Topic 1.1 Biomass potentials and biomass mobilisation

The BABET REAL 5 Project - Setting the scene for a really sustainable second generation (2G) bioethanol production in Bavaria

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ABSTRACT: Can the production of 2G bioethanol be really sustainable when all parameters (a.o. soil carbon, climate change) that could have an influence on the potential biomass are thoroughly considered? When looking for agricultural residues that take into account all sustainability aspects, the available potential is reduced considerably. Still, it is possible to find promising regions and crops that make the sustainable production of 2G bioethanol possible. In the South-East of Germany, in Bavaria, it was investigated whether regions can be found, in which more than 30,000 t_{dm}/y are available in a 50-km radius and the preconditions for a sustainable feedstock are fulfilled. For all 96 official districts of Bavaria, the theoretical, technical and agronomical potential, as well as the competitive use was analysed for the feedstocks wheat straw, rye straw, barley straw, oat straw, rapeseed straw, triticale straw and corn stover. It could be shown, that in the region Lower Bavaria, in two 50-km radius areas between the cities Landshut and Passau enough wheat straw (~ 121,000 t_{dm}/y) and corn stover (~ 172,000 t_{dm}/y) is available for the production of 2G bioethanol. Furthermore, it was found, that in Bavaria these amounts (i.e. the yields) can be also be provided when the local consequences of climate change are considered, as the negative impacts (i. e. heavy precipitation or heat waves) are presumably compensated by positive impacts (i. e. longer vegetation period, more CO_2 for plants growth). Assuming the use of biofuels in agricultural vehicles, a first calculation of the environmental impact of the feedstock supply revealed that per supply ton of wheat straw 11.0 kg CO_{2eq} need to be taken into account, and 18.9 kg CO_{2eq} per supply ton of corn stover.

Keywords: bioethanol, feedstock, supply, sustainability, environmental impact

1. INTRODUCTION

A few decades ago, second generation biofuels from lignocellulosic biomasses were foreseen as attractive alternatives or complements to first generation biofuels. This perspective was based on the hypothesis that the lignocellulosic biomasses, principally from crop and forest residues and agro-industrial wastes, were not competing against human and animal nutrition and were available in large quantities and at competitive costs (or for free). Preliminary studies about biomass feedstock, ran under the former EU funded project BABETHANOL, demonstrated that the conditions for obtaining lignocellulosic biomass were not as favourable as initially thought. Most of the crop residues, except the straws that have a well-established use and market for animal littering and food, are currently left in the fields as a natural way of returning organic and mineral nutrients to the soil. A massive removal and exportation of the crop residues is not feasible in many countries and areas where soil conditions already suffer from erosion and lack of organic and mineral nutrients due to climate conditions and intensive agricultural practices.

The purpose of this study was to evaluate the real available amounts of lignocellulosic biomasses starting from theoretical harvestable quantities and after taking into account the restrictions due to agronomic and technical constrains and current competitive uses. As transportation is making a high contribution to the supply cost and carbon foot print, the net available amounts were investigated in small catchment areas limited to 50 km radius.

2. THE BABET-REAL5 PROJECT

The major objective of the BABET REAL 5 (Program Horizon 2020/ N° 654365) Project is to develop an alternative solution for the production of ethanol from lignocellulosic biomass at small-industrial-scale suitable for a variety of feedstocks, rural areas and countries in Europe and worldwide.

The project's specific objectives are set:

- Achieve adequate technical-economic and environmental performances for the production of second generation ethanol in small-scale industrial plants
- Identification of sustainable and reliable feedstocks
- Analysis of realistic evaluation and scale up of selected business cases

3. FROM THEORETICAL TO SUSTAINABLE POTENTIAL

The feedstock investigation started with the selection of suited feedstocks for the production of 2G bioethanol. In the EU funded project BABETHANOL, several feedstocks have been analysed and for Germany, wheat straw, rye straw, barley straw, oat straw, rapeseed straw and corn stover were considered as suited feedstocks. In the study, also the potential of triticale was investigated as it is a hybrid of the suited feedstocks rye and wheat.

Following, the different potentials in Bavaria are shown from theoretical to the sustainable potential.

