low, while significant amounts of straw are required to meet the requirements of the livestock sector and horticultural sectors. The situation in Poland is different in that although considerable straw is produced this is more than offset by the straw requirement in the livestock sector. In practise, according to our analysis, the straw currently being removed exceeds the sustainable removal rate.

Denmark is estimated to have a potential of 1.4 million tonnes, however this already met by the current use for energy generation (almost exclusively heat and power).

Straw can be used to produce ethanol. Around 4,500 tonnes of straw is needed to produce 1,000 tonnes of ethanol.[117] This means that of the estimated quantity of 21.4 million tonnes of low ILUC straw available in the EU, around 4.8 million tonnes of low ILUC ethanol could be produced, or around 3 MTOE. This represents just over 10% of the forecasted total EU biofuel production in 2020.[118]

2.7.2 Conclusions

This study shows that cereal straw is widely available in the EU, can be sustainably harvested in large quantities of which a significant amount can be used as a low ILUC biofuel feedstock. This is especially true for France, Germany and Spain. Although, in Poland, the Netherlands, Denmark and Hungary no, or almost, no straw is available as a low ILUC feedstock.

A number of straw-based bioethanol installations have been constructed in the EU and more are in planning. This shows that the biofuels industry is keen to use straw as a low ILUC feedstock.

[117] http://www.biofuelstp.eu/cell_ethanol.html#ce1
[118] The National Renewable Energy Action Plans forecast a total EU biofuel production of 29MTOE in 2020.

3 Bark, branches, leaves, sawdust and cutter shavings

This chapter aims to identify the quantity of bark, branches, leaves, sawdust and cutter shavings which can be collected in a sustainable way and used to produce biofuel without causing ILUC. The assessed materials form a heterogeneous feedstock category mentioned in Annex IX of the European Commission's ILUC proposal.[119] After some descriptive sections first the *technical* available potential of the materials will be estimated, followed by the *sustainable* potential and finally the *low ILUC* potential.

3.1 Defining bark, branches, leaves, sawdust and cutter shavings

Broadly we distinguish four distinct sources of bark, branches, leaves, sawdust and cutter shavings:

1. Residues from managed forests;
2. Arboricultural residues (prunings from parks, motorways, railways etc.);
3. Woody farm residues (e.g. olive grove or fruit tree cuttings);
4. Sawmill residues.

This section starts with a brief description of the processes which lead to the four sources of residue materials. We describe which materials arise from which sources, and detail our assumptions about which materials would and would not be included in the Commission's feedstock category. Table 23 shows an overview of all the materials and sources, as well as listing their existing uses, a topic which is covered in further detail in section 3.6. The assessment of feedstock potential and existing uses in this chapter focuses on the feedstocks assumed to have the largest potentials, namely residues from managed forests, woody farm residues and sawmill residues. Arboricultural residues are not assumed to have a large potential compared to the size of the forestry or sawmill industries.

Currently, managed forests in Europe are harvested primarily for the timber or pulp and paper industries. Tree trunks and larger branches are used for timber, while off-cuts, smaller diameter branches or lower quality timber are chipped and used by the pulp and paper or panel industries. Those industries will make use of the main 'roundwood' and 'stemwood', but other parts of the tree including bark, tops, smaller branches, leaves and needles, and stumps are typically not used by these industries.

Note that the terms 'roundwood' and 'stemwood' are sometimes used interchangeably. Technically 'stemwood' refers to the vertical wood only (i.e. the trunk, or the brown section in Figure 9), while

[119] COM(2012)595

‘roundwood’ is used to refer to both the vertical wood and can also include branches if they are large enough in diameter (typically greater than 7cm in diameter, e.g. the brown and yellow sections in Figure 9). For coniferous (softwood) trees, there is little difference in practice as the branches are small. For some non-coniferous (hardwood) tree species (e.g. beech) the branches can be large in diameter and are comparable in their characteristics to stemwood.

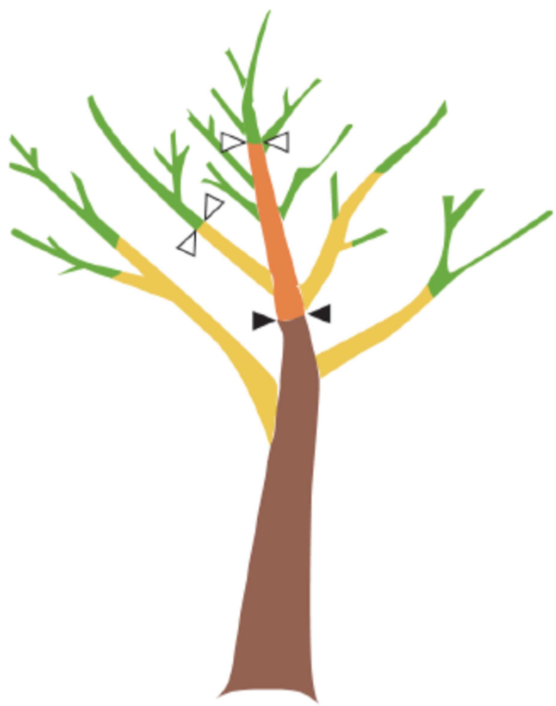

Figure 9: Diagrammatic representation of a tree showing the harvestable sections (Adapted from FranceAgriMer, 2012[120]). Green, orange, yellow – tops and branches; Brown – stemwood.

Forest management practices differ depending on, for example, the country, climate and tree species. Coniferous plantation forests will typically be thinned part way through the growing cycle to remove smaller or lower quality trees to allow room for the remaining trees to grow more strongly. In practice such ‘thinnings’ are often used for bioenergy. However as they are whole trees and not branches, for the purposes of this study, we do not include them in the category eligible for quadruple counting and do not therefore distinguish between thinnings and other roundwood or stemwood in our estimates. At maturity, coniferous trees may be selectively harvested or areas within the forest may be clear cut. Non-coniferous trees will more typically be selectively harvested. When trees are harvested, most often the tops and branches will be removed from tree trunk before onward transport of the roundwood to the first processing stage (e.g. sawmill). Typically, bark is left

[120] France AgriMer (2012), L’observatoire national des ressources en biomasse Évaluation des ressources disponibles en France, ÉDITION octobre 2012, Available at: http://www.franceagrimer.fr/content/download/15926/119849/file/DOC_FINAL_Obs_Biomasse_12-12.pdf

on the roundwood and travels on it to the first processing stage, where it is then removed before the roundwood is further processed. Some tops and branches should always be left in the forest to enhance biodiversity and to sustain the natural nutrient cycle. In many Member States today, tops and branches are largely left in the forest as the additional cost of collection is not justified by market demand. (Bark and leaves/needles are also naturally left on those tops and branches, although it should be noted that non-coniferous trees are usually harvested in winter in which case the leaves would have already fallen from the tree.) Increasingly though, tops and branches are collected for bioenergy purposes. In this case the harvesting method is adapted so that logging residues are piled during the timber processing. Tops and branches are then either collected loose, if they are to be chipped nearby, or bundled (Figure 10), if they are to be transported first and chipped at the plant. Either way, before transportation or chipping, the logging residues are typically left in the forest for several months to reduce their moisture content.

Although not common practice today, there are some instances where whole coniferous trees are being used for energy, in which case the quality of the wood is less important. In this case tops and branches might be left on to save the cost of removal as the whole tree can just as easily be chipped. In that case no tops or branches would be left in the forest.

Figure 10: Forest residue bundles and bundling machine. Source: Northern Woodheat [Source: http://elearn.ncp.fi/materiaali/kainulainens/nwh/woodfuel_supply_chains/forest_chips/bundling.htm]

The following lists show Ecofys' assumptions about which forestry materials would and would not be included in the category "bark, branches, leaves, sawdust and cutter shavings" which the European Commission proposes to incentivise by allowing it to count four times towards renewable transport targets (quadruple counting). The lists below describe the rationale for the Ecofys assumptions.

This classification acts as the starting point for estimating potentials in this study, although it should be noted that the available literature on forest residue potentials varies in the assumptions made about the materials included and in the terminology used.

It is assumed that the following materials **would** be eligible for quadruple counting:

- **Bark from the forest.** Bark is named in the Commission's category. However, it can be assumed that the available resource from this route will be negligible. Typically bark is left on trees and travels with the roundwood from the forest to the next processing stage (e.g. sawmill or paper mill) and becomes available at that stage (see 'Bark from the mill', section 3.1.3). Any bark that falls off the tree during harvest would be uneconomical to collect as the volume is so low compared to that of the roundwood, and would therefore be left on the forest floor. In Europe, only a very small percentage of trees (<0.1%[121]) are de-barked in the forest.
- **Branches** are named in the Commission's category. Ecofys assumes, however, that branches that are large enough to be classed as roundwood should not be included in the estimate of technical potential of branches, as they are used already in the timber and pulp and paper industries. In this study no maximum diameter for branches that should be included is defined, but from a sustainability and a practical implementation perspective, branches that are already transported to sawmills or paper mills are not included in our estimates of forestry residue potentials as they are already included in statistics on 'roundwood removals'. This study aims to quantify only those smaller branches that are left behind in the forest after harvesting.
- **Leaves and needles.** Ecofys assumes that both leaves (hardwood) and needles (softwood) would be included in the Commission's category. However, again it can be assumed that the available resource via this route will be negligible. Leaves and needles will be uneconomical to collect and should be left on the forest floor (as is typically the case already) to support biodiversity and soil nutrients. A key point to note is that hardwood trees are typically harvested during the winter months when there are no leaves on the tree in any case, so leaves would have to be collected off the ground, which is impractical and in some cases is also not permitted by law (for biodiversity and soil nutrient reasons).
- **Sawdust from the forest.** As with bark and leaves, sawdust is named in the Commission's category, but Ecofys assumes that the available resource from this route will be negligible as the small amounts produced at this stage make it uneconomical to collect. It is currently left on the forest floor.
- **Tops.** Tops are not named in the Commission category, but they are similar in characteristics to small branches and are collected and harvested in the same way. Ecofys therefore assumes for the purposes of this study that tops can be considered within this feedstock category for quadruple counting. Tops are typically not used for pulp and paper because their diameter is too low and they have a high share of bark and needles.

It is assumed that the following materials **would <u>not</u>** be eligible for quadruple counting:

- **Roundwood and stemwood.** Not included as these are not residues but main products, used already in the timber and pulp and paper industries.

[121] Professor Udo Mantau, University of Hamburg, *pers comm.* May 2013

- **Thinnings** are whole trees. They are therefore treated as roundwood and stemwood for the purposes of this study, although bark, small branches, tops and leaves from thinnings would be included in the normal way.
- '**Unmerchantable stemwood**' is the "part of the stem that is unsuitable for industrial use because of undesired dimensions, species or quality" (Antilla, 2009). Ecofys doubts whether this would be included in the Commission's category as it is likely to be perceived as stemwood and not a branch. However it is questionable whether it will always be feasible in normal harvesting practices to distinguish between the streams of unmerchantable stemwood and other logging residues (tops and branches).
- **Stumps.** There is a substantial debate over the sustainability of harvesting tree stumps, due largely to concerns over biodiversity and soil quality (nutrient levels and erosion). Arguments for stump harvesting include improvement of site preparation for re-planting, reducing root infection of new forest stands and providing a further source of biomass (Diaz-Yanez et al., 2013). The decision whether or not to allow stump harvesting lies with national authorities and it therefore varies from country to country whether stumps are harvested in practice. Due to sustainability concerns, the fact that stumps are not explicitly mentioned in the Commission's category and because stumps would be harvested in a separate step to other forest residues, it is unlikely that stumps would be included within this category for quadruple counting, and therefore stumps are excluded from the estimate of potential.

In estimates of forest material potentials, the terms '**supplementary fellings**' or '**complementary fellings**' are used to refer to additional roundwood that could be sustainably removed by increasing overall forestry harvesting rates. Supplementary fellings are not included in the scope of this study. Further research into supplementary fellings could be useful in order to get more clarity on which quantities of additional biomass could be sustainably harvested and which specific sustainability aspects or requirements are relevant to such additional fellings. For example, Antilla et al.[122] estimate that one quarter of the annual surplus forest growth (in commercial forests) could be sustainably harvested in countries where the annual rate of change in growing stock is demonstrated to have been positive for a prolonged period of time (in this case between 1990 and 2005). Such supplementary fellings are interesting for the bioenergy industry in general as they represent a sustainable forest resource in addition to what is harvested to meet today's market demand. However, for the purposes of this study supplementary fellings are additional whole trees and are not forestry residues. Therefore we assume that roundwood from supplementary fellings would not be eligible for quadruple counting, although residues (bark, branches, tops, leaves and sawdust) from supplementary fellings would be eligible for quadruple counting in the same way as any other logging residues.

3.1.1 Description of arboricultural residues

Arboricultural residues includes sources of bark, branches, leaves and sawdust from prunings from maintenance of, for example, parks, road sides, motorways and alongside railways etc.

[122] Antilla, Perttu, Timo Karjalainen and Antti Asikainen, 2009, Global Potential of Modern Fuelwood, METLA

The extent to which such streams are centrally collected and could therefore be economically used for bioenergy varies between countries. Typically if such streams are centrally collected, they are done so by municipalities. Overall, the potential for this feedstock stream is not significant compared to forestry residues, although for some individual countries, especially those with large urban areas and centralised collecting systems, the source can be significant.

Ecofys assumes that any material sourced via this route would be eligible for quadruple counting. However, there is a lack of statistics collected in most Member States on the volume of arboricultural arisings and therefore the estimate of potential in this study focuses on the larger sources of feedstock – forestry residues, woody farm residues and sawmill residues. It would be desirable to perform more research into the availability of these residues in a locally detailed manner.

3.1.2 Description of woody farm residue harvesting

Woody farm residues include bark, branches, leaves and sawdust from farmed trees such as olive groves, fruit trees or vineyards. These residues become available during regular management and re-establishment of orchards and tree nurseries. The Mediterranean countries of Italy, Spain and Greece produce significant quantities of these residues. However, despite this, management of pruning residues generally represents a disposal problem since the residues have limited existing uses. They are typically either mulched or piled and burned in the field, or sometimes landfilled.

3.1.3 Description of sawmill process

In the timber industry, logs are transported from the forest to a sawmill with the bark still on, where they are first inspected and then graded. The logs are debarked prior to sawing and the bark is collected. The log ends may also be trimmed before sawmilling.

Sawmilling produces a number of residues, the proportion of which depends to a large extent on the sawmill technology and whether the trees are coniferous or non-coniferous.

- **Slabwood:** These are the long rounded sides of the log that are sawn off the outside as lumber is being produced. Slabwood can be kept intact or further chipped. Non-coniferous sawmills typically produce proportionally more slabs than coniferous sawmills as the value of the slabwood is higher (than if it were chipped) and can be potentially used for other purposes.
- **Sawmill chips:** Additional offcuts that are generated during the sawmilling process, for example when wood edges are removed or the planks trimmed to the correct length or to take out defects. These offcuts are then typically chipped. Log trimmings may also be sent to the chipper.
- **Sawdust:** Sawdust is generated as the logs are cut into planks. Sawmills can use a number of different saw types, including circular saws or band saws. Circular saw blades are thicker than band saw blades and thus create more sawdust with each cut.

Large size mills predominantly use chipper / chipper canter saw lines, whereas small and medium size mills rather apply frame and band saw technology. As a consequence, the proportion of chips arising from a large sawmill is greater than for a small sawmill, which will produce proportionally more slabwood. The proportion of sawdust is similar for both sawmills types.[123]

Following sawing the wood is dried in a kiln (it can also be air-dried initially – but this is not practised in Scandinavia as the wood would rot). The sawmill industry typically uses its residues (bark) as a fuel source for the drying kiln. The sawnwood is then inspected for any defects which may have resulted during the drying process, such as split-ends or loose knots. These may be removed by trimming, producing additional offcuts.

The wood is then 'planed' in the planer mill producing cutter shavings.

- **Cutter shavings:** These are produced when dried lumber is smoothed and shaped into its final form. Cutter shavings differ from other sawmill residues in that they are produced from dried lumber and consequently have a lower moisture content and therefore higher energy content.

Figure 11 describes the typical process for sawnwood production.

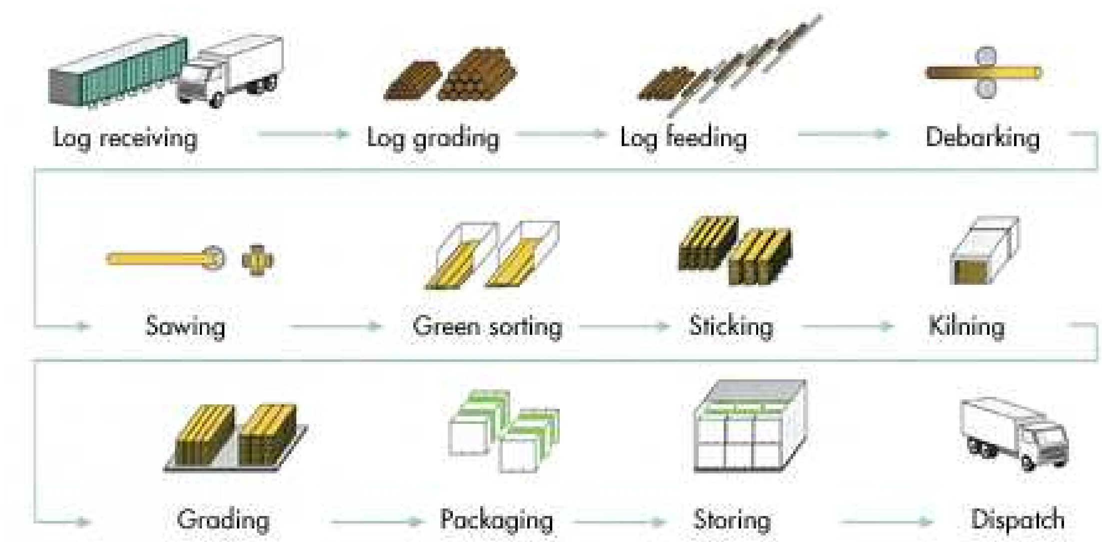

Figure 11: Overview of sawmill production process. Source: UPM[124]

[123] Mantau et al (2010) EUwood: Real potential for changes in growth and use of EU forests
[124] http://timber.upm.com/en/timber-products/sawn/standard-sawn/production-process/Pages/default.aspx

It is assumed that the following materials **would** be eligible for quadruple counting:

- **Bark from the mill.** Bark is a residue and named in the Commission's category. Typically bark is still on the tree when it reaches the mill.
- **Sawdust from the mill.** As with bark, sawdust is clearly a residue and named in the Commission's category.
- **Cutter shavings from the mill.** Cutter shavings are residues and named in the Commission's category.
- **Cutter shavings from manufacture of finished products (e.g. furniture).** Ecofys assumes that cutter shavings from sources other than sawmills would be included in the feedstock category. However these sources of cutter shavings would be too dispersed to be economical to collect, and they are therefore excluded from the potential estimates. In addition, wood has often been chemically treated by this point, making it less suitable for biofuel production.

It is assumed that the following materials **would <u>not</u>** be eligible for quadruple counting:

- **Sawmill chips.** Sawmill operators indicate that sawmill chips are a significant source of non-sawnwood output from a sawmill (see Figure 12 in section 3.4.6). Sawmill chips are chipped offcuts of wood and can arise from a number of different stages of the sawnwood production process (e.g. slabwood). It is unlikely that sawmill chips would count in this feedstock category as they represent a large share of the outputs from a sawmill and have a number of existing uses (e.g. pulp and paper). They are not the same as cutter shavings. Sawmill chips are therefore excluded from the estimate of potential.
- **Slabwood.** The production ratio of slabwood and sawmill chips is closely related as the sawmill operator can chose either to keep the slabwood intact or to chip it. Again, slabwood can represent a large share of the output from a sawmill (Figure 12). Furthermore, slabwood has a number of existing uses, both in its whole or chipped form. For these reasons it is unlikely that slabwood would count in this feedstock category.

3.2 Qualities and use as biofuel feedstock

3.2.1 Qualities of woody residues

Commercial conversion of woody residues to liquid biofuel is still in its infancy. Therefore there is no defined maximum moisture content or minimum density per se of woody residues that can be converted into biofuel. However it is clear that the lower the moisture content and the higher the bulk density, the more economically viable the feedstock is to transport and convert. One industry source stated that cleanliness or purity of the feedstock stream is the most important consideration when selecting their woody biomass streams. As with any biofuel production plant, securing the price and consistency of feedstock supply are also key when plants are deciding which feedstock streams to use. If plants are able to run on multiple feedstock streams, this allows them more flexibility in feedstock sourcing. Industry sources suggest that a feedstock sourcing radius of up to 100km is typical for woody residues, significantly more than that would not make economic sense.

Bark, tops and branches harvested straight from the forest have a relatively high moisture content, similar to a tree, of 40% or more.

A lower moisture content is desired, both for cheaper transportation and ease of converting into a biofuel. For this reason tops and branches will be collected and left to dry naturally for several months after harvest before use to allow time for the moisture content to decrease to around 20-30%. As discussed, leaves are very unlikely to be collected from the forest floor as they have a high moisture content and would also contain a high proportion of dirt and soil etc, which would need to be removed before converting into a liquid biofuel. In some countries this is also explicitly not allowed for soil nutrient and biodiversity reasons.

Sawdust varies widely in its moisture content, depending on the exact stage of wood processing that it is generated and collected. Sawdust from tree harvesting would have a high moisture content of around 30-40%, similar to the tree itself. Whereas sawdust generated towards the later stages of wood processing in the sawmill, after natural drying and kiln drying, will have a much lower moisture content of around 10%. Sawdust has a low bulk density of around 150 kg/m^3.

Cutter shavings typically have a low moisture content (8-15%) as they are produced during finishing of the sawnwood, but they also have a low density (~175 kg/m^3). This compares to typical densities for roundwood of around 650 kg/m^3, for wood chips of 250-300 $kg/m^3$and 650-700 kg/m^3 for wood pellets.

Due to the purity of the streams and their low moisture content, sawdust and cutter shavings are usually in demand, either for the pulp and paper or panel board industry, or for pellet production for heat or power. However it does not make economic sense to transport these large distances because of the low bulk density.

3.2.2 Cellulosic ethanol production installations using woody residues

There are a handful of biofuel plants using woody residues as feedstocks, to date located mainly in the United States, where two demonstration plants and one commercial plant are operational. Table 15: Overview of operational and planned cellulosic ethanol biofuel initiatives using woody residues as feedstock (pilot, demonstration and commercial scale projects only). Source: Advanced Ethanol Council, 2013 , UPM. shows an overview of key initiatives.

KiOR[125], a biofuel conversion technology company based in the US, have developed a proprietary catalyst system with a process based on Fluid Catalytic Cracking (FCC) technology. The company has one demonstration scale plant that has been operational since 2010, one commercial plant that came online at the end of 2012 and a second commercial scale plant in development. The company claims

[125] http://kior.com/

they can run their plants flexibly on a number of different cellulosic feedstocks, including wood chips, whole tree chips, logging residues, sugar cane bagasse, switchgrass and corn stover.

ZeaChem[126], also a US-based biofuel conversion technology developer, uses a combination of biochemical and thermochemical processing steps in their advanced biofuel conversion process. The company claims the process can use any form of cellulosic biomass. In practice poplar trees and straw are used in their demonstration-scale plant. A commercial-scale plant is under development, due 2015.

In Europe, UPM, a Finnish company with its origins in the timber and pulp and paper industries, is planning to build biomass-to-liquids (BTL) plant in Strasbourg, France. The plant received funding from the European Commission's NER300 technology programme in December 2012[127]. The planned plant will have a capacity of 100,000 tonnes biofuels per year and will use forestry residues to make an advanced biodiesel through biomass gasification and followed by Fischer-Tropsch conversion.

Although the plants could in theory use bark, branches, leaves, sawdust or cutter shavings, it is clear that the drier and purer streams such as branches, sawdust or cutter shavings would be preferred as a feedstock. Bark and leaves, particularly if collected from the forest floor, would contain a high level of moisture and impurities such as earth that would need to be removed before processing, and are not favoured as a first choice of feedstock. Some industry sources claim it is possible to run plants on a single feedstock stream, although it is much preferred to build plants with feedstock flexibility as this puts plant owners in a stronger position to deal with changes in prices and feedstock supply.

[126] http://www.zeachem.com/

[127] http://www.upm.com/EN/MEDIA/All-news/Pages/EU-awards-NER300-technology-grant-for-UPM's-biorefinery-project-in-France-001-Tue-18-Dec-2012-16-05.aspx

Table 15: Overview of operational and planned cellulosic ethanol biofuel initiatives using woody residues as feedstock (pilot, demonstration and commercial scale projects only). Source: Advanced Ethanol Council, 2013 , UPM.

Company	Country	Location	Feedstock(s)	Product(s)	Scale	Date of operation
KiOR	US	Pasadena (TX)	Forestry residues	15 barrels per day cellulosic gasoline and diesel	Demonstration	2010
KiOR	US	Columbus (MS)	Forestry residues – currently operating on commercial thinnings, plan to use logging residues in near future.	13 MGY cellulosic gasoline and diesel	Commercial	Q4 2012
KiOR	US	Natchez (MS)	Forestry residues	40 MGY cellulosic gasoline and diesel	Commercial	2014
Zea Chem	US	Boardman (OR)	Poplar trees (and wheat straw)	0.250 MGY cellulosic ethanol and bio-based chemicals	Demonstration	2012
Zea Chem	US	Boardman (OR)	Poplar trees (and wheat straw)	25+ MGY cellulosic ethanol and bio-based chemicals	Commercial	Q1 2015
UPM	France	Strasbourg	Forestry residues and bark	100,000 tonnes Fischer-Tropsch biodiesel	Commercial	~2016

Key: GPY = Gallons per year, MGY = Million gallons per year, TPY = Tonnes per year

3.3 The chosen feedstock-region combination

As described in section 1.3, the LIIB methodology states that only the share of wastes or residues which is not used for non-bioenergy purposes within a certain region, is eligible for certification as low ILUC biofuel. For example, if 20% of a residue is already used for other purposes, only the remaining 80% of the residue in a region can claim LIIB compliance.

The extent to which wastes and residues are ILUC free is thus determined per region from which a certain biofuel feedstock is typically sourced. This is called the **feedstock-region combination**.

In the case of bark, branches, leaves, sawdust and cutter shavings, the high moisture content and low density of most of the material (see section 3.2.1) make long distance transport costly. The fragmented structure of production of several of the materials also makes collection and transport difficult. Significant extra-EU trade in these residue materials is therefore only likely to take place after pelletisation or another form of processing that increases the energy density. It is unlikely to be economically viable to process the raw feedstock (e.g. into pellets) and then to export it to the EU for further processing into a liquid biofuel in the EU. There are some examples with straw where the material is shipped long distances in containers or trucks that would otherwise be empty, i.e. on the return trip, which could be an option to improve the economics of long distance transport. Nevertheless, this is considered unlikely as companies could more easily convert the biomass to pellets at the feedstock source and transport those pellets for heat or power. Based on this, this study is limited to bark, branches, leaves, sawdust and cutter shavings being generated **within the EU.** Since no information on inter-EU trade exist the assessment will not be performed at Member State level. The focus on the EU does not preclude the fact that finished biofuel produced outside the EU from these feedstocks could be exported to the EU if the financial incentives are worthwhile.

The assessment of available quantities of the material which could be collected in a sustainable way (first theoretical potential, then sustainable potential and then low ILUC potential) covers all 27 EU Member States. Data gathering for the existing uses of the materials focuses on the largest and most relevant Member States, and results are extrapolated for the EU-27 as a whole. Key data from Eurostat that can be used as a basis to calculate the scale of the forestry and sawmill residues likely to be available are: Area managed forest available for wood supply; annual roundwood removals; and sawnwood and panel production. Together the eight largest Member States in terms of forest available for wood supply (Sweden, Finland, France, Spain, Germany, Poland, Italy, and Romania) plus the Netherlands represent 110.1 Mha forest available for wood supply from a total area of 132.6 Mha, or 83%.[128]

[128] Based on Eurostat statistics

The top countries on the basis of managed forest area correspond broadly to the top countries on the basis of roundwood removal and sawnwood and panel production levels, although Austria and the Czech Republic have relatively large sawnwood production and therefore represent interesting potential sources of material if the other two metrics are used.

Table 16: Area of managed forest available for wood supply, annual roundwood removal and sawnwood and panel production by Member State (2010). Source: Eurostat

Member State	Area managed forest available for wood supply (1,000 ha)	Annual roundwood removals (1,000 m^3 over bark)	Sawnwood and panel production (1,000 m^3)
Austria	3,343	19,971	9,636
Belgium	672	5,474	1,369
Bulgaria	2,864	6,605	728
Cyprus	41	11	3
Czech Republic	2,330	18,865	4,454
Denmark	581	3,002	372
Estonia	2,013	8,000	1,800
Finland	19,869	58,322	9,750
France	15,147	66,108	8,675
Germany	10,568	61,058	22,628
Greece	3,595	1,377	106
Hungary	1,726	7,002	324
Ireland	460	2,880	759
Italy	8,086	9,295	1,250
Latvia	3,138	13,879	3,432
Lithuania	1,875	8,010	1,260
Luxembourg	86	318	78
Malta	0	0	0
Netherlands	295	1,300	238
Poland	8,532	39,404	4,422
Portugal	1,822	12,182	1,044
Romania	5,193	15,351	4,442
Slovakia	1,775	10,687	2,204
Slovenia	1,175	3,207	703
Spain	14,915	19,255	2,162
Sweden	20,554	86,640	16,800
UK	2,411	10,895	3,279
EU-27	**133,066**	**489,097**	**101,919**

Definitions:

- **Forests available for wood supply:** Forests where no legal, economic, or environmental restrictions have a bearing on the supply of wood (Eurostat).
- **Annual roundwood removal** is not defined per se in Eurostat, but it described the wood removed from the forest in a year. The term removal differs from fellings as it excludes felled trees left in the forest, but includes removals from fellings in an earlier period or from trees killed or damaged by natural causes (Asikainen et al., 2008) [129].
- **Sawnwood:** Wood that has been produced either by sawing lengthways or by a profile-chipping process and that exceeds 6 mm in thickness. It includes planks, beams, joists, boards, rafters, scantlings, laths, boxboards and "lumber", etc., in the following forms: unplaned, planed, end-jointed, etc. It is reported in cubic metres solid volume (m^3). (Eurostat)

3.4 Methodology to estimate the theoretical and sustainable potential

This section describes the approach taken to estimate the potential availability of bark, branches, leaves, sawdust and cutter shavings, including key assumptions and their rationale. First the 'theoretical potential' of the materials is identified and subsequently the 'sustainable potential' is estimated, taking into account a conservative estimate of residue removal rates to ensure that sustainability, techno-economic and more general feasibility constraints are taken into account. Section 3.6 covers existing uses to estimate the low ILUC potential.

