Future European Biogas: Animal Manure, Straw and Grass Potentials for a Sustainable European Biogas Production

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ABSTRACT: Biogas is expected to play an important role in reaching the future energy policy targets of the European Union (EU). The sustainability of biogas substrates has however been recently critically discussed due to the increasing shares of agricultural land used for energy crop production. The aim of this study was to project and map the biomass and biogas energy potential from a selection of potentially sustainable agricultural residues, which have been documented to improve in biogas yields when co-digested in biogas production, for the EU28 in year 2030. The investigated types of residual biomasses were animal manure, straw by-products from cereal production, and excess grass from rotational and permanent grasslands and meadows. The biogas energy potential from the investigated biomass was projected to range from $1.2 \cdot 10^3$ to $2.3 \cdot 10^3$ PJ y^{-1} in year 2030 in the EU28, depending on the biomass availability. Alone the biogas energy potential projected in the scenario representing low substrate availability corresponds to a doubling of the European biogas production in 2015. The results shows that sustainable alternatives to the use of maize are present in all the member states of the EU28 to an extent that is sufficient to ensure a continuous progressive development of the European biogas sector.

Keywords: biogas, geographical information system (GIS), grass, manure, straw, sustainable biomass

1 INTRODUCTION

In the European Union (EU), political targets for climate and energy in 2030 are 40% reductions in greenhouse gas emissions, 27% renewable energy installed capacity for the entire EU energy supply and 27% improvement in the energy efficiency [1, 2]. Biogas is expected to play an important role in reaching these energy targets due to the flexibility and storability of biogas as an energy carrier, the very diverse biological sources which can be used for its production, and its already established application in a wide range of applications (heating, transportation and electricity production) [3]. The application of anaerobic digestion (AD) for biogas production remains widespread as a useful bioenergy production route due to the robustness of its main design configurations and pathways [3]. Anaerobic digestion serves multiple purposes. It provides a treatment platform for decreasing large amounts of complex organic materials, converting the majority of such molecules into monomers i.e. methane and carbon dioxide (biogas) utilizable in the energy sector in multiple pathways. Secondly, but equally important, the nutrient rich digestate emanating from the AD process is mainly recycled to farmlands to serve as organic fertilisers replacing increasing amounts of chemical fertilizers and decrease negative environmental impacts (i.e. eutrophication of fresh water systems) which would be the situation if the disposal of such nutrients is not properly managed and controlled [3].

From 2000-2015, biogas production in the EU has witnessed more than a sevenfold increase (Table 1) [4]. In 2015, sewage sludge gas and landfill gas represented respectively 17% and 9% of the total production, whereas other biogases from anaerobic digestion (decentralised agricultural plants, centralised co-digestion plants, and municipal solid waste methanisation plants) represented 74% of the total production [5, 6].

EU28	1990	1995	2000	2005	2010	2015
PJ	28	48	92	167	357	654

Table 1: The primary production of biogas in the European Union (EU28) from 1990-2015 [4].

Since 2010, 50% of the total European production of biogas was produced in Germany. Due to an attractive feed-in tariff system, the German biogas production has expanded significantly. However, this expansion has happened with a substrate supply strongly based on maize, which is worrying due to the potential damage to the environment caused by intensive cultivation of energy crop monocultures [7]. The choice of substrates used for biogas production has been recently critically discussed, in particular, with respect to the use of energy crops. Negative environmental and economic issues associated with the use of cultivated energy crops for bioenergy production have been largely reported in the literature [8, 9]. Such substrates are therefore increasingly expected to fall out of favour as primary feedstock considered for the biogas AD process and hence alternative sources needed.

The substrate supply for a growing European biogas sector should be carefully considered in order to ensure that the biogas production is sustainable with respect to potential impacts in the environment, nature and climate, and current food and biomaterial production chains.

In 2010, the Biomass Energy Europe project (BEE) published a report comparing more than 70 assessment papers on biomass for energy production [10]. Forty-two of these papers address the potential of agricultural and organic residues on global to national scale, with the energy potentials on EU level also highlighted. The BEE found that in many of the studies, the specific type of agricultural residue was not well defined (i.e. types of animal manure) and only few of the assessments were joined with spatial data in order to map the distribution [10]. In 2012, the Biomass Futures project published the "Atlas of EU Biomass potentials". The authors concluded that the largest potential could be obtained from agricultural residues defined as manure, straw and cutting/prunings from permanent crops. In total, this potential was estimated to correspond to $4.4 \cdot 10^3$ PJ in 2030 [11]. Animal manure is recognized to be a very favourable substrate for biogas production, as it combines energy production, nutrient recycling and decreases emissions of CH_4 and N_2O compared to conventional manure management [3, 12]. Due to high concentrations of water in animal manure is it seldom economically feasible to run biogas plants solely on animal manure. Green vegetation i.e. Poaceae has been documented to improve biogas yields by 18-40% when co-digested with animal manure, while increases of 10-80% were observed with crop residues i.e. wheat straw, rice straw, maize stalks depending on pre-treatment conditions and contents of dry matter [13]. Thus, the availability and distribution of such residues for co-digestion is an interesting aspect for maintaining and expanding the biogas sector in Europe.