3.1 Theoretical potential

To calculate the theoretical potential, official statistics of the Bavarian State Office for Statistics were used. In order to receive one single value for each feedstock, data sets were elaborated that take into account average values of the past years. Each data set contains information about 3 years average of agricultural used lands, 10-year average of crop yields and straw rates for investigated crops. The formula used for the calculation can be expressed as following:

$$\overset{n}{\underset{i=1}{SY}} = \sum_{i=1}^{n}(CF_i * CF_i * FGS_i)$$

SY = straw yield [t]

CF = cereal fields [ha]

CY = cereal yield [t/ha]

FGS = factor grain:straw-relation

i = cereals

The theoretical potential for the different feedstocks is given below in Table I.

Table I: Bavaria - theoretical feedstock potentials

Investigated feedstocks in Bavaria	Theoretical potential $[t_{dm}/y]$
Wheat straw	2,710,785
Rye straw	198,01
Barley straw	2,454,788
Oat straw	263,247
Rapeseed straw	1,781,221
Corn stover	929,337
Additionally investigated:	
Triticale straw	422,965

3.2 Technical potential

Starting from the theoretical potential, the share that is limited by technical restrictions and can be finally recovered with equipment is called technical potential. The restrictions can be technically like recovery rates but also legal or social limits (i.e. fodder production or composting). Thus, the technical biomass potential describes the “time and location related, primary from the technical perspective materially or energetically” usable amount of biomass [1]. For the calculation of the technical potential, for all different straws but corn stover, it was assumed that 67 % of the theoretical potential can be recovered from the field [2]. For corn stover, according to a recent study [3] by Thurner et al., a technical potential of 49 % needs to be considered (see Table II).

Table II: Bavaria: technical feedstock potentials

Investigated feedstocks in Bavaria	Technical potential (in % of theoretical potential) $[t_{dm}/y]$
Wheat straw	1,816,227 (67 %)
Rye straw	132,667 (67 %)
Barley straw	1,644,708 (67 %)
Oat straw	176,376 (67 %)
Rapeseed straw	1,193,418 (67 %)
Corn stover	455,375 (49 %)
Additionally investigated:	
Triticale straw	283,387 (67 %)

3.3 Agronomic potential

To guarantee that the soil quality is not affected in a negative way, for Bavaria also the issues of erosion, soil biodiversity and soil organic matter were being looked at. In brief, it can be said that **soil erosion** is the biggest threat for the Bavarian agricultural land, heavily depending on agricultural use and topography. Especially in the region Lower Bavaria care must be taken to avoid soil erosion. The medium, long-term soil erosion based on the utilised agricultural area in Bavaria as result of the natural conditions combined with agricultural management shows that Lower Bavaria is the region most affected by erosion in Bavaria with values of losses partly over 6 tons per hectare and year [4].

To prevent the soils from erosion, it is recommended that conservation tillage is fostered. This measure includes all tillage techniques, that reduce losses of soil and water. Furthermore, after the cultivation, at least 30 % of the soil surface shall be covered with plant remains. Conservation tillage is characterised by two basic principles:

- Reduction of the usual intensity of soil tillage according to method, depth and frequency of the mechanical operation. The extended soil regeneration period shall lead to a stable, firm soil structure with the objective of preventing soil compaction by following vehicles

- •Leaving crop residues of previous and/or catch crops close to or on the soil surface with the objective of a (in the best case) year-round soil cover over an intact soil structure, which shall prevent capping and erosion [5]

It has already been proven, that conservation tillage is an effective cultivation technique when soil carbon matters need to be addressed [6].

For Bavaria, regarding the issues of **soil biodiversity**, maps like for erosion do not exist. However, results from the Global Soil Biodiversity Atlas which was published in 2016 allow the conclusion that the soil biodiversity situation is not alarming, the soil biodiversity index for Bavaria ranges between medium and high [7]. In Bavaria, the soil biodiversity issue is not only recognized as special task for farmers, yet seen as task for the whole society.