3.4.1 Bark (from mills)

Theoretical potential

Eurostat publishes roundwood removal data per Member State in 'thousand m^3'. Data is published both with the bark *included* (termed "over bark"), and with the bark *excluded* (termed "under bark"). The theoretical maximum bark potential is therefore estimated as the difference between the two. Eurostat data from 2010 is used as the basis.

Sustainable potential

In Europe debarking of trees typically takes place at the first processing stage (most often the sawmill or pulp and paper mill), rather than in the forest. Bark is therefore not collected from in the forest, but rather it is collected at the first processing stage. In some cases, for example in Austria, it is recommended to debark and leave the bark in the forest if soil conditions are weak. However this situation is not the norm. The potential availability of bark is therefore expected to be relatively close to the theoretical potential as the infrastructure required to collect it is already in place, although in this study we make conservative estimates of bark losses to account for the desire to leave more bark in the forest in some instances.

[129] Asikainen et al. (2008), Forest Energy Potential in Europe (EU27), METLA

It is assumed that 1% of bark is lost from the tree in the forest during harvesting and in transport (this is likely to be a conservative estimate, and in reality losses are lower)[130]. A further 5% is assumed to be lost at the sawmill or paper and pulp mill. For example some of the bark will fall off the logs in the wood yard and rot away (again this is likely to be a conservative estimate and in reality losses will be lower).

3.4.2 Branches (and tops)

Theoretical potential

Eurostat roundwood removals (over bark) data from 2010 are used as the basis for the estimate of the potential for branches and tops).

The ratio of tops and branches to roundwood varies according to the tree type (coniferous / non-coniferous), the species and also to the tree age and growing conditions. The dry mass of branches, without foliage, can be equal to as little as 5% of the mass of the harvested industrial roundwood (e.g. for mature Pines and Eucalyptus). In contrast, the crown of a mature Norway spruce, including foliage, can be equivalent to more than 60% of the mass of the merchantable stemwood[131].

A recent study to assess the global potential of fuelwood by METLA, the Finish Forest Research Institute, uses the concept of "Biomass Expansion Factors" (BEF), a factor which is used to estimate the volume of tops and branches on a tree (referred to as "crown biomass") from the volume of roundwood. The BEFs were first published by the Intergovernmental Panel on Climate Change (IPCC) (Penman et al. 2003) and were used to assess the amount of crown mass for different species groups according to the climatic zone. The BEFs available include both a "low" and an "average" value. The "low" values approximate mature forests or those with high levels of growing stock, whereas the "average" values are for younger forests with lower levels of growing stock.

Table 17: Biomass Expansion Factors (BEF) used to estimate volume of tops and branches (Source: Antilla et al., 2009, Table 3)

Climatic zone	Species group	Low	Average
Boreal	Conifers	1.15	1.35
	Broadleaf	1.15	1.3
Temperate	Conifers	1.15	1.3
	Broadleaf	1.15	1.4

130 Udo Mantau, University of Hamburg, *pers comm.*
131 Antilla et al., 2009

The Member States are categorised by climatic zone. Within the EU-27, Member States are predominantly located in the temperate climatic zone, with only Estonia, Finland, Latvia, Lithuania and Sweden in the boreal zone.

An estimate of the *theoretical* potential of tops and branches is made using the roundwood removal volumes multiplied by the appropriate BEF (taking into account the climatic zone and the share of coniferous versus non-coniferous wood in the roundwood removals). Roundwood over bark is used so as to include the bark on the tops and branches in the estimate. Tops and branches are typically not de-barked, so the bark on them is included in the estimate of tops and branches, rather than separately in the estimate of bark. Roundwood removals, and therefore the theoretical potential calculated here, are reported in 'thousand m^3'. A more common unit for bioenergy feedstocks is oven dried tonnes (odt). Thousand m^3 can be converted to odt by using an approximate conversion of one 1,000 m^3 to 500 odt[132].

Sustainable potential
The key assumption is how much of this theoretical potential of tops and branches could be sustainably harvested. Some of the theoretical potential of tops and branches will not be technically or economically feasible to collect, for example because of steep terrain or selective logging leading to residues scattered over a large area. Crucially it is also not environmentally sustainable to remove all tops and branches as it is important to leave some material behind in the forest to promote soil preservation (nutrient recycling, soil organic matter and soil erosion) and biodiversity. For biodiversity it is important to leave a range of material behind, as for example different sizes of logs and branches at different stages of decay provide habitats for different species. Leaving small branches in the forest is particularly beneficial also because of the relatively high nutrient levels they contain compared to larger branches. Forests are often located on lower quality soils, making it important to retain sufficient levels of nutrients in the forest. At the moment most forest soils have sufficiently large nutrient levels and the level of residue removal could be increased in many areas, but problems are likely to occur if high levels of forest residues are harvested. It is therefore important to monitor the effects of increased forest residue removal. These effects can vary from region to region. Despite these uncertainties it is necessary for the purpose of this study to assume a general sustainable forest residue removal rate.

The extent to which tops and branches can be sustainably removed depends on the specific technical and environmental conditions of the specific forest in question. It is recommended that forest owners be required to take local soil and biodiversity issues into consideration before embarking on any residue removal programme to ensure an appropriate level of residue removal. Few countries have in place legal guidelines on maximum residue removal rates (examples of Sweden and Massachusetts in the US are given in Box 1). Even for established sustainability certification schemes such as the Forest Stewardship Council (FSC), national interpretations of the standard's principles and criteria

[132] U. Mantau, University of Hamburg, *pers comm* and UK Forestry Commission: http://www.forestry.gov.uk/website/forstats2009.nsf/0/8B4784E90B2A535480257361005015C6

vary in the extent to which forest residue removal is currently permitted. The main FSC standard requires environmental integrity, including aspects such as biodiversity and soil quality, to be enhanced or maintained, but does not include specific or quantitative requirements on forest residue removal. Decisions on such details are set out in national interpretations, called 'National Standards'. These decisions are taken locally by a committee of national forestry experts and FSC members. Forest residue removal is currently practised to a different extent in different countries and so has had a differing amount of attention in the different discussions on National Standards. As such, the permitted rate varies widely. Some countries' national FSC standard, such as the German, do not permit forest residue removal at all, whereas Finland and Sweden permit up to 70 or 80% respectively. Other National Standards do not include any quantitative guidelines. It is clear also that as well as national circumstances, local circumstances must be taken into account.

Box 1: Examples of countries with legal guidelines on maximum forest residue removal rates

Sweden is one of the few EU Member States to have developed detailed guidelines on sustainable harvesting rates of logging residues. Sweden allows up to 80% of the logging residues to be removed from the forest[133]. However, logging residue removal is not permitted from forests with 'high natural value' or wetland forests. The guidance also states that it is 'particularly important to leave tops, coarse branches and dead wood from deciduous trees as well as tops of pines'. Guidelines are also provided for application of bioenergy ash that should be applied to the land under certain soil conditions or if high levels of logging residues are removed.

Recently, the Massachusetts Department of Energy Resources set similar limits on the amount of logging residues that can be removed in the regulations relating to the Renewable Energy Portfolio Standard[134]: on "good soils" up to 75% of logging residues can be removed, but on "poor soils" no logging residues can be removed. Although specific to Massachusetts, the guidelines represent one of the most comprehensive legislative guidelines for logging residue removal.

Table 18: Examples of forest residue removal rates in FSC National Standards.[135]

Country	Maximum permitted logging residue removal rate	Extract from National Standard
Finland	70%	"…a minimum of 30% of the residues shall be retained"
Germany	0%	"Whole-tree harvesting is not practiced"
Netherlands	No explicit threshold	"The management plan contains objectives for achieving a certain percentage of old trees and dead wood"
Sweden	80%	Removal rate has to be in line with Swedish Forestry Agency guidelines (see Box 1).

[133] Skogsstyrelsen (Swedish National Board of Forestry), June 2008, Recommendations for the extraction of harvesting residues and ash recycling. http://www.skogsstyrelsen.se/en/forestry/Forestry/News-Archive/Guidelines-in-English/ [English translation published 2011].
[134] Massachusetts Executive Office of Energy and Environmental Affairs. Department of Energy resources. Renewable Energy Portfolio Standard. Eligible Woody Biomass Fuel Restrictions. http://www.mass.gov/eea/docs/doer/renewables/biomass/biomass-eligibility-and-certificate-guideline.xlsx
[135] FSC National Standards available from: https://ic.fsc.org/national-standards.247.htm

Country	Maximum permitted logging residue removal rate	Extract from National Standard
UK	No explicit threshold	"Whole tree harvesting or stump removal shall not be practised where it is likely to have significant negative effects"

As can be seen in the national guidelines, for example for Sweden and Finland, in some circumstances, up to 70 or 80% of forest residue removal could be considered appropriate, but this should only be from an individual forest stand with good soil conditions. This level of residue removal will not be sustainable or technically feasible from all forest stands. An appropriate removal rate will always have to be determined at the forest stand level as the local nutrient conditions must also be taken into consideration. Further research would be beneficial to determine appropriate removal rates at a more site-specific level, for example through mapping commercial forest areas against soil characteristics, terrain, and protected areas, to enable a more detailed scientific approach to estimating the percentage of forest residues that could sustainably be removed across the EU as a whole. In the absence of such EU-wide research, this study aims to make a conservative estimate of sustainable forest residue removal.

This study refers to the sustainable harvesting rates from the European Climate Foundation study[136] "aggressive EU supply mobilisation scenario" to 2020. The ECF scenario is ambitious or 'aggressive' in terms of the speed of ramp-up of logging residue capture across Europe, given that residue capture is low across Europe today, but the scenario still sets residue harvesting rates at a level that is significantly below maximum permitted harvesting rates and is therefore assumed to be "compatible with strong sustainability criteria". The scenario also takes into account the land available, the availability of different types of feedstock and the time needed to increase supply. Given the starting point and the time needed to increase forestry residue removal to 2020, the assumption in the ECF aggressive mobilisation scenario is that Scandinavia could reach 40% residue capture by 2020 and continental Europe could get to half of those capture rates (i.e. 20% in continental Europe). This would appear to be achievable, but ambitious to 2020 given the starting point. Also because in some key forestry countries FSC does not currently permit zero logging residue removal, we have chosen to use a lower assumed harvesting rate than the ECF scenario and assume a 20% sustainable logging residue removal rate for all EU Member States.

The Antilla et al*.* study estimates that a further 5-15% forestry residues is available from 'unmerchantable stemwood'[137].

This uplift is not included in our study, as it is feasible that this wood (or at least a portion of it) could still be used in the paper and pulp industry despite not being suitable for lumber production.

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[136] European Climate Foundation (2010) Biomass for heat and power – Opportunity and Economics. http://www.europeanclimate.org/documents/Biomass_report_-_Final.pdf

[137] The Antilla *et al.* study defines unmerchantable stemwood as 'that part of the stem that is unsuitable for industrial use because of undesired dimensions, species, or quality'.

Furthermore, as this wood is stemwood rather than branches or tops it is likely that the European Commission would not intend it to be included in the category eligible for quadruple counting.

To be conservative, this study does not consider the additional potential associated with logging residues from supplementary fellings, i.e. logging residues from any increase in roundwood removals that could occur. Additional roundwood removals could be possible in countries where the annual increment of forest growth is higher than the wood harvested, which is currently the case in most European Member States. Those additional roundwood removals would not be included in the potential here, but logging residues from additional roundwood removals could be included.

3.4.3 Leaves (and needles)

This study does not quantify leaves or needles separately from the potential for branches, as it is assumed that where they fall or have fallen from the branch they will be left at source and will be of too poor quality for biofuel production.

3.4.4 Arboricultural arisings

As mentioned in section 3.1.1, no statistics are collected on the volume of arboricultural arisings. Therefore the estimate of potential in this study focuses on the larger sources of feedstock – forestry residues, woody farm residues and sawmill residues – and an assessment of the potential for arboricultural arisings was not undertaken as part of this study.

3.4.5 Woody farm residues

Data from the EUwood study[138] is used as the basis for the estimate of woody farm residue potential. This study uses Eurostat data on the planted areas of orchards, vineyards and olive trees per Member State and estimates the annual increment using country studies and through engagement with stakeholders. EUwood assumes that 75% of the annual increment is harvested each year in order to be able to calculate the total wood farm residues per Member State. Our assumption is that this data includes the bark as well as the branches as it would be impractical to remove the bark.

3.4.6 Sawdust and Cutter shavings (from mills)

For sawmill residues we assume that the theoretical potential and the sustainable potential are the same as all sawmill residues can already be feasibly collected at the sawmill so there are no sustainability concerns related specifically to the collection of the material.

The starting point for our estimate is the 2010 total sawnwood and panel production volume per Member State, as published by Eurostat. Eurostat only publishes the total production, and does not

[138] Mantau et al. (2010) EUwood: Real potential for changes in growth and use of EU forests, Methodology report, section 5.1.2.1.1

provide data for coniferous and non-coniferous trees separately. This split impacts the ratio of different sawmill residue streams produced. The European Organisation of the Sawmill Industry (EOS)[139] publishes the coniferous and non-coniferous sawmill production data for 11 Member States[140] (i.e. for those countries that are members of the EOS). The relative share of coniferous to non-coniferous sawnwood production (relating to 2009) is calculated for those 11 Member States, enabling the total sawnwood volume to be split out into these two categories. Eurostat data for coniferous versus non-coniferous roundwood removals is used as the basis for the relative share of coniferous versus non-coniferous sawnwood for the remaining 16 Member States. This is considered a sound basis to calculate the split for those remaining Member States, although it does not take into account the share of coniferous to non-coniferous in exports or imports of roundwood.

The EUwood study provides estimates of the relative shares of sawnwood versus the different sawmill products per Member State for both coniferous and non-coniferous trees. The product types included are sawdust, slabwood and chips, see Figure 12. Sawdust is eligible for quadruple counting, although as discussed in section 3.1.3, we assume that slabwood and chips would not be eligible.

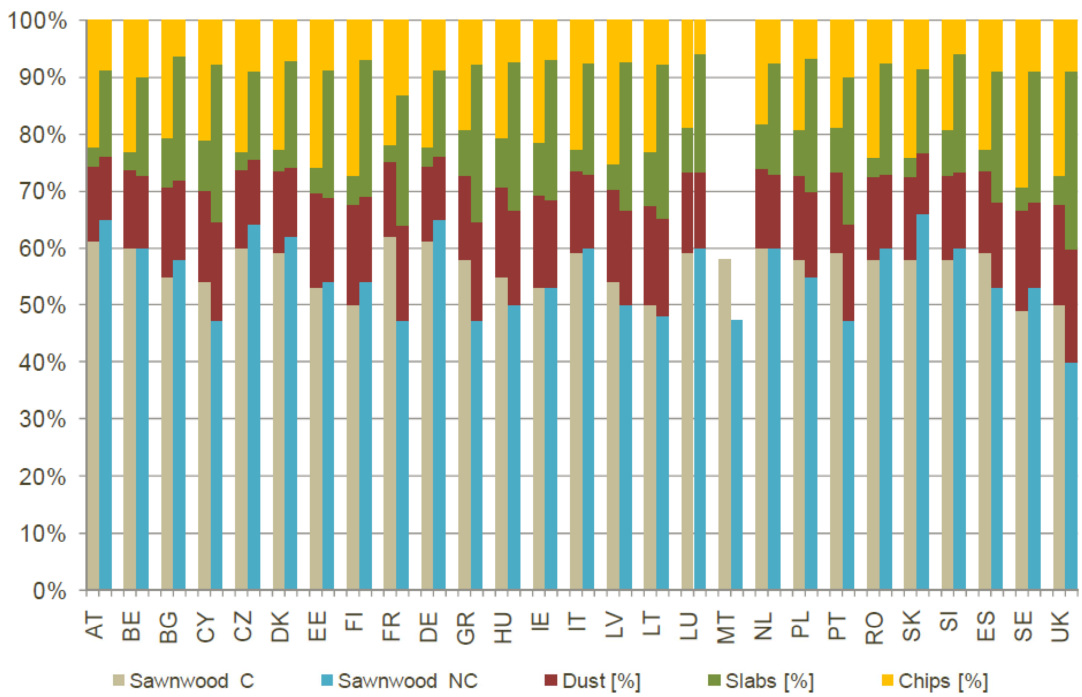

Figure 12: Percentage shares of sawnwood and sawmill residues per Member State, for coniferous and non-coniferous wood (Source: EUwood, 2010, Figure 5-10)

[139] http://www.eos-oes.eu/en/

[140] These are: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Italy, Latvia, Romania, Sweden (Norway and Switzerland are also members)

Cutter shavings arising at the sawmill are not included in the EUwood study. In the absence of a value this has been estimated as 10% of the total volume of sawmill residues for both coniferous and non-coniferous sawmills (i.e. 10% of the sawmill residues are cutter shavings), in line with FAO estimates[141].

The EUwood study defines three different sawmill size structures within the EU-27 countries, namely A, B and C. The typical size of the sawmill impacts the ratio of different types of sawmill residues produced. For example, larger sawmills will tend to invest in chippers to chip a higher proportion of the offcuts, whereas smaller sawmills may leave the offcuts whole. Countries of structure type A are characterised by mostly large and very large (>500,000 m³) sawmills, type B by large mills, and type C is characterised by medium and small sawmills only. A selection of country classifications is indicated in the table below.

Table 19: Examples of classification of EU-27 countries by sawmill structure type (Source: EUwood Table 5-9)

Coniferous sawmill size type			Non-coniferous sawmill size type		
A	**B**	**C**	**A**	**B**	**C**
Austria	Denmark	Bulgaria	Austria	Romania	Bulgaria
Czech Republic	Finland	Greece	Germany	Estonia	Finland
Germany	Latvia	Ireland	Slovakia	Netherlands	Hungary

The study then provides the relative shares of the different sawmill residue types for each sawmill size category, as indicated below.

Table 20: Percentage shares of sawmill residues by sawmill type and tree type (Source: EUwood, 2010, Table 5-10)

Sawmill type	Coniferous			Non-coniferous		
	Dust	**Slabs**	**Chips**	**Dust**	**Slabs**	**Chips**
A - large and very large (>500,000m^3)	33.32	4.53	62.15	31.66	43.40	24.97
B - large	35.26	4.93	59.82	32.12	48.84	19.09
C – medium and small	35.05	11.49	53.48	32.97	52.12	14.96

Using the above information, the proportions of all sawmill products are estimated.

Finally, the production volume of each sawmill product stream can be estimated using the above shares and the sawnwood volume per Member State. This is calculated separately for both coniferous and non-coniferous sawmills.

[141] FAO (1990), The potential use of wood residues for energy generation, Appendix VI, see: http://www.fao.org/docrep/t0269e/t0269e0e.htm#TopOfPage

3.5 Sustainable potential of woody residues in the EU

This section presents the estimated sustainable potential of the different sources of woody residue (excluding arboricultural arisings): residues from managed forests, woody farm residues and sawmill residues. In quantifying the potential the data described in the previous section are used.

3.5.1 Bark (from mills)

Bark potential in the EU-27 is estimated to be just over 62 million m^3 per year, with the largest potential in Sweden (13.6 million m^3), followed by France (9.7 million m^3), Finland (6.9 million m^3) and Germany (6.2 million m^3), see Figure 13. This potential assumes 6% loss of bark compared to the theoretical maximum potential. As bark travels to the first processing stage on the tree and the tree is de-barked at that point before processing, we would consider that this level of bark potential is feasible.

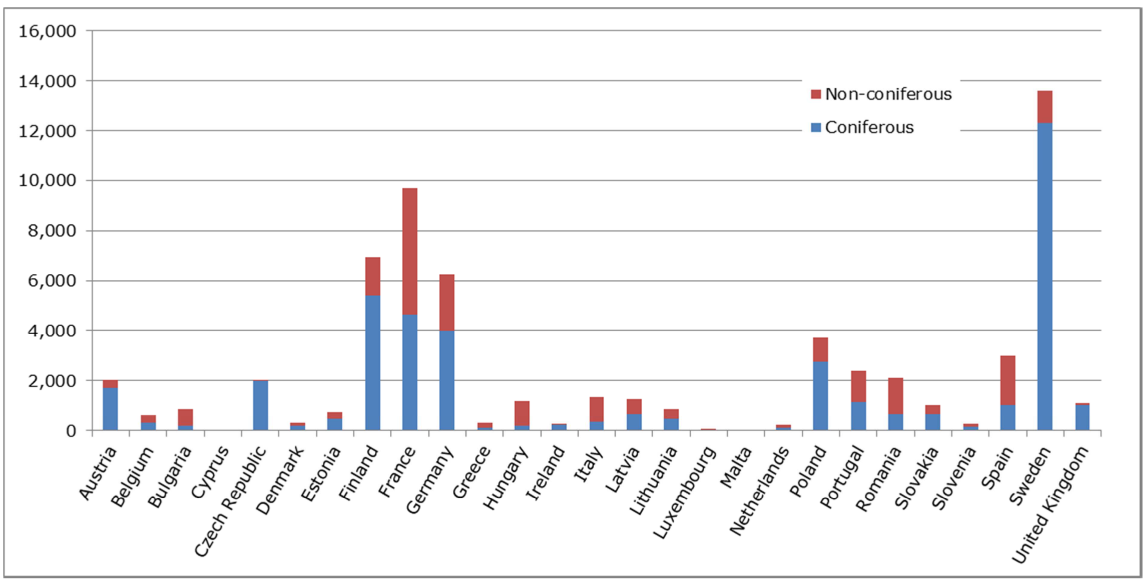

Figure 13: Bark potential in EU-27 for coniferous and non-coniferous, based on roundwood removals in 2010 from Eurostat (1000 m^3)

3.5.2 Branches and tops from managed forests

Literature estimates of potentials of forestry residues gives a wide range of estimates, in part because of the different definitions used, which can make it difficult to directly compare results. Estimates include many different assumptions, as well as different types of potentials (theoretical, technical, economic, ecological). Estimates of "forestry residues" include different assumptions about what should be included: logging residues, stumps, unmerchantable stemwood and supplementary cuttings.

The EUwood study estimates a total annual felling residue potential of 118 million m^3 including branches, tops, lower quality wood and thinnings, and stumps (stumps are only included to the extent that it is allowed to harvest stumps in each country). This estimate includes a larger scope than the estimate in this study, which focuses only on branches and tops.

Asikainen et al.[142] estimates a total annual felling residues in the EU-27, including branches, tops, stemwood loss and needles, of 211 million m^3. Of this they estimate 76.5 million m^3 to be harvestable, equivalent to 36% of estimated residues being harvestable.

The breakdown of total felling residues estimates 125 million m^3 theoretical potential from branches and tops only, therefore we extrapolate that the harvestable potential of branches and tops from this study would be roughly 45 million m^3, which is higher than the calculations for this report, but mainly because of the higher assumed residue removal rate.

Using the methodology described in this report, the total theoretical potential of branches and tops from managed forests in the EU-27 is estimated at 143.5 million m^3 over bark[143] based on the average Biomass Expansion Factor[144], or 73.4 million m^3 over bark based on the low Biomass Expansion Factor.

In line with the rationale in section 3.4.2, with a sustainable removal rate of 20% for <u>all</u> EU Member States, the sustainable potential is reduced to 28.7 million m^3 over bark using the average factor (Figure 14) and 14.7 million m^3 over bark using the low factor. Similar to bark, the highest potential for branches and tops from forests is in Sweden, followed by France, Germany, Finland and then Poland (Figure 14). It should be noted, however, that this removal rate represents an average across the EU. The actual realised potential in individual countries is likely to be higher in Sweden and Finland where significant residue removal is already practised. The potential in Germany is unlikely to be reached, with current practices not permitting residue removal.

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[142] Asikainen et al. (2008), Forest Energy Potential in Europe (EU27), METLA.

[143] The calculation is done using data for roundwood removals 'over bark', i.e. including the bark. Bark on branches and tops is included within this estimate as it is unlikely that branches and tops would be debarked.

[144] Biomass Expansion Factors is a factor used to estimate the volume of tops and branches on a tree from the volume of roundwood.

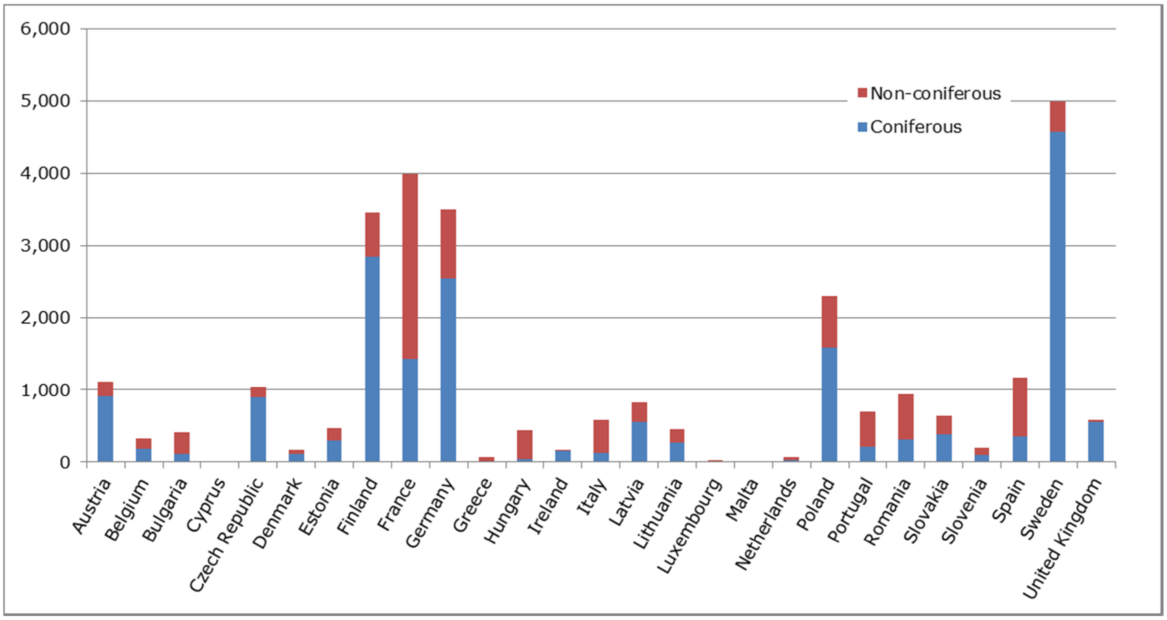

Figure 14: Sustainable potential of branches and tops in EU-27 for coniferous and non-coniferous, based on roundwood removals in 2010 from Eurostat and an average Biomass Expansion Factor (1000 m^3 over bark). Note that sustainable removal rate of 20% is assumed for all Member States.

3.5.3 Woody farm residues

EUwood[145] estimate the sustainable potential of harvested woody farm residues from olive trees, vineyards, and orchards in the EU-27 to be just under 16 million m^3, with 8.3 million m^3 from olive trees, 3.2 million m^3 from vineyards and 4.5 million m^3 from orchards. This assumes that 75% of the annual increment is harvested each year. Three quarters of this total feedstock potential is in Spain, Italy and Greece (Figure 15).

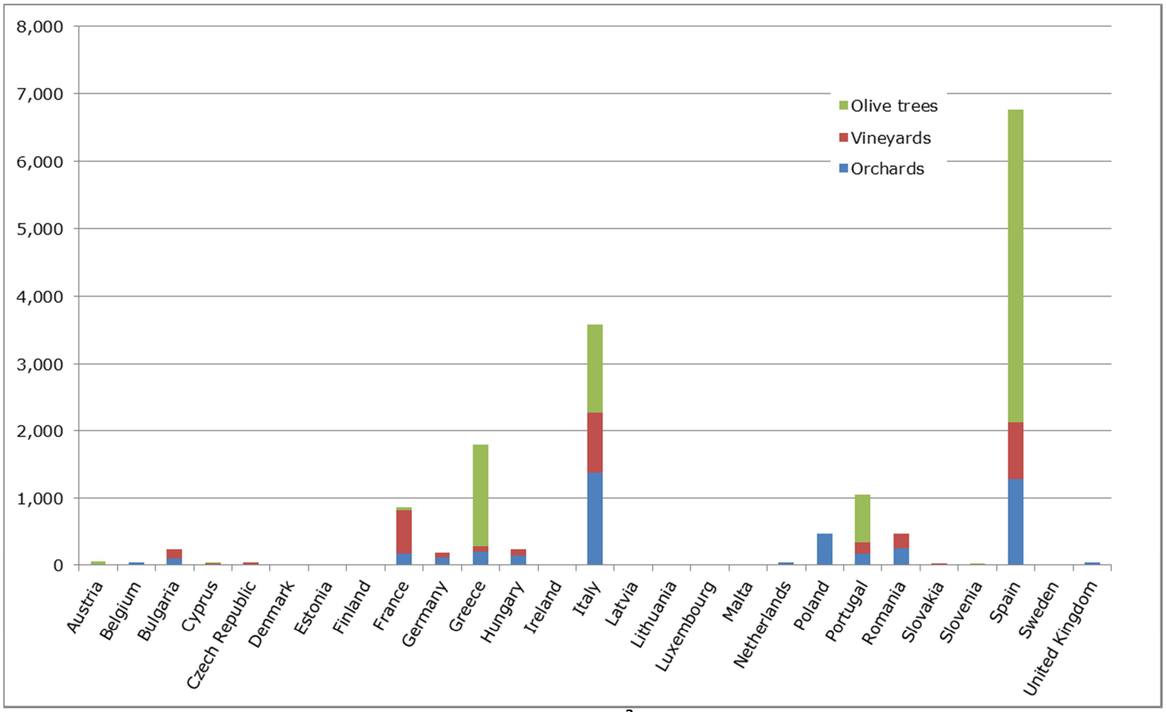

Figure 15: Potential for woody farm residues in EU-27 (1000 m^3), based on EUwood study (2010)

[145] See Mantau et al. (2010), EUwood: Real potential for changes in growth and use of EU forests, Methodology report, Annex 1, Table 1-1.