Residues from agricultural production can be argued to incorporate well with the EU directive on promotion of the use of energy from renewable sources sustainability criteria [14]. For the use of solid and gaseous biomass in electricity, heating and cooling a set of non-binding recommendations for ensuring sustainability has been set, these are:

I. The biomass use should ensure greenhouse gas savings of at least 35% compared to fossil fuels (increasing to 50% in 2017, and 60% in 2018 for new plants).

II. Resources cultivated on areas converted from land with high carbon stocks and land with high biodiversity should not be used.

The second recommendation from the European Commission recognises that negative land use changes should not take place with the aim of producing biomass for energy production, thus potentially biodiversity loss and species extinction. None of the recommendations, however, takes into account that biomass production on farmland (both directly and indirectly) could contribute to crossing the planetary boundaries as discussed and outlined by Steffen et al. [15] due to e.g. extensive fertilisation, fresh water use and soil erosion.

In contrast to the existing literature on the topic, this study solely focus on the biomass and biogas energy potential from a selection of specific agricultural residues which have been documented to improve in biogas yields when co-digested in biogas production. The assessed substrates in this study are residual grass from permanent and rotational grasslands, straw from cereal production, and manure from cattle, swine and poultry.

2 DATA AND METHODS

2.1 Biomass types in focus

The task of evaluating whether a bioenergy production process or the biomass feedstock used is sustainable is not trivial, especially when considering the above-mentioned concerns related to the sustainability of biomass production. The biomass resources assessed in this study can neither be claimed to be sustainable in all aspects, as the final impacts of utilising them will depend on the local conditions for cultivation, harvest, transport, storage and the eventual applied conversion technologies.

However, an overall condition for the assessed biomass resources has been that they are low environmentally impacting biomass, residues from agricultural production, and are potentially sustainable when handled efficiently and with respect to nature and the environment.

Crops cultivated on farmland with the sole purpose of being utilised for energy production have been excluded in this study, prioritising that the farmland is used for food, raw material (bio-based) and fodder production.

2.2 Assessing the quantity of animal manure and the biogas energy potential

For estimating the manure potential in the EU28 in year 2030, the average number of cattle and pigs (number of animal heads) and poultry (number of slaughtered animals) registered by Eurostat from year 2011 to 2015 were applied as base values [16-18]. Forecasts for the agricultural production of meat, milk and dairy in Europe and Central Asia [19] were applied for estimating the livestock numbers in 2030. The annual growth rate for the production of beef and dairy cattle are forecasted to be respectively 0.32% and 0.33% while the annual growth rate for the production of pork and poultry is forecasted to be respectively 0.47% and 1.24%. The estimated pig and cattle manure quantities were distinguished based on the age of the animals and the purpose of breeding (i.e. for dairy or meat production). For estimating the produced amounts of poultry manure, a distinction of the poultry groups was necessary: chicken, broiler, duck, turkey and goose. The amounts of produced animal manure (faeces and urine combined) were estimated using the American Society of Agricultural Engineers (ASAE) standards [20]. The quantities of manure are estimated in total solids (TS) representing the dry matter of faeces and urine combined. For animals bred for meat, manure production was estimated based on excreted manure per “finished animals”. The manure production from other animals was estimated based on the values of manure excreted per day per animal. However, only the manure when the animals are housed can be collected and used for energy conversion purposes. The housing period will depend on the local production methods, thus they are expected to vary depending on the specific farming practices. Conventional farming methods usually imply that the animals are housed during most of their lifetime. An important exception, however, is cattle farming. Pasture grazing is a traditional method of feeding cattle. The application of grazing as a method of feeding, however, varies over Europe depending on i.e. climate, topography, genotype of the cattle and farm infrastructure Nevertheless, due to the tradition of grazing in cattle farming, the housing period for cattle is assumed shorter than for pig and poultry. Considering this, three different scenarios for the practical availability of the excreta was applied as presented in table 2. The biogas yield from anaerobic digestion of the excreta quantified in total solids was estimated based on values from Jørgensen [21] assuming normal pressure and temperature (298 K and 101.3 kPa**)**. However, the actual biogas yields from anaerobic digestion of manure will vary depending on several factors i.e. retention time in the biogas plant, fodder composition, and the storage time and management of the manure before applying it for biogas production [22]. Based on the estimated quantity of biogas, the energy potential was estimated by assuming a lower heating value of 21.6 $MJ.kg^{-1}$. The energy potential was thus reduced by 15% assuming that the biogas is applied in a combined heat and power plant with a conversion efficiency of 85%.