Therefore, in 2008, the Bavarian biodiversity strategy was implemented. It has four central objectives:

1. Securing environmental diversity
2. Conservation of biodiverse natural habitats
3. Improvement of ecological measures to facilitate wildlife migration for passing barriers such as roads or dams and weirs
4. Education on environmental knowledge

The four objectives are subject of special working groups within the Bavarian Ministry of Environment [8].

When looking at the issue of **soil organic matter** (in Germany mostly referred to as humus) and the sustainable supply of a residual feedstock, it is known that farmers can have an impact on the humus content development by the way they cultivate their lands. That means, that the external impacts (i.e. wind and water erosion) need to be observed and the consequences controlled, so that the soil carbon content is kept at a stable level.

In Bavaria, since 1986, the humus content is regularly monitored to know more about the long-term development of the humus supply. Therefore, more than 100 representative agricultural used areas have been chosen (90 fields, 25 grasslands and 6 fruit and special crops sites). After 26 years of monitoring (i.e. from 1986 to 2012), the average C_{org} (organic carbon) and the N_t (total nitrogen) contents on the monitoring sites remained stable. In order to find out early enough whether the soil quality is changing, in Bavaria it is recommended that farmers control the humus content on their agricultural areas every 5 to 6 years on a pre-determined field area of 10 to 29 m^2. The sample collection shall be carried out in the spring before the application of fertilizers.

To sequestrate soil carbon also in the times of climate change, farmers play the decisive role. Depending on the way how the lands are cultivated, carbon can be stored in the soils if farming methods like conservation tillage with cover crops and crop residue mulch, nutrient cycling including the use of compost are adapted [9]. In Bavaria, the Bavarian State Research Centre for Agriculture recommends the following agricultural measures to the farmers to preserve and foster the humus (or soil carbon) on their fields:

- Well balanced crop rotation, catch crops, nurse crop
- Sufficient supply of the soil with organic matter, ploughing in of plant residues or organic fertilizers
- Location adapted soil cultivation to prevent erosion and compaction
- Consideration of the codes of good agricultural practices when fertilizing
- Needs-based chalking to achieve or preserve pH-neutral soils
- Grassland preservation [10]

Regarding the agronomic potential that can be recovered from the fields, and which takes into account the above-mentioned issues, a sustainability factor was considered in the study which says that only a certain amount of biomass can be exported from the field so that enough humus can be reproduced on site.

The German IFEU (Institut für Energie- und Umweltforschung - Institute for Energy and Environmental Research) investigated the maximum amount of crop residue which can be taken from the fields without putting the soils at risk of nutrient degradation. According to the IFEU. a maximum factor of 33 % of the total grain straw (i.e. the theoretical potential) can be taken from the fields if the soil quality shall be maintained. Still, research is ongoing on this issue as the development of soil carbon is very location-specific and thus, the sustainability factor of 33 % can only be seen as a first approximation [11]. For this investigation, the sustainability factor was used for all investigated crops.

Table III: Bavaria - agronomic feedstock potentials

Investigated feedstocks in Bavaria	**Agronomic potential** (33% of theoretical potential) **[t_{dm}/y]**
Wheat straw	894,559
Rye straw	65,343
Barley straw	810,08
Oat straw	86,872
Rapeseed straw	587,803
Corn stover	306,681
Additionally investigated:	
Triticale straw	139,579

The values that were obtained as agronomic potential for the different feedstocks were visualized on GIS maps (Figure 1) and facilitated the decision, which feedstocks were further investigated.