3.5.4 Sawmill residues

Potential by-product streams from sawmills are estimated to be over 100 million m^3 per year in the EU-27 (see Table 21). However this number includes slabwood and sawmill chips as well as sawdust and cutter shavings. Only sawdust and cutter shavings would be eligible for quadruple counting and are being assessed in this study. Figure 16 shows the estimated potential of sawdust and cutter shavings from sawmills per Member State, which totals 47.7 million m^3. The highest potential is in Sweden (9.6 million m^3), followed by Germany (8.9 million m^3), Finland (5.6 million m^3), Austria (3.8 million m^3) and France (3.4 million m^3), see Figure 16.

Table 21: Estimated annual sawmill by-product streams in the EU-27 (1,000 m^3)

Sawmill by-product stream	Annual potential (1,000 m^3)
Sawdust	*27,461*
Cutter shavings	*20,219*
Total	**47,680**

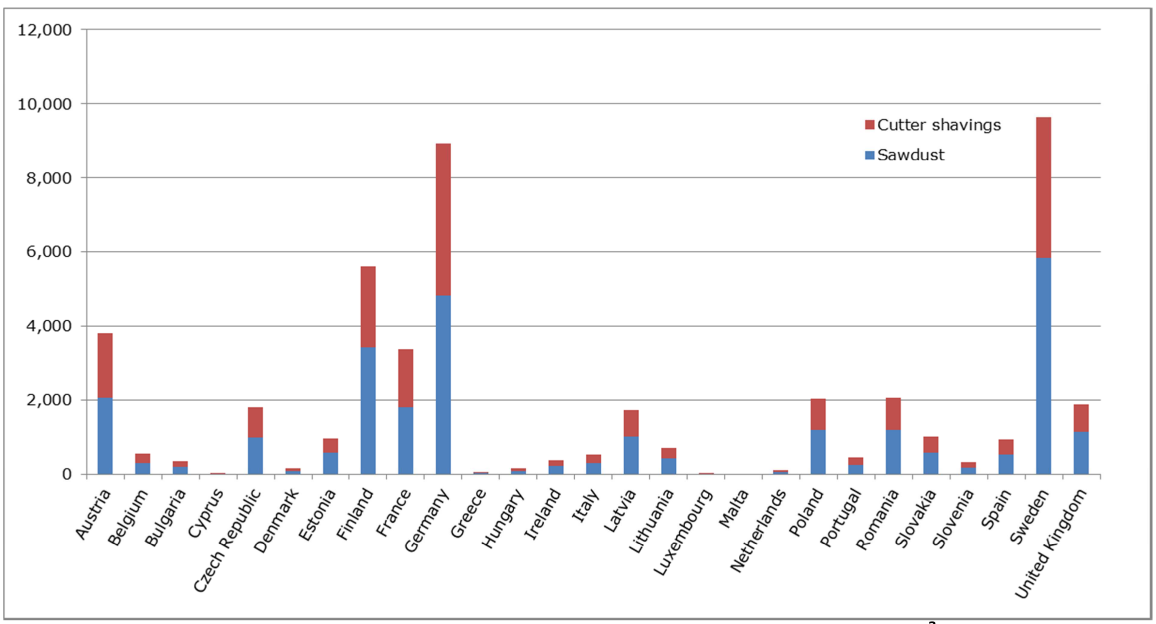

Figure 16: Potential for sawdust and cutter shavings from sawmills in EU-27 in 2010 (1000 m^3), based on Eurostat, EUwood and FAO

3.5.5 Total

The total sustainable potential of woody residues in the EU-27 (excluding arboricultural arisings) is estimated to be 162.8 million m^3 per year, with the breakdown shown in Figure 17.

Table 22: Total sustainable potential woody residues in EU-27 (1,000 m^3)

Category	Annual potential (1,000 m^3)
Bark	62,005
Branches and tops from managed forests (average scenario)	28,699
Woody farm residues	15,982
Sawdust (from sawmills)	27,461
Cutter shavings (from sawmills)	20,219
Total	**154,366**

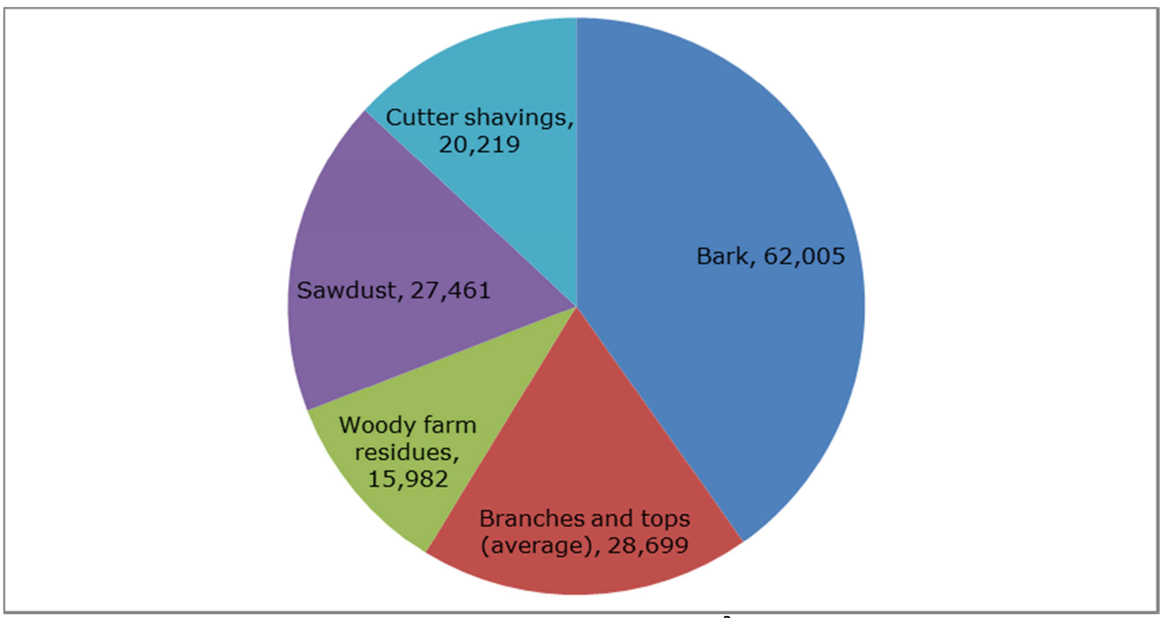

Figure 17: Overview share of woody residue sources in EU-27 in 1,000 m^3.

3.6 Current uses and their relative importance

This section discusses the existing uses of bark, branches, sawdust and cutter shavings. It is assumed that leaves are left at source. Little data is published on the uses of forestry and sawmill residues. This section is therefore based on literature review and interviews with experts from key Member States.

Summary of existing uses of woody residues and possible alternativesTable 23 gives an overview of the various sources of woody residues and their main existing uses. For each existing use, Table 24: Existing uses of woody residues and alternative materialsgives examples of alternative materials that could be used if these feedstocks were to be used for biofuel.

Table 23: Overview of sources of bark, branches, leaves, sawdust and cutter shavings.

Category	Raw material	Existing uses
Forestry residues (managed forests)	Bark (in forest)	Left in forest
	Branches (includes tops)	Often left in forest, but can be used for: wood pulp, panel board production[146], mulch, animal bedding (as fine wood chip), landscaping (parks, gardens and playground surfacing), energy generation (heating or power) and wood pellet and briquette production
	Leaves (and needles)	Left in forest
	Sawdust (in forest)	Left in forest
Arboricultural residues	Bark	Energy generation (heating) landscaping (parks, gardens and playground surfacing, including bark mulch)
	Branches	Either left at source or can be used for: Composting, mulch, animal bedding (as fine wood chip), landscaping (parks, gardens and playground surfacing), energy generation (heating or power) and wood pellet and briquette production
	Leaves (and needles)	Composting
	Sawdust	Left at source
Woody farm residues	Bark	Incineration[147], landfill
	Branches	
	Leaves	Left at source
Sawmill residues	Bark (at sawmill)	Energy (heat and power), mulch, landscaping, playground surfacing

[146] Including Medium Density Fibreboard (MDF), Particleboard or Chipboard
[147] http://www.befarmex.com/files/222_olive%20trees%20pruning%20for%20biomass%20energy.pdf; http://www.crbnet.it/File/Pubblicazioni/pdf/1450.pdf, http://www.oliveoiltimes.com/olive-oil-basics/world/olive-tree-biomass-fossil-fuel-alternative/26331

Category	Raw material	Existing uses
	Sawdust (at sawmill)	Panel board production, pulp and paper production, wood pellet and briquette production, animal bedding
	Cutter shavings	Energy generation (heat and power), wood pellet and briquette production, panel board production, animal bedding, building material

Table 24: Existing uses of woody residues and alternative materials.

Existing use	Raw material	Alternative material(s)
Left in forest	Bark, branches, leaves	Ash (from combustion of forest fuel), mineral fertiliser
Pulp and paper, panel industry	Branches, sawdust, cutter shavings	Straw (uncommon)
Mulch	Bark	Conventional compost, paper mulch, mineral fertiliser
Animal bedding	Branches, sawdust, cutter shavings	Straw, wood chips, wooden slats, other plant material (e.g. bracken, miscanthus, reed grass)
Landscaping, playground surfacing	Bark, branches	Grass (other vegetation), hard paving, synthetic materials
Energy (heat and power)	Bark, branches, sawdust, cutter shavings	Conventional fuels, other biomass feedstocks
Wood pellet or briquette production	Branches, sawdust, cutter shavings	Conventional fuels, other biomass feedstocks

3.6.1 Bark (from mills)

Experts interviewed for the purpose of this study indicated that there is no excess availability of bark from mills (sawmills and pulp and paper). Bark is stripped onsite from the roundwood and combusted in boilers to provide heat/steam and power (see section 3.6.4). In some places heat and power is also exported to the local community.

In Central and Eastern Europe, where plants are not typically integrated, a small amount of bark may be sold for mulch or landscaping / playground surfacing (e.g. in parks and municipal areas). Mulch is a relatively small end use with few recorded statistics.

The majority of the existing bark collected at mills is used to provide heat and power at the mill. If bark prices would rise significantly, if could become interesting to sell the bark and substitute energy at the mill with another fuel, but especially for integrated mills, it seems unlikely that they would want to sell the bark to another processor to produce liquid biofuel, as the bark currently provides a cheap renewable fuel source that is already available on site. Diverting bark would mean that mills would have to find an alternative fuel source, and this could be a fossil fuel source. However, as the majority of bark is used for energy generation, for the purposes of this study the bark potential can be included in the low ILUC potential.

Note it is not generally feasible to remove bark from forestry residues or woody farm residues, so this material is included implicitly in the following sections.

3.6.2 Branches and tops from managed forests

Branches and tops vary in the extent to which they are currently collected and harvested from the forest, and the extent to which it is feasible to collect and harvest them. It is more efficient to collect and harvest forestry residues if the area of forest is being clear cut, rather than if trees are selectively harvested because in the latter case the material would be too scattered.
Typically areas of forest are more often clear cut in Scandinavia where they have large unbroken areas of forest and long-established forestry industries, and more often selectively harvested in continental Europe. The nature of the terrain also impacts the ease with which forestry residues can be collected and harvested.

ECF (2010)[148] estimates that currently around 3% of forestry residues in the EU are harvested. Experts interviewed concurred that the majority of forestry residues in Europe today are left in the forest, as there is little demand for the material from the conventional wood-based industries. Only in Scandinavia is there significant level of industrial forestry residue collection, estimated to be up to 40% of technically harvestable logging residues in Sweden[148]. In Poland there is collection of forest residues for small scale local energy generation (see below). However it was stated several times that there would be significant potential to increase harvesting of forest residues if there is a demand, and therefore a price, for the material. Routa et al.[149] estimate a cost of 20-22 €/m^3 for chips from logging residues, chipped and delivered to site. The study states that efficient long-distance transport is currently the most important bottleneck for increasing the use of forest residues for energy in Finland and Sweden, which can be solved by more efficient concentration, densification and improvement of material value to allow large-scale transport. The high moisture content, high level of impurities (soil, dirt etc) and low bulk density of the material may be improved by drying, storing, screening, and sorting, combined with chipping to increase homogeneity, handling properties, and density of the material. Integration with conventional logging operations may also cut costs and increase efficiency, although this would require changes to the machinery used.

Currently the main use for harvested forestry residues is for energy generation, either directly as chips or by being processed into wood pellets or briquettes. The material could theoretically be used, for example, for wood pulp, panel board production, mulch, animal bedding or landscaping, however feedback from experts interviewed is that the main use of forestry residues collected today is energy generation. Bioenergy is also the main driver for increasing the collection of forestry residues. It is assumed that those industries that could otherwise use the material would do so if it was economically viable for them to today. As current collection rates are so low in the EU as a whole, we

[148] European Climate Foundation (2010) Biomass for heat and power – Opportunity and Economics. http://www.europeanclimate.org/documents/Biomass_report_-_Final.pdf
[149] Routa et al (2012) Forest energy procurement : state of the art in Finland and Sweden. *WIREs Energy Environ* 2012. See Figure 5.

assume that the majority of the estimated potential does represent an excess in the market that could be used for low ILUC biofuel.

The following sections give some more detail for specific Member States.

Sweden and Finland

Sweden and Finland have well established bioenergy industries. In Sweden, for example, around 85% of renewable fuels from forests are by-products from conventional forest industries, such as black liqueurs, bark, sawdust, and shavings[150].

However as those by-products are fully utilised, there is a drive to increase the collection and use of “primary” forest residues (residues from within the forest) for use for bioenergy.

According to Routa et al, the annual consumption of forestry residue chips in heating and power plants has already increased over fivefold since the year 2000 in Finland, although this includes thinnings and stumps which are not assessed in this study, but which have increased at a higher rate than more conventional logging residues (branches and tops). Logging residue use is estimated to have been 2.2 million m^3 solid in Finland in 2010[151].

To date logging residues (branches and tops) have been the most important raw material for forest chips in Sweden. Use for energy stood at 4.3 million m^3 solid in 2010.

Typical logging residue removal was approximately 35–50 m^3 per hectare. In 2010, logging residues were removed from more than 50,000 ha in Finland and 70–80,000 ha in Sweden. For both Sweden and Finland, use of logging residue chips is about half the estimated *technical* potential[152].

Poland

In Poland logging residues are currently only used for energy generation. Logging residues are collected and used mainly by local people for smaller scale local energy generation (in the countryside)[153]. It is estimated that the large scale energy industry bought 176 thousand m^3 (chips and bundles) from state-owned forests in Poland in 2011, which represents just under 8% of the estimate of sustainable logging residue potential for Poland in this study.

Spain

Similarly, in Spain the only current use for logging residues is energy generation. There is reported to be little demand for biomass for energy generation in Spain currently, but Spain is exporting solid biomass, for example to Italy. Specific collection of logging residues for bioenergy is low in Spain today. However demand from the timber industry is also lower than it has been currently, therefore in some cases, if trees are destined for a bioenergy use, foresters will harvest the tree whole (i.e.

[150] Routa et al (2012)
[151] Routa et al (2012)
[152] Routa et al (2012)
[153] Tadeusz Moskalik, Department of Forestry, Agricultural University of Warsaw, *pers comm.*

stemwood plus branches and tops). It is cheaper to chip the tree whole for bioenergy than to remove the branches and tops and then subsequently collecting them for chipping.[154]

Netherlands
Currently most of the logging residues are left on the forest floor. Clear-cut forestry is rare in the Netherlands, making the collection of logging residues less economically viable. Collection of logging residues started a few years ago, but the percentage collected is still very low. There is no structured data collection on harvest of logging residues. The only use for logging residues in the Netherlands currently is for energy generation. There are initiatives starting in the Netherlands to develop guidelines for harvesting of logging residues and for monitoring the effects on the soil and the extraction of nutrients.[155]

3.6.3 Woody farm residues

Woody farm residues are currently either incinerated or landfilled, mainly due to a lack of cost-effective harvesting technology.[156] Diversion of woody farm residues to biofuel would therefore be low ILUC.

3.6.4 Sawmill residues

Limited data is available on specific end uses of sawmill residues. Such data is not published in official statistics. Our analysis in this section is primarily based on discussions with industry experts.

A consistent view expressed is that there is <u>no</u> excess availability of sawmill residues. The residues are fully utilised in existing markets, typically in the wood processing industry, either within the sawmill itself or in pulp and paper or panel board mills, or used by local communities for heating and power. Residues are not landfilled or otherwise disposed of. The European sawmill industry has been in existence for the past 50 to 100 years, and during this time has developed integrated solutions to deal with and utilise its residues. The uses for sawmill residues varies according to the geographical region.

Scandinavia
In Scandinavia, the larger sawmills tend to be integrated with pulp and paper mills. The residues have the following uses:

- **Bark:** Combusted in boilers to provide heat/steam and power both at the sawmill and pulp and paper mill. Some heat and power is exported to local communities.
- **Cutter shavings:** Combusted in boilers to provide heat/steam and power both at the sawmill and pulp and paper mill. Some heat and power is exported to local communities. Some cutter

[154] Judit Rodriguez, Forest Technology Centre of Catalonia, *pers comm.*
[155] Anjo de Jong, Wageningen University, *Personnal communication.*
[156] Spinelli, R. and G. Picchi (2010) Industrial harvesting of olive tree pruning residue for energy biomass, Journal of Bioresource Technology 101 (2010) 730-735

shavings are also used as a construction material in Finland (for small huts), as it is a cheaper material than conventional building materials[157]. In Sweden, cutter shavings are also pelletised and used to generate heat and power or sold directly to the domestic market[158].
- **Sawdust (and chips):** These are used as a raw material in the pulp and paper industry. They are an attractive raw material due to their high fibre content, arising from the inner part of the wood.

In the smaller sawmills, some heat and power is reported to be exported to local communities. Sawmills are self-sufficient in energy production and in some cases produce more energy than they need.

Central and Eastern Europe
The situation here is very different to Scandinavia. Sawmills are not normally integrated with the pulp and paper industry. Furthermore, the pulp and paper industry is significantly smaller compared to Scandinavia, and recovered paper and recycled fibre are more widely used as a raw material instead of virgin wood.

Sawmill residues are typically used as follows:

- **Bark:** Combusted in boilers to provide heat/steam and power both at the sawmill and pulp and paper mill. Some heat and power is exported to local communities. Bark is also sold on for use as mulch.
- **Cutter shavings:** Combusted in boilers to provide heat/steam and power both at the sawmill and in separate boilers providing heat and power to local communities. Note: These plants would also take residues from the forest.
- **Sawdust (and chips):** These are in general used exclusively by the panel board industry. In Germany, sawmill residues comprise around 60-70% of the raw material input of this industry, the remainder of material comes directly from the forest[159].

A study by Döring and Mantau[160] estimates that in Germany just over 30% of sawdust and cutter shavings (combined) was sold by sawmills for energy end uses. A further 40% was sold to the wood products and pulp and paper industries. The bulk of the remainder was sold to traders, so the end use is unknown.

3.7 Low ILUC potential for woody residues biofuels in the EU

According to the LIIB methodology, a material is low ILUC if no current uses of the material are displaced, other than current bioenergy uses or forms of disposal such as landfilling and burning. This means that the low ILUC potential of bark, branches, leaves, sawdust and cutter shavings is quantified by taking the total sustainable potential and deducting all current uses except bioenergy, landfilling and burning.

[157] Kimmo Järvinen, EOS, *pers comm.*
[158] Lina Palm, Skogsindustrierna, *pers comm.*
[159] Norbert Buddendick, Deutsche Säge und Holzindustrie, *pers comm.*
[160] Döring and Mantau (2012) Sageindustrie - Einschnitt und Sagenebenprodukte 2010

Section 3.5.5 describes a total sustainable potential of woody residues in the EU-27 (excluding arboricultural arisings) of 154.4 million m^3 per year. The current collection and uses of the different materials is summarised below:

- Bark is already collected at mills. The over-riding current use for bark is energy production in the mills. **Bark from mills would be low ILUC but is unlikely to be diverted to biofuel.**
- It is estimated that around 3% of branches and tops are currently collected in the EU. Experts estimate that there is significant potential to increase collection of branches and tops in the EU in a sustainable manner. However there are important reasons to be cautious, given the ecological risks of a significant increase in the removal of branches and tops. The main existing use and the main driver for their collection is bioenergy. **Branches and tops would be low ILUC when taking ecological restrictions into account.**
- Woody farm residues are not currently collected as there is no market demand. They are currently either incinerated or landfilled. **Woody farm residues would be low ILUC.**
- Cutter shavings are currently fully utilised within the sawmills, mainly for energy. They are a preferred renewable fuel because of their low moisture content and therefore high calorific value. **Cutter shavings from mills would be low ILUC but are unlikely to be diverted to biofuel.**
- Sawdust is currently fully utilised, mainly by the pulp and paper or panel board industries. **Sawdust from mills is unlikely to be low ILUC.**

Based on the above, the potential for low ILUC branches and tops from logging activities and woody farm residues is **44.7 million m^3** in the EU-27. Bark and cutter shavings from mills could contribute a further 82.2 million m^3, totalling 126 million m^3 material, although these are considered unlikely to be diverted from their existing use providing energy generation in the sawmill. The existing uses are well established for feedstocks that arise at the sawmill. Furthermore diverting the feedstocks that provide energy in the sawmill could result in unintended consequences such as substitution with fossil alternatives.

There is a variety of possible conversion technologies in development to convert woody residues to liquid biofuel. The yield of biofuel from woody residues will depend on many sensitivities, not least the actual conversion technology and the feedstock mix. Significant efforts are going into developing technologies that would increase the yield substantially. However currently, an industry expert estimates that a (mass) yield of around 20-28% biofuel might be expected from oven-dry tonnes of woody material. With an estimate of 24%, the estimated126 million m^3 low ILUC woody material might currently be converted to around 15 million tonnes biofuel[161]. Both ethanol and biodiesel can be produced from forestry residues, see also the table on page 67. Because it is unclear which conversion technology will prevail, we assume that 50% of residues are used to produce 7.5 million tonnes biodiesel and 50% for 7.5 million tonnes bioethanol. This equals around 6.5MTOE of biodiesel

[161] Conversion factor of woody material to oven dry tonnes depends on moisture content and exact feedstock mix, but an approximate conversion factor of 1,000 m^3 woody material to 500 oven dried tonnes is used here. Source: U. Mantau, University of Hamburg, *pers comm* and UK Forestry Commission: http://www.forestry.gov.uk/website/forstats2009.nsf/0/8B4784E90B2A535480257361005015C6

and 4.8MTOE of ethanol, together a total of 11.2MTOE of low ILUC biofuel from forestry residues, which is nearly 40% of the estimated EU biofuel consumption in 2020.[162]

This study gives a good indication of the scale of possible woody residues that could be used for low ILUC liquid biofuel in the EU, but it should be noted that data on existing uses of these materials is not structurally collected and data availability is therefore very limited. Further research into the scale of existing uses, for example in particular the extent to which excess energy is currently generated in sawmills would be beneficial to provide a more accurate assessment.

[162] The National Renewable Energy Action Plans forecast a total of 29MTOE biofuel consumption in 2020.

4 Used cooking oil

This chapter aims to identify the quantity of used cooking oil which can be collected and used to produce biofuel without causing ILUC.

4.1 Defining used cooking oil

Used Cooking Oils (UCO) are oils and fats that have been used for cooking or frying in the food processing industry, restaurants, snack shops and at a consumer level. UCO can be collected and recycled to be used for other purposes. UCO can originate from both vegetable and animal fats and oils. It has to be noted that UCO from vegetable oil could nevertheless include small quantities of animal fats, depending on the products that have been fried.

In this study we will focus on UCO from vegetable oil used for cooking. Animal fats or tallow as a result of rendering processes or other waste oil that is not derived from cooking will not be taken into account.

Throughout the literature other words might refer to UCO like Waste Vegetable Oils (WVO), Used Vegetable Oils (UVO), Recycled Cooking Oil (RCO) or Recycled Vegetable Oil (RVO). We will therefore carefully assess in the literature review whether these terms are in line with our definition. Sometimes a clear distinction of UCO from vegetable oils or animal fats is not available, like for instance in the USA, UCO is the main part of "yellow grease" which might include animal fats of minor quality from rendering processes as well. So for the USA we will use the terms UCO and yellow grease synonymously. In the USA the term FOG for "fats, oils and grease" is also quite common, but defines wastes and resides from sewer pipes. Also in the USA waste derived biodiesel is produced from brown grease, which is collected from waste water treatment plants. Neither FOG nor brown grease will be assessed in this study.

In China UCO and "gutter oil" describing UCO that is blended with some fresh vegetable oil and re-sold for human consumption, cannot be differentiated, so again we will use the terms interchangeably.

4.2 The chosen feedstock-region combination

The LIIB methodology states that only the share of wastes or residues which is not used for non-bioenergy purposes within a certain region is eligible for certification as a low ILUC biofuel. For example, if 20% of a residue is already used for other purposes, only the remaining 80% of the residue in a region can claim LIIB compliance.

UCO has become an international commodity which is traded globally; it is difficult to limit the assessed region. The feedstock-region combination 'UCO from Germany' would be too narrow. While, alternatively, 'UCO globally' would not allow any differentiation between the available potential and current uses in different continents. This study therefore, assesses the low ILUC available quantities of UCO for the following five larger regions or countries: EU, US, China, Indonesia and Argentina.

4.3 Approach to estimate the potential of collectable UCO

As no statistics and reliable trade data on available UCO exist it is difficult to estimate the total potential of UCO that can be collected. Two approaches can be used to estimate the collectable UCO potential, a **top-down** approach and a **bottom-up** approach. Both methods and their pros and cons are briefly described below.

The top-down approach comprises the following steps:

(1) identify how much vegetable and animal cooking oil is used in a country;
(2) establish a UCO to cooking oil ratio (percentage of cooking oil which is left as UCO after cooking);
(3) multiply (1) and (2) to obtain the total available quantity of UCO in the country.

Benefits and challenges of top-down approach are presented in the table below.

Table 25: Pros and cons of a top-down approach

Benefits	Challenges
- Statistics on cooking oil use are usually available; - If a reliable UCO to cooking oil ratio can be identified the total quantity of UCO can be estimated in a relatively robust way.	- Very difficult to establish a reliable UCO to cooking oil ratio; - Cooking oil often does not lead to UCO but is often absorbed in the food product (cookies, margarine etc.); - Large quantities of cooking oil are used in households where it is difficult to collect UCO. Not easy to take this fact into account in the approach.

We found out during the interviews that the top-down approach was not feasible, as even big UCO generating restaurant chains are struggling to determine a ratio from fresh cooking oil to UCO due to the variety of influencing parameters.

Therefore we chose to apply a **bottom-up** approach, which works as follows:

(1) identify how much UCO becomes available at formal restaurants, fast food restaurants, snack bar per restaurant or per restaurant category;
(2) identify how much UCO becomes available at potato snack producing industry (per processing company);

(3) identify the number of restaurants in each of the different restaurant categories;
(4) identify the total size of the potato processing industry;
(5) multiply (1) with (3) and multiply (2) with (4) to obtain the total available quantity of UCO in the country.

Table 26: Pros and cons of a bottom-up approach

Benefits	Challenges
- If done well, the results can be reliable and focus on collectable UCO instead of total UCO potential (i.e. leave households out of the scope); - Enables a focus on the most relevant sectors where UCO becomes available: restaurants and potato snack industry; - Enables an insight into UCO collection practices and the UCO trading market	- Interview process is time-consuming and difficult, relies on willingness of interview partners to participate; - Approach requires aggregating results of a limited number of interviews to an entire country

If available, reliable UCO potential studies are used in this study, also when based on a top-down approach. The results of these studies are compared with the results of our assessment. Performing successful interviews with UCO collectors was crucial for the quality of this study and were the main source of information for estimating both the UCO available potential and current UCO uses and their relative shares.

Scope of the bottom-up approach

Focus on UCO collected from restaurants/snack sellers
Early in the interview process it became clear that food processing companies such as Aviko, McCain and Fritolay were not willing to share relevant information with Ecofys. This led to a decision to focus this assessment on UCO which becomes available in restaurants only and to disregard food processing companies. UCO collection from households requires a collection infrastructure which is non-existent in most EU-27 Member States. We therefore decided not to include households in our assessment. Our focus on the restaurant sector means our estimation of the collectable quantity of UCO in the various assessed regions potential will be a conservative estimate.

Focus on several cities or regions
For each region we chose the extrapolation method best suited to the local data availability. In Indonesia we focus on the capital Jakarta and two regions (East Java and West Sumatra). The focus in Argentina was on the capital Buenos Aires and a small regional city. In China we focussed on Beijing and Shandong province.
We estimated the UCO potential of the gastronomy in the EU-27 with a special focus on Spain and Germany, which have been identified as the major UCO generating countries within a previous

project where Ecofys was also involved.[163] In Spain, a UCO collectors association exists which provided us with data on the total collected UCO in the whole of Spain and the sectors which the UCO is subsequently sold to. This was an exception and usually we had to use extrapolation of interview results to come to a country-wide potential estimation. Obtaining information on the US UCO market proved difficult as no UCO collector was willing to be interviewed. An extrapolation towards a US-wide potential estimate was therefore not possible.

