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Executive Summary

The defossilisation of the transport sector is one of the major challenges in meeting the climate targets of the Paris Agreement. In contrast to other sectors, greenhouse gas (GHG) emissions from the transport sector in Europe continuously increased from 1990 to 2007 and, after a decline between 2008 and 2013, are on the rise again since 2014. They are projected to remain at a high level of around 1,100 Mt CO_2eq until 2035 if no additional measures were implemented [EEA 2021]. Over those three decades, extensive research was conducted on renewable fuels for transport. Biofuels have experienced a rollercoaster development and are currently considered as not fully environmentally sustainable due to land use-induced impacts. Therefore, innovative renewable transport fuels that ideally are independent of agricultural or forestry land use, have gained growing attention.

Against this background, the EU-funded BioMates project ('Reliable Bio-based Refinery Intermediates – BioMates', GA ID 727463) aims to effectively convert lignocellulosic biomass (biomass residues and non-food crops) into high-quality bio-based intermediates (BioMates), of compatible characteristics with conventional refinery conversion units, allowing their direct integration to any refinery towards the production of hybrid fuels. As for any major new process to be introduced on industrial scale, risks can emerge. They have to be identified, assessed, treated and monitored. One essential element of this is an approach to the management of feedstock risks that is presented here.

Currently and in the foreseeable future, the demand for liquid transportation fuels in the EU is so high that the **market for biofuels** is generally limited by feedstock availability. Therefore, securing feedstock supply is a major element of a risk mitigation strategy for potential future BioMates facilities. Limitations of feedstock supply, resulting risks and strategies for their mitigation are analysed in this report.

Availability of lignocellulosic feedstocks has been analysed in many studies with substantially deviating boundary conditions and results. We screened the literature for appropriate studies covering the EU-wide availability of the feedstocks cereal straw, Miscanthus and forest residues, which are relevant for the BioMates project, harmonised boundary conditions and summarised the results. Starting from the technical biomass potential, those parts were subtracted that should not be used for sustainability reasons such as preserving soil organic carbon content to obtain the sustainable potential. Then the parts that are currently already being used were subtracted to determine the sustainable, available biomass potential.

The biggest sustainable, available potential can be found for cereal straw. While some studies report up to around 100 million tonnes dry matter (Mt_{DM}) per year, the lower end of the range of around 30 Mt_{DM}/year seems more realistic because it results from taking a wider range of various limitations to sustainable use into account. The use of forest residues is currently heavily debated among researchers coming to different conclusions on how much residues can be extracted from forests where and under which conditions in particular to preserve soil ecology and carbon stocks in the top soil. It is therefore largely unclear whether at EU level substantial additional amounts of up to about 35 Mt_{DM}/year can be used sustainably or whether even current uses have to be restricted, which would leave no additional forest residues for other applications. An option to certainly and sustainably increase the amount of forest residues available for lignocellulosic fuels or material use would be to replace other uses, i.e. primarily combustion for heat and power generation, by other renewable alternatives such as solar and wind power and by substantially decreasing the demand through better insulated buildings. For the perennial crop Miscanthus, the availability of suitable cropland is limiting. Currently, Miscanthus cultivation is very limited but could theoretically be expanded massively at the expense of other energy, feed or food crops. Given the increasing demand for food and feed and global deforestation for new agricultural land at a largely constant rate, sustainable availability of Miscanthus is very low. To minimise feedstock risks, biomass supply concepts for potential BioMates facilities should therefore concentrate on lignocellulosic residues. The sustainably available residues in the EU would theoretically be sufficient to feed 50 to hundreds of BioMates facilities.

While EU-wide availability of lignocellulosic residues can guide the further development of the BioMates concept, **local availability** and distribution of cereal straw and forest residues is decisive for planning concrete facilities. It is very heterogeneous and can also fluctuate from one year to another. Identifying a location with minimised straw feedstock risks needs to take location-specific sustainability criteria, existing regional users including traditional uses such as for animal bedding, and mitigation options for feedstock shortages into account. Alternative feedstocks should be considered, too, as far as technically possible to diversify risks. This way, economic pressure to resort to unsustainable feedstocks in particular in times of shortages can be avoided from the beginning. A location scouting process is not in the scope of this project but it is expected that the number of suitable locations is much lower than the theoretical number of BioMates facilities derived from EU-wide potentials in particular because of the limited transport worthiness of cereal straw. The decentralised BioMates concept involving several distributed pyrolysis units feeding one central facility gives a competitive edge compared to other approaches to valorise lignocellulosic residues, notably lignocellulosic ethanol which typically requires larger central facilities due to economies of scale. It can also use biomass that is not as locally concentrated as needed for other larger scale facilities.

To evaluate **price risks**, pricing for cereal straw in Western and Eastern Europe have been assessed based on historical data. Average prices were estimated as constant over time extrapolating trends seen for straw over the last ten years. Also available amounts are estimated to be constant on average but variable over the years due to variable weather conditions. Climate change might increase the probability of supply disruptions in the future or even lead to a declining supply.

Price differences based on location: Average prices are significantly different between Eastern and Western Europe. Typically straw is less expensive by almost a factor of two in Eastern Europe as there are lower transportation and labour costs and less competing uses of straw are in place. Moreover, there are significant regional variations in a country.

The major **risk on the feedstock market** is the **emerging competing use** of the main feedstock straw and hence a risk for BioMates is the increasing commercial production of second generation (lignocellulosic) ethanol such as by Clariant. Even if all planned production units are realised after 2023 in Eastern Europe, mainly Poland and Romania next to Slovakia still could provide sufficient remaining quantities of straw for several BioMates facilities of about 200 ktonnes biomass input/year. Due to the high prices of typically 90 to 130 €/t in Western Europe and several emerging competing uses for straw as construction materials compared to the low price in Eastern Europe paired with low labour and logistical cost infrastructures and no competing uses it is less likely to see construction of straw based biofuels facilities in Western Europe.

Mitigating feedstock risks is essential when planning and operating biofuel facilities such as those devised in the BioMates project. The recommendations on risk mitigation strategies presented in this report can support a sustainable implementation of biofuels from lignocellulosic residues. In particular cereal straw is currently sustainably available in sufficient amounts to become a major feed for several biofuel facilities according to the BioMates concept. Taking environmental, social and economic restrictions into account from the start enables a long-term profitability and viability of investments.

1. Introducing BioMates

1.1. The BioMates Project

The BioMates project aspires in combining innovative 2nd generation biomass conversion technologies for the cost-effective production of *bio*-based inter*mediates* (BioMates) that can be further upgraded in existing oil refineries as renewable and reliable co-feedstocks. The resulting approach will allow minimisation of fossil energy requirements and therefore operating expense, minimization of capital expense as it will partially rely on underlying refinery conversion capacity, and increased bio-content of final transportation fuels.

The BioMates approach encompasses innovative non-food/non-feed biomass conversion technologies, including **ablative fast pyrolysis (AFP)** and single-stage **mild catalytic hydroprocessing (mild-HDT)** as main processes. Fast pyrolysis in-line-catalysis and fine-tuning of BioMates-properties are additional innovative steps that improve the conversion efficiency and cost of BioMates technology, as well as its quality, reliability and competitiveness. Incorporating **electrochemical H_2-compression** and the state-of-the-art **renewable H_2-production** technology as well as **optimal energy integration** completes the sustainable technical approach leading to improved sustainability and decreased fossil energy dependency. The overall BioMates-Concept is illustrated in Figure 1.

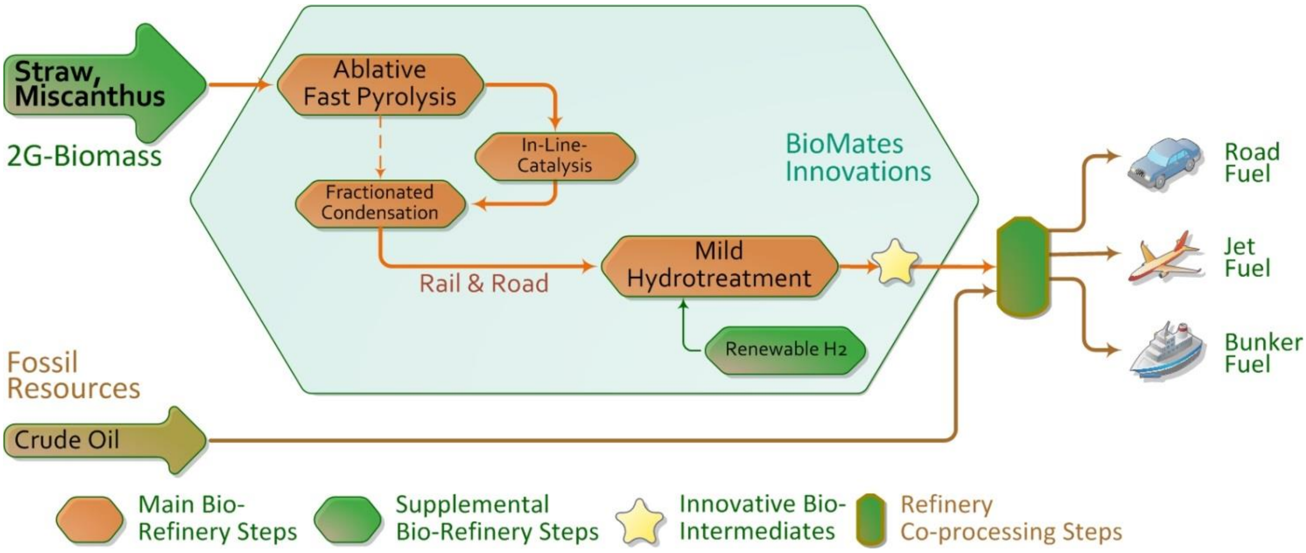

Figure 1: The BioMates-concept

The proposed technology aims to effectively convert residues and non-food/feed plants or commonly referred to as 2nd generation (straw and short rotating coppice like miscanthus) biomass into high-quality bio-based intermediates (BioMates), of compatible characteristics with conventional refinery conversion units, allowing their direct and low-risk integration to any refinery towards the production of hybrid fuels.