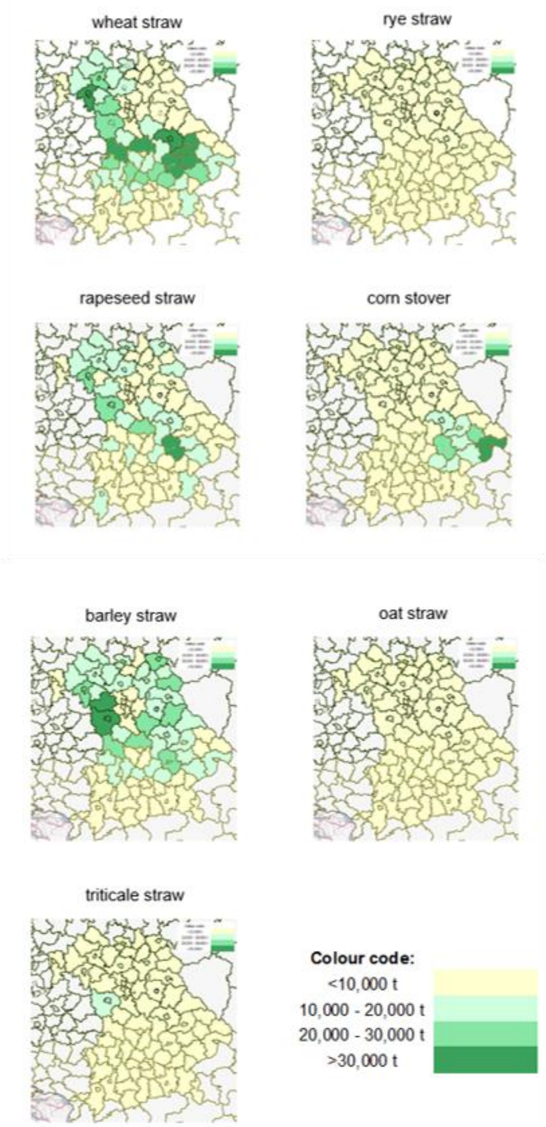

Figure 1: Bavaria - GIS mapping of agronomic potentials

The feedstocks wheat straw, barley straw and corn stover are available in some regions, spatially distributed in the North-West and the Central-Eastern parts of Bavaria. Overall, the region Lower Bavaria has the biggest crop residue potentials of all investigated crops. The feedstocks that were further investigated in the selected most favourable region are wheat straw and corn stover.

3.4 Non-competitive potential

In Germany, since 1990, straw stalling in cattle and pig breeding has decreased continuously. While in 1990 the share of straw bedded cattle used to be 33.8 % (in 66.2 %, manure is driven out via gutters), in 2008 only 16 % were bedded on straw and in 84 % the manure was derived via gutters [12]. An explanation for this trend is the significant increase of biogas plants in Germany within that time. It is less complicated to use a feedstock in biogas plants that does not contain a high percentage of fibrous structure, so it makes sense for the farmers to have the manure in a liquid form for further use in these plants.

<u>Wheat straw</u>

For grain straw, Witzelsberger (2006) [13] examined the competitive use that could limit the available amounts of straw. From all possible competitive uses, using straw for bedding or as fodder needed the biggest share of the available straw, with 30 %. This means that 30 % of the technical potential (i.e. 30% of 67 %) or 20 % of the theoretical potential would be the competitive use.

However, as investigation so far has only considered grain straw as a whole, it is thinkable that other straw than wheat straw can be used for bedding. Furthermore, regarding the competitive use, latest research has shown that farmers are willing to sell all crop residues if the price is considered high enough for them. Interviews with farmers in Bavaria that were carried out for a doctoral thesis revealed that farmers start to think about selling straw at a price of 50 €/ton and are willing to sell all available straw that would be considered sustainable at a price of 122 €/ton. That means that regardless of the competitive use, enough straw could be purchased if the overall economic benefit is considered high enough [14]. It is further assumed that the use of straw for bedding will further decrease as there are other substrates that better bind the animal faeces (i.e. sawmill residues).

As the focus of BABET-REAL5 is the production of sustainable bioethanol that considers sustainability aspects throughout the value chain, and as it can be assumed that the competitive use will continue to decrease, in this study it is assumed that 30 % need to be subtracted from the sustainable straw potential (instead of the technical potential).

As already described before, the exportable sustainable potential is 33 % of the theoretical potential. However, it is technically respectively economically impossible to recover only 33 % of the wheat straw from the field. Instead, the full technical potential is recovered (i.e. 67 %) which means that twice the sustainable amount is recovered during one harvest process. Farmers need to monitor the recovery and calculate when again to recover the full technical potential can be carried considering sustainability.