Legal restrictions on UCO uses

Many countries have introduced legal restrictions on the use of UCO. In the EU UCO cannot be processed into animal feed following animal diseases in the early 2000s. UCO can only be used to produce biodiesel and oleochemical products. In the USA, China, Argentina and Indonesia, using UCO to produce animal feed is allowed. It is forbidden to use UCO for human consumption in any of the regions we assessed except for Indonesia. Although in China UCO collected from restaurants is often sold for human consumption, this is prohibited by Chinese law. For each of the assessed regions we will provide an overview of the relevant laws and regulation for dealing with UCO.

4.4 Assessing the low ILUC potential of UCO in the EU

In this section, we will assess the collectable potential of UCO and its current uses in the EU-27, without taking into account the recent new member state Croatia.

The EU-27 with its renewable energy target of 10% in the transport sector (see chapter 1) has become one of the largest markets for biofuels in the world. This market is also of great interest for non-European biofuels or biofuels feedstock producers. The double-counting of UCO is seen as an incentive also for US and Chinese UCO collectors to export to Europe. We will therefore not only cover the intra-European perspective, but also assess to what extent significant amounts of UCO are traded for biodiesel production in the EU-27.

4.4.1 Background

The EU-27, with its 500 million inhabitants, has the second highest consumption of vegetable oil worldwide; only China uses more vegetable oil. In 2009 the domestic supply of vegetable oil in the EU-27 was more than 25 million tonnes. Germany, the largest EU Member State, supplies a major share with 5 million ton[164]. Therefore, while this section focuses on the entire EU, special attention will be given to Germany.

[163] BioDieNet (2009), El Libro, the handbook for: Local Initiatives for Biodiesel from Recycled Oil (Libro)
[164] FAOSTAT (2013), Domestic supply of vegetable oil worldwide

A further focus is on Spain, due to its cooking culture, which includes a lot of frying. This focus is in line with the "El Libro" the UCO study by BioDieNet, which concludes that Germany and Spain are leading in UCO availability[165].

Due to different eating habits varying from country to country an extrapolation to the whole EU-27 cannot lead to a robust figure, but can only provide an indication of the estimated UCO potential within the EU-27.

The use of vegetable oils in the EU

In the EU-27 vegetable oils are used for food production, cooking and biodiesel production. According to FEDIOL, the federation representing the European Vegetable Oil and Protein Meal Industry, 38% of vegetable oil consumed in the EU-27 was processed into biodiesel in 2010/2011 with 48% of this vegetable oil being rapeseed.

Laws and regulations relevant to UCO

There are several regulations at EU level, which deal with the management of UCO and its use for energy and oleochemical purposes. In addition, each Member State could introduce additional regulations. In this section we will outline the European directives and the specific additional laws implemented in Spain and Germany in box Box 2 and

[165] BioDieNet (2009)

Box 3.

According to the **Landfill Directive 99/31/EC** UCO is not accepted as waste at landfills. The incineration of UCO is possible as long as the plant complies with the **Waste Incineration Directive 2000/76/EC,** setting stringent criteria for plants which intend to burn UCO**.**

As a reaction to the BSE[166] scandals in the early 2000s UCO cannot be used for the production of animal feed in the EU. The respective **Animal-By-Products Regulation 1069/2009** was lastly amended in April 2013, so that the use of animal fats of all categories for oleochemical products[167] is possible in the future. This of great importance as the oleochemical industry relies on animal fats and UCO, which could equally be substituted. The more animal fat that is available for the oleochemical industry the less UCO is needed, thereby increasing the share for the biodiesel industry. In addition, the oleochemical industry prefers animal fats due to lower risk of contamination and constant quality[168].

As described in chapter 1, the EU currently discusses a legislative proposal to amend the RED and the FQD with measures aimed to address Indirect Land Use Change.

The European Biodiesel Board (EBB) is developing a database for the traceability of UCOME in order to ensure a transparent and fair market for UCOME. This initiative follows a discussion on possible fraudulent activities in the production and trade of biodiesel from UCO. Ecofys heard about amounts of UCO which have been traded twice by only duplicating the documents. The UCO industry would prefer a system similar to the US system (see chapter 4.5.1), where each drop of UCO gets a Renewable Identification Number (RIN).[169] Germany has recently introduced a law, demanding certification of all double-counting material. The point is that certification goes further up the chain, all the way to the UCO supplier instead of the point of collection. This means that the auditor has to check a sample-size of restaurants providing UCO to collectors.

As it seems, UCO collectors might be reluctant to comply with an even more stringent sustainability regime. The short-term effect could be that UCO is not sold on the German but on another European market. In the long run some UCO collectors might refrain from selling to the biodiesel industry at all. We like to stress such possible effects, although these statements were not confirmed by the UCO collectors we spoke to.

[166] Bovine spongiform encephalopathy (BSE) is an animal disease also known as mad cow disease.
[167] Oleochemical products comprise a wide range of chemical products for use in lubricants, soaps and detergents, cosmetics, pharmaceuticals, food additives, leather, paints and coatings, printing inks, rubber, plastics, metal-working. Oleochemical feedstocks are vegetable and animal oils and fats and/or petrochemicals feedstocks (www.apag.org)
[168] APAG (2013), Interview with Klaus Nottinger, Senior Counsellor APAG
[169] Petrotec (2013), Interview with Michael Fiedler-Panajotopoulos, Director Sales & Marketing Petrotec AG

4.4.2 UCO collection system in the EU

In order to understand the UCO market in the EU, information has been obtained from selected UCO collectors. Some are listed below, please note that this is not the complete list of UCO collectors who participated in the study, some prefer to stay anonymous.

- **Gelsenchem Oleochemicals Gmbh**: Based in Hamburg, Germany, Gelsenchem is a Europe-wide operating distributer of plant based products like UCO, fatty acids, soap stock and glycerine. They collect several thousand tonnes of UCO per year directly form food producers and from UCO collectors, thereby covering between 60-70% of the UCO collectors in Germany[170].
- **Petrotec AG:** A pioneer and leader in biofuels production from waste and residues, mainly UCOME, in Europe the German Petrotec has its own fat smelting plant, Vita Fettreycling GmbH. Directly and indirectly from well-known UCO collectors Petrotec collects UCO from 200,000 restaurants within Europa, but also from food processors. Individually customised storage tanks are exchanged with cleaned tanks at the UCO generating site. The collected UCO is filtered, refined and distilled after esterification. Petrotec is the largest player in the German wastes and residues biofuel market.
- **Tecosol GmbH:** With its multi-feedstock plant in Ochsenfurt, Tecosol is the second largest waste and residue derived biofuel producer in Germany. The plant runs on rapeseed oil, UCO and fatty acids resulting from rapeseed refining.[171] Each month Tecosol collects 1000t of UCO from five big UCO collectors and from their own distribution system. Tecosol provides the gastronomy with fresh vegetable oil and collects the UCO afterwards.
- **Arrow Oils:** The "Associated Reclaimers & Recyclers of Oil Waste" (ARROW) collects UCO in the UK and Ireland.
- **GEREGRAS:** The Spanish National Association of Waste Managers of Edible Oils and Fats (GEREGRAS) currently has 25 partners and management companies. GEREGRAS member companies cover about 65% of vegetable oils and animal fats collected in Spain.
- **Stocks del Valles:** Recently, Stocks del Valles became part of the SARIA Group, after the fusion of the Spanish Garnova group with SARIA España. The core business of SARIA España is rendering to produce feed and food products. The activities of the group cover the whole supply chain, from collection through transport to processing of animal by-products and used cooking oil. Stock del Valles produces biodiesel from UCO and animal fats.
- **NFK (UK) Ltd:** Directly collecting UCO from catering establishments in East Anglia, NFK also buys UCO from other collectors in the whole UK. All collected UCO is sold to biofuels generation.

In Europe, most UCO is collected from restaurants. The dominant collection system is the simple replacement of full tanks with empty tanks at the UCO generating site. However some UCO collectors

[170] Gelsenchem (2013), Interview with Thorsten Camman, CEO Gelsenchem Oleochemicals GmbH
[171] Since January 2013 fatty acids from plant oil production count double in Germany.

provide their customer with fresh oil as well to strengthen the customer relationship and to increase the response rate.

McDonald's has established in some European countries systems to take back UCO with their own distribution trucks. The UCO is transferred from the fryer in the restaurant into a rolling tank and is then pumped into a special compartment underneath the load area of the truck. With this system back haulage can be further increased. In addition to increased logistics efficiency, the traceability of the UCO collection is also further improved.
Many markets have established 'closed loop' recycling systems with UCO being recycled into bio fuels and used within their distribution fleet.[172]

Quality of UCO

UCO quality is volatile not just because it is collected from different sources. The main parameters to determine the quality of UCO are the level of cleanliness, the level of Free Fatty Acids (FFA) and the water content. The cleanliness and the amount of FFAs depends on the products that are fried, the frequency of replacing UCO with fresh cooking oil and the vegetable oil used for cooking. Preferably there are not more than 5% of FFAs in UCO. Due to the collection from diverse gastronomic entities preparing different foods, the final UCO mix needs to be hydrated and filtered in order to produce biodiesel according to the EU standard EN14214[173]. The amount of animal fats within UCO can also be different for each restaurant. Purity of variety is only guaranteed by UCO from food processors or fast-food companies[174], which always use the same vegetable oil for the same products with strict internal regulations for replacement.
On average 5-6% of pollutants such as small pieces of fried food need to be removed from the collected UCO [175]. Until 2003 it was difficult to process UCO in winter into standardised biodiesel, due to the high amount of palm oil in the UCO resulting in a higher Cold Filter Plugging Point (CFPP). Hence there was a shift of UCO from the biodiesel to the olechemical industry and to cogeneration units in winter. With the help of developed cold stabilizers this problem no longer exists and UCO with high palm content could be used for biodiesel production in winter [176].

Prices of UCO and UCOME

The higher the quality of UCO the higher the price. Our interview partners mention the following pricing order along the process.

Table 27: Comparison between prices for UCO and rapeseed in Germany

	UCO	Rapeseed
Crude oil	250-300 €/tonne	880-920 €/tonne

172 McDonald's (2013), Interview with Dr. Rolf Huwyler, Senior Manager Environment & CSR, McDonald's Europe
173 Petrotec (2013)
174 Gelsenchem (2013)
175 Tecosol (2012)
176 Gelsenchem (2013)

Filtered UCO/ Refined oil	500-550 €/tonne (small UCO collectors) 800-880 €/tonne (big UCO collectors)	950-1000 €/tonne
Biodiesel	950-1050 €/tonne	1050-1150 €/tonne

Source: Interviews with UCO collectors, UFOP-Marktinformationen Ölsaaten und Biokraftstoffe

It could be concluded that UCOME is still cheaper than rapeseed methyl ester (RME), although the UCOME is driven up due to double-counting and higher productions costs.

Our interview partners expect that the price of filtered UCO will remain slightly below the price for refined fresh vegetable oil. [177]

Existing UCO potential assessments

The main sources of UCO generation are restaurants, food processors and households. The UCO generation of food processors is difficult to extrapolate due to the different production processes and the reluctance in providing information. UCO collection from households requires an existing infrastructure, which is only in place in a few EU-MS, e.g. the Netherlands, Spain and partly Austria. Our chosen approach to focus on restaurants will therefore lead to a conservative currently collectable result, which is below the outcomes of the studies outlined here, who cover all UCO generating sources.

Only a few studies assess the availability of UCO for the whole EU-27. The majority of these studies deal with the potential of UCO in a specific region or branch. We will briefly outline the outcome of the most relevant studies.

According to Greenea, a French brokerage company dealing with waste-based feedstocks, 621,000 tonne of UCO were collected in the EU in 2010, of which 90% were used for the production of biodiesel (Greenea, 2011).

The BioDieNet project, an Intelligent Energy Europe Project for the promotion of used cooking oil for biodiesel production, where Ecofys was a project partner, assessed the collected and dumped UCO for 10 EU-MS and extrapolated their findings to the whole EU-27. According to the authors the total available potential in the EU-27 is 3.55 million tonnes, which equals 8l of UCO per capita. Restaurants have been identified as the primary source for UCO, followed by households and the food processing industry.[178] As we focus solely on the gastronomy sector in this study, the 3.55 million tonnes are considered to be the maximum theoretical potential that could currently be realised in the EU-27. However, collection of UCO from households requires a well-established logistical infrastructure, which is especially lacking in Central–Europe (eastern Member States). Bearing this in mind the

[177] Tecosol (2013), Interview with Dr. Ralf Türck, CEO, Tecosol GmbH

[178] BioDieNet (2009)

authors of the BioDieNet study estimated a lower potential of 6.26 litres per capita. Using the figures provided by BioDieNet this would result in 2.78 million tonnes of UCO available in the EU-27.

RecOil, a still running Intelligent Energy Europe project, aims to enhance household cooking oil collection for the production of Biodiesel. First outcomes are expected to be published in 2013.[179]

BIOSIRE, another Intelligent Energy Europe project, focussed on sustainable tourism in Italy, Greece, UK, Spain and Croatia by promoting the use of electric vehicles and biodiesel, also derived from UCO.[180]

4.4.3 UCO collectable potential in the EU

As described in section 4.4.1, no statistics exist on UCO and market actors active in UCO collection and UCOME production often consider all market related information as confidential. Collectors that are willing to share information do not always track the number of restaurants where they collect the UCO from and do not differentiate between the types of restaurants. This makes it challenging to obtain a reliable estimate of the total EU collectable potential of UCO. Apparently the restaurants themselves do not always gather the amount of UCO generated, which is hard to believe as they get a price per litre. In addition big UCO collectors gather mainly from sub-collectors and therefore do not have access to the source. A complete tracking of UCO down to the source is still not mandatory and therefore not common practice.

At least for UCO used for biodiesel in Germany, this will now change with the need for certification of double-counting material according to the latest German Emission Control Act (BImSchG §36), which demands traceability of UCO up to the source.

The UCO market in Europe is a highly competitive market. There is a fierce struggle to get access to UCO generating sources, and organised crime has also discovered UCO collection.[181] To ensure a reliable supply chain and avoid theft, big UCO collectors and traders often collaborate with reputable regional sub-collectors, who already have well-established contacts with the regional gastronomy. One large UCO generating company added that they could sell their UCO at a higher price, but prefer to work with a reputable organisation instead. In addition to that, increasing theft of UCO tanks has been reported.

Data on the amount of collected UCO and the availability of UCO in the EU-27 are not available. As presented above, estimations on the available collectable potential in literature sources range from less than 1 Mt to above 3.5 Mt. Our interview partners estimate that 620,000 tonnes to 1,000,000 tonnes of UCO is currently collected with a maximum potential of up to 3 Mt. This figure includes

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[179] http://www.recoilproject.eu
[180] http://www.biosire.eu/
[181] http://www.bbc.co.uk/news/uk-21858841

gastronomy, food processors and households. In the next paragraph we try to obtain an indicative figure of the UCO collectable potential from the gastronomy sector.

Extrapolation of the UCO potential with the bottom-up approach
The UCO potential was estimated by multiplying the number of restaurants in the EU-27 with an identified annual UCO ratio per entity derived from the interviews. For fast-food restaurants a higher ratio was used.

Gastronomy
The European hospitality sector, hotels and restaurants, is characterised by micro-enterprises. 92% has less than 10 employees and 99% has less than 50 employees.[182] According to Eurostat there were 840,327 restaurants and mobile food services in the EU-27 in 2010, plus an additional 69,673 event catering and other food services. According to Eurostat the category "restaurants and mobile food services" with 840,237 entities includes the following:

- Restaurants;
- Cafeterias;
- Fast-food restaurants;
- Take-out eating places;
- Ice cream truck vendors;
- Mobile food carts;
- Food preparation in market stalls;
- Restaurant and bar activities connected to transportation.

Unfortunately there are no detailed data available at HOTREC, the European umbrella association of the hospitality industry, or Eurostat regarding the different types of restaurants: small, medium and large restaurants, as well as chip or snack shops. Separate data only covering restaurants is also not available. We therefore have to use the figure of 840,327 as a basis for calculation plus the 69,673 catering and other food entities. It has to be considered that this will lead to an overestimation of the UCO potential as ice cream truck vendors and cafeterias will not generate UCO.

Within the gastronomy sector the fast-food sector, selling French fries and fried meat products, is generating most of the UCO (see chapter 4.4.3). The global fast-food sector is dominated by independent single unit enterprises, like the fish and chips shops in the UK or the döner kebab shops in Germany, which make up 55% of the global market share.[183] For the purpose of this study we will focus on the worldwide leading fast-food chains, which are active in the EU. These are in decreasing order:

1. McDonald's Corporation;
2. Doctor's Associates Inc. (i.e. Subway, which is not interesting here, as sandwich production does not generate UCO);

[182] http://www.hotrec.eu/about-us/facts-figures.aspx
[183] Wikinvest (2012), Global market share in the fast-food sector

3. Yum! Brands Inc, brand owner of Kentucky Fried Chicken (KFC), Pizza Hut (also not taken into account, due to no UCO generation) and Taco Bell;
4. Burger King Corporation.

The following table provides an overview of the number of considered fast-food restaurants in the EU-27 with detailed data for Germany and Spain where possible. For these restaurants we will use a higher ratio than for other restaurants.

Table 28: Fast-food restaurants in the EU. Sources: McDonald's Annual report 2012, Yum! Brands Annual Report 2012, Burger King Annual Report 2012

Region	McDonald's	KFC	Taco Bell	Burger King	TOTAL
Germany	1,440	93	7	684	2,217
Spain	444		10	522	966
EU-27	7,300	1,000	24	2,337	**10,661**

In Europe, KFC is mainly active in the UK with around 840 restaurants; separate figures for Spain were not available. The 7 Taco Bell restaurants in Germany are located on US military basis and are not accessible by the public. These 10,661 fast-food restaurants were excluded from the total number of restaurants, as their UCO potential was estimated with a different ratio.

None of the stakeholders Ecofys spoke to in the context of this study were willing to be directly quoted with actual figures. However some of them agreed to anonymous use of data provided by them.

We have assessed the number of restaurants and amount of UCO collected from them to calculate an average minimum and maximum ratio per entity. Due to lack of data a differentiation was only possible between traditional restaurants, which might include chip shops as well, and fast-food restaurants. The identified ratios are displayed in the table below:

Table 29: UCO ratios per unit

UCO ratio t/unit/a	Minimum	Maximum
Traditional restaurants	0.43	0.96
Fast-Food restaurants	3.37	4.11

We used the minimum ratio of 0.43 tonnes, the maximum ratio of 0.96 tonnes of UCO per unit per year and the 899,341 restaurants in the EU-27 including catering and mobile food services to determine the collectable UCO potential from the gastronomy in the EU-27. For the 10,661 fast-food restaurants the ratio of 3.37 tonnes, respectively 4.77 tonnes was used. It has to be clearly stated that due to difficulties in getting specific data and the limited number of interview partners willing to be quoted, this potential can only be considered as a rough estimate. For Germany we will use the higher ratio for traditional restaurants of 0.96t/unit/a on the basis of insights into the German UCO market.

Reliable information on collected UCO in Spain is available from GEREGRAS, the Spanish Association of UCO collectors. Its members collect 120,000 tonnes per year from the gastronomy, covering 65% of the total UCO collected in Spain. This means that 184,600 tonnes of UCO is currently collected in Spain. Almost 80%, or 146,000 tonne, of this UCO is collected from the Spanish gastronomy sector. Our interview partners in Spain unanimously state that collection from restaurants is already well organised, but additional UCO could be collected from households. We estimate the UCO collectable potential from Spanish gastronomy to be 146,000 tonnes annually (see Box 3).

The table below provides an overview of the minimum estimated UCO potential of the gastronomy in the EU-27.

Table 30: Minimum estimated UCO potential from gastronomy

Region and UCO ratio[184]	Trad. restaurants, catering & mobile food services	Fast-Food Restaurants	UCO potential trad. restaurants, catering & mobile food services	UCO potential fast-food restaurants	Total UCO potential gastronomy
UCO ratio t/unit/a			0.96	3.37	
Germany	129,448	2,224	124,270	7,486	131,756
Spain	80,314	976	UCO collected from gastronomy in 2011:		145,846
UCO ratio t/a			0.43	3.37	
EU-25 (excl. Germany & Spain)	689,579	7,461	296,519	25,115	321,634
TOTAL	899,341	10,661			**599,000**

The minimum estimated potential of collectable UCO of almost 600,000 tonnes in the EU-27 seems too low, compared with the estimations in literature and the estimations of our interview partners. The ratio of 0.43t/unit/a seems not to reflect the real situation and is apparently too low.

[184] UCO ratio means here the average collected UCO per restaurant.

Table 31: Maximum estimated UCO potential from gastronomy

Region	Trad. restaurants, catering & mobile food services	Fast-Food Restaurants	UCO potential trad. restaurants, catering & mobile food services	UCO potential fast-food restaurants	Total UCO potential gastronomy
UCO ratio t/unit/a			0.96	4.11	
Germany	129,448	2,224	124,270	9,141	133,411
Spain	80,314	976	UCO collected from gastronomy:		145,846
UCO ratio t/a			0.96	4.11	
EU-25 (excl. Germany & Spain)	689,579	7,461	661,996	30,665	692,661
TOTAL	899,341	10,661			**971,917**

Based on our analysis we estimate that a maximum of 972,000 tonnes UCO could be collected from the EU gastronomy sector. This figure is in line with estimations of interview partners on the quantity of UCO which is currently collected in the EU-27, but well below the maximum estimated potential of 3Mt. The 3 million tonnes does include UCO generated by households. As the gastronomy sector is already well covered by UCO collectors, the potential for additional UCO is expected to come mainly from households. In addition there is a further UCO generated in the food processing industry. For Germany the estimated maximum 133,000 tonnes of collectable UCO from the gastronomy also fit with the expected total available potential. Our interview partners mentioned a range from 100,000 tonnes to 200,000 tonnes of UCO for Germany.

We assume that there is no restriction in collection of the UCO from all gastronomy entities within the EU-27. The gastronomy sector in Spain is already well covered and the situation in Germany and other Western European countries is likely to be rather similar. As long as the economic incentive, through double-counting, justifies the logistical disclosure of potentially not yet covered restaurants for instance in Eastern Europe, UCO will also be collected from them.

A further extrapolation to the total UCO potential in the EU-27 is not feasible, without obtaining reliable information on UCO generated in the food processing industry and in households. In our BioDieNet project we found out that restaurants are the dominating source of UCO in five out of nine assessed EU-MS. However in three EU-MS there was more UCO generated at households and in one MS the food processing industry was dominating.[185]

[185] BioDieNet (2009)

Box 2: UCO Market in Germany

In Germany vegetable oils are used for consumer products, cooking and for biofuels production. Rapeseed oil is the main feedstock for biodiesel production with a share of 63%. In 2012 almost 22% of the biodiesel was derived from waste and residues of which 77% were vegetable residues. Half of the waste and residues originated from Germany and 27% from other EU-MS.[186]

Following the implementation of RED with the legal order on sustainability for biofuels (German: Biokraftstoffnachhaltigkeitsverordnung) only sustainably produced biofuels could be used to fulfil the national quota of 6.25% until 2015. From 2015 onwards the quota is related to GHG savings (Law on amendments in the promotion of biofuels) of 7% compared to fossil fuels. Whereas the German waste management and recycling act (Kreislaufwirtschaftsgesetz) allows the use of vegetable oil based UCO for biodiesel production, the German animal by-product regulation limits the use of animal fats for biodiesel production. According to the 36th federal emission control regulation (BImSchG §36) vegetable oil derived UCO is defined as a residue eligible for double-counting. A contamination below 10% with animal fat might be accepted, but currently there is no official definition for the level of contamination available.[187] The BImSchG §36 sets strict requirements for UCO which shall be double-counted.
These requirements have to be demonstrated by a specific certificate to ensure the following main conditions:

- Traceability up to the UCO supplier (e.g. restaurants)
- Self-declaration from UCO supplier to UCO collector with exact wording as in BImSchG §36
- Clear segregation of double-counted certified UCO and single counted UCO.
- For each batch an identification number has to be created to demonstrate when the specific quantity was received or delivered.
- Imported UCO has come from an eligible country. China (with the exception of Hong Kong), Argentina and Indonesia are not eligible countries.

Currently ISCC DE Double Counting Standard and REDcert are the only recognized sustainability schemes dealing with the requirements for German double-counting. Any UCO certified with another sustainability scheme accepted under RED will only count as single. There is a higher price for double-counted UCO, but it is also a pre-condition from fuel suppliers for buying UCOME.[188] With the implementation of the BImSchG §36 Germany sets very high requirements for double-counted UCO. We were told by commodity traders that this might prevent UCO collectors from selling UCO on the German market. In the US there is no clear distinction between used vegetable oil and animal fat, so there will be hardly any UCO from the USO being sold on the German market.

[186] BLE (2013), Bundesanstalt für Landwirtschaft und Ernährung. Evaluations- und Erfahrungsbericht für das Jahr 2012
[187] Intertek (2013), Summary UCO/UCOME requirements for ISCC DE Double Counting Standard
[188] Gelsenchem (2013)

Our interview partners report a UCO potential in Germany of 170,000 tonnes up to 200,000 tonnes.[189] Market analysts however told us that they assume a potential of double-counted certified UCO of only 100,000 tonnes. The estimated potential of 133,000 tonnes of UCO from the gastronomy sector in Germany is in line with the estimations of our interview partners, who also consider households and food processors.

According to our interview partner 80-90% of the UCO in Germany is processed into biodiesel with the rest being used for oleochemical purposes and incineration.

We can therefore conclude that in Germany 80% of the UCO could be seen as a low ILUC risk biofuel feedstock, as long as the need of the oleochemical industry can be covered by the remaining UCO and animal fats without leading to unwanted substitution of missing UCO with palm oil.

[189] Gelsenchem and Tecosol (2013)

Box 3: UCO Market in Spain

Spanish UCO management regulation is embodied in the waste management regulation (Act 22/2011). Within the context of the law, UCO can be classified as a non-hazardous municipal waste. An official UCO definition does not exist[190], as Spain has no specific legislation for UCO management.

In Spain, vegetable oils are used in the gastronomy sector, the food processing industry and private households. In households, vegetable oil is mostly used for partial frying, i.e. food is only partially submerged in oil.[191]

As for the collection, most of the UCO collectors offer the service of collection, transport and treatment. The collection system depends on the type of generator. In the gastronomy, UCO are usually collected in vessels with 50 l capacity. In the industry, collection is made using 1000 l containers. Households that collect UCO put them in plastic bottles and dispose of them in public containers (collection points).

According to a market assessment by GEREGRAS (the Spanish UCO collectors association), the UCO collectable potential in 2011 was around 300,000 t/a:

- GEREGRAS members collect around 120,000 t/a which represents around 65% of the UCO collected. Around 79% of the UCO is collected from the gastronomy, 17% from households and 4% from the industry. The collection rates in the gastronomy have declined in recent years due to the economic crisis.
- The additional collectable potential is estimated to be 130,000 t/a. This potential is expected to come mainly from private households. There are several initiatives aiming at increasing UCO collection from households, one of the lead by the local supermarket chain Eroski[192]. Collection is considered an important strategy in reducing water treatment costs.

Regarding the use, in Spain, UCO are mainly used for biodiesel production.[193] The use for human consumption and for feed is not allowed. None of the sources consulted revealed use in the oleo-chemical sector.

The low ILUC UCO potential depends on the current use in other high-value applications. Within the framework of the present assessment, no evidence was found that UCO is used for applications other than biodiesel. Based on this, the low ILUC UCO potential is estimated as similar to the UCO collectable potential.

[190] GEREGRAS (2013), Interview with Francisco Mora Jordano, Director Commercial GEREGRAS
[191] RECOIL (2013), Results of a households survey in the Cádiz province within the framework of the IEE RECOIL project ("Encuesta sobre la gestión doméstica del aceite usado en cocina en la provincia de Cádiz. Informe de resultados."). Retrieved in June 2013.
[192] http://www.consumer.es/web/es/medio_ambiente/urbano/2010/06/24/193915.php
[193] GEREGRAS (2013)

4.4.4 Current UCO uses and their relative importance

According to our interview partners 80-90% of the UCO collected in the EU-27 is used for the production of biodiesel. Other purposes include the use by the oleochemistry and energetic use. Companies like Petrotec and Tecosol with their own UCOME biodiesel plants use 100% of their collected UCO for biodiesel production.

The EU biodiesel industry competes with the oleochemical industry on the use of UCO and animal fats as a raw material. Both industries are eager to obtain the feedstocks and the promotion of the use of residues for biofuels by the EU has led to an erosion of the previous status-quo under which animal fats were reserved for oleochemistry and UCO for biodiesel. We will briefly touch upon the opposing interest and position of the two industries.

According to APAG, the European association of oleochemical industry, around 1.4Mt of oils and fats are used per year by the oleochemical sector in Europe. 700,000 tonnes of the total oils and fats used are animal fats and UCO, the latter only having a share of 70,000 tonnes. The reason for the low amount of UCO is the volatile quality. As UCO can consist of different vegetable oil the length of the carbon chain cannot always be guaranteed, this however is an essential criteria for the processing into oleochemical products. In addition the oleochemical industry struggles to compete with biodiesel producers who benefit from double-counting and could therefore pay a higher price for UCO.[194] Despite the relatively low amount of UCO used by the oleochemistry APAG is worried about the increasing use for energy purpose and states that each UCO or animal fat missing in the oleochemical sector will have to be substituted with palm oil. Thorsten Camman, CEO of Gelsenchem Oleochemicals GmbH, has stated that the lobbying aim of the oleochemical industry is that all imported UCO is classified animal fat category I[195], which would prevent the use of imported UCO for biodiesel production in Germany.