1.2. European Commission support

The current framework strategy for a Resilient Energy European Union demands energy security and solidarity, a decarbonized economy and a fully integrated and competitive pan-European energy market, intending to meet the ambitious 2020 and 2030 energy and climate targets “ [European Commission 2014a; b]. Towards this goal, the European Commission is supporting the BioMates project for validating the proposed innovative technological pathway, in line with the objectives of the LCE-08-2016-2017 call [European Commission 2015]. This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 727463.

1.3. The BioMates team

The BioMates team comprises nine partners from industry, academia and research centres:

- Centre for Research & Technology Hellas / CERTH - Chemical Process & Energy Resources Institute / CPERI, Greece (Project Coordination) - http://www.cperi.certh.gr
- Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT, Germany - www.umsicht.fraunhofer.de
- University of Chemistry and Technology Prague UCTP, Czech Republic - http://www.vscht.cz
- Imperial College London ICL, United Kingdom - www.imperial.ac.uk
- Institut für Energie und Umweltforschung Heidelberg gGmbH / ifeu, Germany - www.ifeu.de
- HyET Hydrogen B.V. / HyET, Netherlands - www.hyethydrogen.com
- RANIDO, s.r.o., Czech Republic - http://www.ranido.cz
- BP Europa SE, Germany - www.bp.com/en/bp-europa-se.html
- RISE Energy Technology Center / RISE- www.ri.se

For additional information and contact details, please visit www.biomates.eu.

2. Background

Risk management framework in general

Risk management in general aims at identification, assessment, treatment and monitoring methods to reduce risk connected with various activities. Successful risk management process should be carried out continuously with accented proactivity. Appropriate strategies for risk mitigation should comprise of identification, assessment, treatment and monitoring. For setting up a feedstock risk management strategy at this stage of technology development, in particular risk identification and assessment are relevant with first approaches to risk treatment.

Feedstocks for the BioMates concept

Fast pyrolysis is a versatile technology that can utilise various feedstocks. It is particularly suitable for feedstocks that are available at low water content because the pyrolysis process requires quite dry biomass. Moist biomass needs to be dried prior to processing. For the BioMates concept, lignocellulosic biomass such as residues from agriculture, forestry and forest industry as well as dedicated energy crops are technically suitable as feedstock. Residues from agriculture can be straw from different crops i.e. wheat, oats, barley, rye, rice, corn but also rice husks and olive kernels etc.. Examples of residues from forestry are branches, tops and roots. Examples of residues from forest industry are bark and saw dust. Examples of energy crops can be woody crops such as willow and poplar or herbaceous crops such as Miscanthus. Within the BioMates project, wheat and barley straw (=cereal straw) as well as Miscanthus were selected as the two main feedstocks. The biomass potential analysis within this report focusses on how the chosen feedstocks are technically and sustainably available in the EU and to what extent local availability needs to be taken into account for managing risks during the selection process for potential sites of future biorefineries according to the BioMates concept (chapter 2). The analysis of market and price risks focusses on price risks and market risks resulting from emerging competition (chapter 4).

3. Feedstock potentials and availability

The first step towards a risk management strategy for feedstock supply is the determination of feedstock potentials and availability. This has been studied widely in the EU context with diverging results. Therefore, a literature review was conducted that analyses and harmonises data available from previous studies on cereal straw and Miscanthus based on the methodology outlined in section 3.1. The results of this work are presented in sections 3.2 and 3.3 for cereal straw and Miscanthus, respectively. This is supplemented by an excursus on forest residues (section 3.4), which is an additional important biomass residue that is suitable as feedstock for the BioMates concept. A summary of results, conclusions and recommendations are presented in section 3.5.

3.1. Methodology and definitions

To estimate the sustainable available biomass potentials at EU level for the feedstocks cereal straw and Miscanthus that are primarily considered for the BioMates project, we performed a literature review based on peer-reviewed scientific literature and scientific project reports.

3.1.1. Definition of terms: different biomass potentials

Usually, for biomass potential analyses / biomass resource assessments, a **theoretical potential** is calculated, which includes the total biomass stock e.g. grown in a certain area. To account for technical limitations due to losses during harvest, transportation or storage, a **technical potential** is differentiated. To furthermore specify the biomass potential that can be extracted without harming the environment, e.g. by reducing soil quality, in some cases studies communicate a **"sustainable potential"** (alternative nomenclature: "base potential"). In a second step shares for existing competing uses are deducted to get a **"sustainable, available potential"** (alternative terms: "user potential", "removable potential").

The **"local sustainable, available potential"** is the sustainable, available potential within a given region. This density of biomass per region is of importance for location search if new technological concepts should be implemented in large-scale biorefineries.

3.1.2. Approaching inconsistencies within the data basis

We focussed on lignocellulosic biomass feedstocks relevant for BioMates by looking at wheat straw, other straw-like material (barley, rye, oat and rice straw), here also called "other cereal straw", and further agricultural crop residues (maize stubbles, sunflower and rapeseed straw, potato and sugar beet leaves). Furthermore, Miscanthus biomass potentials have been assessed. Forest residues are covered in an excursus.

We found several high-quality reports and peer-reviewed publications with focus on biomass potentials in the EU which where suitable for a comparison of biomass potentials. The studies differed in several boundary conditions which had to be addressed for reliable results.

General inconsistencies

Main differences were varying geographical scales and scopes within the studies examined for example in terms of the number of European countries (EU-27, EU-28, geographically). The methods used to estimate current and future biomass potentials ranged from geospatial analysis to yield statistics.

Whereas some studies reported the biomass potentials on a country-wise level, others showed their results on an overall European basis.

The differences between EU-27 and EU-28 concerning the biomass potentials is low and could be neglected, as Croatia is not one of the main cereal or Miscanthus producing countries within Europe and therefore of minor relevance for BioMates.

The United Kingdom has been included within the considered studies (since it was still part of the EU at the time the studies were conducted) and is therefore also covered in our analysis.

In terms of conversion factors e.g. for calculation of dry matter amounts from wet matter, the respective factors mentioned in the studies were used if not stated otherwise. The standard for this study is tonnes_{DM}/year.

Straw-specific inconsistencies

The straw biomass potential can be obtained by serval methods like for example via yields and product/residue (e.g. straw/grain) ratios but also via modelling. Only few studies reported the biomass potential on species level [García-Condado et al. 2019], whereas most publications and reports focused on more general boundaries like crop type (cereals, oil crops) or type of residue (dry – straw and stubbles, wet – manure) to define the biomass stocks observed. As no study showed the sustainable, available potential of wheat straw, we estimated the ratio in the sustainable, available potential between wheat straw, other cereal straw and further cropping residues based on data from [García-Condado et al. 2019; EuroStat 2020] if the studies did not report this ratio. The ratio applied was: 50% wheat straw, 28% other cereal straw and 22% further cropping residues. For Helin et al. [2012] no values for other cropping residues have been included. García - Condado et al. [2019] did not report a sustainable or a sustainable, available potential.

Wheat/cereal straw has been accounted under multiple different terms, like: “straw and stubbles”, “agricultural waste”, “removable straw” or “cereal residues”. This also touches the question whether maize, sunflower and rapeseed straw has been addressed together with cereals. Additionally, the definition of “sustainable potential” (and “sustainable, available potential”) varied widely as the term “sustainable” could be defined in various ways (e.g. due to different methods to calculate the soil carbon stock balance).

Furthermore, the projections and scenarios of biomass development within the future are also highly different. For example, in the S2Biom project [Dees et al. 2017] decreasing biomass potentials were reported, while scenarios developed by Building Research Establishment (BRE) [Jones et al. 2015] reported an increase in biomass potentials for technical and sustainable, available biomass potentials in future.

Concerning differences in the definition of sustainable, available biomass potentials, Jones et al. [2015] deducted a proportion of 33% of the total technical potential for competing demands and another 33% for sustainability constraints (i.e. a removal rate of 33% was used), while Elbersen et al. [2016] used a fixed removal rate of 40% for cereals and 50% for other stubbles. In Helin et al. [2012] the “removable straw” was calculated, taking into account competing uses and requirements for the soil carbon stock balance, based on

EUROSTAT data and with data derived from the European Office for Statistics. Two thirds (66%) of the technical potential is left on the fields to account for sustainability constraints. Dees et al. [2017] applied the good agricultural practice guidelines of the CAP (Common Agricultural Policy) and added restrictions for protected areas and restrictions as a result of RED (Renewable Energy Directive). However, no deduction for competing uses has been included as the "base potential" instead of the "user-defined potential" has been taken here. This leads to a slight overestimation, but offers the possibility to look at the shares of different feedstocks accordingly. Scarlat et al. [2010] used sustainable removal rates and accounted for different types of competing uses (e.g. animal bedding, mushroom production and mulching in horticulture). Scarlat et al. [2019] mainly focussed on soil organic matter content as sustainability constraint, using modelling approaches. This study is an update of Scarlat et al. [2010].

Inconsistencies related to forest residues (excursus)

The term „forest residues" is used in different ways for multiple biomass potential studies and reports. Most authors count branch material of differing size and tree tops to this biomass fraction, whereas needle/leaves, stumps, undergrowth trees, early thinning and complementary felling have been included in some studies only.

The biomass potential for forest residues can be derived by application of different methods. Studies in this field went for example via the national forestry inventories, applied statistical approaches or spatially explicit methods. Furthermore, single analyses were expanded and complemented by wood market data.