<u>Corn stover</u>

For corn stover, until now, there is no significant competitive use. The corn stover remained on the fields, were chaffed and then the plant residues were ploughed under. Recent research by the Bavarian State Research Center for Agriculture has identified this unused potential as promising feedstock for the production of biogas. Reason for this is, that in Germany for the use of corn stover, other than for corn and grain in biogas plants, at the moment there are no legal restrictions. According to § 39h EEG 2017, the use of corn (whole plant, corn-shaft-mix, corn maize and bruised grain) and cereal grains in biogas plants is limited to 44 %. Results from laboratories showed that the methane yield of corn stover (300 – 330 l/kg_{dm}) corresponds to 90 % of the silage corn methane yield. If corn stover are available for free (i.e. from the own fields), the full costs, until entry into fermenter, amount to 0.05 €/kWh_{el}. Thus, the feedstock is considered to be a price competitive substrate for the use in biogas plants [15]. It needs to be further investigated, if the BABET-REAL5 economical concept can offer more beneficial conditions to the farmers.

As for wheat straw, in practice, the technical potential (i.e. 49 % of the theoretical potential) is recovered from the field. Farmers need to calculate how much crop residues can be taken from the fields without putting the soil quality at risk.

3.5 Result for Lower Bavaria

The identified feedstock potentials for Lower Bavaria are also presented on a map with the necessary background information (Figure 2).

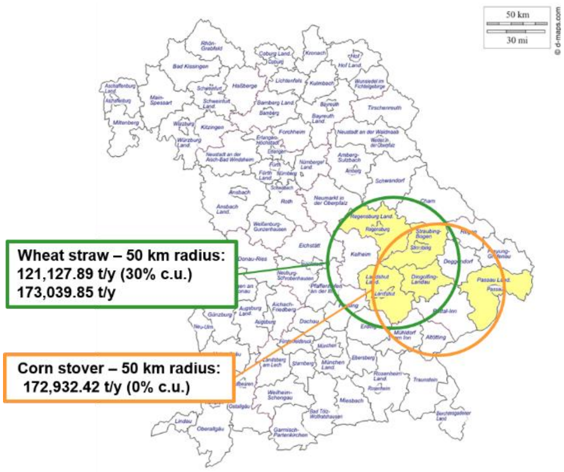

Figure 2: Bavaria - sustainable straw potential in Lower Bavaria

The evaluation of the available feedstock in a 50-km radius shows, that for wheat straw, around 121,000 t_{dm}/y would be sustainably available (considering a competitive use factor of 30 % of the residual potential), and for corn stover, almost 173,000 t_{dm}/y would be available with no competitive use considered. In Figure 5, districts in which one feedstock exceeds the 30,000 t_{dm}/y-threshold are marked in yellow. To get the complete 50-km radius potential, also the districts with lower feedstock potential are finally included (e. g.: district Mühldorf for corn stover). Table IV and Table V show all considered districts with the respective available sustainable straw amount.

Table IV: Wheat straw - 50-km radius

District	sustainable residue [t/y]	30% competitive use [t/y]	Net available residue [t/y]
Landshut	49,594.50	14,878.35	34,716.15
Regensburg	37,078.32	11,123.50	25,954.82
Straubing-Bogen	35,236.81	10,571.04	24,665.77
Dingolfing	32,661.55	9,798.47	22,863.09
Kelheim	18,468.67	5,540.60	12,928.07
50-km radius	**173,039.85**	**51,911.95**	**121,127.89**

Table V: Corn stover - 50-km radius

District	sustainable residue [t/y]	no competitive use [t/y]	Net available residue [t/y]
Passau	54,309.05	-	54,309.05
Landshut	26,056.47	-	26,056.47
Deggendorf	20,375.21	-	20,375.21
Rottal-Inn	19,642.15	-	19,642.15
Dingolfing	16,955.89	-	16,955.89
Straubing-Bogen	14,899.11	-	14,899.11
Mühldorf	11,632.42	-	11,632.42
Altötting	9,062.12	-	9,062.12
50-km radius	**172,932.42**	**-**	**172,932.42**

4. LOGISTICS AND OPERATIONAL COSTS

For wheat straw and corn stover, the logistics from field to gate and the related expected costs were investigated. As the exact location of the potential 2G bioethanol plant was not known when the study was carried out, it is assumed that all feedstock is transported over 25 km from field to gate.