Manure type	**Biogas yield based on TS ($m^3.t^{-1}$)**	**Scenario**		
		High availability	**Moderate availability**	**Low availability**
Pig	370	90%	80%	70%
Poultry	400	90%	80%	70%
Cattle	240	70%	60%	50%

Table 2 The applied assumption for manure availability and biogas yields

2.3 Assessing the quantity of unutilised grass from rotational and permanent grasslands and the biogas energy potential

Grasslands play an important role in the European agricultural sector, mainly as a source of fodder for livestock production. Grasslands have also been vital in preventing potential negative environmental impacts such as preventing reductions in soil carbon storage, greenhouse gas emissions and soil erosion, and supporting of the thriving of biodiversity.

In the agricultural sector, grass is mainly consumed for cattle (dairy or beef) and sheep production.

Examples of excess grass available for biogas production could include grass from unutilised or low yielding grasslands, and grass which has matured to the point where the forage value is too low for utilisation as animal fodder. The use of grass for energy purposes is sustainable if the produced grass cannot be used for any other economic purpose and is therefore considered excess, a by-product or a residue. The methods used for the estimation of the biomass quantities and energy potential from the two grassland types considered in this study are highlighted below:

2.3.1. Rotational grassland

Eurostat contains information about the area registered as temporary grassland in rotation in EU countries [23]. These dataset were applied for estimating the energy potential from this resource. The grass yields obtainable from rotational grassland must be expected to vary according to the climate-conditions [24]. The soil type and management practices are expected to also influence the grass yields. Grass produced on temporary grasslands is assumed mainly to be used as feedstock for ruminant production, thus the total production of grass cannot be designated for energy production.

For this assessment three scenarios were developed for estimating the potentially available grass quantities from rotational grassland for energy production. The assumptions behind these scenarios are presented in table 3. In all scenarios storage losses of 25% total solids (TS) was assumed and the volatile solids (VS) mass fraction of the total solids was assumed to be 92% [25]. A methane yield based on VS of 298 $L.kg^{-1}$ at normal pressure and temperature was assumed (298 K and 101.3 kPa) [25]. Based on the estimated quantity of methane, the energy potential was estimated by assuming a lower heating value of 36.0 $MJ.kg^{-1}$. The energy potential was thus reduced by 15% assuming that the methane is applied in a combined heat and power plant with a conversion efficiency of 85%.

Scenario	**TS ($t.Ha^{-1}$)**	**Share allocated for energy production**
High availability	14	20%
Moderate availability	12	10%
Low availability	10	5%

Table 3 The applied assumptions with respect to the yield of total solids obtained from rotational grassland and the share of grassland area which can be allocated for harvest with the purpose of utilising it for biogas production.

No specific forecast for the future development of rotational grassland was identified. However, grass production is expected to increase due to the anticipated rise in livestock production. Thus, the annual growth rate of 0.33% in the agricultural area representing the annual growth rate for beef and dairy production [19] was applied for rotational grassland and used to project the potential of cultivated rotational grassland areas to 2030.

2.3.2. Permanent grassland and meadows

All permanent grassland and meadow areas in EU countries are registered in Eurostat [26]. These data was applied for estimating the biomass potential from this resource. Part of the registered permanent grasslands and meadows are designated as unused, hence it is assumed that the full area can be harvested and the biomass used for biogas production. Permanent grasslands and meadows represent valuable open landscape habitats for many flora and fauna species. If the areas are not used for fodder purposes due to decreasing livestock population, harvesting the areas for energy purposes could be used to help maintain the grassland features and biodiversity.

Permanent grassland and meadow classified as “utilised” by Eurostat was assumed partly available for energy production, as they are expected to supply fodder for the livestock production. Due to the European Common Agriculture Policy, at least 5% of the EU member states agricultural area must be permanent grassland [27]. Unless this policy changes the area of permanent grassland and meadows is assumed to remain at a level corresponding to at least the average area registered from 2011-2015 over the next decades. Significant increase in the area of permanent grassland and meadow is not expected, with more land utilised to meet the intensive agricultural goals.