Across studies, the sustainable potential includes several and different sustainability assumptions besides the technical feasibility and availability already included in the technical potential. Dependent on the aim and scope of a study, the following exemplary sustainability aspects are included to account for sustainable utilisation, leading to a sustainable potential: recovery rate of the forest, soil bearing capacity, biodiversity protection, water protection and others [Boeraeve 2012].

Since there is no EU standard for fine woody debris removal limits, the member states set their own recommendations for sustainable harvesting of forest biomass. While Finnish guidelines recommend to leave 30% of forest residues in the forest, French guidelines suggest a rate of 10% - 30% dependent on soil sensitivity to mineral exports [Bessaad et al. 2021].

In summary, the main differing boundary conditions were: number of countries, different methods to estimate the biomass potentials as well as different assumptions to set a sustainable potential, different set of included biomasses, different assumptions on the future increase or decrease in crop yield and cultivation area. Besides few different assumptions and slightly differing boundary conditions, different studies could be included in our analysis to show the range of biomass potentials and to subsequently conclude on available biomass potentials in the EU.

3.2. Results on straw biomass potentials

3.2.1. Potentials at EU level

This section focusses on the sustainable, available biomass potential of wheat straw, other cereal straw (barley, rye, oat and rice straw) and other agricultural crop residues (including maize stubbles, rapeseed or sunflower straw or potato and sugar beet leaves). Starting with the overall technical potential, the sustainable, available potential is derived by deducting the biomass that cannot be used due to sustainability constraints (e.g. for maintaining the soil organic carbon content) and the biomass that is already used (see section 3.1.1 on definitions).

Technical potentials

The reported overall technical potential varies highly between the different studies as the boundary conditions were different (see chapter 3.1.2). The largest deviations resulted from the varying feedstock pools, to which the wheat straw was counted, as well as from the different methods applied. The results of the overall technical and the overall sustainable potential are depicted in Figure 2.

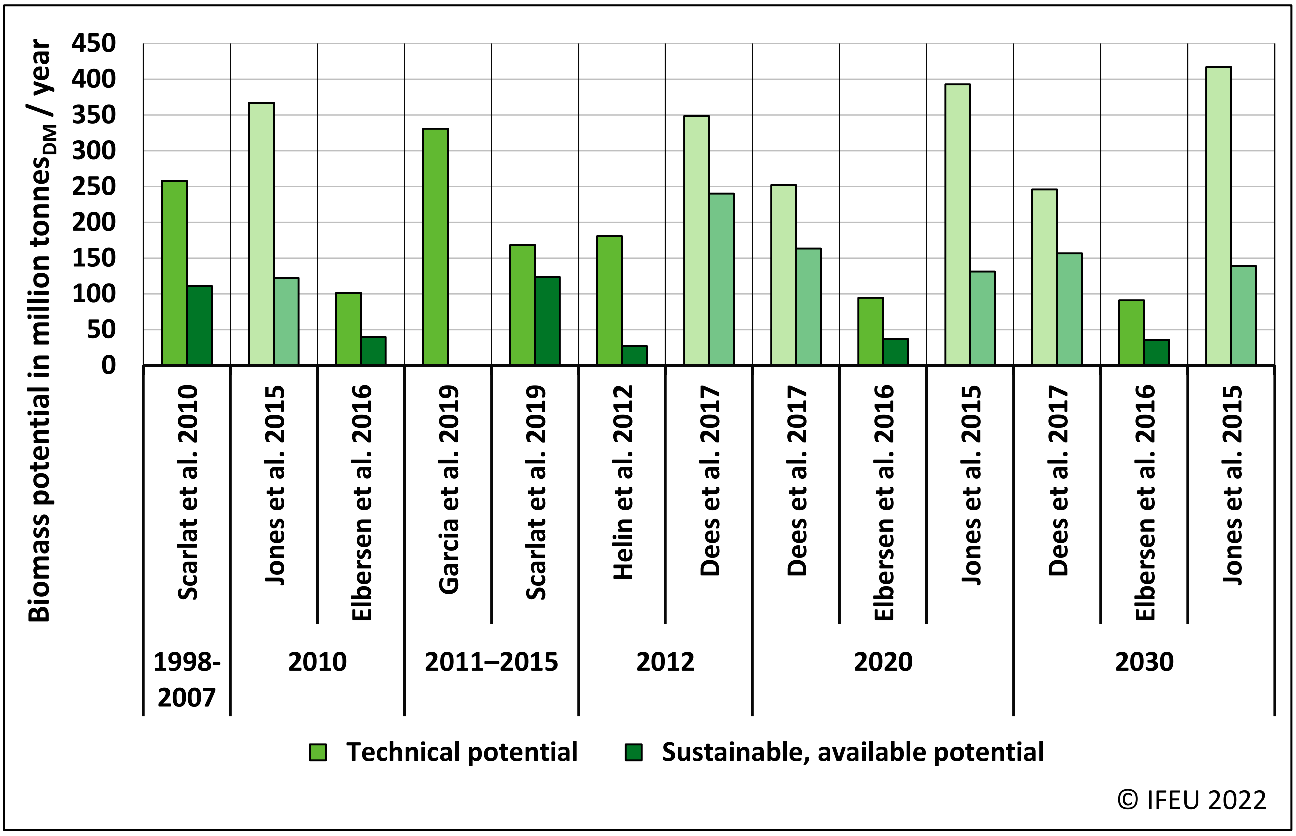

Figure 2: Biomass potentials for wheat straw, wheat straw-like and further agricultural crop residues in million tonnes$_{DM}$/year in the European Union by base year of reporting/scenarios. Some studies include additional biomass and therefore report higher values (Jones et al. [2015] and Dees et al. [2017], lighter coloured bars, see text for details).

Three out of seven studies [Jones et al. 2015; Dees et al. 2017; García-Condado et al. 2019] reported results for the overall technical potential within the EU in 2010-2015 of around 350 million tonnes$_{DM}$/year, whereas three studies reported results between 100 and 200 million tonnes$_{DM}$/year [Helin et al. 2012; Elbersen et al. 2016; Scarlat et al. 2019]. An earlier study (1998-2007) calculated a value of 250 million tonnes$_{DM}$/year [Scarlat et al. 2010]. The large differences in the technical potential can be partially explained as Helin et al.

[2012] and Elbersen et al. [2016] did not include any other agricultural residues besides cereal straw in their evaluation of the technical potential[1]. Additionally, these differences might come due to different methods used for estimation of the technical potential (statistical approach for Helin and Elbersen vs. spatially explicit approach in other studies). Results by Jones et al. [2015] might be overestimated, as residues from crop processing were partially included.

Possible future developments

Three studies [Jones et al. 2015; Elbersen et al. 2016; Dees et al. 2017] applied scenarios for the future development of straw biomass potentials. Looking at the future of straw biomass potentials, an approximation has to come with major uncertainties. On the one hand, an increase is possible due to high economic margins for cereals, new cultivation areas due to climate change, a lower use of straw-shortening growth regulators or an increased straw demand for energy or fuel production. Furthermore, an increase of organic agriculture might come with an increased use of long-straw varieties due to lower pathogen susceptibility, need for livestock bedding material.

On the other hand, also a decrease is possible due to a reorganization of the EU´s common agricultural policy (CAP), an increase in so called “Greening areas” or due to climate change and conversion of areas in southern Europe.

This uncertainty can be spotted in the results for the years 2020 and 2030. Whereas Elbersen et al. [2016] and Dees et al. [2017] reported a decrease in the total technical potential down to 120 and 250 million tDM/year, respectively, Jones et al. [2015] projected a slight increase to 416 million t_{DM}/year till 2050.

Sustainable, available potentials

Looking at the sustainable, available potential (Figure 3) by deducting shares for soil organic carbon maintenance and shares for competitive use from the technical potential, we clearly see differences in the extent of deductions between the studies examined. They are a result of different sustainability and competing use assumptions of the studies (see chapter 3.1.2).

[1] They did, however, include further agricultural residues for the sustainable potential. Therefore this graph does not show a meaningful ratio between technical and sustainable potential.