Wheat straw

Wheat straw in Bavaria is usually harvested in the form of bales. The harvest process is subdivided into the following steps: picking & baling, on field transport, loading, transport and storage. After the harvest of the wheat, the cut straw is ejected from the rear part of the combine harvester and remains as swath on the field. The straw is then recovered by a combined pick-up and bale pressing system. The bales can be produced in different sizes and shapes. The most used bale presses produce square bales and can reach performances of more than 30 tons per hour. One average square bale measures 2.40 m*1.20 m*0.80 m (l*w*h) and weighs between 140 and 220 kg/m^3. Specialised bale collectors can store between three and five straw bales at the same time and offload them together at a storage position. This saves time and costs, as on field logistics is reduced. The transport of the straw bales depends on the distance between the field and the final storage. Either a tractor with a platform trailer or a truck and low loader are used for the transport. The tractors have speed limits of 25 to 40 km/h and cannot charge more than to a total weight (vehicle and load) of between 4 to 18 tons. In Germany, agricultural vehicles can be loaded with maximum heights of 4 m and a maximum width of 2.55 m. In Germany, 4 m is also for trucks the maximum transport height [16]. Table VI shows the costs that are related to these logistical process steps.

Table VI: Supply costs for wheat straw [16]

Picking & baling	**On field transport & loading**	**Transport I**	**(Intermediate) Storage**
Euro/t_{dm}	Euro/t_{dm}	Euro/t_{dm}	Euro/t_{dm}
12.31	11.77	2.07	7.40 - 28.50
Transport II	**Nutrient compensation**	**application of fertilisers**	**Full supply costs**
Euro/t_{dm}	Euro/t_{dm}	Euro/t_{dm}	Euro/t_{dm}
1.00 - 9.00	12.36	1.21	**47.78 - 69.76**

Altogether, for wheat straw, full supply costs of 47.78 to 69.76 Euro/t_{dm} can be expected. The full supply costs depend mainly on the storage and transport costs, the storage parameter being the key parameter. The lowest costs (around 48 Euro/t) can be expected if the feedstock is stored in an old building and the transport is realized with an AMG-truck (Agricultural Machinery Group). Should the construction of a new building be necessary, and a regular truck is used, then almost 70 Euro/t need to be calculated for the wheat straw supply.

<u>Corn stover</u>

The harvest of corn stover differs from the harvesting of wheat straw (which can be called conventional). The corn stover cannot be picked up directly after the use of the combined harvester but needs to be prepared in an extra step. In Germany, corn stover has been investigated recently by the Bavarian State Research Centre for Agriculture as it is considered to be a promising feedstock for the biogas industry. With recovery rates for corn stover of around 50 %, the latest results have shown considerable harvest losses which occur at the process steps swathing (around 43 % of theoretical potential) and pick-up (around 8 %). Still, the feedstock is available in sufficient amounts.

In Germany and Austria, three basically different harvesting techniques are used for the harvesting of corn stover. One possibility after the threshing is to use band swathers, which pick up the corn stover centrally and swathe them centrally or sidewards via a cross conveyor belt. Another possible technique to harvest corn stover is the use of modified mulchers, which flail the corn stubbles above the ground, crush the corn stover and pick them up using the suction of the flail-shaft. With a conveyor belt, the corn stover are then placed sidewards in swaths. The third harvesting technique is done in a single step. It is carried out with a modified picking machine (in the trial, a modified picking machine by German company Geringhoff was tested). Angled blades cut the remaining plant parts which fall then into a collecting trough that is installed below the picker. The collected corn stover are transported within the vehicle via a conveyor belt and are swathed centrally under the picker. Using this technique, also the remains of the threshing are captured and put onto the swath. Loading of the corn stover can be done using either a field chopper with a pick-up unit or with a (self-) loading wagon. Other than in the USA, where the corn stover after the harvest is dryer and then collected in bales, in Bavaria the collected corn stover occurs as chipped corn stover feedstock which means a considerably lower density of the feedstock in terms of logistics.

Table VII shows the costs that are related to the logistics from field to gate for corn stover.