For assessing the future energy potential from utilisation of grass from permanent grassland three scenarios were developed reflecting the span of available grass yields for energy production. The assumptions behind these scenarios are presented in table 4. In all scenarios storage losses of 25% TS was assumed and the volatile solids content of the total solids was assumed to be 92% [25]. A methane yield based on volatile total solids of 150 $L.kg^{-1}$ at normal pressure and temperature was assumed (298 K and 101.3 kPa) was applied for estimating the energy potential, reflecting the yields from similar grass types identified in the literature (60–309 $L.kg^{-1}$ [28], 155–293 $L.kg^{-1}$ [29]). Based on the estimated quantity of methane, the energy potential was estimated by assuming a lower heating value of 36.0 $MJ.kg^{-1}$. The energy potential was thus reduced by 15% assuming that the methane is applied in a combined heat and power plant with a conversion efficiency of 85%.

Scenario	TS in t. Ha^{-1}	Share of currently unutilized grassland and meadow assumed allocated for energy production	Share of currently utilized grassland and meadow assumed allocated for energy production
High availability	4	100%	50%
Moderate availability	3	100%	30%
Low availability	2	100%	20%

Table 4 The applied assumptions with respect to the yield of total solids of grass obtained from permanent grassland and meadows, and the share of grassland area which can be allocated for harvest with the purpose of utilising it for biogas production.

2.4 Assessing the quantity of straw from cereal production and the energy potential

The straw residuals from the production of cereal are often considered an agricultural by-product. The nutritional value of straw is low and thus not considered a suitable livestock feedstock, hence the straw is often left in the fields for increasing the soil carbon stock or used for the livestock housing and bedding or in horticultural applications. Even when used for livestock housing, the straw must be periodically disposed.

Straw have also been found to be a suitable substrate for anaerobic digestion, however mechanical or thermochemical or biological pre-treatment of the straw is needed to reduce the digestion retention times compared to other substrates, in order to achieve the highest methane yields possible.

Unutilised straw from cereal production represents an interesting resource for the development of the future European biogas sector. In the years 1990 - 2013, European cereal production accounted for 26-38% of the total utilised agricultural area in Europe, while from years 2000-2013, this share increased to 31-38% [23].Thus the straw from cereal production could potentially constitute a quite large resource available for biogas production.

The grain-to-straw TS ratio can be used to estimate the theoretical yields of straw obtainable in the EU. In the literature, the ratios have been found to vary from 1:0.62 to 1:1.10. However, the technical yields are expected to be lower, depending on the harvest machinery and environmental constraints related to the soil organic matter [30-32].

For estimating the potential yields of straw obtainable from the EU28 countries, the average annual production data of grain in the years 2011 – 2015 were applied as base values [23]. The production of cereal was assumed to increase by a growth rate of 1.1% per year based on forecasts for the agricultural production of cereals in Europe and Central Asia [19]. The lowest grain-to-straw ratio found in the literature (1:0.62) was applied in order to reflect a realistic "optimistic" scenario for how much straw can be obtained. The ratio was subsequently further reduced by 10 and 20% respectively in order to reflect a moderate and a pessimistic scenario for the obtainable straw yields. The estimated yields were then further reduced by 10, 20 and 30% respectively with the consideration that part of the straw could be applied for other purposes. In all scenarios storage losses of 15% TS was assumed. The volatile solids mass fraction in the total solids was assumed to be 95%. The summarised assumptions used for estimating the straw potential in the member states of the European Union are presented in table 5.

Scenario	**Grain – straw ratio**	**Share utilised for other purposes**
High Availability	0.62	10%
Moderate availability	0.52	20%
Low Availability	0.42	30%

Table 5 The applied assumptions for the grain-straw ratio from cereal production and the share of straw utilised for other purposes than biogas production .

In all scenarios a methane yield based on volatile total solids of 242 L.kg^{-1} at normal pressure and temperature was assumed (298 K and 101.3 kPa) [25] in order to estimate the biogas energy potential. Based on the estimated quantity of methane, the energy potential was estimated by assuming a lower heating value of 36.0 MJ.kg^{-1}. The energy potential was thus reduced by 15% assuming that the methane is applied in a combined heat and power plant with a conversion efficiency of 85%.