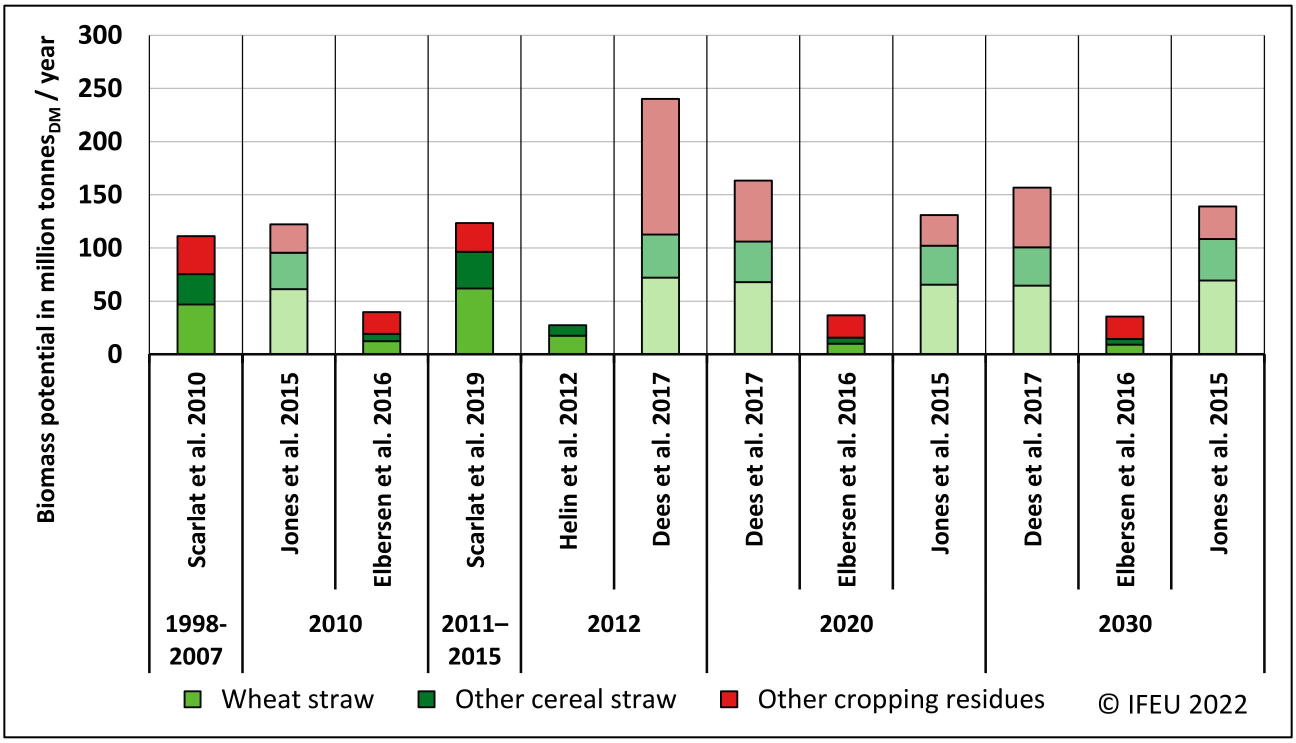

Figure 3: Sustainable, available biomass potential for straw and similar agricultural residues in million tonnes$_{DM}$/year in the European Union. Some studies include additional biomass and therefore report higher values (Jones et al. [2015] and Dees et al. [2017], lighter coloured bars, see text for details).

Jones et al. [2015], Scarlat et al. [2010], Dees et al. [2017] and Scarlat et al. [2019] reported similar results of around 100-240 million tonnes$_{DM}$/year for agricultural crop residues in general, of which around 60 million tonnes$_{DM}$/year have been counted as wheat straw, around 35 million tonnes$_{DM}$/year as wheat-straw like material/other cereal straw, which is relevant for BioMates, too, and further crop residues amount to another about 30 million tonnes$_{DM}$/year. The overall results of Helin et al. [2012] and Elbersen et al. [2016] are lower than the results of the other studies analysed. For both studies, this could largely be explained by methodological reasons in terms of calculation of the technical potential, e.g. due to the application of statistical approaches instead of other methods like spatially explicit approaches. For Helin et al. [2012] particularly high sustainability constraints have been taken into account in addition. Jones et al. [2015] report higher values because residues from crop processing were partially included. Results of Dees et al. [2017] rather depict the sustainable but not the sustainable, available potential because competing use has not been accounted for (see chapter 3.1.2).

Summary

Estimations of straw biomass potentials vary substantially. The studies used different feedstock pools and a diversity of methods to derive biomass potentials from agricultural crop residues, making it difficult to compare the respective results, especially if specific models have been used e.g. to account for sustainability constraints. For BioMates, the use of wheat, barley and rye straw is of primary importance while the use of rice straw, rapeseed and sunflower straw, maize stubbles or potato and sugar beet leaves depends on technical suitability.

Overall, there is sufficient straw available in Europe for a certain number of selected new applications, although sustainability guidelines to maintain soil organic carbon stocks are applied and current straw users will continue to require feedstock.

3.2.2. Local sustainable, available potentials

This section analyses the local sustainable, available potential of wheat straw and other cereal straw with high relevance for the BioMates concept. Furthermore, the competitive uses and the maintenance of soil organic matter content are discussed in more detail.

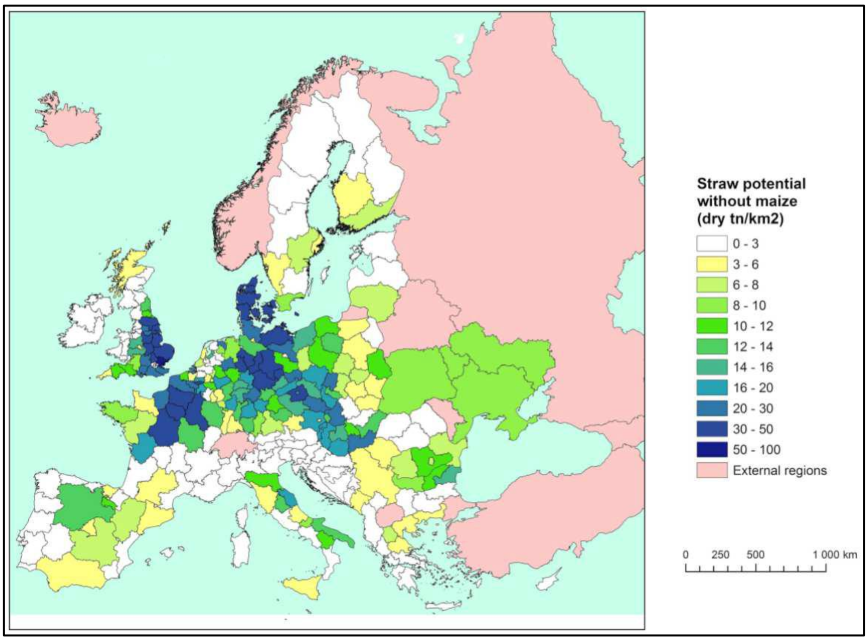

Figure 4: Annual quantity of sustainable, available straw (called 'removable straw' in the study) from cereals without corn (dry tonnes/km^2) at regional level (NUTS2) for European countries (EU-27; Ukraine; Balkan countries), Source: Helin et al. [2012].

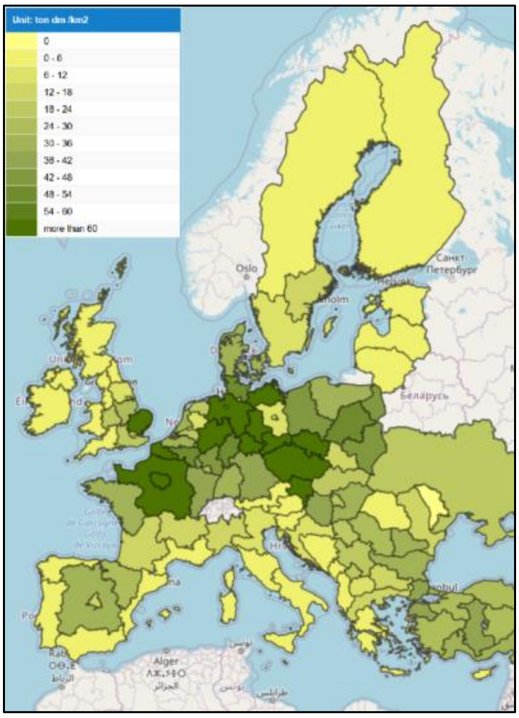

Figure 5: Cereal straw and stubbles sustainable potential (called 'base potential' in the study) distribution (2030). Please note: in contrary to Figure 4, competing uses have not been deducted for the sustainable potential (see text for details). Source: S2Biom-Project [2012].

Local sustainable potentials

For the use of cereal straw in biorefineries, not only the total amount of sustainably available feedstock is important, but also the distribution in order to find regions for future pyrolysis/biorefinery sites with high absolute biomass potentials within a certain radius ("straw hot spots").

Here, maps are helpful as depicted in Figure 5 [S2Biom-Project 2012][2] and Helin et al. [2012]. The amount of "removable straw" already includes the deduction for sustainability reasons (soil quality and competing uses) and therefore is equal to our sustainable, available biomass potential with respect to the size of the area needed for provision (local sustainable, available potential). In S2Biom-Project [2012] the "base potential" comprises higher numbers compared to our sustainable, available biomass potential as no competing uses where deducted. Not surprisingly, a coincidence of the local sustainable, available biomass potential with the main cereal producing regions (e.g. central France, Denmark, the east of England as well as central Germany, Czech Republic and Poland) can be seen.

Sustainability constraints and competition

As mentioned above, the sustainable, available and the local sustainable, available biomass potential has to be projected by deduction of identified competitive uses (current and future) from the technical potential and by application of sustainability coefficients to maintain the soil organic matter. Large-scale competitive uses, like power plants, have been addressed and depicted in Helin et al. [2012] (Figure 6).

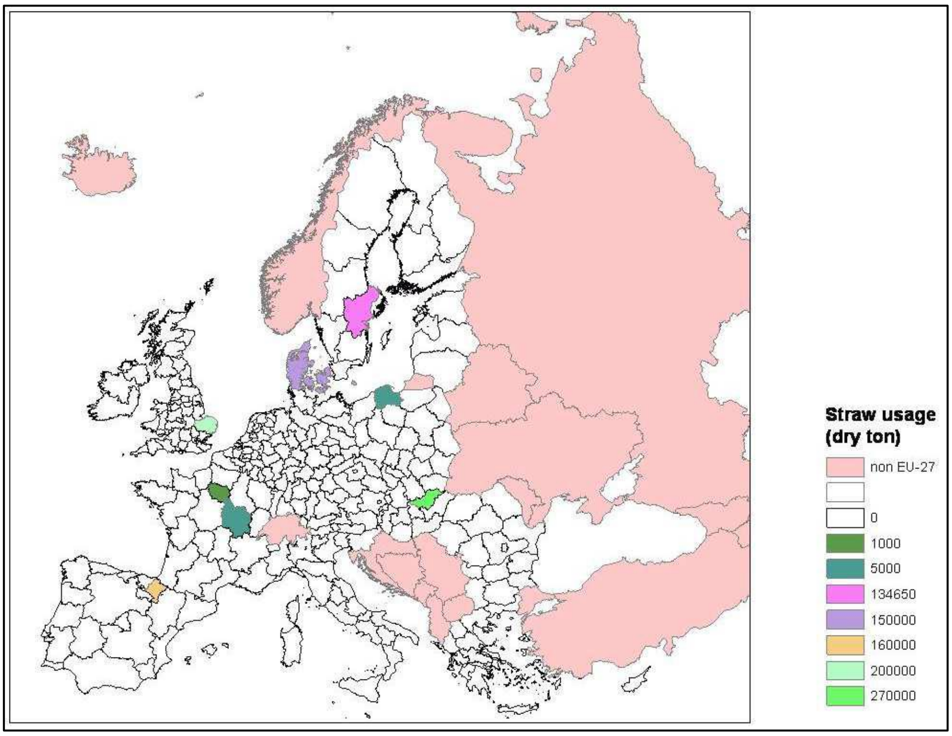

Figure 6: Straw to energy in Europe – identified power plants in 2010 and quantities of straw used, Source:Helin et al. [2012].