Table VII: Supply costs - corn stover [17]

Full costs (no space costs)	**Harvest, transport & ensilage**		**Storage in bunker silo**
Euro/ha	Euro/ha		Euro/ha
0	162.00		62.00
Extraction & feeding	**Full costs (no space costs)**		
Euro/ha	Euro/ha	Euro/t_{fm}	Euro/t_{dm}
19.00	243.00	27.00	**54.00**

The full costs for corn stover of 243 Euro/ha comprise the process steps from swathing until entry point into the conversion plant (in the study: biogas plant). The price was calculated with a recovery rate of 4.9 t_{dm}/ha. The chopped corn stover was then transported around 5 km to the bunker silo. During the storage, a mass loss of 8 % could be observed [17].

The small difference of the shown costs between wheat straw (lowest costs of around 48 Euro/t_{dm}) and corn stover (54 Euro/t_{dm}) occur because of the different provision of feedstock. Wheat straw is provided in bales, whereas in Germany, at the moment, corn stover is collected and provided only as chipped feedstock, thus no costs for baling occur.

5. POTENTIAL RISKS

To find out whether also in the future a reliable feedstock supply can be provided in the region potential risks were being looked at. In the near future (until 2035) feedstock provision can be endangered by losses due to erosion and due to extreme weathers, the exhaustion of soils and also the willingness of the farmers to supply the feedstock for the future.

It can be said that, in Lower Bavaria, none of the identified risks necessarily means that it is impossible to provide enough feedstock in the near future. Soil erosion can be prevented by adapting suited tillage techniques (conservation tillage) and the exhaustion of soils can be controlled if the practical advice, given by Bavarian agricultural authorities, is observed. Soil monitoring plays a decisive role here, as beginning deterioration can be detected and mitigation measures thereupon applied. Yield losses due to extreme weathers are not predictable, yet may occur in limited small areas in Lower Bavaria. Farmers can insure themselves against these losses. For the operators of the potential 2G bioethanol plant it would mean to purchase extra feedstock from other suppliers. However, it needs to be stated that the expected losses are rather low. The willingness to supply the feedstock at all is depending on ecological and economic conditions for farmers. The elaboration of fair contracts and maybe also a further cooperation can mitigate this near future risk.

On the long term, and additional to the mentioned risks, the consequences of the climate change seem to be the biggest risk for a reliable feedstock supply. In Bavaria, the expected impacts of climate change on conventional farming of food crops were investigated by the Bavarian Agricultural Research Institute between 2009 and 2016. The conclusion that was made there was rather optimistic. The main results were that the higher CO_2-content, which is positive for the crops, almost completely offsets the negative impacts like heat waves and heavy precipitation. For yield risks, the experts recommend the farmers to take out harvest failure insurances [18].

This outlook is supported by a publication from the European Environment Agency from 2012 about future crop yields on irrigated lands. There it was shown that southern European regions will face more problems due to less water availability, meanwhile central-eastern and northern European regions will even profit from expected changes (EEA, 2012). Bavaria lies in a zone that is, concerning crop yields, probably not too much affected in the future, with expected changes in the crop yield between -5 to 5 %.

Although these predictions sound not alarming, in Bavaria a common research project called BayKlimaFit (http://www.bayklimafit.de/) is also carried out to find culture crops (including maize/corn) that are especially resilient against abiotic stress like waterlogging, cold, drought or heat. The researchers use genome analysis to find markers that carry the properties (i.e. resilience against cold, heat or drought) and continue with conventional breeding using the identified suited plants [19]. The project still runs until January 2019. After this, it is expected that other researchers will use the data to breed new climate change adapted crops. However, it is not expected that the resilient plants will be available for the agricultural sector before 2030.