It is illegal to dump UCO in the EU. All UCO is re-used. In that sense UCO is no longer a true waste, if true waste still exists at all. Large UCO generating companies such as McDonald's or PepsiCo, owner of Frito Lay chips and world's largest snack producer have turned their waste treatment into a revenue stream. McDonald's reports that almost 90% of their UCO is sold for biodiesel production.[196] According to Richard Profit from PepsiCo all UCO generated in the UK is used for biodiesel production. In the rest of the EU-27 the UCO is used in one of PepsiCo's five own anerobic digesters at the production site or sold for biodiesel and oleochemical purposes.[197]

[194] APAG (2013)

[195] Animal fats category I defines animal by-products that have a high risk for human consumption, e.gs animals suspected of being infected by BSE.

[196] McDonald's (2013)

[197] PepsiCo (2013), Interview with Richard Profit, European Sustainable Energy Strategy Manager PepsiCo

UCO imports

Only a small quantity of Chinese UCO is reported to be imported to the EU. The UK Government reports that 163 tonnes of Chinese UCO have been processed into biodiesel in the second half of 2012.[198] As stated in Box 2: UCO Market in Germany does allow UCO imports from China. The total amount of US UCO imported to the EU-27 in 2012 was 129,446 tonnes.[199] Due to the double-counting incentive it could be well assumed that the UCO imports are completely used for the production of biodiesel.

4.4.5 Low ILUC potential for UCO in the EU

According to the LIIB methodology, a waste or residue is low ILUC if no current uses of the material are displaced, other than current bio-energy uses or forms of disposal such as land-filling and burning. This means that the low ILUC potential of UCO is quantified by taking the total sustainable potential of UCO and deducting all current uses except bio-energy and dumping.

In the EU-27 the alternative uses of UCO are biodiesel production or use for oleochemical products. According to LIIB incineration of UCO is not an alternative use and therefore does not have to be taken into account. As stated above the amount of UCO processed by the oleochemical industry is quite low. In addition animal fats are preferred by the oleochemical industry due to their longer carbon chain.

We estimate that 90% of the estimated maximum UCO potential from gastronomy of 972,000 tonnes is used for biodiesel production already and its continued use for biodiesel, does therefore not impact other current UCO uses and can thus be classified as low ILUC risk. This means that 874,800 tonnes of EU UCO is low ILUC risk. In addition the UCO imports can be added, due to their assumed use for biodiesel production. Altogether around 1 million tonnes of UCO could be processed into biodiesel in the EU-27 with a low ILUC risk. If the untapped potential of household UCO is taken into account, the potential for ILUC-free UCO use in the EU might total 3 million tonnes.

4.5 Assessing the low ILUC potential of UCO in the USA

The available potential of used cooking oil in the US which could be used to produce biodiesel without causing negative indirect impacts was researched by the Ecofys office in the USA.

4.5.1 Background

In the USA several waste and residues are used for the production of biodiesel with animal fat as the dominant feedstock.

[198] Renewable Transport Fuel Obligation Statistics (2013), Year 5, report 3, 2012/13 data tables

[199] NRA Market Report (2013), National Renderers Association, Market Report –US Rendering a $10 billion industry, Render Magazine, April 2013

In 2009 three times more animal fat were used for biodiesel than yellow grease.[200] Although yellow grease mainly consists of UCO it might include animal fats of minor quality from rendering processes as well. According to the Environmental Protection Agency (EPA) 3.8 to 11.4 billion tonnes of waste grease are produced annually, including yellow grease, brown grease, animal tallow, fish oils and FOG (fats, oils and grease) from sewer pipes and waste water treatment plants. There is a trend in the USA to go deeper into waste stream from waste from restaurants to waste from waste water treatment plants, due to lower feedstock prices. However this requires techniques to deal with higher amount of unwanted free fatty acids.[201]

It is important to note that this study focuses only on yellow grease, which is interchangeably used as UCO but not limited to cooking oil and might include lower quality residues from rendering.[202]

The use of cooking oil in the USA

The USA consumed 12 million tonnes of vegetable oil in 2009, thereby ranking as third position after China and the EU-27. Vegetable oil is used for cooking, especially frying, and for the production of biodiesel.

Gastronomy and culinary tradition

As for the other regions assessed in this study, the main focus in our assessment is on the gastronomy sector. See section 4.3 for further details. The USA has a large restaurant sector. The NPD group, a global market information provider, puts the number of total restaurants in the country at 616,018 in 2012, with 276,238 of those being chains.[203] Restaurants in the USA are mostly fast-food restaurants. Whereas the six leading fast-food chains, not taking into account Subway, have a market share of only 1.3% in the EU-27, they have a share of around 6.6% of total restaurants in the USA. Market leader McDonald’s has almost twice the number of restaurants in the USA than in the EU-27.

Table 32: Fast-food restaurants in the USA

Region	Mc Donald's*	KFC	Taco Bell	Wendy's	Jack in the Box*	Burger King	TOTAL
USA	14,157	4,618	5,800	5,817	2,877	7,183	**40,452**

***Figures also include restaurants in Canada.**

Sources: McDonald’s Annual reports 2012, Yum! Brands Annual Report 2012, Wendy’s Annual Report 2012, Jack in the Box Annual Report 2012, Burger King Annual Report 2012

[200] BioCycle (2010), Recycling local waste and grease into biodiesel, July 2010
[201] Ibid.
[202] NRA, Market Report (2013), National Renderers Association, Market Report –US Rendering a $10 billion industry, Render Magazine, April 2013
[203] https://www.npd.com/wps/portal/npd/us/news/press-releases/us-total-restaurant-count-increases-by-4442-units-over-last-year-reports-npd/

As the main products of the fast-food restaurants require frying, a higher amount of UCO per capita than in the EU-27 is expected.

Laws and regulations relevant to UCO

In 2007 the Energy Independence and Security Act amended the Renewable Fuels Standards (RFS2), thereby setting a target of more than 122 billion tonnes (i.e. 36 billion gallon) of biofuels in 2022. At least 3.4 billion (i.e. 1 billion gallon) tonnes have to be advanced biodiesel with more than 50% greenhouse gas savings compared to conventional biodiesel.[204] On federal level the USA has introduced a tax credit for 1$ per gallon for biodiesel from UCO.[205]

The USA uses Renewable Identification Numbers (RINs) to track the creation of biofuels; these RINs are generally sold as credits to fuel manufacturers who are mandated by US law to use a certain amount of biofuels in their gasoline. Each physical gallon of renewable fuels gets a specific RIN, which is registered at EPA.[206] Note that the mandate is for a fixed amount, not for a percentage, leading to unintended economic consequences as the demand for fuel in the US has dropped. Although the RIN system has been generally successful for incentivising biofuels, there have been several noteworthy cases of RIN fraud, where entities sold RINs from biofuel that was never created. Most prominently, Jeffery David Gunselman, former CEO of Absolut Fuels, was arrested on charges of selling $50 million (€38 million) of fake RIN credits, as the fuel was never actually produced.[207]

Existing UCO potential assessments

The most recent available study on the amount of UCO or yellow grease in the USA is the market report of the National Renderers Association (NRA) from April 2013. According to this report 885,000t of UCO have been produced in 2012. This projected amount was calculated by using the yellow grease production and the cooking oil consumption.[208]

Anelia Milbrandt from the US National Renewable Energy Laboratory (NREL) quoted a potential at around 9 lb/person/year, which would be 4.5 litres per capita annually.[209] Compared to the average UCO generation per capita calculated by the BioDieNet project for the EU-27 of 8 litres this seems to be too low.

4.5.2 UCO collection system in the USA

Greenergy, leading provider of transport fuel in the UK, collects about 3,000-5,000 tonnes of UCO per month from other big collectors like Baker Commodities or DARPRO Solution, a new brand comprising the restaurants and rendering services of Darling International and Griffin Industries. David Shiflett

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[204] Lamers et al (2011), International bioenergy trade—A review of past developments in the liquid biofuel market, Accepted for publication in Renewable & Sustainable Energy Reviews
[205] USDA, 2011
[206] http://www.afdc.energy.gov/laws/RIN
[207] http://www.biodieselmagazine.com/articles/9025/gunselman-sentenced-to-15-plus-years-in-prison-for-rin-fraud
[208] NRA Market Report (2013)
[209] NREL (2013), Interview with Anelia Milbrandt, Senior Energy Resources Analyst National Renewable Energy Laboratory

from Greenergy told Ecofys that Griffin alone collects from about 150,000 restaurants with different use of products for frying and variety of meals.

According to Shiflett a differentiation between used animal fats and used vegetable oils from cooking is not feasible, as some of the restaurants use vegetable oils and others use animal fat for cooking and the UCO collector is just putting everything in the same tank. He therefore doubts that UCO from the USA will be able to meet the ISCC DE Doubling Counting Standard (see Box 2: UCO Market in Germany), so that US UCO is unlikely to be sold on the German market. The UCO collected in the USA by Greenergy is completely exported to the UK for the production of biodiesel.[210]

Many UCO collectors provide collection bins to restaurants, but the theft of the entire collection bin is not uncommon. Generally UCO collectors are using a set route for their collections, driving trucks to each local, but again, this regularity plays into the hands of thieves, as they can arrive the night before when the bin is almost full. Kent Swisher from NRA even reported gun fights between two parties intending to steal the same UCO.[211]

4.5.3 UCO collectable potential in the USA

The US UCO collectors are unfortunately unapproachable and refused to provide information. Even the vice-president of the National Renderers Association, Kent Swisher did not get any response when disseminating a survey to NRA members dealing with UCO.[212] There is a general scepticism about giving information to Europeans in this highly competitive market. A biodiesel producer also operating in the USA told Ecofys that we would be very lucky if we would find a US UCO collector, who is willing to share information. As it turned, indeed no UCO collectors were willing to share information, meaning that bottom-up approach to determine the UCO potential in the USA, as described in section 4.3, could not be applied.

4.5.4 Current UCO uses and their relative importance

The U.S. Energy Information Administration gives the total use of UCO for biodiesel production in 2012 as 613 million pounds which is 278,000 tonnes.[213] This number is also confirmed in the NRA report, which stated a total UCO production of 885,000 tonnes. Therefore 31.4% of the total US UCO production has been processed into biodiesel in 2012.

As stated above some UCO collectors like for instance Greenergy export US UCO to the UK. The total amount of US UCO to the EU-27 in 2012 was 129,446 tonnes. A small quantity of 457 tonnes of UCO

[210] Greenergy (2013), Interview with David Shiflett, Director USA Division Greenergy
[211] NRA (2013), Interview with Kent Swisher, vice-president National Renderers Association
[212] NRA (2013)
[213] http://www.eia.gov/biofuels/biodiesel/production/table3.pdf

collected in the US has been exported to China. In total, the USA exported 342,782 tonnes of UCO in 2012.[214]

This leads to a current domestic UCO supply in the USA of around 542,000 tonnes of which around 50% is processed into biodiesel. The remaining share is used by the oleochemical industry or as an additive in animal feed production. According to Pacific Alternative Energy Resource (PAER) LLC for animal feed producers the free fatty acid (FFA) content of UCO has to be above 17%, whereas US biodiesel producers will not accept an FFA content above 10% and prefer an FFA content of below 5%.[215] However biodiesel producers will accept UCO with a FFA higher than 10%, depending on the installation they have. UCO with an FFA content of 10% can be used in an ordinary FAME installation. Processing of UCO with an FFA content of more than 10% requires retrofitting of the plant.

4.5.5 Low ILUC potential for UCO in the US

According to the LIIB methodology, a waste or residue is low ILUC if no current uses of the material are displaced, other than current bio-energy uses or forms of disposal such as land-filling and burning. This means that the low ILUC potential of UCO is quantified by taking the total sustainable potential of UCO and deducting all current uses except bio-energy and dumping.

The estimation of a UCO potential in the USA was not possible due to lack of information from UCO collectors, therefore the low ILUC potential for UCO needs to be assessed for the amount of UCO available in 2012.

UCO that is already used for the production of biodiesel at the time of the assessment can claim a low ILUC risk, as it is already used for biodiesel, no current non-bioenergy uses are displaced. We have good reason to assume that all UCO exported to the EU-27 will be used for the production of biodiesel, like it is done by Greenergy. Therefore the UCO used in the US for biodiesel plus the exported UCO to the EU-27 summing up to around 407,000 tonnes have a low ILUC risk.

With regard to other exports than to the EU-27 the use of UCO would have to be assessed in order to claim a low ILUC risk as well. Note that the results described above use the currently collected quantity of UCO as a starting point. We have been unable to estimate the total quantity of UCO which could potentially be collected in the USA.

[214] NRA Market Report (2013)
[215] http://pacaltenergy.com/uco.html

4.6 Assessing the low ILUC potential of UCO in China

The available potential of used cooking oil in China which could be used to produce biodiesel without causing negative indirect impacts was researched by the Ecofys Beijing office.

Figure 18: China [Source: http://commons.wikimedia.org/wiki/File:Beijing_locator_map_%28China%29.svg]

4.6.1 Background on China

The People's Republic of China is the most populous country in the world with 1.35 billion inhabitants. Due to increasing urbanisation just over 50% of Chinese citizens live in cities. China consumes about one fifth of the global total of vegetable oils each year, i.e. more than 29 million tonnes of domestic supply in 2009.[216] As China is a very heterogeneous state comprising different ethnic groups with a variety of cooking traditions, it is almost impossible to extrapolate a realistic UCO potential for the entire country. This study focuses on Shandong Province and Beijing, where relevant stakeholders were interviewed.

- **Shandong Province:** Shandong is located on the eastern coast of North China. In 2010 Shandong's total population was 95 million, which makes it the second most populated province. Shandong's economy follows the Chinese average development in China. The province was chosen as a case for our Chinese UCO study due to its high population, high cooking oil consumption as well as high UCO and biodiesel supply. In 2012, Shandong biodiesel's production reaches more than 150,000t, which makes Shandong the province with the second largest biodiesel production in China, following Jiangsu province with a biodiesel

[216] FAOSTAT (2013), Domestic supply of vegetable oil worldwide

production of 280,000t.[217] In Shandong province we interviewed UCO collectors in **Qingdao** (8.7 million inhabitants) and **Weifang city** (9 million inhabitants).

- **Beijing:** The capital of China has a population of almost 21 million people. It is the political centre of China, but has also the second highest national output per capita, after Shanghai, not taking into account the two special administrative regions, Hong Kong and Macao. Beijing was chosen as one of the most prosperous regions in China. The gastronomy in Beijing is quite diversified. Hence Beijing is a good representative of gastronomy in Chinese cities. Besides, Beijing has rolled out one of the first pilot programmes on monitoring of food waste resource utilisation in 2010.

The biofuel industry in China is very different to the biofuel industry in Europe. Conventional biodiesel (i.e. biodiesel from agricultural crops) is not produced in China due to the lack of agricultural land per capita and water issues, which prevent the use of food crops for bioenergy purposes. [218] Crop-based biofuels have been almost completely excluded as a feedstock for biodiesel by the Chinese Government, with the exemption of Jatropha and rapeseed on fallow land.[219] China is carefully looking at the bioenergy market in Europe and started to promote the use of waste and residues such as UCO. According to Chinese biofuel industry association statistics, 46 large-scale biodiesel installations were in operation with a total production of 0.88 million tonnes in 2012. However, the combined production capacity of the biodiesel producers is 2 million tonnes. The large overcapacity is partly caused by lack of economically available feedstocks and insufficient political support. Currently Hainan is the only province in China where a mandatory 5% biodiesel blend has been introduced. The latter means that there is no incentive for large fuel suppliers such as Petro China and Sinopec to blend biodiesel.

Most biodiesel in China is produced from used cooking oil and animal fat. The Middle and Long Term Development Plan of China's Renewable Energy targets a biodiesel from UCO of 200,000 tonnes in 2010 and 1 million tonnes by 2015, driven by the Government's effort to improve food security. The target has not been reached in 2010 and it is highly questionable whether the 2015 target will be met, as it is not mandatory to use biodiesel in transport. Currently Hainan is the only province in China where a mandatory 5% biodiesel blend has been introduced.

In July 2011 the Chinese Ministry of Finance exempted the fuel consumption tax of 900 RMB/t (115 €) for UCO derived biofuel to support UCO as a resource.[220] The market price of diesel is about 7600 RMB/t (966 €).[221]

[217] www.cncic.gov.cn/

[218] China Europe Bio-Energy Consortium (CEBC) (2013), Interview with Martijn Hoogerwerf, Chief Strategy Officer

[219] Qiu, et al. (2012), Liquid biofuels in China: Current status, government policies and future opportunities and challenges. Accepted for publication in Renewable & Sustainable Energy Reviews

[220] http://www.cs.com.cn/xwzx/ms/201302/t20130206_3854212.html

[221] http://www.chinatax.gov.cn/n8136506/n8136593/n8137537/n8138502/10514634.html

4.6.2 The use of cooking oil in China and relevant legislation

Fried food products play an important role in Chinese cuisine. This means that cooking oil is used in large quantities, leading to large quantities of used cooking oil in households and the gastronomic sector. The UCO quantities generated from restaurants is not constant across China.
One reason is that every restaurant has a different demand for cooking oil due to various tastes, e.g. Sichuan regional food requires more frying oil than Beijing food. Also, the quality of UCO from different restaurants varies a lot with regard to impurities. The restaurant sector is not only a source of UCO; it is also a major *consumer* of waste cooking oil. Around 10% of China's cooking oil is estimated to be illegally derived from already used cooking oil, which is simply processed and blended with fresh cooking oil and then re-sold as cooking oil to the market. This mix makes monitoring and testing of this so-called "Gutter Oil" very difficult. Using gutter oil to produce biofuels would require more complex processing compared to, for example, European used cooking oil, due to a higher degree of impurities. Used cooking oil in China is therefore more regarded as a food security issue than as a source for sustainable biofuels. Whereas the gastronomic sector sees an economic profit by using gutter oil, the collectors also benefit from lower need for machinery and investments compared to legal collection of waste oil. The illegal re-use of gutter oil for food supply creates a lot of controversies and the Chinese government has realised this as an important issue threatening the health of consumers.

In addition to gutter oil China also generates two other types of waste oil: acid oil a by-product from vegetable oil and animal feed production as well as rice bran oil derived from rice milling (Liang et al., 2012). As this study focuses on *cooking* oils, only gutter oil will be assessed further. It has to be noted that a differentiation between gutter oil and used cooking oil that is only used once, is not feasible due to lack of data and transparency. Therefore, where the term UCO is used in this chapter, it will mean gutter oil and single used cooking oil. Our interview partners told us that the illegal gutter oil market has a mafia-like structure making it very difficult to get proper information.

As it seems, the illegal black market for gutter oil is very well established and employs around 300,000 people only in Beijing.[222] This high number can be explained by the structure of waste oil collection systems in China with many sub-collectors acting as intermediaries between big traders and the generating source (see chapter 4.6.2). This structure makes it difficult and expensive for biodiesel producers to collect UCO as the collectors have a huge alternative market to sell to.

Gastronomy and culinary tradition
Dining is an important part of Chinese culture. Chinese dining is about showing respect and hospitality for guests. Chinese people increasingly visit restaurants with family, friends or for business dinners.

[222] Chinese Europe Bio-Energy Consortium (CEBC) (2013)

According to the Chinese Ministry of Commerce there are 2,367,000 restaurants in China, including traditional restaurants, caterings units and fast-food restaurants.[223] The Chinese fast-food market is dominated by McDonald's and KFC (see table below).

Table 33: Big fast-food restaurants in China

Region	Mc Donald's	KFC	Burger King	TOTAL
China	2,000	4,260	44	6,304

Sources: McDonald's Annual reports 2012, Yum! Brands Annual Report 2012, Burger King Annual Report 2012

Shandong Province has 400,000 restaurants.[224] Within Shandong Province the situation in Weifang City with 23,000 restaurants[225] and Qingdao with 22,000 restaurants was assessed.[226] Beijing has 62,000 catering entities including restaurants and hotels.[227]

Hailianghongxin Bioenergy Technology ltd. reported that UCO supply is in decline due to a new anticorruption policy by the Chinese government, which prevents the use of public money for official banquets. This policy has a negative effect on the catering business.

Laws and regulations relevant to UCO

The problem of using UCO for human food supply, i.e. gutter oil, got increased attention in recent years, so the Chinese government has introduced a stringent regulation and has implemented pilots to monitor the flow of UCO. In 2010, the Chinese state food and drug administration released a law to "strictly forbid the use of waste cooking oil for human consumption". It is thus important to note that the use of UCO for human consumption is forbidden in China.

Also in 2010, the National Development Reform Commission, Ministry of Housing and Urban-rural development, Ministry of Environment Protection, Ministry of Agriculture commonly started a pilot project aiming to improve UCO management through centralised gathering, processing and shipping. In addition these pilots shall encourage the use of waste cooking oil for biofuel, industrial oil, fertilizer or bio methane production.

Each pilot city or region has its own approach for UCO collection and use, e.g. in Yunnan province the government published a regulation that all UCO can only be used for biofuel production in order to regulate the UCO market and to promote the biofuel industry. Beijing and Shanghai have started initiatives to give financial and technical assistance to restaurants to improve UCO collecting for industrial usage. In Shandong, a pilot programme exists providing subsidies for UCO use for biodiesel production.[228]

[223] http://fms.mofcom.gov.cn/article/tongjiziliao/201306/20130600166744.shtml, figure for 2012.
[224] http://zqb.cyol.com/html/2012-07/09/nw.D110000zgqnb_20120709_6-06.htm
[225] http://Shandong.qudao.com
[226] http://business.sohu.com
[227] http://big5.xinhuanet.com/gate/big5/news.xinhuanet.com/food/2012-01/11/c_122570901_2.htm
[228] http://www.tech-food.com/news/2012-4-27/n0780270.htm

The policy and regulations in place deal mostly with the prevention of the use of UCO for further human consumption. More political support is needed to promote the legal UCO collecting industry and UCO use as a biodiesel feedstock.

Existing UCO potential assessments

There have been several attempts to assess the potential of UCO or gutter oil in China.

Prof. Ren Lianhai from Beijing Technology and Business University presented a top down approach to estimate the UCO potential in 2009. For this purpose he undertook the following calculation:

1. In 2009, the population registered in city in China is 622 million. If non-registered migrant workers are also taken into account the total city population in China sums up to 810 million.
2. Each person living in the city is estimated to generate 0.1kg of organic waste (without packaging) through cooking at home and visits to restaurants per day.
3. Therefore 81,000t of kitchen waste are generated each day in China, which results in 29.5 million tonnes per year.
4. Prof. Lianhai assumes that UCO will account for 10 or 20% of the kitchen waste.
5. The annual UCO potential in 2009 according to Prof. Lianhai ranges from 3 to 6 million tonnes.[229]

China produces more than 60 million tonnes of kitchen waste every year, according to statistics from the department of environmental science and engineering of Tsinghua University.[230]
Researchers from the Tsinghua University and the Chinese Academy of Science estimated a production of 6.58 million tonnes of gutter oil in China in 2010, which according to the authors is 2.7 times more than the UCO production of the EU, USA and Canada together.[231]

According to a SkyNRG[232] study, China produces 4.5 million tonnes of gutter oil every year. Only some of this UCO is collected, refined and resold illegally for human consumption,[233] whereas the remaining share seems to be dumped.

In 2010, Prof. He Dongping from Wuhan Polytechnic University carried out an analysis concluding that 2 to 3 million tonnes of UCO flowed back to human food production through illegal gutter oil collectors. The publishing of this study received substantial media attention and further fuelled the ongoing nationwide debate on food security in China. However, Prof. He Dongping later denied his findings. A journalist stated that Prof. He Dongping was put under pressure by government officials to deny his earlier claims.[234] UCO has since been a sensitive topic because of its direct link to food

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[229] http://www.doc88.com/p-5955999690359.html
[230] http://www.tsinghua.edu.cn/publish/env/index.html
[231] Liang, et al. (2012), Waste oil derived biofuels in China bring brightness for global GHG mitigation. Accepted for publication in Renewable & Sustainable Energy Reviews
[232] SkyNRG is a service provider for the construction of a sustainable biokerosene supply chain, which was founded by AIR FRANCE KLM Group, North Sea Group and Spring Associates (http://skynrg.com)
[233] http://www.wantchinatimes.com/news-subclass-cnt.aspx?id=20120713000060&cid=1206
[234] http://opinion.people.com.cn/GB/11219569.html

security. The study of Prof He Dongping has not been published and the professor was not willing to speak to Ecofys.

According to Prof. Wamg Cheng Ming from Huazhong Agriculture University 4 million tonnes of UCO were sold as gutter oil for human consumption in 2009.[235] This was the result when taking the national cooking oil consumption of 22.5 million ton in 2009 and deducting the domestic cooking oil production plus the imports of cooking oil summing up to 18.5 million in 2009.[236]

4.6.3 UCO collection system in China

Most restaurants in China sell their UCO to collectors. There are two types of UCO collectors:

1. **Market-driven private collectors:** acting in small teams and established a dense network of sub-collectors in Chinese cities. As mentioned in the previous chapter private collectors are accused of having ties with organised crime. As it seems a large share of private collectors can therefore be categorised as 'illegal collectors', as they are called in China. The UCO collection at the source is not professional, but undertaken with poor equipment. Due to the lack of supervision in the UCO trading market, UCO collected by private collectors is often refined and resold illegally for human consumption. This gutter oil market dominates the UCO collection in China.
2. **Official collectors:** Selected by the Government this UCO collector will collect UCO from certain listed restaurants, using a collecting vehicle with company logo and the collector wearing a uniform. Usually, this collector has an off-take contract with the industry which uses UCO as a feedstock for biodiesel or oleochemical products. The Chinese Governments want to increase the number of official collectors, in order to monitor the UCO trade and prevent the illegal re-use for cooking.

Strong competition exists between official UCO collectors and well-established illegal collectors. Due to the absence of regulation in the past the gutter oil market has grown to a huge market with many employees and a logistical network of sub-collectors in each city. Official collectors struggle to gain access to UCO generating restaurants. Some restaurants have a private deal with illegal collectors because they offer higher prices than official collectors due to higher profit margins.

Wang Qunhui, a professor at the School of Civil and Environmental Engineering in Beijing's Science and Technology University, told China Daily, a newspaper, in late July 2011 that "few scientists and scholars now want to research [biofuels], because this kind of technology is hard to commercialize as it can barely create a profit."[237] Wang qualified that gutter oil sells at about 5,000 RMB/tonne (approximately 593 €). He says the cost of biofuel processing in China is already some 4,000 to 5,000 RMB/tonne.

[235] http://roll.sohu.com/20121117/n357847522.shtml
[236] http://www.tech-food.com/news/2011-9-15/n0609670.htm
[237] China Daily (July 2011)

It will not come as a surprise that obtaining reliable data from illegal UCO collectors is near to impossible. Therefore the interview process focussed on official collectors. The following collectors have been interviewed by us:

- **China Europe Bio-Energy Consortium (CEBC):** CEBC is the shareholder of **ASB Biodiesel**, the largest UCO collector in Hong Kong and operator of a multi-feedstock plant there. CEBC focusses on the production of bioenergy from waste and has a cooperation agreement with the central Government of China, who helps them in contacting municipalities. The idea is that the Chinese government takes care of the waste collection so that CEBC can focus on the processing of bioenergy. The multi-feedstock plant of ASB Biodiesel in Hong Kong uses UCO and also animal fat as well as palm oil, as UCO is not available in sufficient quantities. The plant has a capacity of 100,000 t of biodiesel, which in theory will use 100% UCO. ASB Biodiesel collects UCO from roughly 3000 restaurants, but the collection process as such is operated by third parties.
- **Hailianghongxin Bioenergy Technology ltd.:** Hailianghongxin is the biggest government selected collector in Beijing. The company installs water oil separators at more than 1000 big restaurants and fast food shops, including McDonald's, in Beijing thereby collecting 6000 tonnes of UCO per month. All collected UCO is sold to the biodiesel production plant near Beijing. The capacity of this plant is designed for 10,0000 tonne per year. However, due to lack of UCO feedstock the actual production is 30,000 per year.
- **Shandong Weifang Sanyou Oil Company:** Sanyou is a free UCO collector which collected 50-60 tonnes every day from Weifang city area. The UCO collection involves many sub-collectors, each one selling it to a bigger entity until it finally arrives at Sanyou. This system makes it very difficult to track down the UCO to a specific generating source. Also no records or statistics are provided within the trade. Sanyou is operating as a UCO collector on city level, working together with 10 smaller UCO collectors distributed in the city. Sanyou is selling the UCO to animal feed production, oleochemical industry and biofuel producers.
- **Shanghai Lvming environment co., Ltd:** Shanghai Lvming is a biodiesel producer based in Shanghai. They purchase 1000 tonnes UCO from official collectors monthly.

4.6.4 UCO collectable potential

Almost no reliable data is available regarding the UCO generation per restaurant or food processing plant in China. It was not possible to obtain quantitative data from Chinese UCO collectors, due to the fact that they themselves do not know which quantities of UCO are collected per individual restaurant or food processor. The reason for this is the structure of the UCO collection system in China, which involves many sub-collectors selling UCO on to larger UCO collectors. Local Ecofys staff based in China did not manage to obtain access to sub-collectors. Restaurants do not track their UCO generation either. In addition the illegal gutter oil market is an obstacle in terms of getting transparent information.

Based on the information which has been obtained for the purpose of this study, a UCO ratio has been quantified, which is presented below.

The coloured cells highlight own calculation based on provided information in the given source. All sources are in Chinese and have been carefully assessed by the Ecofys office in Beijing.

For each of the targeted areas, i.e. Shandong province with Weifang City and Qingdao and Beijing, we found information about the amount of UCO generated in restaurants and the number of restaurants. Unfortunately the correlation between the restaurants and the UCO generation is only correct for Beijing. The provided amount of UCO in Weifang city is from 2012, whereas the number of restaurants is outdated and has not been updated. The same is true for Qingdao, which is a touristic area with increasing number of restaurants each year. As a result of that the calculated UCO ratios per entity for Weifang city and for Qingdao are too high and will not be used for the rough estimation of UCO potential.