Exemplary, further competitors that have been researched are a bioenergy power plant in Emsland (Germany) with an annual demand of 75 ktonnes_{WM} straw (20-25% water content) [Bioenergiekraftwerk Emsland GmbH 2021] and a biorefinery in Schwedt (Germany) for bioethanol production with 40 ktonnes straw [Verbio Schwedt GmbH 2021]. In Podari (near Craiova), in the southwestern part of Romania, Clariant

[2] Data from this project for the sustainable potential (remark: without competing use) was included above in Dees et al. [2017].

currently builds a production unit for bioethanol with a yearly demand of 250 ktonnes straw [Clariant AG 2021]. This illustrates that the use of straw is slowly but steadily gaining momentum in Europe.

The second aspect, the awareness for soil fertility maintenance is highly controversial. It depends on various features and location-specific properties like: type of soil, crop rotation, agricultural practices applied such as no-till vs. tillage, location of nature reserves and waters (due to distance regulations), climate change (due to changed rotting rates) and the targeted soil organic matter content. Nevertheless, the studies examined got similar results, with similar conclusions regarding the local sustainable, available potential and the spatial distribution of the sustainable technical potential around Europe.

3.2.3. Identifying a location with minimized straw feedstock risks

This chapter gives an outlook on further aspects related to location search beyond finding regions with high local sustainable, available biomass potentials (see chapter 3.2.2) to identify locations with minimised straw feedstock risks.

The location search for a pyrolysis unit or biorefinery should include more than biomass potentials. Socio-economic aspects have to be taken into account in addition to biomass potential feedstock risks. These socio-economic aspects include:

Ownership, agricultural structure and infrastructure

A diverse compilation of the biomass suppliers is desirable to lower the risk of unreliability of suppliers, but comes with higher transaction costs/effort needed for negotiations. Furthermore, regional supply with biomass is of importance to lower the transportation expenditures. The logistics concept should be elaborated with care. Storability, density and degradation should be taken into account besides the seasonality of the business planned. Regions with high shares of cereals in crop rotation should be preferably chosen.

Overall sustainability (including balanced social, economic and environmental aspects)

An overexploitation of biomass potentials can be avoided by establishing location adapted removal limits. This point is of importance to maintain soil fertility and long-term biomass supply. Moreover, minimum criteria for crop rotations are required to avoid monotonous/uniform landscapes with limited biodiversity value. Fair prices for suppliers support long-term partnerships and a reliable supply with biomass.

Further local competitors

To avoid resentments, local competitors besides power plants and bioethanol production such as strawberry production, mushroom production, animal bedding (organic agriculture, horse keeping) need to be taken into account. Furthermore, regions with emerging competition (facilities under construction or in the development phase) should be evaluated cautiously, too (further examples see chapter 3.2.2).

Taking these criteria into account, the risks of feedstock shortages can be minimised.

3.3. Results on Miscanthus biomass potentials

The following section discusses Miscanthus biomass potentials in the EU. Miscanthus is a perennial, herbaceous grass, which can be used for many purposes, including paper production and animal bedding, as building material or in power plants for energy production [Alexopoulou 2018].

Miscanthus can be grown in large parts of central and southern Europe (Figure 7)[von Cossel et al. 2018]. The main difference to biomass residues is that Miscanthus is a dedicated energy crop that needs to be cultivated on arable land. This raises issues related to land-use, land-use change (direct or indirect) and competitive land-use (fuel, fibre, flower, food, feed - discussion) with implications on biodiversity, sustainable soil use, water retention, crop rotation, nature conservation, and marginal land use.

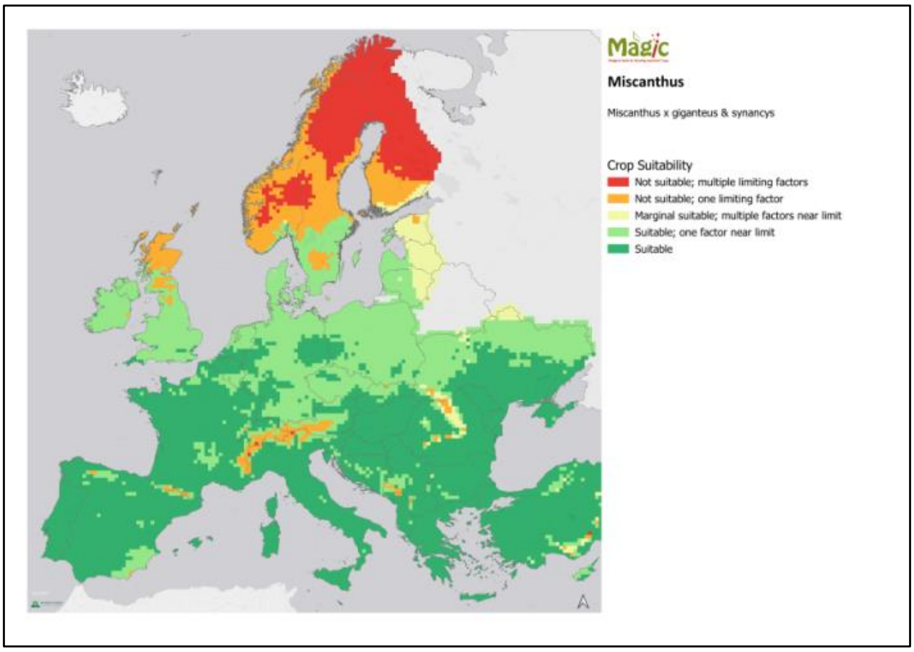

Figure 7: Area within Europe, suitable for Miscanthus growth in terms of climate, soil and terrain. Source: von Cossel et al. [2018]

The land available for Miscanthus and other dedicated crops for non-food/feed purposes (bioenergy, biofuels, bio-based products) is the main influencing factor in the discussion about sustainable, available Miscanthus biomass potentials in the EU. Subsequently, the second question is how to allocate this area of land between the different dedicated crops, which compete with each other. In this regard, attention has to be paid that the extent of perennial crops is compatible with the rest of the agricultural system in order to keep crop rotation possibilities for annual crops (more diverse crop rotations are desirable from an environmental point of view). In general, Miscanthus could be grown with high yields in the main cereal-producing regions of Europe, like for example in Central France, Central Germany, Southern UK or Poland.

The amount of land in Europe, that could be available in the future for energy crop production, has been estimated between 2 million ha and 110 million ha (Figure 8) [Rettenmaier et al. 2010]. The majority of studies reviewed by Rettenmaier et al. show a clustering around 10-40 million ha land that could be made available in the future. This included both unused and abandoned land as well as surplus land, i.e. land that is not needed any more for food and feed production due to yield increases as a result of improved agricultural practices (mainly intensification). In the last decade, however, the discussion around indirect land use changes (iLUC), world population increase and changing diets (especially in the global south) made clear that agricultural markets act globally and that it is not an option to reallocate the agricultural land that is already in use. The only real option is to make additional currently unused or abandoned agricultural land available [Fehrenbach & Rettenmaier 2020; Rettenmaier et al. 2018, 2021] The main reason for this shift in views is that competition about productive cropland rather increased than decreased and that detrimental indirect effects of this competition including deforestation at largely unchanged speed and local impacts of intensified agriculture on ecology on biodiversity, water and soil became more prominent. From today's perspective, a shift from meat-based to plant-based diets and corresponding changes in EU's Common Agricultural Policy (CAP) would be required to make a substantial reallocation of productive cropland possible in magnitudes corresponding to the figures presented in the studies mentioned above.