6. ENVIRONMENTAL IMPACT ASSESSMENT

At this stage of the BABET-REAL5 project, only a preliminary environmental impact assessment of the supply from field to gate was carried out. It looked at the expected impacts related with the use of the crop residues, especially at the nutrition loss when taking the straws from the fields, the related CO_2-emissions and again the climate change issue related to agriculture. It could be shown, that nutrition loss can be avoided by preventing soil erosion, and the nutrition loss that is related with the recovery can be compensated by applying compost on the field (for wheat straw: 11.42 t /ha of compost per 3 years; for corn stover: 17.97 t/ha of compost per 3 years). The expected CO2-emissions related with the agricultural vehicles are 17.4 kg CO_{2eq} per supply ton of wheat straw and 40.2 kg CO_{2eq} per supply ton of corn stover. The emissions for corn stover are considerably higher in Bavaria because the feedstock cannot be baled because the water content is too high at the time of harvest and thus corn stover needs to be transported in a loose bulk with ordinary tractors and which requires a lot more tours than with the compacted wheat straw bales which is being transported with loading trucks. When simulating the use of agricultural vehicles that have proven their functionality (regardless of the economic costs), then a CO_2-footprint reduction of 38 to 83 % can be achieved by using biodiesel, HVO or waste vegetable biodiesel [20]. The expected environmental impact of the feedstock recovery related with climate change has already been discussed above and will probably not play a role in Lower Bavaria if the predicted scenario will develop (climate change related events are compensated by climate change related favourable conditions), and from 2030 on adapted crops will be available that might even lead to higher yields.

7. CONCLUSIONS

In this study, it was investigated whether enough lignocellulosic residual biomass can be provided for a new 2G bioethanol plant concept, considering theoretical, technical and sustainable aspects and also the competitive uses that could limit the feedstock provision. The available amount of residual feedstock is mainly limited by the sustainability factor of 33 %, which means, that for the preservation of soil carbon on average 67 % of the crop residues need to remain on the fields. Considering this issue, it could be shown, that it is possible to find sustainable potentials of at least 30,000 t_{dm}/y for wheat straw, barley straw and corn stover in some regions of Bavaria.

The sustainable potentials of wheat straw and corn stover were further investigated in the region Lower Bavaria. The impact of a regional changed climate to predict a mid-to long-term reliable feedstock supply and furthermore the environmental impact that goes along the residue recovery was also investigated.

Residual wheat straw would be available in a 50-km radius zone near the city of Landshut in amounts estimated at 121,000 t_{dm}/y and corn stover in amounts of 172,000 t_{dm}/y in the region around Passau. Both residual crop potentials exceed by far the project set threshold of 30,000 t_{dm}/y.

In the investigated region, mainly the risk of erosion needs to be addressed by farmers, especially when growing corn on hilly slopes. The Bavarian agricultural authorities have already taken action to raise more awareness for this threat among the farmers.

Surprisingly, the expected consequences of climate change seem not to affect the expected yields in Bavaria (and thus the residual feedstock potential). The negative impacts (i.e. heat waves or heavy precipitation) are expected to be compensated by more favourable conditions for the plants (i.e. longer growing periods and higher CO_2-content in the air which is favourable for plants). Although the impacts of climate change might be more severe in other regions of the world, Bavarian scientists are working to prepare the agricultural sector for the changed conditions.

Mitigation measures of the recovery related impact were investigated also and it was found that the whole residue recovery process can have a considerably lower carbon footprint if known measures are applied (i.e. nutrients compensation with compost and CO_2-emissions reduction by the use of biofuels in the recovery vehicles). At the moment, wheat straw seems to be the more sustainable feedstock of the two investigated crop residues. Mainly, this is because of the smaller erosion risk related with the cultivation of wheat and also because of the lower costs for transport due to the possibility of baling the wheat straw and thus being able to transport higher weights per transport.

It needs to be stated that these measures have not been investigated in detail from the economical point of view. This will be done in the next part of the BABET-REAL5 project.

The detailed report about the German case study, and also the case studies from Argentina, Uruguay and France will be available soon (expectedly before autumn of 2018) at the project website: www.babet-real5.eu.

ACKNOWLEDGEMENTS

The authors would like to thank the colleagues of WIP Renewable Energies as well as the BABET-REAL5 partners for their contributions in the project: The authors would like to thank the European Commission and the Innovation and Networks Executive Agency (INEA) for the support of the BABET-REAL5 project. BABET-REAL5 has received funding from the European Union`s Horizon 2020 research and innovation programme under grant agreement No 654365. The project duration is February 2016 to January 2020.

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