Table 34: Literature on UCO ratio per entity

City	Restaurants	UCO t/d	UCO t/a	Ratio UCO t/a/unit	Source
Days			365		
Weifang city (2011)	23,000	200	73,000	3.17	Shandong.qudao.com, Shandong.gov.cn wfcmw.cn/html/cmwss/330409_2.shtml
Qingdao	22,000	300.00	109,500	4.98	Business.sohu.com
Beijing	62,000	240.00	87,600	**1.41**	Big5.xinhuanet.com

The calculation shows a potential of 1.41 t of UCO per restaurants in Beijing, which is considerably higher than the maximum UCO ratio calculated for the EU-27 (0.96t), but it is probably a realistic figure when taking into account the fact that the Chinese cuisine uses a lot of vegetable oil for frying.

We will use the estimated UCO ratio for Beijing to extrapolate to the gastronomy sectors in Shandong Province and China. Although Beijing is representative for the restaurants culture in China, this extrapolation based on one figure could lead to an indicative outcome, which could only give a first impression on the UCO potential from gastronomy in China.

For large fast-food restaurants a ratio of 4.11t of UCO per entity will be used, which is the same as for the EU-27. This is defendable because the type of restaurants and their menu are the same or very similar in China compared to the EU.

Table 35: Estimated potential of UCO from gastronomy units in China

Region	Traditional Restaurants catering units	Fast-Food Restaurants	UCO potential trad. Restaurants & catering units	UCO potential fast-food restaurants	Total UCO potential gastronomy
UCO ratio t/unit/a			1.41	4.11	
Beijing	62,000	*Not available*	87,600		
Shandong	400,000	*Not available*	565,161		
China	2,138,198	6,304	3,021,067	25,909	**3,046,976**

A rough estimated potential of just over 3 million tonne of UCO from gastronomic entities in China has been calculated. This is in line with the estimations by Prof. He Dongping and is the minimum potential estimated by Prof. Lianhai, who estimated the UCO potential per capita (see above). Higher estimations on UCO potential, e.g. from Tsinghua University, also estimate the UCO potential per capita, thereby including visits to restaurants and kitchen waste. For this reason, the indicative figure of 3 million tonnes of UCO from Chinese restaurants is a rough, but probably realistic, estimation.

4.6.5 Current UCO uses and their relative importance

As mentioned in chapter 4.6.1 most UCO in China is expected to become gutter oil, which is illegally used for human consumption. This illegal trade is not recorded so the numbers are only rough estimates. According to Prof. Ren Lianhai from Beijing Technology and Business University, 90% of collected UCO goes to the black market.

Interestingly, none of the stakeholders interviewed for the purpose of this study mentioned the re-use of gutter oil as cooking oil as one of the uses for collected UCO. Hailianghongxin reported that all collected UCO is sold to the biofuel plant in Hebei province. The same is true for ASB Biodiesel. As both of them are official collectors collaborating with the Chinese Government it is probably true that they indeed are not dealing with gutter oil.

Sanyou, a market-driven free collector operating in Weifang City, reported that 40% of their UCO are sold to animal feed producers, 20% to the oleochemical industry and 40% go to biofuel producers. Apparently no UCO is sold as gutter oil to restaurants.

With regard to the large amount of gutter oil in China of up 6.5 million tonnes per year (see chapter 4.6.1), it is clear that none of our interviewees is representing the real situation of the UCO market in China. As market regulation is weak and yet to be established, a clear market share for different industries cannot be provided. There is a debate in the EU about 'fake UCO' being imported from China and possible fraudulent practices. It is difficult to provide evidence for such practices.

However it seems that the debate led to caution on the side of potential UCO buyers from the EU to source UCO from China.[238]

Companies such as SkyNRG say that they are approaching the China market carefully and will ensure that potential future deals on sourcing are accountable and legal. No actual sourcing of Chinese UCO by SkyNRG has been confirmed to date.[239]

Some Chinese UCO is exported to the EU. The UK Government reports that 163 tonnes of Chinese UCO have been processed into biodiesel in the second half of 2012.[240]

4.6.6 Low ILUC potential for UCO in China

According to the LIIB methodology, a waste or residue is low ILUC if no current uses of the material are displaced, other than current bio-energy uses or forms of disposal such as land-filling and burning. This means that the low ILUC potential of UCO is quantified by taking the total sustainable potential of UCO and deducting all current uses except bio-energy and dumping.

We estimate a UCO collectable potential from the gastronomic sector in China to be 3 million tonnes, which is highly conservative since food processors and households are not taken into account. Based on the literature review and the interviews with stakeholders Ecofys has the impression that the largest use of UCO in China is human consumption, which is illegal in China. Some UCO is used to produce biodiesel and the Chinese government provides a financial incentive for the consumption of UCO. Whereas the Official collectors supply UCO only for biodiesel production and oleochemical processing, private collectors are accused of selling UCO mainly for human consumption to the gastronomy sector.

Around 90% of the 3 million tonnes or 2.7 million tonnes of UCO is estimated to be used gutter oil collected by private collectors. Only 10%, or 0.3 million tonnes of UCO is collected by official collectors. The 2.7 million tonnes of UCO collected by private collectors probably have a high ILUC risk since diverting UCO used as cooking oil towards biodiesel production would lead to an increased use of vegetable oil to produce food. The 0.3 million tonnes of UCO collected by official collectors is at least partly ILUC free because it is used to produce biodiesel at the time of our assessment already. From this, it seems the potential of Chinese UCO as a low ILUC biodiesel feedstock is limited, although again the situation could be different if food processors and households would be taken into account. However, UCO use for food is illegal in China and forms a threat to public health. Therefore, even though diverting UCO currently used as cooking oil probably has a positive indirect impact: it would be beneficial for Chinese public health.

[238] http://www.linkedin.com/groups/Is-there-anyone-who-has-4232424.S.115479348, Martin Hoogerwerf from the Chinese Europe Bio-Energy Consortium (CEBC) also reported this scepticism and even reluctance in Europe with regard to opportunities for UCO from China.
[239] http://www.wantchinatimes.com/news-subclass-cnt.aspx?id=20120713000060&cid=1206
[240] Renewable Transport Fuel Obligation Statistics, 2013

4.7 Assessing the low ILUC potential of UCO in Indonesia

The available potential of used cooking oil in Indonesia which could be used to produce biodiesel without causing negative indirect impacts was researched by Tractus Asia, a strategy and operations management consultancy focusing on building business in Asia. This section is based on a report by Tractus.

4.7.1 Background on Indonesia

Indonesia is one of the most populous countries in Asia with nearly 240 million inhabitants. The country consists of more than 17,000 islands of which Sumatra, Borneo (partly Malaysian), Papua (western part), Sulawesi and Java are the largest. Java is the most populated island with around 138 million inhabitants, more than 55% of the total Indonesian population. The capital Jakarta is situated on Java.

Figure 19: Indonesia [Source: http://commons.wikimedia.org/wiki/File:Indonesia_in_its_region.svg]

Indonesia has a substantial biodiesel production sector, with 1.52 billion litres of biodiesel being produced in 2011, of which 1.2 billion litres are exported. This biodiesel is mostly produced from palm oil.[241] Recently, some small initiatives have looked into using UCO as a biodiesel feedstock. Earlier in 2013, a small 1,000 tonne UCOME biodiesel plant has started operation on Bali. The plant sources UCO from 150 hotels and restaurants.[242]

Tractus research incorporated publicly available, secondary market information but is based mainly on primary data from in-person and phone interviews with governmental and industry stakeholders. Both English and Indonesian language sources were used. Interviews were focused on Jakarta, the capital city with the highest population and most restaurants.

[241] http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Jakarta_Indonesia_8-14-2012.pdf
[242] http://www.biodieselmagazine.com/articles/8924/first-biodiesel-plant-in-bali-indonesia-undergoes-commissioning

Other interviews were conducted in West Sumatra, Central Java, and East Java. It should be understood that there is very little public data on Indonesian UCO while the archipelago hardly addresses the usage and/or disposal of the waste product. Aside from the availability of information on UCO itself, there is little data on the number of small restaurants and food stall vendors in Indonesia, significant users and producers of UCO. It is also important to recognise that Tractus only interviewed one type of food processor due to the chosen focus in this study on the gastronomy sector. However, it is important to mention that many food processors may have economically viable volumes of UCO that should be examined more closely. Given the constraints to the research, Tractus estimated the total volume of UCO based on the available data and our extrapolation of this data. As indicated already in chapter 1, the total collectable UCO potential is only an estimate and should not be taken as a definitive value, but instead as a guideline on whether Indonesia presents significant potential for UCO and should be further examined and analysed.

4.7.2 Gastronomy in Indonesia

As in the other regions assessed in this study, the UCO potential assessment focuses on UCO generated in the Indonesian gastronomy sector, although some attention will be given to food processors as well.

The Indonesian food culture involves a lot of fried dishes, with products such as tofu, tempeh and meat products being fried. Typically, most restaurants in Indonesia are informal restaurants, so called 'padang' and 'warteg' restaurants. Padang and warteg restaurants are typically informal food vendors that sell a variety of fried and un-fried Indonesian foods. Padang restaurants typically cook a majority of the food in the morning before opening for business and sell the food throughout the day. A limited amount of cooking actually takes place at a Padang restaurant; instead the food is cooked at home or at a centralised kitchen, and then brought to outlets. The Jakarta Warung Padang Association estimates that there are approximately 20,000 Padang restaurants operating in Jakarta alone. *Wartegs* usually make food to order. *Wartegs* use varying types of cooking oil. Jakarta local government estimates that there are approximately 35,000 *wartegs* operating in Jakarta. In addition to the padang and warteg restaurants, many street vendors or 'kaki limas' who roll out a cart each day and sell their specialty snacks are active in Indonesia; this category is taken into account as well. It is almost impossible to determine the number of kaki limas in any locality in Indonesia as no statistics are available due to their informal, transient nature. A more in-depth description of the various types of gastronomy and the number of actors involved is given in section 4.7.4 below.

Laws and regulations relevant to UCO

Tractus compiled a list of rules and regulations that may apply to the usage and/or disposal of UCO in Indonesia. Based on Tractus' research, the only regulation pertaining directly to UCO is Ministry of Environment Law Number 04 of 2010 on Waste Water Quality Standards for Business and/or Industrial Cooking Oil Company Activities. This law simply includes UCO as a type of pollutant that must be considered when industrial companies dump any type of waste and/or waste water into rivers, the sea, or other water resources.

Tractus did not find any relevant regulations on restaurants and small-scale cooking oil using companies or health codes on the use of used cooking oil for human or animal consumption. This means that **UCO is allowed to be used for human consumption in Indonesia.** Moreover, stakeholders along the supply chain confirmed that they have not faced any regulations on using UCO for food products. Additionally, no environmental laws are highlighted other than 04/2010 on waste water standards. Stakeholders interviewed stated that there are no regulations applied to how they use or dispose of UCO. It should be noted that legal enforcement is quite weak in Indonesia, especially on environmental and health issues, although there may be a mechanism that Tractus did not find which prohibits excessive dumping or using UCO for human consumption.

Existing UCO potential assessments
No useful literature on the available quantity of UCO in Indonesia is available. Tractus' research therefore heavily relied on interviewing relevant stakeholders.

4.7.3 UCO collection system in Indonesia

Collecting UCO in Indonesia is challenging given the fact that the country consists of over 17,000 islands which poses a logistical issue. Another challenge is the decentralised generation of UCO. Street side vendors or kaki limas generate considerable quantities of UCO but in small quantities per kaki lima. Collecting them requires a considerable effort. Three large UCO collectors are active in Indonesia, especially on the most populous islands of Java, Sumatra and densely populated Bali. In addition, several smaller collectors are active. The large collectors typically use sub-collectors who amass UCO through their own strategies. Both a large collector, several smaller collectors and several subcollectors have been interviewed for the purpose of this study.

Collectors interviewed in this study stated that they prefer sourcing from food processors and large restaurants as the volume and quality is better. Collectors do find it difficult to source from kaki limas as they are spread out across the country, have smaller volumes and it is a challenge for the kaki limas to store UCO until pickup. If the price of UCO would increase, collectors would extend their reach to accumulate more of the resource, especially on the islands of Java, Bali, and Sumatra where they are already active. Even if the price of UCO was substantially higher, it is unlikely that Papua, Kalimantan, or Sulawesi would ever become centres for UCO as the low population density and underdeveloped infrastructure hinder efficient transportation. The largest UCO collector in Indonesia stated that they only collect a small amount of UCO from one city on the island of Sulawesi, Makassar, while the company does not collect any from Papua or Kalimantan.

4.7.4 UCO collectable potential in Indonesia

Based on an interview with Indonesia's largest collector we estimate that the three large UCO collectors active in the country currently collect approximately **10,000 tonnes per month or 120,000 tonnes a year**, assuming they source a similar amount. In addition to these large collectors several smaller collectors are active. The aim of this study is not to establish how much UCO is currently collected but how much UCO could potentially be collected.

The section below details the estimated total quantity available in Indonesia. The focus is on UCO generated in gastronomy, although also the food processing sector is taken into account.

UCO from food processors

Food processors are a large source of UCO in Indonesia. Tractus found decent data on the number of food processors in Indonesia from the Ministry of Industry. The data is differentiated by product, but does not delineate the size of the factories nor the total unit output. Below is a table characterising the Indonesian food processing industry, significant producers of UCO.

Table 36: Number of food processors in Indonesia

Category	2013 Factories	2010 Factories	Output value 2010 (in Rp.)
Peanuts, tofu and tempe	502	201	1.936 billion
Noodles	400	298	7.150 billion
Krupuk & keripik (Indonesian chips)	644	872	2.087 billion
Other processed foods	891	201	1.971 billion
Total	2,437	1,572	13.144 billion

Source: Indonesia Ministry of Industry

Tractus' interviews with UCO collectors highlighted that food processors are consistent suppliers of UCO. The largest collector in Indonesia stated that 70% of their UCO comes from food processors. If this would be the case for all three large collectors, **the quantity of collected UCO from food processors would be 70% of 120,000 tonnes, which is 84,000 tonnes.** This quantity should be regarded as the minimum quantity to be available from food processors. One food processing company, Wings, sells a tanker truck of UCO to the largest Indonesian collector every day. Indofood, the largest food processor in Indonesia did not respond to repeated requests for interviews. The number of food processors has grown rapidly in the past three years offering an increased supply of UCO. We believe that this trend will continue as foreign and local investors continue to set up operations to sell to Indonesia's populace and take advantage of the low-cost manufacturing environment.

Tractus focused on one segment of the food processing industry, fried chips factories (krupuk & keripik) and interviewed nine from West Sumatra and Java. Interviews with both the *krupuk* and *keripik* factories resulted in a wide variation of responses, but all indicated potential as a source of UCO. A majority of these factories did not sell their UCO to a collector, nor have they been approached by collectors.

One company stated that they use their UCO as machine grease, another that they dump their UCO as waste, one gives their UCO away to employees to use at home for human consumption, while others either filtered and reused or added additional crude palm oil to UCO and continued to fry, similar to 'gutter oil' used in China. Although each of these respondents did not sell their UCO, all of them expressed interest in selling their UCO to a collector if one came to pick up the waste.

Averaging the wide ranging interview responses of a limited number of interviews, *krupuk* and *keripik* factories produce approximately 2.8 tonnes of UCO per month. In 2013, Indonesian statistics estimate that there are 644 ***krupuk* and *keripik* factories** that could potentially **supply up to** 1,803 tonnes of UCO per month or around **22,000 tonnes per year.** It should be noted that this is a *potential* amount of UCO able to be collected as many of these chips factories would likely continue to use old UCO in their production process. Companies stated that if somebody were to purchase their UCO, they would use less to refry.

For this research project, Tractus focuses mainly on the restaurant industry. More research would need to be conducted in order to determine how much UCO each of the food processor segments use and/or produce and what they are currently doing with UCO. Tractus feels that this is an important piece of information to determine Indonesia's potential for UCO as the largest UCO Collector in Indonesia stated that 70% of his UCO comes from food processors. As described above, the minimum quantity of UCO available at Indonesian food processors is 84,000 tonnes per year.

UCO from gastronomy

As stated above, the Indonesian food culture involves a lot of fried food products and Indonesians are used to regularly eating out, often in small informal padang or warteg restaurants or at kaki lima street side vendors. Below the quantities of available UCO will be assessed for each gastronomic category. A description of the categories will be given as well as an estimate of how many restaurants/vendors are active in Indonesia. This data, combined with an estimate of UCO which is generated per individual restaurant/ventor, will lead to an indicative estimate of available UCO from Indonesian gastronomy. Below is a description of the findings from restaurants.

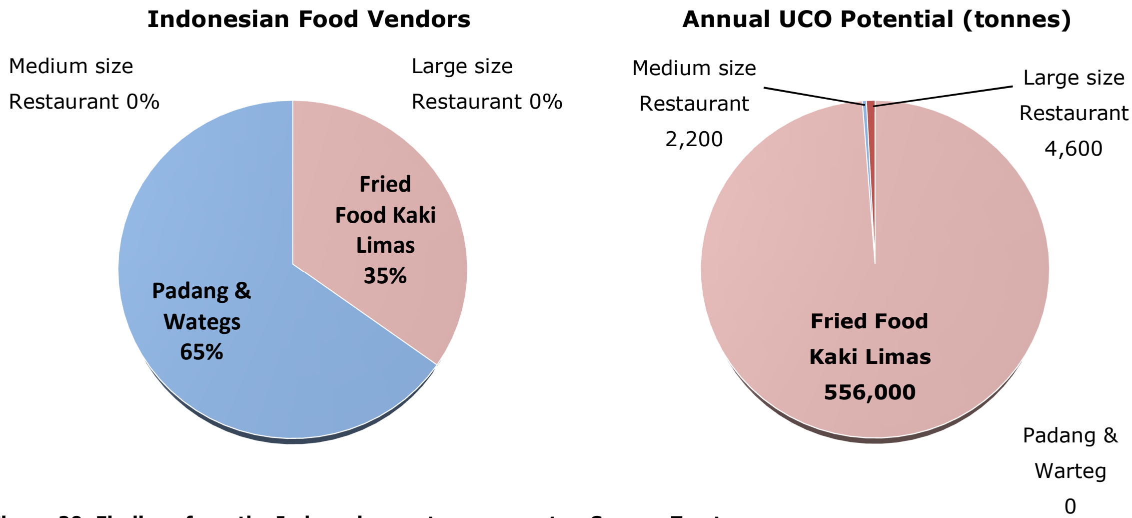

Figure 20: Findings from the Indonesian gastronomy sector. Source: Tractus

<u>Medium and large size restaurants</u>

In 2011, the Indonesia Statistics Agency (BPS) stated that there are 2,977 medium and large sized restaurants across Indonesia, 1,361 (46%) of which are in Jakarta, the capital. 55% of these restaurants are Indonesian, 25% American/European, 14% Chinese and Japanese, and the other 6% classified as other.

Tractus interviewed two medium sized restaurants and one hotel with five large sized restaurants. On the low end, based on the data provided we estimate one medium sized restaurant produced approximately 70 kg of UCO per month, while the Le Meridien's overall food and beverage operations generated over 1.875 tonnes per month (averaging 340 kg per restaurant). Most medium and large sized restaurants sell their UCO to collectors, while the hotel paid a waste management company to dispose of their UCO.

Aside from the restaurants above, Tractus interviewed four fast food chain outlets including KFC, McDonald's, Burger King and J. Co Donuts. Aside from J. Co donuts, which uses all of its cooking oil in its products, KFC, McDonald's and Burger King each use varying amounts of cooking oil where quantities used depend on the popularity of the outlet.

Each of the fast food restaurants has contracts with UCO collection companies who purchase the used cooking oil. McDonald's corporate stated that they typically sell their UCO for approximately Rp. 4,000/litre (approximately €0.30) which equates to about €300 per tonne.

To make a conservative estimate on the total amount of UCO available from restaurants, Tractus assigned an estimate of 70 kg of UCO per month for medium sized restaurants and 570 kg per month for large restaurants.

Based on the small sample of interview responses and associated restaurant data we calculate that Indonesia has approximately 2,367 medium sized restaurants and 610 large sized restaurants that could potentially supply 2,200 tonnes and 4,600 tonnes of UCO per year, respectively.

Padang and Warteg Restaurants

Padang and warteg restaurants are typically informal food vendors that sell a variety of fried and unfried Indonesian foods. Padang restaurants typically cook a majority of the food in the morning before opening for business and sell the food throughout the day. The Jakarta Warung Padang Association estimates that there are approximately 20,000 padang restaurants operating in Jakarta alone.

A majority of padang restaurants are not legally registered or regulated. Tractus interviewed a number of padang restaurants, including "Murah Meriah," a group that owns 80 padang restaurants across Java. Padang restaurant owners stated that they **do not have leftover cooking oil** because they use it to make a number of other dishes with the UCO such as curries, sambal (chili pepper sauce), and rendang (beef dish).

Wartegs usually make food to order. Wartegs use varying levels of cooking oil, depending on the fare. Jakarta local government estimates that there are approximately 35,000 wartegs operating in Jakarta. Tractus interviewed 3 different wartegs, where each of them stated that they waste/sell very little UCO because, similarly to padang restaurants, they use almost all of their UCO for various dishes.

In order to estimate the total number of padang and warteg restaurants in Indonesia, Tractus took the total population of Jakarta, 10.19 million, and divided by the total number of these restaurants in Jakarta, 55,000. That equals 185 people per padang or warteg. Applying this number to the total population, 240 million, Tractus estimates that there are approximately 1.3 million of these small restaurants across Indonesia.

As both warteg and padang restaurants use almost all of their UCO as raw materials for their food production and each of the stakeholders interviewed stated that they waste very little to no UCO, Tractus does not think this is a reliable source for UCO and is not calculating it as a potential supply.

Kaki limas

Kaki limas are small, mobile food stall vendors. They are informal and unregulated, where the operators roll out a cart each day and sell his/her specialty snack. It is almost impossible to determine the number kaki limas in any locality in Indonesia as no statistics are available due to their informal, transient nature. Although no data is available, they are significant users, sellers, and disposers of UCO.

As there is no data available on the number of kaki limas in Indonesia, Tractus applied a rough methodology to estimate a number. A Tractus representative walked for 1 kilometre in a neighbourhood in Jakarta.

The Tractus representative counted a total of 23 kaki limas during this walk, 6 of which sold fried food (26%) and 17 non-fried foods. The total road area of Jakarta is 40.1 km^2 or 7,640 kilometres. After calculating a total number of kaki limas for Jakarta and discounting the total number by 33% (as there are fewer kaki limas in business districts and along highways/toll ways) Tractus estimates that there are approximately 30,650 kaki limas that produce fried foods in Jakarta alone. Using population data of 10.19 million people living in Jakarta, this means that there are approximately 332 people per kaki lima selling fried food. Applying this formula to all of Indonesia, where there are 240 million people, Tractus estimates that there are over 700,000 kaki limas selling fried food across Indonesia.

Tractus interviewed five different kaki limas street side vendors who produced varying levels of UCO, ranging from 11 – 360 kg per month. There is significant variation in kaki lima's usage and disposal of UCO, depending on the type of food sold, location, and popularity. Some used new cooking oil and then fry with the same oil for a number of days, while others would purchase filtered UCO, and continue to fry their snacks for a couple days. Additionally, 40% of kaki limas interviewed stated that they sell their UCO to a collector, while the other 60% stated that they simply dump their waste. The only regulatory issues kaki limas face is policemen asking for "rents" for operating on the streets.

Using this estimate of 700,000 kaki limas, averaging UCO production of 60 kg per month (using interview results and discounting the average by 50% as many kaki limas interviewed were heavy fryers in market areas who fry more than typical kaki limas), Tractus estimates that kaki limas across Indonesia generate over 46,297 tons of UCO a month, or **over 556,000 tonnes a year**. Using this estimate of 700,000 kaki limas, averaging UCO production of 60 kg per month (using interview results and discounting the average by 50% as many kaki limas interviewed were heavy fryers in market areas that fry more than typical kaki limas). From Jakarta alone, kaki limas produce 24,326 tonnes per year. It should be noted that this is a rough estimate based primarily on Jakarta interviews and applying an estimated discount rate. Moreover, it may not be economically feasible to collect UCO from kaki limas across the archipelago as kaki limas are spread out, transient and may operate in rural areas where collectors typically do not venture and poor infrastructure hinders efficient transportation of UCO. However, as many kaki limas in Jakarta are currently selling UCO to collectors we believe that there is significant opportunity to source more UCO from Jakarta and other larger cities if there is a viable means of storage and collection and the price for selling UCO is attractive enough for collectors. This would encourage kaki limas to save their UCO in order to earn revenues from their waste. One suggestion to help encourage kaki limas to save their UCO is to open a small storage facility in areas with high concentrations of kaki limas, allowing them to more easily accumulate their UCO in a central location throughout the week.

Collectable UCO from gastronomy

Based on what's described above, Tractus estimates that **restaurants and food stall vendors can supply conservatively 46,864 tonnes per month, 562,364 tonnes of UCO annually**.
These numbers are likely conservative considering the average UCO amount assigned to UCO production facilities and the fact that the three large collectors do not cover the entire country.

The largest three UCO collectors estimate the market potential to significantly increase if prices were to go up.

Total collectable supply of UCO from gastronomy in Indonesia

Tractus estimates that more than 646,800 tonnes of UCO is available per year in Indonesia, including an estimated share of 84,000 of UCO from food processors and the rest mainly coming from kaki limas street side vendors. The breakdown of total available UCO in Indonesia is provided in the diagram below.

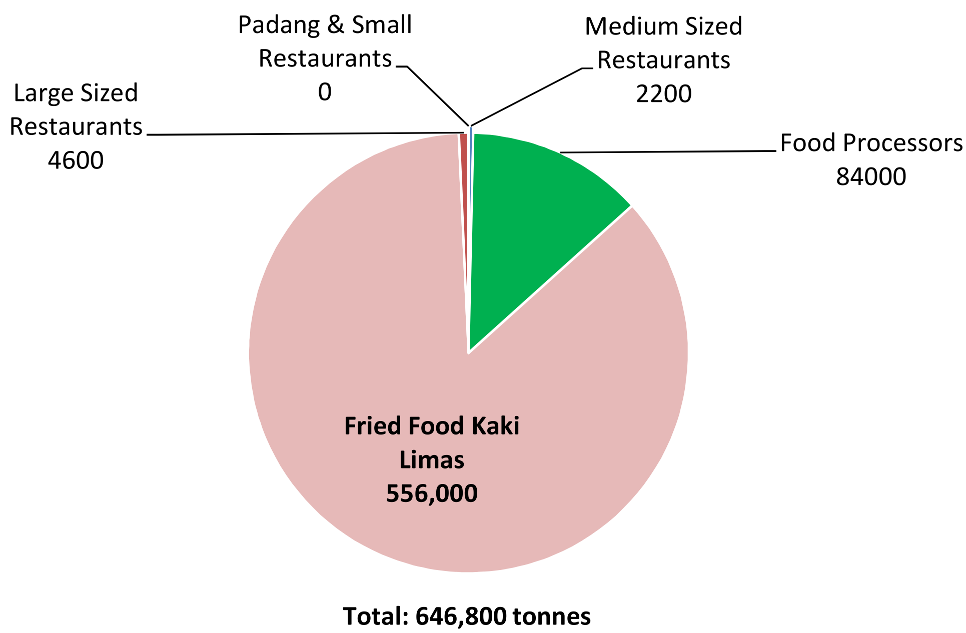

Figure 21: Indonesian Annual UCO Supply (tonnes)

4.7.5 Current UCO uses and their relative importance

Based on interviews with collectors and the prevalence of diverse, often cheaper palm oil derivatives, Tractus believes local demand for UCO to be quite small. Anecdotes from collectors highlighted that some tofu, tempe, and peanut factories, animal feed companies, cosmetics, and oleochemical companies do use UCO in their production process, but this seemed to be a small number. Small-scale oil vendors who sell at traditional markets may source an unknown amount of Indonesian UCO. There are also a small number of biodiesel producers using UCO as a source for fuel.

The current market sale rate for UCO from the large collectors is Rp. 7,500 per kg or €565 per tonne. Shipping is not included in this price. Garupa Mas Lestari stated that they export all of their UCO at this price. Almost all of the 120,000 tonnes of UCO collected by the three large Indonesian collectors is being exported, mainly to the EU.

The largest collector, Garupa Mas, exports all of its UCO to the EU, mainly to Germany[243] and the UK. This means that local industry most likely sources from smaller vendors that probably charge less money for the resource. Below is a table with the Indonesian UCO users, also indicating the size of these sectors.

Table 37: Consumer Goods Manufacturers

Category	2013 Factories	2010 Factories	Output value 2010 (in Rp.)
Soaps and household cleaners	62	49	4.446 billion
Animal feed	99	68	27.945 billion
Cosmetics	83	80	9.196 billion
Tofu, tempe, and peanuts	502**	201	1.936 billion

****Some tofu, tempe, and peanuts producers may or may not use UCO as their primary cooking oil**
Source: Indonesia Ministry of Industry

In addition to the demand for UCO from consumer goods manufacturers, a number of biodiesel producers are already using UCO in Indonesia as a raw material source. Biodiesel's popularity is on the rise as the archipelago is blessed with an abundance of palm and other biomass products that can be turned into biodiesel. Although biodiesel itself is popular, the usage of UCO as a source for biodiesel is quite low as it is much easier, and often more economical, to source other palm derivatives.

Even though UCO is not yet a popular biodiesel resource, there are a number of companies and organisations that collect, clean, and convert UCO to biodiesel. Tractus talked to a UCOME producer in the city of Bogor and to PT Freeport Indonesia. Both Freeport and Bogor collect large amounts of cooking oil and turn it into biodiesel to fuel their vehicles. Freeport collects its UCO from the company's mess halls in Papua, while Bogor sources from a number of large companies and restaurants. The independent biodiesel producer makes approximately 6,000 to 9,000 litres of biodiesel a month (converting 11 to 17 tonnes of UCO per month).