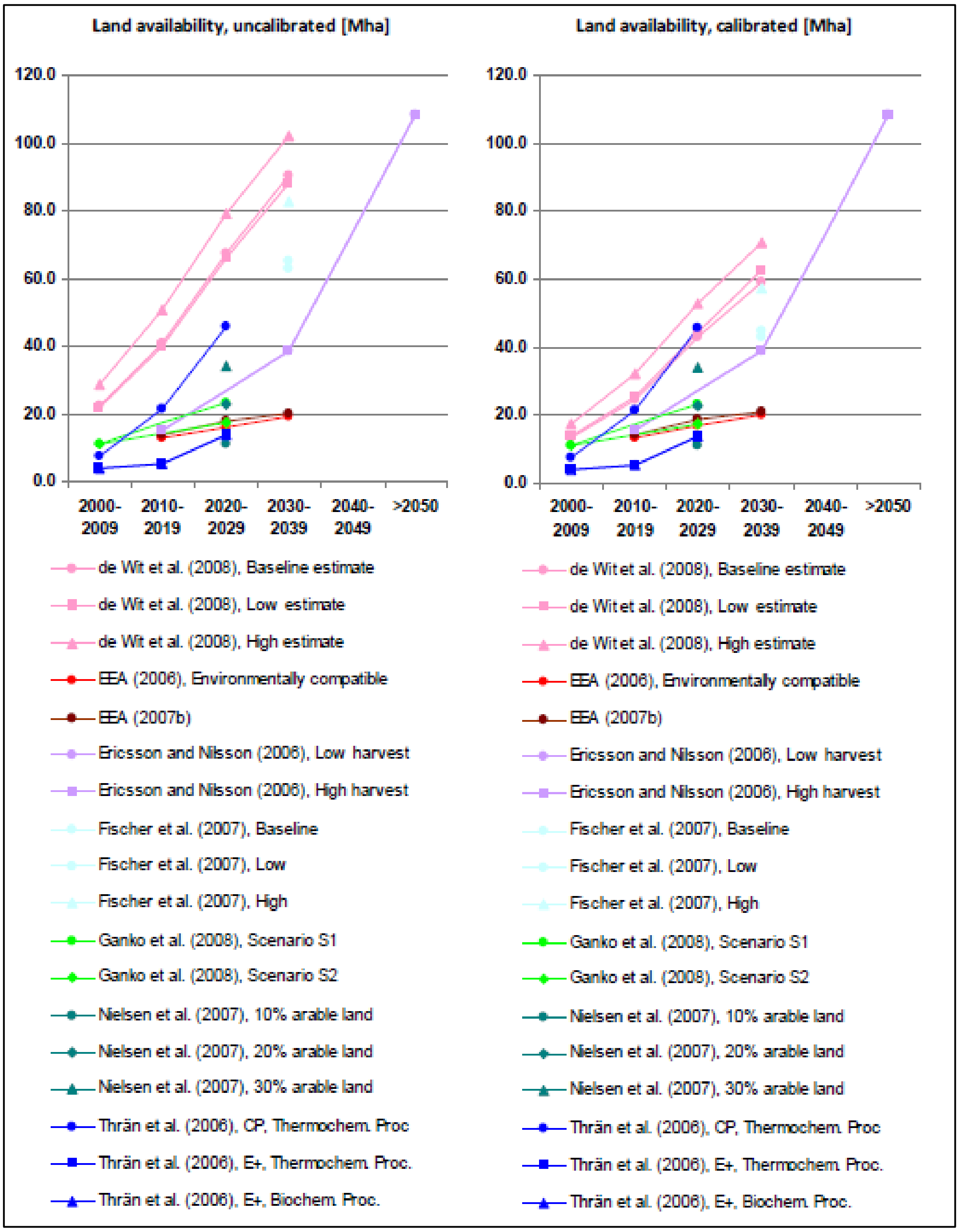

Figure 8: Land availability for energy crop production – uncalibrated (left) and calibrated to EU27 level (right) [Mha], Source: Rettenmaier et al. [2010]

Around 1.4 million ha of additional currently unused or abandoned agricultural land might be available for energy crop production including recently abandoned crop- and grasslands, fallow land in agricultural rotation and suitable contaminated sites [Allen et al. 2014]. Another scientific publication in this field of studies concludes that between 1.2 million ha and 8.3 million ha sustainable available crop rotation area is available including marginal lands, prospective idle land and rotational black fallow [Diaz-Chavez et al. 2019]. This shows that the scenarios regarding the future amount of land available for energy crop production are highly diverse and that it is almost impossible to narrow down this large range.

For further differentiation, the total area available for energy crop production has to be distributed between different energy crops like rapeseed, Miscanthus, switchgrass, maize or sunflower. Besides energy crops, also industrial crop production (e.g. fibre) is aiming at idle and marginal land, leading to further competition with regard to land use (in addition to the use for food and feed production which is always given priority). Further examples for industrial crops, competing with Miscanthus for area, are hemp, linseed and flax. Additionally, conservation areas like green fallow or „greening areas“ [European Commission 2014c; d] and their increase within the agricultural landscape are discussed.

Because of the immense uncertainty, we set three scenarios with low (0.05%), medium (5%) and optimistic (10%) shares of Miscanthus cultivation area of the total current area for energy crop production (40 million ha). The yields of Miscanthus can vary highly dependent on location of growth, genotype and intensity of management (e.g. irrigation) [Rettenmaier et al. 2021]. Here, also scenarios have been applied (see Table 1).

Table 1: Miscanthus biomass potentials based on scenarios (low, medium, optimistic), in relation to boundary conditions with high relevance: available land and yield. Available land in million hectares, biomass potentials in million tonnes dry matter per year.

		Yield		
		Low 8 t_{DM}/(ha*year)	Medium 15 t_{DM}/(ha*year)	Optimistic 20 t_{DM}/(ha*year)
Available land	Low 0.02 Mha	**0.16 Mt_{DM}/year**	**0.3 Mt_{DM}/year**	**0.4 Mt_{DM}/year**
	Medium 2 Mha	**16 Mt_{DM}/year**	**30 Mt_{DM}/year**	**40 Mt_{DM}/year**
	Optimistic 4 Mha	**32 Mt_{DM}/year**	**60 Mt_{DM}/year**	**80 Mt_{DM}/year**

The sustainable, available biomass potential range of 0.16 – 80 million $tonnes_{DM}$ per year shown in Table 1 is an estimation based on yield and land availability scenarios. Dees et al. [2017] calculated a Miscanthus biomass potential of 36 million tonnesDM/year for 2030 (around 2,400 kha – with 15 tDM/ha). However, Lewandowski et al. [2016] and Alexopoulou [2018] identified an area of 20 kha in Europe currently cultivated with Miscanthus. Reasons for this small area can be:

1) too high production costs (including establishment, input costs and clearing),

2) insufficient development of agricultural production technology,

3) concerns and less experience of farmers,

4) no stable markets and demand for Miscanthus biomass established [Lewandowski et al. 2016].

Taken together, current availability of Miscanthus is very low but substantial potentials would be possible if cultivation of Miscanthus would be given priority over other possible uses of limited cropland.

3.4. Excursus on forest residue biomass potentials

This chapter provides an excursus on forest residues, which could be an important alternative to straw and Miscanthus for BioMates.

Technical potential

In a medium mobilisation scenario, 118 million m^3 of forest residues are technically "available" in Europe every year [Mantau et al. 2010; Mantau 2012] (technical potential). In the future (2030), a small increase to 120 million m^3 is expected, of which 44 million m^3 are estimated to be "available" in Northern Europe. Another publication reported the total forest residue biomass potential at 77 million m^3 (EU-27, 2008) [Asikainen et al. 2008]. Similar figures are reported by Bogaert et al. [2017] for scenarios under similar conditions.

Sustainable, available potential

Especially the use for fuel wood and partly the utilisation by the pulp industry show a demand for forest residues as other forestry products (e.g. stems) are used for construction wood and panel production. This use in 2010 amounts to 39 million m^3 forest residues, which is part of the above mentioned „available" forest residue biomass potential [Mantau 2012].

Forest ecosystems require dead wood material especially after felling and subsequent stem removal, with regard to biodiversity and soil carbon storage. Due to no litter fall on clear-cut harvested sites, forest residues could serve as gap-filling nutrient source for soil life and soil protection due to shading and water erosion protection until new trees have been raised. Furthermore, removal of excess biomass quantities (especially of leaves, needles and small branches) can lead to nutrient depletion. This may require fertilisation or ash spreading to at least compensate parts of the depletion.

According to several country-specific guidelines for sustainable harvest of forest biomass, 30% of the forest residues should remain in the forest [Bessaad et al. 2021] (see chapter 3.1.2). However, these guidelines are currently not met in many places and the share of remaining residues can be even less than 10% [Bessaad et al. 2021].

For similar sustainability constraints, Mantau et al. [2010] report 70 million m^3 (34 million $tonnes_{DM}$/year) forest residues that could be classified as sustainably available in 2010, taking into account sustainability and competing uses. Bogaert et al. [2017] confirm these figures and highlight policy options that could substantially increase or decrease the sustainable, available potential of forest residues depending on various options for the decarbonisation of the energy sector e.g. via fuel wood and pellet production.

Distribution of sustainably available biomass

The amount of forest residues is unevenly distributed between the different countries with larger total biomass potentials found in Sweden, Germany, France, Finland and Italy due to the size and forest cover of the countries. The largest forest residue biomass potentials per area (availability density) can be found in

Central Europe, due to higher forest productivity, and Northern Europe, due to higher forest cover ratio, respectively [Mantau et al. 2010].

Outlook

Several counteracting trends make an outlook on future amounts of sustainably available forest residues challenging. These are:

1. Forest residues as analysed here are co-products of stem wood harvest and thus **dependent on the development of stem wood harvesting**. The growing stock in European forests increased over the last years and is theoretically available for usage [Ministerial Conference on the Protection of Forests in Europe 2020]. Whether harvest should be increased, is discussed controversially. Economically, increased wood harvests are mostly favoured. From a climate change perspective, on the one hand harvests would reduce forest carbon stocks immediately with similar stocks growing back only slowly but on the other hand the use of the wood could reduce fossil carbon emissions. How long "carbon payback times" are or how high "carbon debts" could become depends on each use pathway. Their acceptability has led to controversies among scientists and has to be defined politically in accordance with other climate change mitigation measures. In the end, it will depend on which peak atmospheric greenhouse gas concentrations are considered to pose an acceptable risk of irreversible severe damages to planet earth.
2. Climate change and other effects increasingly cause **damages to forests via storms, increase of pests such as the bark beetle, fires etc**. Firstly, all of these damages have the potential to substantially reduce the growing stock of forests, which leaves less potential to increase wood harvests. Instead, they might need to be decreased substantially. Secondly, high amounts of damaged wood are becoming available irregularly in the last years. They could be used e.g. for biorefineries in addition to regularly occurring forest residues if logistical challenges can be solved.
3. The **share of forest residues left on site** has to be increased in many places if several country-specific sustainability guidelines are to be met [Bessaad et al. 2021]. Because it is plausible to assume that all removed forest residues are used (mainly for energy), this would mean that the sustainable available potential would be negative in these places.