Aside from direct consumption, Tractus heard that vendors at traditional markets sell UCO on the secondary market. Tractus interviewed three such vendors. It would be next to impossible to estimate how many such vendors there are across Indonesia. Tractus could not determine whether the oil for sale was filtered and/or cleaned UCO, unbranded crude palm oil (CPO), or a mix of UCO and CPO. The vendors in the markets stated that they source their oil from a variety of distributors that sell cooking oil cheaper than it can be purchased wholesale. These small scale vendors sell one to two tonnes per month to both kaki limas and household consumers.

[243] Currently this UCO would be no longer eligible for double counting in Germany following the implementation of stricter regulation; possibly this information refers to last years' export destination.

4.7.6 Low ILUC potential for UCO in Indonesia

According to the LIIB methodology, a waste or residue is low ILUC if no current uses of the material are displaced, other than current bio-energy uses or forms of disposal such as land-filling and burning. This means that the low ILUC potential of UCO is quantified by taking the total sustainable potential of UCO and deducting all current uses except bio-energy and dumping.

A large quantity of UCO in Indonesia, maybe even the majority, is re-used for human consumption. This because UCO generated in informal padang and warteg restaurants, which form the backbone of the Indonesian restaurant sector, is almost entirely being re-used for food. This means that UCO generated by frying chicken or tofu will be re-used to spice up curry dishes in the same restaurant without any UCO left to be collected. This situation has a negative impact on public health as UCO can contain carcinogenic substances.

The total available quantity of UCO in Indonesia is conservatively estimated to be 646,800 tonnes per year. It is unknown how much UCO is already collected at the moment. The three large collectors collect 120,000 tonnes and Tractus believes that smaller collectors gather another 65,000 tonnes, leading to an estimated total of 185,000 tonnes of UCO currently being collected. The 120,000 tonnes of UCO collected by large collectors is probably nearly all being exported for biodiesel use. The 65,000 tonnes of UCO collected by smaller collectors are thought to go in majority to non-bioenergy uses such as oleochemicals, animal feed and re-used as cooking oil by tofu, tempe and peanut producing or processing companies. Diverting these uses towards biodiesel might lead ILUC, although re-using UCO as cooking oil is detrimental for Indonesia’s public health.

This means that of the total estimated UCO potential in Indonesia of 646,800 tonnes, some 581,800 tonnes could be used for biodiesel without leading to negative indirect impacts. Whether this potential can be reaped depends on the price of UCO which might make it feasible to collect from smaller islands and from kaki limas street side vendors in less densely populated areas.

4.8 Assessing the low ILUC potential of UCO in Argentina

With an area of 2,780,400 km^2, Argentina is the second largest country in South America and the eighth largest country in the world.

Argentina is divided into twenty-three provinces and the autonomous City of Buenos Aires. The form of government is federal. Each province has its own constitution and holds all the power that is not specifically delegated to the national government. The country has around 42 million inhabitants. By population, the largest provinces are the Buenos Aires province (excludes the city of Buenos Aires), followed by Córdoba, Santa Fe, the City of Buenos Aires, Mendoza and Tucumán. The most densely populated area is the City of Buenos Aires with a population density of 14,241 inhabitants/km^2, followed by far by Tucumán (64.3 inhabitants/km^2), Gran Buenos Aires (50.7 inhabitants/km^2), Misiones (36.8 inhabitants/km^2) and Santa Fe (24.1 inhabitants/km^2).

Figure 22: Argentina [Source: http://commons.wikimedia.org/wiki/File:Argentina_in_South_America_%28%2Ball_claimed_territories%29.svg]

4.8.1 Background

The use of vegetable oil and animal fats in Argentina

Argentina's eating culture is a combination of native and Mediterranean (mainly Italian and Spanish) influences with beef as a central ingredient. Argentinians appreciate good food and eating together is an important part of daily life. Fried food is less popular compared to some countries in the EU. The consume per capita of vegetable oil and animal fats is estimated to be 13.5 L/y, which is much lower than in the Netherlands and Germany.[244]

Gastronomy

The gastronomy sector includes "classic" restaurants (formal restaurants, and rotisseries[245]), self-service (establishments similar to canteens located in supermarkets) and fast food restaurants. There are around 40,000 "classic" restaurants[246] which are mostly stand-alone business. A number of self-service restaurants are located in supermarkets. The fast food restaurants belong to few brands including, for instance, McDonald's and the local brand Mostaza. Other food establishments include industrial canteens and catering.

[244] Capriles et al (2010), Apoyo al Programa de Biodiesel a partir de Aceite Vegetal Usado en la Provincia de Buenos Aires (Support Program Biodiesel from Used Vegetable Oil in the Province of Buenos Aires). Commissioned by the government of the Province of Buenos Aires with the support of the Inter-American Development Bank.

[245] Barbecue restaurant

[246] Fehgra (2013), Federación Empresaria Hotelera Gastronómica de la República Argentina (Argentinean Hotels and Gastronomy Federation). Written communication with Roberto Brunello and Georgina Campana.

Food processing industry
The food processing industry in Argentina is diverse. Fried and pre-fried products are produced by several companies including large multinational concerns such as PepsiCo Snacks and McCain. Although these companies generate UCO, there are no figures publicly available on the amount generated and collected.

Governmental regulation on UCO management
The Argentinean national Act 25.916 from 2004 provides the overall framework for waste management in Argentina. This law contains general provisions on waste management (without specifying single waste streams) and transfers the law enforcement responsibility to the province and local authorities.

Within the context of this act, some provinces such as the City of Buenos Aires have developed UCO management regulations. In other provinces, although regulation is not in place, UCO[247] management agreements at province and/or municipal level have been signed (e.g. Plan Bio in the Province of Buenos Aires). In some provinces, UCO management regulation is being prepared (e.g. Santafé). Examples of the regulation and programs in place in some regions are provided below.

In the opinion of a well-established UCO collector, the legislation to avoid the illegal use of UCO for human consumption in the whole country is insufficient and/or not fully effective.

Regulation for the City of Buenos Aires
The city of Buenos Aires established a definition for UCO (see definition in Box 4: UCO definition in the City of Buenos Aires) and provisions for the regulation, control and management of used cooking oils and fats, both of vegetable and animal origin. The provisions refer to the register of UCO producers, transporters and collectors, use of a UCO declaration and general requirements for transport, collection and use.[248] In Buenos Aires it is prohibited to dispose UCO in an uncontrolled manner and using UCO for food is not allowed. While UCO cannot be used for human consumption, it is allowed to use UCO to produce animal feed. [249]

Box 4: UCO definition in the City of Buenos Aires

According to the City of Buenos Aires law, UCO (AVU) is defined as:

"*used frying vegetable oil and fats generated, in continuous or discontinuous form, from cooking or from food preparation activities encompassing total or partial frying, when the physical and chemical composition and the characteristics of the original product have changed to such an extent that it is not suitable for use for human consumption as stipulated in the [Federal] Argentinean Food Code and has to be discarded by the generator*".

[247] UCO is called AVU in Argentina.
[248] Act 3166/2009, modified by Act 3997/2011
[249] In act 3166/2009

The Plan Bio of the Province of Buenos Aires

Plan Bio is a program established by the government of the Province in 2009 to promote the collection and recycling of UCO generated by both households and restaurants.[250] The Plan Bio operates through voluntary agreements between the province sustainable development office[251] and the municipalities. Around 100 of the 135 municipalities are participating in the Plan. The UCO is collected mainly from small restaurants by authorised companies (currently RBA and SODIR). The restaurants receive around 50 peso cents per litre (€0.07 per litre) and are committed to donate this to social projects chosen by the municipalities. Restaurants (and also households) can also dispose of the UCO in collection points ("centro de acopio privado" CAP) without remuneration.

The program was originally developed with the intention to produce biofuels, but UCO collectors are free to sell it for any use, excepting human consumption.

The Federal Argentinean Food Code

The Federal Argentinean Food Code[252] provides precise quality requirements for vegetable oil for human consumption and indicates that UCO is not allowed for further use when:

a) "There are [negative] changes and/or deficiencies in its sensory characteristics: odour, colour, taste, turbidity and other.
b) Has a smoke point of 170 ° C or less. The difference between the smoke points of the unused oil or grease and the used ones should not exceed 50 ° C.
c) Has a content of oxidized fatty acids insoluble in petroleum ether, more than 1.0%.
d) Has acidity greater than 2.50 mg KOH/g[253] (1.25% as oleic acid)."

Existing UCO potential assessments

The overall UCO potential in Argentina has not being investigated to date. However, some regional assessments have been carried out, most notably for the province of Buenos Aires and the city of 7Neuquén.

Province of Buenos Aires

An assessment commissioned by the Inter-American Development Bank and the Government of the Province within the framework of Plan Bio[254] estimated the UCO collectable potential for the province based on literature and data from collectors.

Table 38 below shows the UCO collectable potential from households estimated for the first 5 years of the Plan Bio. Capriles et al.

[250] Plan Bio (2013), Retrieved in June 2013. http://www.opds.gba.gov.ar/planbio/programaBio.html and Rafaelli (2013), Interview with Head of Plan Bio
[251] Dirección Provincial de Economía Ambiental y Energías Alternativas - Organismo Provincial para el Desarrollo Sostenible
[252] Código Alimentario Argentino", Republic of Argentina, 2012, article 552 bis.
[253] mass of potassium hydroxide (KOH) in milligrams that is required to neutralize one gram of chemical substance
[254] Capriles et al (2010)

2010 estimate the expected collection rate based on empirical experiences in Latin America and the framework conditions of the Buenos Aires province at the beginning of the Plan Bio project (with regard to e.g. (non-existent) UCO legislation, incentives, promotion programs).

Table 38: UCO collectable potential from households in the Buenos Aires province

UCO generation per capita in Argentina (kg per person per year)	8.139
Expected collection rate in the Province of Buenos Aires in the first 5 years of the program %	3.5
UCO collectable potential per capita in the in the Province of Buenos Aires (kg/p/y)	0.285
Population (inhabitants)	15,400,000
Total UCO collectable potential from households (t/y)	4,387

Based on Capriles et al. (2010)

The UCO potential from the gastronomy sector was estimated by Capriles et al. assuming a theoretical UCO generation per average restaurant in Argentina and using national statistics on the amount of restaurants in the province (see the table below). The average restaurant is assumed to have between 10 to 20 tables. Although not used in the calculations, Capriles et al. estimated the average amount of restaurant per capita in the province to be 0.07 restaurants per 100 inhabitants.

Table 39: UCO collectable potential from gastronomy in the Buenos Aires province

UCO generation per restaurant in Argentina (t/establishment/y)	0.319
Expected collection rate %	70
Amount of restaurants	19,403
UCO collectable potential per restaurant in the Province of Buenos Aires (t/establishment/y)	0.223
Total UCO collectable potential from gastronomy (t/ y)	4,332

Based on Capriles et al. (2010)

City of Neuquén

A study on the UCO collectable potential was recently commissioned by the city of Neuquén (capital city of the province with the same name).[255] This study assumes that only the UCO generated by gastronomy establishments can be collected and uses collection rates provided by the company RBA. The results are presented in the table below. It is important to note that Neuquén, with a population

[255] López (2012), Analysis: Management of UCO and animal fats in the city of Neuquén

of around 231 thousand inhabitants, is a medium size city in Argentina. The population density is around 31 persons per km^2.

Table 40: UCO collectable potential from gastronomy in the city of Neuquén

	Medium size restaurants	Large size restaurants
Amount of establishments (including restaurants and small food locals)	1,269	50
UCO collectable potential per establishment (t/establishment/y)	0.221	2.2
Total UCO collectable potential in the province (t/ y)	**280**	**110**

4.8.2 UCO collection system in Argentina

The collected UCO in Argentina is actually a mixture of used cooking oil and animal fats, as neither are separately collected.

The UCO collection sector comprises of formal and informal collectors. The formal collection is dominated by two large companies, RBA Ambiental (hereafter RBA) and SODIR.

- RBA[256] collects UCO from all different types of generators (restaurants, food processing industry) in 20 of the 23 provinces of the country (the company does not collect in the three southernmost provinces of Argentina) and is the main operator of Plan Bio (see above). RBA covers the entire value chain including UCO collection, transportation, pre-treatment, refining and biodiesel production. RBA collects the UCO in containers with different capacities that are transported to intermediate collection points. From there, the UCO is transported with tankers to the refinery. There, solids are removed and humidity and acidity are corrected in order to create UCO of a more homogeneous quality. Currently, biodiesel production is on stand-by; a new biodiesel plant which will replace the old installations will be put in operation by the end of 2013. The refined UCO is currently sold for biodiesel production, but this will stop once RBA restarts its own biodiesel production.

- SODIR[257] collects UCO only from the gastronomy sector. Collection is focused in the centre of the country (City of Buenos Aires and the provinces of Buenos Aires) where the company collects just over 50% of its UCO. The remaining 50% is collected in the north and south regions of the country. SODIR does not cover poor provinces such as Jujuy, Santa Cruz and San Luis since the density of UCO generators is very low and transport distances very long (distances of over 100

[256] RBA (2013), Interview with Flavio Porcille
[257] SODIR (2013), Interview with Pablo Zimmermann

km are not profitable). The collection system is similar to the one used by RBA. After collection, the UCO is filtered and decanted. The total amount of cleaned UCO is sold.

Informal UCO collection in Argentina is increasingly displaced by formal collection or transformed in formal collection [258]. A description or figures on the activities of informal collectors are not available. The following example in the city of Rosario illustrates the current situation:

- In Rosario, UCO is collected informally and its use was generally unknown. Within the framework of a project lead by the local government [259], a group of informal collectors has been supported to improve their living and working conditions and formalize its activities. As a result of the project, UCO collection increased from 2,000 to 3,700 litres per month. The collected UCO is being processed to biodiesel and it is expected that biodiesel is used by the state owned transport company. The project was combined with a promotion program to prevent UCO disposal in the sewage system and thus avoid the negative impacts associated to it (corrosion of pipelines, water pollution).

Quality of UCO
The Argentinean Food Code (see section 0) establishes the criteria for discarding vegetable oil or animal grease after use. However, measurements to verify compliance often do not take place.[260] UCO collectors have carried out own sampling and studies to determine the quality they receive (these studies are confidential). In the opinion of one of the collectors, Argentinean gastronomy uses oil in a responsible way and frying oil is normally replaced according to the norms.

4.8.3 UCO collectable potential in Argentina

Figures on the UCO collectable potential for the whole country are not available. For the purpose of the present study, estimations have been made based on data provided by individual collectors (RBA and SODIR) and the gastronomy association (FEHGRA). Data on UCO density is taken from the literature.[261]

The UCO collectable potential in Argentina is defined for the purposes of the present assessment as the amount of UCO currently collected plus the additional amount of UCO that could be realistically collected in the near future, assuming that programs similar to Plan Bio and local agreements are in place.

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[258] SODIR (2013)
[259] Bartolomé (2013), Press article "De la informalidad a la formalidad" (From informal to formal). http://www.lacapital.com.ar/ed_impresa/2013/5/edicion_1634/contenidos/noticia_5202.html. Retrieved in June 2013
[260] RBA (2013)
[261] Capriles et al (2010)

UCO currently collected

The amount of UCO currently collected is estimated based on the data provided by RBA and SODIR (2013). The results are shown in the table below. Most of the UCO is collected in the gastronomy sector. A small fraction (7%) comes from the industrial food processing industry.

Table 41: UCO currently collected in Argentina

Type of generator	Total collected (t/a)
Gastronomy	14,000
Industrial food processors	1,000
Total	15,400

Based on data obtained from RBA and SODIR

The amount collected from households is negligible and not reported by collectors is not included. The UCO collected by informal collectors is also not included, as only punctual information is available and the volume collected is expected to be very low.

The estimated figure does not include informal collection, which is expected to decrease with the increasing formalisation of the sector.

UCO that could be realistically collected

The amount of UCO that could be realistically collected in the near future is estimated based on the following assumptions:

- The realistic UCO collectable potential from households is negligible. This is a reasonable assumption taking into account the experience of UCO collectors. Although the estimations for the Province of Buenos Aires showed a conservative collection potential for households similar to the potential from the gastronomy, the actual collected volume has been very low. [262]
- The realistic UCO collectable potential from the food processing industry is assumed to be already deployed. The food processing industry does not publish or share figures on the amount generated and used. UCO collectors report that the volume collected is relatively low compared with the gastronomy. As for the use, PepsiCo Argentina reports that residual oil out of specifications is being used to produce biodiesel (PepsiCo 2010). Based on the former information, it is assumed that in the future, no additional UCO will be collected from this sector. This is a conservative assumption.
- In the near future, the additional collectable potential will come from the well-organised gastronomy sector. For this sector, it is assumed that no additional potential will come from fast-food restaurants and supermarkets with self-service. This is a safe assumption

[262] RBA and SODIR (2013)

considering that no data on the total number of establishments was available for the present assessment. Additionally, it is likely that the establishments that are part of well-established food chains are already collecting.

- The additionally collectable potential from the gastronomy is the result of multiplying the amount of non-served establishments by the UCO collectable rate:
    - The number of 10,000 non-served restaurants is estimated based on the total amount of establishments associated to FEHGRA (2013) minus the restaurants served by UCO collectors.
    - The UCO collectable rate depends on the size of the gastronomy establishment. A classification of the establishments per size is not available. Therefore, the upper, lower and average values are calculated based on the data provided by UCO collectors and FEHGRA.

The "realistic" additional collectable potential (see table below) estimations resulted in a potential between 1,800 and 4,700 t/y.

Table 42: UCO "realistically" additional collectable potential in Argentina

	Units	Value
Collection rate- lowest value reported by collector	t/establishment/y	0.18
Collection rate- intermediate value reported by collector	t/establishment/y	0.36
Collection rate- intermediate value reported by gastronomy sector	t/establishment/y	0.87
Average collection rate	t/establishment/y	0.47
Amount of non-served gastronomy establishments	Nr.	10,000
UCO additional collectable potential – low	**t/y**	**1,800**
UCO additional collectable potential – high	**t/y**	**8,700**
UCO additional collectable potential – average	**t/y**	**4,700**

UCO collectable potential

The UCO collectable potential results from adding the UCO currently collected and the additional amount of UCO that could be realistically collected in the near future. Results using an average additional collectable potential are summarised in the table below.

Table 43: UCO collectable potential in Argentina

Type of generator	UCO collectable potential (t/a)
Gastronomy	19,099
Industrial food processors	1,000
Total	20,099

As indicated before, we did not include UCO produced by households since current collection is negligible. However, if programs such as Plan Bio and local legislation as in the City of Buenos Aires become effective in the near future and similar programs are in place in the major urban centres

(Rosario, Córdoba, Gran Mendoza), above 6,000 t/a (which is equivalent to the collectable amount generated by around 22 million people living[263] in these areas) could be added to the potential estimated above.

4.8.4 Uses of UCO collected

According to UCO collectors, currently around 80% of the 15,400 tonnes of UCO which is currently collected annually is exported to be used to produce biodiesel. The share of collected UCO which remains in Argentina goes either to the production of oleo chemicals (60% of domestically used UCO) or to domestic biodiesel production (remaining 40%). This will change in the near future, when the new biodiesel plant of RBA is put in operation. RBA aims to export the UCO biodiesel, as there is no domestic market for it.

Table 44: Current UCO uses in Argentina

Use	t/a	%
Biodiesel	13,552	88
Oleochemicals	1,848	12

Table 45: UCO exports and domestic consumption in Argentina

Market	t/a	%
Export (all for biodiesel)	12,050	78
Domestic market	3,350	22

The use for animal feed is not prohibited in Argentina and apparently, a fraction of the UCO has being used for this purpose.[264] However, none of the consulted collectors supply UCO for these purposes.

The illegal use of UCO for human consumption is a problem in Argentina, but there are no figures on the magnitude of it. According to RBA (2013), which has investigated the phenomena in several Latin American countries, the problem in Argentina is similar to countries such as Colombia, where according to research by the University Javeriana[265], UCO is collected, filtered and sometimes mixed with fresh vegetable oil and sold usually in corner shops without brand. According to the University, around 20% of the total vegetable oil sold in the Colombian market is UCO.

4.8.5 Low ILUC potential for UCO in the Argentina

According to the LIIB methodology, a waste or residue is low ILUC if no current uses of the material are displaced, other than current bio-energy uses or forms of disposal such as land-filling and

[263] Population data from INDEC 2010
[264] FEHGRA and Almada (2013), interview with Officer at the Federal Argentinean Ministry of Agriculture
[265] For a documentary film on the illegal UCO commercialization in Colombia see http://www.elespectador.com/video-219763-el-cartel-del-aceite-colombia

burning. This means that the low ILUC potential of UCO is quantified by taking the total sustainable potential of UCO and deducting all current uses except bio-energy and dumping.

As indicated in the previous section, the main high value use of UCO in Argentina is in the oleochemical industry (12% of the UCO currently collected). For the purposes of the present study, it is assumed that 12% of the collectable potential would be delivered to the oleochemical industry as well. Based on this, the low ILUC UCO potential is estimated to be around 17,000 tonnes annually. This potential could be increased up to at least 23,500 t/a, if 3.5% of the UCO from households in the main urban areas were collected.

Table 46: Low ILUC UCO potential in Argentina

	t/a
UCO collectable potential	20,099
UCO currently used in oleo chemical sector	2,000
Amount from additional collectable potential to be used in oleo chemical sector	608
Total high value non-energy UCO use	2,608
Low ILUC UCO potential	**17,490**

There are relatively few legal incentives in Argentina to collect UCO (RBA and SODIR 2013). The uncontrolled disposal of UCO causes environmental impacts (water and soil pollution) and problems in sewage pipelines and waste water treatment facilities[266]. The increasing demand for UCO for biodiesel has helped to incentivise collection. However, the price paid to generators (between 10 and 20 Cent USD per litre[267]) is considered to still be insufficient to prevent collection for illegal processing for human consumption (see Box 5)

Box 5: Project to collect and process UCO in several Latin American countries

RBA, with the support of the Latin American Development Bank (CAF) is planning to establish 13 regional collection and processing of UCO facilities in Latin America. There is a strong interest from local partners in this project. However, the main obstacles are the lack of a proper and/or functioning regulation framework and the illegal processing for human consumption.

[266] see background of province legislation, López (2012) and INTI (2009), Used vegetable oil recycling for obtaining high added value industrial supplies. In: Noticiero Tecnológico Semanal 146. http://www.inti.gob.ar/noticiero/noticiero146.htm
[267] Rafaelli and SODIR (2013)

5 Corn cobs

This chapter contains a quick scan of the EU potential of corn cobs as a sustainable, ILUC-free biofuel feedstock. Less in-depth research has been performed on cobs compared to the other wastes and residues analysed in previous chapters.

5.1 Introduction and Terminology

Corn or Maize (*Zea mays*) is one of the world's most important cereal grains. It is widely cultivated because of its good growth characteristics and its versatility in end use.

A cob is defined as the hard cylindrical core that bears the kernels (or grains) of an ear[268] of corn and is considered to be part of the corn residue (or stover). Other corn residues are the stalks, leaves and husks[269].

Corn crops around the world have unique production cycles of planting and harvest. In Europe planting tends to be from mid-April through early-June and harvest from mid-August through late October.

Several cob harvesting solutions have been researched (table 22). Two of these methods are actually used on a larger scale; the 'Cob Caddy System' (CCS) and the 'Corn Cob Mix' (CCM). CCS uses air and gravity to separate cobs from husk[270], leaves and stalks. CCM harvests a mix of grain and cobs. This can be done by modifying a combine to grind up cobs as it harvests, the resultant mixture is unloaded using the combine's normal grain auger, and the cobs are later separated. CCM is widely used in EU countries. It is unknown if or to what extent CCS is used in Europe. Due to lack of data the potential of corn cobs from CCS in Europe is not considered in this quick scan.

Table 47: An overview of researched cob harvest solutions

Researcher	Description
Chung (1980)	Bounce plates and inclined conveyor
Bargiel et.al. (1982)	Modified straw chopper with fan on the spout
Quaye and Schertz (1983)	Counter-rotating roller attachment
Smith et.al. (1984)	Pneumatic separation after straw walker with a blower and a spout
McBroom (1986)	Corn and Cob Mix (CCM)
Flamme (1999)	Cob Caddy System (CCS)
Stukenholz and Stukenholz (2002)	Cob sieve and fan with on-combine storage
Redkop (2009)	Towed cart with two stage pneumatic cleaning

268 Corn Ear = cob, kernels and chaff
269 Corn Chaff = the husks of corn or other seed separated by winnowing or threshing
270 Husk = the dry outer covering

5.2 Types of maize and their harvesting

There are about 50 different types (sub-species) of maize, all having their own characteristic features and kernel sizes. Colour and structure, as well as the shape of the kernel, differ from one type to another. Equally cob characteristics can differ from one type to the other.

For each maize type there are numerous varieties, designed and produced for a specific end use (e.g. biogas maize with large methane gas potential). Worldwide there are thousands of different varieties of maize.

EUROSTAT distinguishes three main categories of European corn production:

1. Grain Maize & Corn Cob Mix;
2. Green Maize;
3. Sweet corn.

EU Member States report their annual production statistics on these categories to EUROSTAT. Descriptions of categories, processing treatments and end uses are provided below in table 23. Average statistics are presented in paragraph 5.5.

Table 48: Most important European (commercial) categories of Maize as defined by EUROSTAT

EUROSTAT Category	Description	Treatment	Maize End use
Grain Maize & Corn Cob Mix (CCM)	Grain Maize: Kernels only, with a moisture content of approximately 30%	Dried or fermented (silage)	➢ Animal Feed (Sweet Feed) for e.g. chickens ➢ Maize seed ➢ Other (e.g. biogas)
	CCM: Kernels and pieces of cob, with a higher moisture content between 35-40%	Fermented (silage)	➢ Animal Feed ➢ Other (e.g. biogas)
Green Maize	The whole plant, prematurely harvested	Directly consumed by animals (without silage) and whole cobs (cob with grain and husk) harvested for feedstuff or silage, as well as for renewable energy production	➢ Fodder Maize ➢ Biogas Maize
Sweet Corn	Kernels with or without cob	n/a	➢ Human consumption

Sweet corn is one of the three main maize categories but is considered a vegetable in EUROSTAT. Furthermore, the cobs are not available due to human consumption of corn from the cob (and dumping or recycling through household waste). We therefore do not consider sweet corn any further in this report.

Harvesting Grain Maize and CCM is done with a combine harvester, a machine that combines three separate operations (harvesting, winnowing[271] and threshing[272]) into a single process. The remaining corn residues are either chopped and spread on the field or baled for feed and bedding for livestock. As mentioned in the paragraph 5.1, CCM is harvested using a modified combine harvester. Cobs from Grain Maize and CCM could be available for advanced biofuel production.

For the production of maize seed the whole cob is harvested using a cob picker and transported to the processing factory. Subsequently the cobs are dried and threshed and the residues are processed separately. It remains unclear how this process works in detail. However, the remaining cobs could be directly available for advanced biofuels production. This needs further investigation.

When harvesting Green Maize the cobs are chopped-up with the rest of the plant using a forage harvester. A forage harvester (also known as a silage harvester, forager or chopper) is a machine that chops the whole plant into small pieces. The output is often compacted together in a storage silo, silage bunker, or in silage bags and fermented to provide feed for livestock or feedstock for conventional renewable energy. It is clear that in the production of Green Maize all cobs are processed and therefore unavailable for advanced biofuels.

5.3 Corn cob quality and the use as a biofuel feedstock

There are different factors determining corn cob quality e.g. dry matter content and production region. The average dry matter content of corn cobs is about 45% and varies between different varieties from 30 to 60%. In general it will be easier to produce dry cobs in Southern Europe (with a warmer climate) than in the Northern EU Member States.

Corn cob is suitable as a biofuels feedstock to produce ethanol. In the EU cobs are not yet used for biofuels but in the US a first demonstration plant has been constructed. Poet Energy, a US biofuels producer, has run a pilot facility for cob ethanol and experimented with corn cob ethanol production recently in a joint venture partner with DSM.[273] However, it appears that Poet stopped using corn cob due to issues with corn cob harvesting and storage. Instead, Poet started using whole corn stover (stalk, cob and leaves) as feedstock.[274]

It remains unclear if, or which specific quality requirements, there are for corn cobs as a feedstock for advanced biofuels. More information could possibly be obtained from the US where research and development is more advanced than in Europe.

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[271] Removing the chaff from the grain
[272] Separating the grain from the cob
[273] http://www.poet.com/cellulosic
[274] Personal communication with ICM, a biofuels technology provider.

5.4 Sustainable potential of corn cob in the EU

Harvested corn biomass is often fermented into silage, which is high-moisture stored animal feed (or fodder) which can be fed to ruminants (cud-chewing animals such as cattle and sheep) or used as a biofuel feedstock for anaerobic digesters. Additionally the following limited number of other applications for corn residues exist [275]:

1. the use of corn cobs as building material and activated carbon [276];
2. the use of corn leaves as a feedstock for fermentable sugars and supplemental fibre source for paper pulp [277]; and
3. the use of corn stalks as livestock feed and biofertilizer. [278]

Data on corn cob production is not recorded by EU Member States, but an estimate can be made based on the annual volume of crop production and the corn to cob ratio. However, the uses (and volumes thereof) of corn cobs are also not readily available and difficult to estimate based on the available information.

The following methodology was used to estimate the sustainable corn cob potential and existing uses. It follows the approach taken by the Joint Research Centre (JRC) of the European Commission, consisting of the following steps:

1. Obtain crop production data;
2. Estimate technical corn cob potential;
3. Estimate the sustainable corn cob potential

This approach is followed in the sections below.

5.4.1 Crop production data (area, production and yield)

The crop area, production and yield per Member State for Grain Maize & CCM and Green Maize was extracted from EUROSTAT and summarised in MS Excel. The crop production varies between years in line with the crop planting area and yield, and therefore an average was calculated. A 9-year average of the most recent data available (i.e. for the period 2004-2012) was considered to be most representative.

The EU27 total average annual harvested production of Grain Maize and CCM was 60,257,000 tonnes between 2004 and 2012. The four main European producers were France (14,923,000), Romania (8,922,000 tonnes), Italy (9,489,000 tonnes) and Hungary (7,315,000 tonnes). Figure 23 shows a complete overview of the reported average annual harvested production of Grain Maize and CCM per EU27 country.

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[275] Zhang et al., 2012
[276] Pinto et al., 2012; Cao et al., 2006
[277] Shinners and Binversie, 2007; Su et al., 2006
[278] Chen et al., 2010a; Li et al., 2007

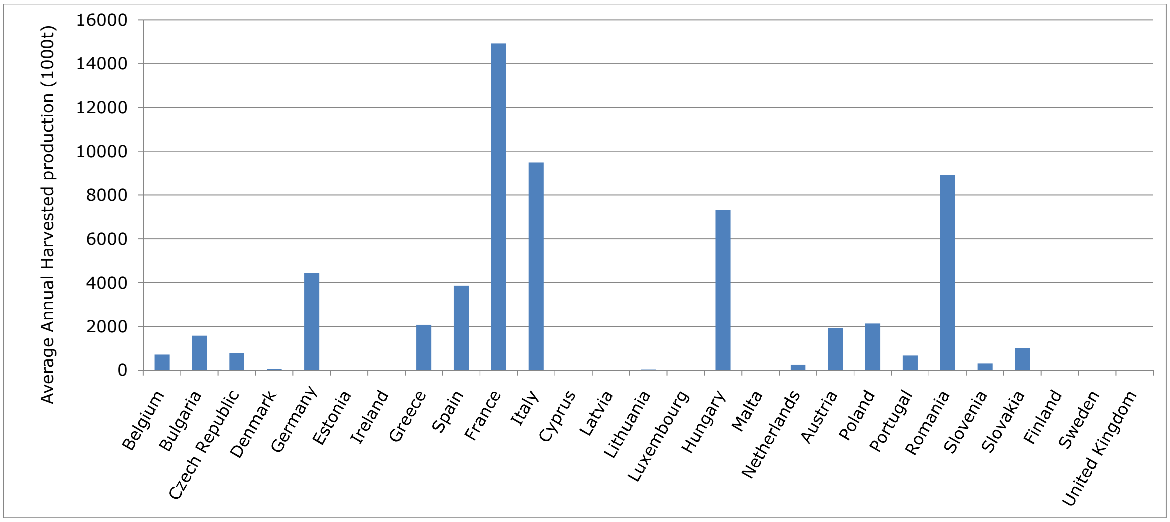

Figure 23: Grain Maize and corn cob mix 2004-2012 average annual production (EUROSTAT)

The EU27 total average annual harvested production of Green Maize was 17,832,400 tonnes between 2004 and 2012. By far the most Green Maize was harvested in Germany (70,000,000 tonnes), followed by France (30,000,000 tonnes), Poland (16,027,000 tonnes) and Italy (12,919,000 tonnes). Figure 24 shows a complete overview of the reported average annual harvested production of Green Maize per EU27 country.

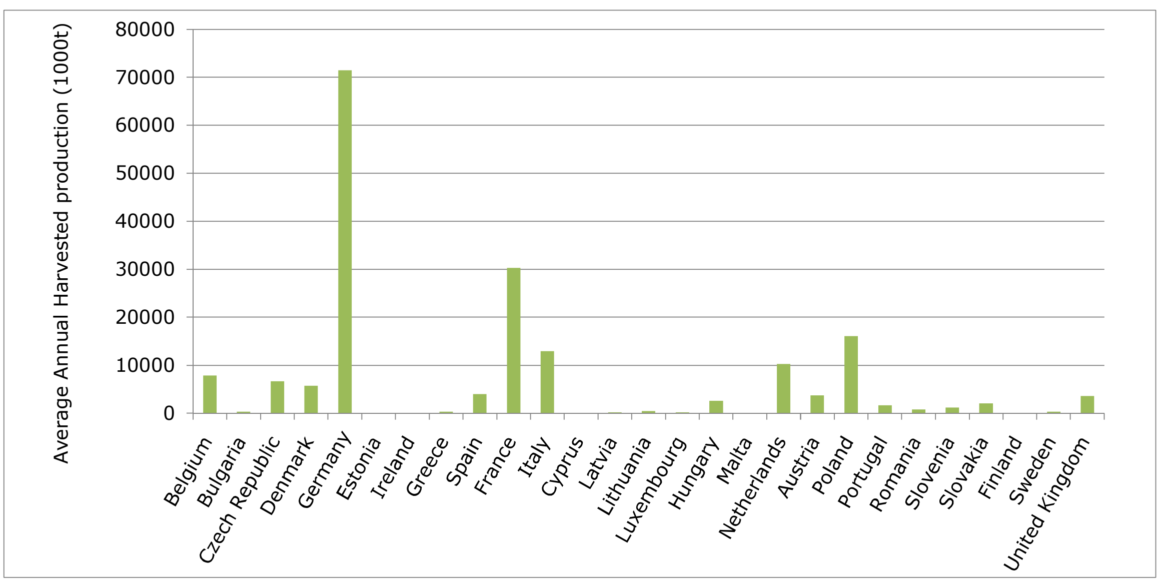

Figure 24: Green Maize 2004-2012 average annual production (Eurostat)

The large amount of harvested Green Maize in Germany can be explained by a high demand from the local biogas industry.

Germany has roughly 6000 operational anaerobic corn digesters, claiming about 1 m ha of (of the reported 1.6 m ha) Green Maize production per year (pers. comm. Jos Groten).

5.4.2 Estimate the technical corn cob potential

An estimate of the corn cob availability can be made by using the ratio of corn grain to cob from available literature. The corn to cob ratio can be based on correlations proposed by Koopman and Koppejan (1997 and 1998) and the Wageningen University and Research centre (WUR, 2003).

A corn to cob ratio of about 5:1 (0.2) has been calculated from field experiments. [279] The ratio varies between different corn varieties, but on average 2t (1.5t-2.5t) cob and 10t grains per ha was recorded in one instance.[280]

This ratio can be explained by the relative dry matter content of the cobs. Cobs only make up a small part of the total dry matter of corn production; the cob (approx. 45% dry matter) contains much more moisture than grains (approx. 70% dry matter).

Using the Corn to Cob ratio it is possible to estimate the total straw production using the following formula:

Total corn cob production [tonnes per year] = Corn to Cob ratio x Grain production [tonnes per year]

Using the EUROSTAT production data (Grain Maize and CCM) and the corn to cob ratio from available literature, the average annual European corn cob production can be estimated at **around 12 million tonnes** (0.2 X 60.257).

5.4.3 Estimate the sustainable corn cob potential

It is impossible to collect all of the available corn cobs. Several factors are limiting the amount of cobs that can be recovered. These include the technical limitations of the harvesting equipment and possible other losses. However, this needs further investigation.

When estimating how many Corn Cobs can be removed it is important to take into account the associated environmental impact(s) this may have. These impacts principally relate to the preservation of soil quality. The term “Sustainable removal rate” is used to describe the total amount of cobs that can be removed from the land without adversely affecting the soil quality.

[279] Koopman and Koppejan, 1998; WUR, 2003
[280] WUR, 2003

Crop nutrients, most notably nitrogen, are removed from the field when corn residue is harvested. Specific removal rates will vary according to soil nutrient levels, growing conditions, hybrid, and the time and method of harvest. The amount of residue, in this case corn cobs, that can be sustainably harvested is generally most limited by the amount that must be left in the field to maintain soil organic matter levels.[281]

Cobs add limited nutritional value to the soil and removal is unlikely to have a negative impact on soil regeneration. Cobs are carbon rich and relatively nutrient poor. Nitrogen, phosphorus and potassium content, as a percentage of dry matter has been reported as 0.87% nitrogen, 0.05% phosphorus and 0.81% potassium.

Nutrients, mainly nitrogen, make up only about 2% of the cob weight. The other 98% is carbon rich cellulosic materials and lignin. Corn cobs left on soil surfaces decompose slowly and remain for long periods of time and in relationship to the rest of the corn residue, cobs add back a much smaller portion of carbon than cornstalks do.

The amount of nitrogen (and some other nutrients) that is removed in cob harvest will most likely be offset by the fact that cobs have such a high carbon to nitrogen ratio. In continuous corn production the need for nitrogen in soil regeneration might actually be reduced because of the removal of carbon rich cobs that tends to tie up nitrogen. A prerequisite would be that all other residue material (stalks, leaves and chaff) remains on the field.

Scarlat *et al*. (2010) lists sustainable removal rates for maize residues (stalk, leaves, chaff and cob) between 30 and 70%. No specific information about the sustainable removal rate of corn cobs is available at this time. With this in mind the total sustainable corn cob potential was estimated with a sustainable removal rate of 30% and using the following formula.

Sustainable Corn cob availability [tonnes per year] = Total Corn cob production [tonnes per year] x Sustainable removal rate [%]

Using a sustainable removal rate of 30%, the total sustainable corn cob removal can be estimated at **around 3.6 million tonnes** (12.051 X 0.7) per year.

5.5 Current uses and their relative importance

In parts of Europe corn cobs are currently being used for the generation of heat, while in the US this agricultural waste product is already being developed as a feedstock for cellulosic ethanol, co-firing, and gasification projects.

[281] Jeschke and Heffenstaller, 2012- Available from: http://biofuels.dupont.com/fileadmin/user_upload/live/biofuels/DCE_Cornstover_CropInsights.pdf

Corn cobs have a heat value of about 18.4 to 18.7 MJ/kg or approximately 8,000 Btu/lb. As described in section 5.3, corn cob is not yet used as a biofuel feedstock and a first pilot project by Poet Energy, a US biofuels producer, failed for economic and logistical reasons..

Other uses of corn cob include:

- building material and activated carbon;
- Industrial source of the chemical furfural;
- Fibre in fodder for ruminant livestock, despite low nutritional value;
- Thickeners for soup or sweetened corncob jelly;
- Livestock bedding;
- Raw material for bowls of corncob pipes;
- Charcoal production;

There is no additional information (e.g. quality, quantity, geographic locations etc.) available on (European) corn cob use at this time.

5.6 Low ILUC potential for corn cobs

Because quantitative data on current corn cob use is unavailable it is impossible to estimate the possible excess potential for advanced biofuels. A more detailed study would be necessary to obtain this potential.

6 Summary and Conclusions

This study aims to provide insights in the availability of several important waste and residue materials as well as to analyse to what extent the available materials could be used for biofuel production without leading to negative indirect impacts. The wastes and residues assessed are straw, forestry residues, used cooking oil and corn cobs. These materials can play an important role as biofuel feedstock in the future, or in the case of used cooking oil, are already widely used at the moment.

The analysis uses the requirements included in the Low Indirect Impact Biofuels (LIIB) certification module. Section 1.3 provides more details on this module. According to the LIIB methodology, a waste or residue is low ILUC if no current uses of the material are displaced, other than current bio-energy uses or forms of disposal such as land-filling and burning. This means that the low ILUC potential of straw is quantified by taking the total sustainable potential of straw and deducting all current uses except bio-energy, burning and incorporation.

The LIIB methodology states that only the share of wastes or residues which is not used for non-bioenergy purposes within a certain region[282], is eligible for certification as low ILUC biofuel. For example, if 20% of a residue is already used for other purposes, only the remaining 80% of the residue in a region can claim LIIB compliance. For each of the feedstocks assessed in this study, the most appropriate assessment region has been chosen.

6.1 Theoretical, sustainable and low ILUC potential

In order to assess the low ILUC potential for each of the assessed materials in each of the relevant regions, this study first identifies the available **theoretical potential** of each of the materials. This is the quantity of the material which is available and could in theory be harvested or collected. Subsequently the **sustainable potential** is estimated. This is the quantity which can be harvested or collected in a sustainable way. The sustainable potential for straw for example, takes into account the need to leave a certain share of the total available quantity of straw on the land for the purpose of soil regeneration. Finally the **low indirect impacts or low ILUC potential** is estimated. This potential takes into account the current non-bioenergy uses of the material. Displacing these uses could lead to ILUC and is deducted from the sustainable potential. Naturally the low ILUC potential is smaller than the sustainable potential which in turn is smaller than the theoretical potential. For UCO the technical potential and the sustainable potential are identical as all UCO which is technically available could be collected without leading to serious sustainability impacts.

[282] A region can either be a country, part of a country or a group of countries. In this report the region is either a country or group of countries.

As stated in the introduction it is not possible to obtain highly reliable, accurate results on the available quantities of the materials. This stems from the fact that almost no statistics on wastes and residues exist. The data situation for straw, Bark, branches, leaves, sawdust and cutter shavings and corn cobs is better than for used cooking oil. This is unrelated to the fact that the UCO analysis in this study focuses not only on the EU but also on other regions. It proved to be more difficult to obtain reliable information on available UCO within the EU compared to the other assessed materials and less relevant literature is available. Most information on UCO is obtained through a large interview process in which dozens of relevant stakeholders where interviewed in the five assessed regions. This means that this study goes beyond just a literature and data review, it also means that **the quantitative results of this study can only be regarded as best estimates.**

6.2 Straw

Straw can be used to produce ethanol. The research focuses on the most widely available types of straw which are straw from cereal crops. The cereal crops assessed are wheat, barley, oat, rye and triticale. Cereal straw it is usually not traded over large distances due to its low bulk density. International trade in straw does occur however the volumes traded are relatively small when compared to the domestic use. For this reason this study will assess the straw use and production at a country level (e.g. straw produced and used in Germany). This because the ILUC risk might be considerable in a certain region but insignificant somewhere else.

Ten Member States were selected to assess in detail. The basis of selection was the average annual production of the five straw generating crops under review. The Member States selected (in order of production) were: France, Germany, Poland, UK, Spain, Denmark, Italy, Romania and Hungary. In addition, the Netherlands was also selected.

This study shows that a substantial quantity of 72 million tonnes of cereal straw can be sustainably harvested in the EU, taking into account soil regeneration. Part of this straw is used for the multitude of existing straw uses; ranging from animal bedding, animal feed, mushroom production, frost protection in horticulture, roof thatching and wall panel production. Diverting straw used for these purposes towards biofuels could lead to negative indirect impacts. Part of the straw that could be sustainably harvested is currently used for bioenergy, burned on the field or ploughed under the soil. This straw could be used to produce biofuels without leading to ILUC.

Our assessment shows that this low ILUC potential is substantial in France, Germany and Spain. France has the largest low ILUC estimated potential at 8.7 million tonnes, followed by Germany at 6.0 million tonnes and Spain at 5.5 million tonnes. Romania and Italy have estimated potentials of around 2.4 million tonnes each, while Denmark and the UK have estimated potentials of 1.4 and 1.1 million tonnes respectively. However, in Poland, the Netherlands and Hungary no, or almost, no surplus straw is available as a low ILUC feedstock.

Straw can be used to produce ethanol. Around 4,500 tonnes of straw is needed to produce 1,000 tonnes of ethanol.[283] This means that of the estimated quantity of 21.4 million tonnes of low ILUC straw available in the EU, **around 4.8 million tonnes of low ILUC ethanol could be produced, or around 3 MTOE.** This represents just over 10% of the forecasted total EU biofuel production in 2020.[284]

6.3 Bark, branches, leaves, sawdust and cutter shavings

This heterogeneous group of residues can be generated from a variety of sources and could be used to produce both ethanol or biodiesel. The materials can be residues from managed forests, arboricultural residues (prunings from parks, motorways, railways etc), woody farm residues (e.g. olive grove or fruit tree cuttings) and sawmill residues. It was decided to leave leaves out of the scope of this study as it is very unlikely that they will be harvested separately and its quality will be too poor for biofuel production.

Bark, branches, leaves, sawdust and cutter shavings have a high moisture content and low energy density. This makes long distance transport costly. The fragmented structure of production of several of the materials also makes collection and transport difficult. Significant extra-EU trade in these residue materials is therefore only likely to take place after pelletisation or another form of processing that increases the energy density. It is unlikely to be economically viable to process the raw feedstock (e.g. into pellets) and then to export it to the EU for further processing into a liquid biofuel in the EU. Therefore this study is limited to bark, branches, leaves, sawdust and cutter shavings being generated within the EU. Since no information on inter-EU trade exists the assessment has not been performed at Member State level. This does not preclude the fact that finished biofuel produced outside the EU from these feedstocks could be exported to the EU if the financial incentives are worthwhile.

A very large quantity of the materials is available in the EU. The total sustainable potential of woody residues is estimated to be 154.4 million m^3 per year. This figure includes 62 million m^3 of bark, 28 million m^3 of branches and tops, 16 million m^3 of woody farm residues, 27 million m^3 of sawdust and 20 million m^3 of cutter shavings. We assume that harvesting these quantities can be done without negative impacts on soil quality. This is a general estimate, it is important to keep in mind that a sustainable level of residue removal can vary from region to region.

Especially sawdust is already widely used in the pulp and paper industry and panel board production. No surplus quantity for ILUC-free biofuels can be assumed. The other materials have little current uses except for bioenergy (bark, branches and tops). Woody farm residues are usually burned or landfilled. This means that a total of around 126 million m^3 of low ILUC material is available.

283 http://www.biofuelstp.eu/cell_ethanol.html#ce1
284 The National Renewable Energy Action Plans forecast a total EU biofuel production of 29MTOE in 2020.

With an estimate of 24%, the estimated126 million m^3 low ILUC woody material might currently be converted to around 15 million tonnes biofuel[285]. Both ethanol and biodiesel can be produced from forestry residues, see also the table on page 67. Because it is unclear which conversion technology will prevail, we assume that **50% of residues could be used to produce 7.5 million tonnes biodiesel and the other half for 7.5 million tonnes bioethanol.** This equals around 6.5MTOE of biodiesel and 4.8Mtoe of ethanol, together a total of **11.2Mtoe** of low ILUC biofuel from forestry residues, which is nearly 40% of the estimated EU biofuel consumption in 2020.[286]

6.4 Used cooking oil

UCO is the waste product of using vegetable or animal oils to cook or fry food products. It is widely used in the EU to produce biodiesel, called UCOME. UCO has become an international commodity which is traded globally; it is difficult to limit the assessed region. The feedstock-region combination 'UCO from Germany' would be too narrow. While, alternatively, 'UCO globally' would not allow any differentiation between the available potential and current uses in different continents. This study therefore, assesses the low ILUC available quantities of UCO for the following five larger regions or countries: EU, US, China, Indonesia and Argentina. Early in the interview process we found that food processing companies are not willing to provide information on the quantities of UCO they generate. A choice was therefore made to focus mainly on the UCO generated in gastronomy (restaurants, snack shops etc.). At a later stage we saw that food processors in Indonesia were willing to talk. This sector could be researched further in the future.

UCO in the EU
Estimations on the available collectable potential in literature sources range from less than 1 Mt to above 3.5 Mt. Our interview partners estimate that 620,000 tonnes to 1,000,000 tonnes of UCO is currently collected with a maximum potential of up to 3 Mt. This figure includes gastronomy, food processors and households. Based on our analysis we estimate that a maximum of 972,000 tonnes UCO could be collected from the EU gastronomy sector. This figure is in line with estimations of interview partners on the quantity of UCO which is currently collected in the EU-27, but well below the maximum estimated potential of 3Mt. The 3 million tonnes does include UCO generated by households. As the gastronomy sector is already well covered by UCO collectors, the potential for additional UCO is expected to come mainly from households.

We estimate that 90% of the estimated maximum UCO potential from gastronomy of 972,000 tonnes is used for biodiesel production already and its continued use for biodiesel, does therefore not impact other current UCO uses and can thus be classified as low ILUC risk. The rest is used to produce

[285] Conversion factor of woody material to oven dry tonnes depends on moisture content and exact feedstock mix, but an approximate conversion factor of 1,000 m^3 woody material to 500 oven dried tonnes is used here. Source: U. Mantau, University of Hamburg, *pers comm* and UK Forestry Commission: http://www.forestry.gov.uk/website/forstats2009.nsf/0/8B4784E90B2A535480257361005015C6
[286] The National Renewable Energy Action Plans forecast a total of 29Mtoe biofuel consumption in 2020.

oleochemical products. This means that 874,800 tonnes of EU UCO is low ILUC risk. In addition the UCO imports can be added, due to their assumed use for biodiesel production. Altogether around 1 million tonnes of UCO could be processed into biodiesel in the EU-27 with a low ILUC risk.
If the untapped potential of household UCO is taken into account, the potential for ILUC-free UCO use in the EU might total 3 million tonnes.

UCO in the USA
According to the US National Renderers Association 885,000 tonnes of UCO was collected in the US in 2012. We have not been able to estimate the quantity which could potentially be collected in the United States. Of the currently collected 885,000 tonnes, some is used for animal feed and to produce oleochemical products. Different from in the EU, it is allowed to use UCO to produce animal feed. If these current uses are deducted from the total collected quantity of UCO, an estimated total of 407,000 tonnes of ILUC-free UCO would be available from the US, of which some 130,000 tonnes are thought to be already exported to the EU in 2012.

UCO in China
The Chinese restaurant sector is not only a source of UCO; it is also a major *consumer* of used cooking oil. Around 10% of China's cooking oil is estimated to be illegally derived from already used cooking oil, which is simply processed and blended with fresh cooking oil and then re-sold as cooking oil to the market. This mix makes monitoring and testing of this so-called "Gutter Oil" very difficult. An estimated annual quantity of 3 million tonnes of UCO could be collected from restaurants in China. Note that this figure does not include UCO from food processors and households, meaning that the real figure will be higher.

Ecofys has the impression that the largest use of UCO in China is its re-use as cooking oil (gutter oil), which is illegal in China. Some UCO is used to produce biodiesel and the Chinese government provides a financial incentive for the consumption of UCO. Whereas the official collectors supply UCO only for biodiesel production and oleochemical processing, private collectors are accused of selling UCO mainly for human consumption to the gastronomy sector.

Around 90% of the 3 million tonnes or 2.7 million tonnes of UCO is estimated to be used gutter oil collected by private collectors. Only 10%, or 0.3 million tonnes of UCO is collected by official collectors. The 2.7 million tonnes of UCO collected by private collectors probably have a high ILUC risk since diverting UCO used as cooking oil towards biodiesel production would lead to an increased use of vegetable oil to produce food. The 0.3 million tonnes of UCO collected by official collectors is at least partly ILUC free because it is used to produce biodiesel at the time of our assessment already. From this, it seems the potential of Chinese UCO as a low ILUC biodiesel feedstock is limited, although again the situation could be different if food processors and households would be taken into account. However, UCO use for food is illegal in China and forms a threat to public health. Therefore, even though diverting UCO currently used as cooking oil probably has a positive indirect impact: it would be beneficial for Chinese public health.

UCO in Indonesia

The total available quantity of UCO in Indonesia is conservatively estimated to be 646,800 tonnes per year. This figure could be much higher if not most informal restaurants would use used cooking oil to spice up dishes such as curries, meaning no UCO is left. Using UCO for human consumption appears not to be prohibited in Indonesia, which is remarkable. Large quantities of currently uncollected UCO from street side vendors and food processors are currently dumped in rivers and elsewhere.

It is unknown how much UCO is already collected at the moment. The three large collectors collect 120,000 tonnes and it is thought that smaller collectors gather another 65,000 tonnes, leading to an estimated total of 185,000 tonnes of UCO currently being collected.

The 120,000 tonnes of UCO collected by large collectors is probably nearly all being exported for biodiesel use. The estimated 65,000 tonnes of UCO collected by smaller collectors are thought to go in majority to non-bioenergy uses such as oleochemicals, animal feed and re-used as cooking oil by tofu, tempe and peanut producing or processing companies. Diverting these uses towards biodiesel might lead ILUC, although re-using UCO as cooking oil is detrimental for Indonesia's public health.

This means that of the total estimated UCO potential in Indonesia of 646,800 tonnes, some 581,800 tonnes could be used for biodiesel without leading to negative indirect impacts. Whether this potential can be reaped depends on the price of UCO which might make it feasible to collect from smaller islands and from 'kaki limas' street side vendors in less densely populated areas.

UCO in Argentina

Argentina is with 42 million inhabitants the least populated country assessed in this study. This is reflected in the available potential of collectable UCO, which is estimated to be only around 20,000 tonnes per year. This figure reflects the current quantity of collected UCO plus the amount which realistically could be collected in the near future. Households are excluded, food processors not.

There are relatively few legal incentives in Argentina to collect UCO (RBA and SODIR 2013). The uncontrolled disposal of UCO causes environmental impacts (water and soil pollution) and problems in sewage pipelines and waste water treatment facilities

According to UCO collectors, currently around 15,400 tonnes of UCO is currently collected annually, of which 80% is exported to produce biodiesel. The share of collected UCO which remains in Argentina goes either to the production of oleo chemicals (12% of total) or to domestic biodiesel production (8% of total). This will change in the near future, when a new UCOME plant starts operations.

Using UCO for animal feed is not prohibited in Argentina and apparently, a fraction of the UCO has being used for this purpose. However, none of the consulted collectors supply UCO for these purposes. Illegal use of UCO as cooking oil or for human consumption is a problem in Argentina, but no figures are available on its magnitude.

As indicated in the previous section, the main high value use of UCO in Argentina is in the oleochemical industry (12% of the UCO currently collected). For the purposes of the present study, it is assumed that 12% of the collectable potential would be delivered to the oleochemical industry as well. Based on this, the low ILUC UCO potential is estimated to be around 17,000 tonnes annually. This potential could be increased up to at least 23,500 tonnes annually, if 3.5% of the UCO from households in the main urban areas were collected.

Low ILUC biofuels from UCO
This study shows that a total of 7.8 million tonnes of UCO could be collected in the assessed regions. In reality this sustainable potential will be higher since most of UCO from the food processing sector and households is not included. Taking into account existing non-bioenergy uses, the total low ILUC potential of UCO is 3.6 million tonnes. Both the sustainable and low ILUC potentials would be considerably higher UCO used for human consumption in China and Indonesia would be diverted to biofuels. From 1 tonne of UCO around 0.9 tonne of biodiesel can be produced. This means that **3.2 million tonnes of low ILUC UCO biodiesel (UCOME) could be produced** in the assessed regions. This equals around **2.8Mtoe** or almost 10% of the forecasted quantity of biofuels consumed in the EU in 2020.[287]

6.5 Corn cobs

A cob is the hard cylindrical core that bears the kernels (or grains) of an ear of corn and is considered to be part of the corn residue (or stover). Corn cobs can be used to produce ethanol. The three main categories of corn cobs are (1) Grain Maize & Corn Cob Mix, (2) Green Maize and (3) Sweet corn. Since the latter is produced for human consumption it is left out of the scope of this study.

In this study we only performed a quick scan into the low ILUC potential of corn cobs. It was found that around 3.6 million tonnes of corn cob can be sustainably harvested in the EU annually. This takes into account the fact that some cob needs to be left on the land for soil regeneration purposes.

In parts of Europe corn cobs are currently being used for the production of heat. Corn cobs could also be used for a range of other uses including as building material and activated carbon, Fibre in fodder for ruminant livestock, despite its low nutritional value, livestock bedding or thickeners for soup or sweetened corncob jelly. It is unclear in what relative shares corn cobs are currently used for these purposes.

Because quantitative data on current corn cob use is unavailable it is impossible to estimate the possible excess potential for advanced biofuels. A more detailed market study and analyses could be carried with this aim.

[287] The National Renewable Energy Action Plans forecast a total 2020 biofuel consumption of 29Mtoe.

6.6 Significant low ILUC potential

This report shows that the assessed waste and residue materials assessed here all have considerable theoretical potentials, smaller but still substantial sustainable potentials and varying low ILUC potentials. For corn cobs the low ILUC potential could not be established, while straw, woody residues and used cooking oil all have a substantial low ILUC potential. Results can differ significantly from Member State to Member State. Germany, France and some other Member State for example have a large surplus of straw available while the Netherlands and Poland currently have a straw deficit. Using straw to produce ethanol in the latter two Member State poses a serious risk of negative indirect impacts. UCO is widely used as a biofuel already and this study shows that on the one hand ample ILUC-free potential is available, whilst on the other hand that UCO collection can be a dodgy business in certain regions, which makes quality control challenging. The use of UCO as cooking oil or for human consumption in China, Indonesia and possibly Argentina and dumping of UCO in rivers in some regions poses particular problems for public health and the environment. Using UCO which would otherwise be dumped to produce biodiesel can be highly beneficial beyond it being low ILUC.

The potential for corn cobs could not be established. From all of the other assessed materials **a total quantity of 17Mtoe of low ILUC biofuels could be produced**, 11.2MTOE from woody residues, 3Mtoe from cereal straw and 2.8MTOE from UCO. This estimated total would equal almost 60% of the total forecasted quantity of biofuels in the EU in 2020 when counted single. With double counting in place, all EU consumed biofuels could be produced from cereal straw, woody residues and UCO. The challenge is not the availability of ILUC-free feedstocks but in the willingness to invest in sufficient biofuel production plants which can reap this potential.[288]

6.7 Be cautious: maximum removal rate for primary residues

This study shows that a substantial quantity of cereal straw and forestry residues could be harvested and used for biofuels, but that an even greater quantity *cannot* be harvested without risking serious negative sustainability impacts. The current proposed positive lists for multiple counting do not limit the quantitative use of specific materials, in theory allowing both straw and 'bark, branches, leaves, saw dust and cutter shavings' (woody residues) to be completely harvested and used for biofuels. In order to reconcile the need for truly sustainable biofuels and the need to avoid negative sustainability impacts it would be necessary to introduce a maximum removal rate for primary land-using agricultural and forestry wastes and residues before these materials are included in the positive lists. It would be good to specify the removal rates at Member State level and if feasible an even more detailed regional specification. More research is needed to determine appropriate maximum removal rates.

[288] The National Renewable Energy Action Plans forecast a total EU biofuel consumption of 29 Mtoe in 2020.

When creating effective incentives for the use of wastes and residues as sustainable biofuel feedstocks it is advisable to take into account current uses of the feedstock. This study shows that this can require great efforts for policy makers and results are often estimates, but in order to promote truly sustainable biofuels it is worth the effort.

7 Literature and data sources

In addition to an extensive interview process and personal communication with numerous relevant experts, the following literature and data were used in the preparation of this report.

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