4. Current trends show an increased use, production and, even more so, **net import** of wood pellets to Europe [UNECE & FAO 2021], which can be considered as tradable alternative to forest residues in several energy applications. This can be an indication that an increased use of forest residues is already now meeting its limits. Furthermore, because parts of the imported pellets stem from logging primary forests, an increase of imports is connected with a severe risks of various unsustainable consequences.

Taken together, an increased utilisation of forest residues for energy and/or material use is debated controversially. Whether this biomass could be increasingly used for biorefineries such as discussed in BioMates depends on several counteracting and uncertain trends. An option to certainly and sustainably increase the amount of forest residues available for lignocellulosic fuels or material use would be to replace or reduce other uses, i.e. primarily combustion for heat and power generation, by other renewable alternatives such as solar and wind power and by substantially decreasing the demand through better insulated buildings.

3.5. Summary, conclusions and recommendations on feedstock potentials

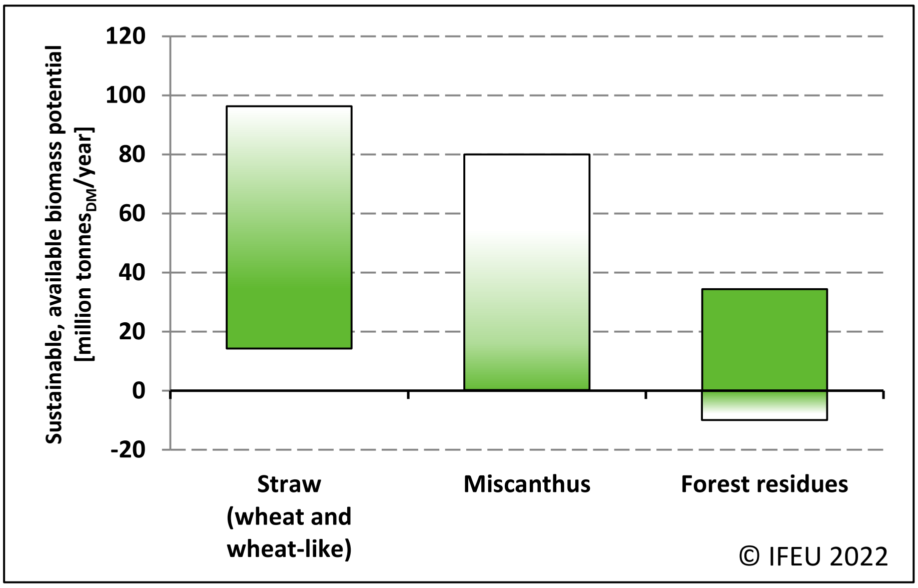

Figure 9: Overview of sustainable, available biomass potentials for straw (wheat and wheat-like), Miscanthus and forest residues

The sustainable, available biomass potential in the European Union offers the possibilities to establish new, innovative usage pathways. Based our review of research project reports and peer-reviewed scientific literature of straw, Miscanthus and forest residue potentials in the European Union summarised in Figure 9, we concluded the following aspects:

Conclusions straw:

- Up to 60 million tonnes$_{DM}$/year of available sustainable wheat straw are reported for the EU. Besides wheat straw, there are several other wheat straw-like feedstocks like barley and rye straw (additional potential of up to 35 million tonnes$_{DM}$/year). Rapeseed straw and maize straw together with other agricultural crop residues (additional potential if up to 30 million tonnes$_{DM}$/year) might be suitable for use in BioMates, too.

- The range of reported values is large, which mainly results from different limitations of sustainable availability that are taken into account and different data availability on these limitations. These limitations primarily result from straw to be left on the field to maintain soil fertility and from existing uses including e.g. animal bedding. A part of these uses does not involve trade and may thus not be covered by available statistical data. Generally, it seems most plausible that the more limitations are taken into account and the better the data is, the lower is the reported estimate for sustainable available straw potentials. For wheat, barley and rye straw values at the lower end of the reported range, i.e. around 30 million tonnes$_{DM}$/year, seem most plausible.
- Theoretically, based on up to 30 million tonnes$_{DM}$/year cereal straw, 150 biorefineries of about 200 ktonnes$_{DM}$/year straw demand could be built with respect to the overall sustainable biomass potential.

- The straw is distributed unevenly, leading to some regions with clustered and high straw potentials in a small area and others with scattered availability, where fuel demand for collection and transportation outweighs the benefits of using the straw. So, the number of potential locations for biorefineries is expected to be much lower than the theoretical number.
- For BioMates, the locations of the pyrolysis units need to be in a certain distance to the central hydrotreatment facility. This additionally lowers the potential number of locations.
- Taking all feedstock limitations into account, there are still sufficient amounts of straw available for the establishment of several facilities according to the BioMates concept. Regions with a medium density of local sustainable biomass availability can be considered, too, because of the decentralised BioMates concept with four or more pyrolysis facilities feeding one biorefinery with an intermediate of much higher energy density.
- Based on maps, derived by EU consortia, projects and interdisciplinary researchers, an idea of potential locations could be obtained, which regions might come into question for further location search.

Conclusions Miscanthus:

- The Miscanthus biomass potential depends on the amount of land dedicated to non-food and non-feed purpose, beside the further distribution of this area between different industrial and energy crops.
- Given the increasing demand for food and feed and global deforestation for new agricultural land at a largely constant rate, sustainable availability of Miscanthus is very low. To minimise feedstock risks, biomass supply concepts for potential BioMates facilities should concentrate on lignocellulosic residues.

Conclusions forest residues:

- The use of forest residues needs to be considered carefully due to the possibility of over-exploitation. Especially soil organic carbon, biodiversity and soil nutrient stock are examples for parameters with proven sensitivity to excess forest residue removal.
- The limits of sustainably removable forest residues is very location-dependent and researchers come to very different conclusions on how much of the forest residues can be sustainably extracted at which location.

  Forest residues could already be overused in some regions [DBFZ 2019; Fehrenbach & Rettenmaier 2020] while other regions still show some potentials leading to uncertain net potentials. Sustainable available potentials could range from close to zero to up to about 35 million $tonnes_{DM}$/year.

- An option to certainly and sustainably increase the amount of forest residues available for lignocellulosic fuels or material use would be to replace other uses, i.e. primarily combustion for heat and power generation, by other renewable alternatives such as solar and wind power and by substantially decreasing the demand through better insulated buildings.

Risks:

- Environmental risks include: Climate change might increase uncertainty and decrease the stability of supply with residual and cultivated biomass increasing the risk of more frequent feedstock shortages. Furthermore, increased and/or shifted pest pressure (e.g. black cereal rust) could lead to less available biomass via less cereal production within Europe.
- In the range of social risk factors, shifted consumption pattern with less cereal demand (a lot of grain is used for meat production) might be a first example. A second could be a low acceptance of non-food biomass cultivation. Furthermore, regional conflicts with competitors like strawberry production or horse keepers might increase.
- Economic risks related to straw and Miscanthus biomass potentials include changes in the EU common agricultural policy (CAP) and related payments. Furthermore, the increased competition due to several emerging technologies based on straw use could lead to high prices for straw and Miscanthus biomass.
- Taking all feedstock risks into account, there could be high competition and shortages even at very suitable locations.
- If more straw was used by the pyrolysis units than sustainably available, the main effect might be a lower soil microbial activity, lower soil organic carbon stocks and subsequently lower yields in the following years.

Recommendations:

- For biorefineries with straw as main feedstock, regions with a high amount of sustainably available straw within a small area (“straw hot spots”) should be preferred to lower the transportation expenditures. Location search should therefore start with the main cereal production regions and take into account already established medium and large-scale uses (e.g. power plants or bioethanol production) to avoid competition.

- Biorefineries with forest residues as main feedstock should only be considered after a thorough analysis of sustainable extraction limits, taking a broad range of scientific studies into account.
- In case of increasing competition about straw, the concept involving distributed pyrolysis units should be preferentially used in regions with biomass residue densities that do not support central large biorefineries and thus competition by straw-based bioethanol production is less likely. With regard to feedstock risk mitigation, decentralized approaches with multiple, linked biomass processing units (in this case pyrolysis units) should be preferred.

- Environmentally friendly and socio-economically acceptable location-specific removal limits per hectare have to be established taking into account local conditions such as soil properties (e.g. soil organic matter and soil biodiversity) and competing uses.
- To minimize the discussed risks, conservative, location-adapted planning of size and area of biomass collection for the pyrolysis facilities should be followed. The capability of future biorefineries to use various biomass feedstocks as input streams is of importance to further lower risks.

4. Feedstock market and price risks

4.1. Feedstock pricing risks and historical trend

Pricing forecasts in the time frame of 2020 to 2030 has been structured in four raw material categories and has been reported separately in July 2021 as “Milestone M13: Techno-socio-economic data relevant for business case development gathered”. Pricing for Cereal Straw in Western and Eastern Europe have been assessed based on historical and geographical data reported from websites of agricultural associations [Agrarheute n.d.; Agrarmarkt-Aktuell n.d.]. Prices are estimated as constant over time extrapolating a trend seen for straw in Germany (Figure 10) over the last 10 years. Available amounts are estimated be constant on average but variable over the years due to not constant weather conditions [REHAP 2021]. Climate change might increase the probability of supply disruptions in the future or even lead to a declining supply.

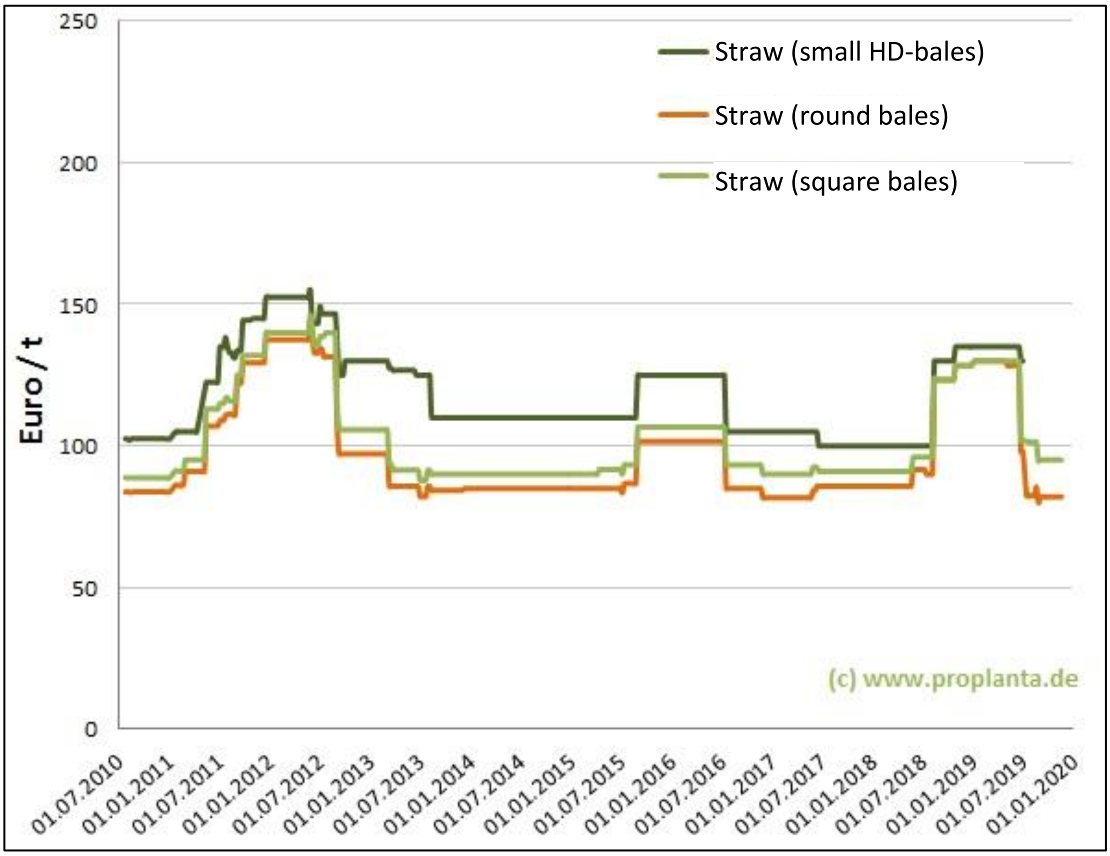

Figure 10: Straw prices 10-year-trend in Germany for three common types of bundled straw

Average prices are significantly different between Eastern and Western Europe. Typically straw is less expensive by almost a factor of two in Eastern Europe as there are lower transportation and labour costs and no competing uses of straw for chemicals, biofuel or materials, e.g. as insulation for houses [European Straw Building Association 2016], are in place. Moreover, there are significant regional variations in countries, e.g. within Germany +/- 25 %.

For Miscanthus and residues from wood average pricing in the EU was assumed. For wood and its by-products there is already a sophisticated trade and logistic infrastructure available for long.

4.2. Competing use and feedstock risks in the straw residue market

The major **emerging competing uses of straw** is the manufacturing of so-called second generation ethanol (EtOH). Clariant, which is a leading European actor in this field, claims to have a fully validated technology on commercial scale after seven years of development. Multiple feedstock had been tested with an identical process but with feedstock-specific enzymes and yeast. Feedstock tested are straw, Miscanthus, rice straw/husks, corn stover, bagasse and sugarcane tops & leaves. Like BioMates, currently the technology hinges mainly on cereal straw due to its availability and due to established logistics. It is claimed that one hectare results in a harvest of 4 to 5 tonnes of cereal straw (average 4.5 tonnes) yielding 1 tonne ethanol, 1 tonne of vinasses, 1 tonne of CO_2 and 1.5 tonnes of lignin [Clariant AG 2020; Hortsch & Corvo 2020].

The following Table 2 gives an overview of the removable straw according to the EU-project-BIOCORE [Helin et al. 2012] together with the calculated land use implying a yield of 1 tonne of Ethanol (EtOH) per hectare.

Table 2: Removable straw (BIOCORE) and new use of straw for Ethanol (Clariant)

Removable straw and consumed agricultural area earmarked for Ethanol production in the European Union	ktonnes/year earmarked for EtOH (Clariant)	**Km^2 earmarked for EtOH (Clariant) (100 ha = 1 Km^2; 1 t EtOH / ha)**	ktonnes/year removable cereal straw	**ktonnes/year removable cereal & maize straw**
Straw DE	—	—	5 320	6 076
Straw FR	—	—	5 474	7 995
Straw UKR	—	—	5 774	7 215
Straw PO	125	1 250	2 252	2 571
Straw RO	250	2 500	1 032	2 602
Straw UK	—	—	2 477	2 477
Straw HU	—	—	1 356	2 698
Straw SLO	250	2 500	496	660
Totals	**625**	**6 250**	**24 181**	**32 294**

It can be concluded that since about 50% of the removable cereal straw in Slovakia will be consumed for Ethanol, this country can be excluded as a location for a BioMates facility. However, in Poland and Romania the remaining quantities of straw are sufficient for several BioMates facilities of about 200 ktonnes biomass input/a, if a BioMates facility brings in additional value and flexibility into the expanding biofuel market.

The quantity of removable straw (available potential) in BIOCORE has been calculated according to the following formula:

RS = HS X A – SL X (1 – B) - SE

With:

· RS: removable straw

· HS: harvestable straw

· SL: straw for litter (bedding)

· SE: straw for energy

· A: coefficient of sustainability (to maintain the soil carbon balance)

· B: percent of manure back to crop plot

The following Table 3 displays the planned and realized ethanol facilities by Clariant, the operating owner, their location and status. The availability of straw seems is not the only factor affecting the choice of a location for a straw-based ethanol facilities. Furthermore, country specific variable and fixed cost for labour, engineering, logistics and transport as well as an existing infrastructure like refineries, as well as chemical and fermentation facilities next to train and waterways play an important role as well.

Table 3: Planned and realized straw-based ethanol facilities of Clariant

Feedstock	Feed [kt/year]	EtOH [kt/year]	Status/year	Type of facility	Operator, Location, Country
Wheat/Barley Straw	250	50	operational 2021	Green-Field	Clariant / ETA BIO, Podaria, Romania
“Ligno-Cellulosics”	4.5	1	operational 2018	Green-Field	Clariant, Straubing, Germany
Undisclosed	250	50	operational 2022	Brown-Field in 1G-EtOH	Enviral, Leopoldov, Slovakia
Straw	125	25	operational 2022	Brown-Field in refinery	Orlen, Południe, Poland
Totals	**629.5**	**126**			

Potential emerging competing uses for straw and wood residues were assessed in the EU-project REHAP [REHAP 2021]. The project has finished in March 2021 und focussed on novel materials from agricultural and forestry waste for use in the green building sector. In this context, the availability of agroforestry residues was analysed for employing them as construction materials as well as raw material for straw based ethanol. The most suited residues from agroforestry investigated were straw and wood bark. Researchers have been collecting data on how much agricultural and forestry residues are available for sustainable use across Europe. It was found that the most suitable sources of material are straw from agriculture and residues from forestry.

For straw from agriculture, the highest potential was found to be in the Bassin Parisien in northern France, accounting for 6.8 Mio t. The Bassin Parisien produces 2.1 Mio t of barley straw and 4.3 Mio t of maize stover. The total amount of straw in the EU is 95 Mio t. The shares of different straws are wheat 46 Mio t, maize stover 31 Mio t, barley straw 16 Mio t and rapeseed straw 14 Mio t [REHAP 2018].

A minimum cost price of 0.76 €/l was found to be economically viable for second generation ethanol. In order to reach the maximum greenhouse gas savings the price might become as high as 0.93 €/l. Eastern Europe was identified as best location for production facilities due to the availability of feedstock as well favourable labour and logistic costs. In total 7 facilities with optimized logistic networks and a total capacity of 2.8 Mil. tonnes Ethanol were estimated as feasible with and without a 50% reduction in excise tax abatement [Wietschel et al. 2021].

4.3. Competing use and feedstock market risks for Miscanthus

Unlike straw and forest residues, Miscanthus is not a residual material but an agricultural and energy crop. It must therefore be explicitly cultivated, which means that the required land area is in direct competition with agricultural land. In addition, Miscanthus is often grown for dedicated applications, such as the production of heating pellets or animal bedding. As a result, producers, and consumers are often identical at this stage and, unlike for straw, there is no free market. These circumstances explain the lack of available literature regarding price and market developments. Hence, price risks for Miscanthus could not be assessed.

5. Disclaimer

This Deliverable report reflects only the authors' view; the European Commission and its responsible executive agency CINEA are not responsible for any use that may be made of the information it contains.

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7. Abbreviations

1G	First generation (biofuels), produced from food and feed crops, e.g. rapeseed
CAP	Common Agricultural Policy
CO_2eq	Carbon dioxide equivalent
DE	Germany
DM	Dry matter
EtOH	Ethanol
FR	France
GA	Grant Agreement
GHG	Greenhouse gas
ha	Hectare (1 ha = 10,000 m^2)
HU	Hungary
km	Kilometre
PO	Poland
RED	Renewable energy directive (EU directive about the renewable energy use)
RO	Romania
SLO	Slovakia
t	Tonne (metric)
UK	United Kingdom
UKR	Ukraine
WM	Wet matter
WP	Work Package

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