3 RESULTS AND DISCUSSION

3.1 The biomass potential from animal manure

The total potential quantities of TS from manure forecasted for the year 2030 in the EU member states were estimated to range from 83 to 122 Mt y^{-1} depending on the applied biomass availability scenario used. The spatial distribution of the manure available is presented in figure 1. Cattle manure (represented in TS) represents a potential ranging from 63 to 88 Mt y^{-1}, whereas the potentials from swine and poultry manure (represented in TS) was 18-23 Mt y^{-1} and 8-11 Mt y^{-1} respectively. The total energy potential via the anaerobic digestion of the available manure from cattle, pigs and poultry in Europe in 2030 was estimated to range from 670-890 PJ y^{-1} depending on the applied availability scenario (Appendix A). Pig manure represents 320-420 PJ y^{-1}, cattle manure 280-390 PJ y^{-1} and poultry manure 60-80 PJ y^{-1} of the total potential. The energy potentials using manure derived biogas in EU member states is spatially presented in figure 2.

Figure 1: The estimated quantities of cattle, swine and poultry manure in 2030 for the member states of the EU.

Figure 2: The estimated energy potentials from anaerobic digestion of cattle, swine and poultry manure in 2030 for the member states of the EU.

Animal manure can be considered a major carbon source for biogas. Anaerobic digestion of animal manure does not reduce the amount of nutrients in the digestate, but the digestate fertiliser characteristics are improved compared to raw manure [3, 33]. The use of animal manure for biogas production would therefore not conflict and compete with any demand for fertiliser in the agricultural sector. The actual greenhouse gas (GHG) balance of utilising animal manure depends on the transportation distances from source to the biogas plant. The practical sustainability in respect to GHG emissions will thus depend on the local acquisition conditions. However, under efficient management animal manure can be considered a sustainable feedstock for biogas production.

3.2 The biomass and energy potential from excess grass production

The total production of excess grass represented in TS from rotational and permanent grassland in the EU28 in 2030 was estimated to range from 20-111 Mt depending on the grass availability. The corresponding energy production from these grass quantities corresponds to 100-570 PJ y^{-1} (Appendix A). The spatial distribution of these potentials (illustrated in figure 3 and 4) shows that a significant potential for energy production from excess grass production is present all over Europe, with France, the UK and Spain having the largest contributions. With a potential ranging to 70-370 PJ y^{-1} the energy potential from permanent grassland and meadows represents the biggest share of the total energy potential from excess grass production.

Figure 3: The estimated biomass potentials from excess production of rotational and permanent grassland in the EU28 in year 2030.

Figure 4: The estimated energy potentials from anaerobic digestion of excess production of rotational and permanent grassland in the EU28 in year 2030.

The assumptions behind the three scenarios influence the results significantly. The actual availability of grass that can be allocated for biogas production will depend on the local conditions, management practices as well as the future trends and developments of the ruminant population. Unfortunately, the current share of grass already used for biogas in the EU has not been extensively identified. However, its use as a biogas substrate has been already demonstrated in some countries, i.e. Germany [34].

A factor, which could affect future grass availability, is related to current human dietary consumption patterns. The prevalence of high meat-based diets (especially in EU states), and higher than average daily energy intakes have been increasingly contested. A reduction in such dietary patterns could potentially decrease the need for fertile land areas for fodder production aimed for livestock production. A long term forecast on global food requirements up to 2050 predict a change in human consumption pattern towards a diet based on smaller amounts of meat and more vegetarian products [35, 36].

3.3 Straw from cereal production

The biomass and energy potential from straw in the EU projected for 2030 is illustrated in figure 5 and 6. It shows that extensive cereal production is expected to occur all over Europe, with a total of 49 million hectares indicated to be cultivated with cereal. The biomass potential from the straw residues (represented in TS) was estimated to range from 70-135 Mt depending on the applied scenario for the availability of the straw.

The corresponding energy yields from the potentially available straw from cereal production in the EU were estimated to range from 440-850 PJ y^{-1} (Appendix A), depending on the straw availability scenarios. Even when assuming a low availability of straw, the potential energy yield is seen to be significant and almost represents the total EU biogas production registered in 2015. Considering that straw very often is treated as a waste or by- product with no or low agricultural use, the actual potential of straw in Europe could play a very significant future role for renewable energy production if processed anaerobically or with more complex technologies.

Figure 5: The biomass potential of straw from cereal production in the member states of the European Union projected for 2030.

Figure 6: The energy potential of straw from cereal production in the member states of the European Union projected for 2030.

As argued in section 2.4, only the part of the straw that is technically possible to harvest and environmentally sustainable should be considered available for energy production. The actual straw yields will vary from the yields assumed in this study, depending on the site conditions for production and the harvest machinery. However, it is not considered unrealistic that yields in the range of what is assumed in this study can be obtained. The share of straw not being used for other purposes can also vary from what is assumed in the estimations. The actual share available for energy production depends on both the individual farming traditions of the European countries, but also on their progressiveness towards using straw for biofuel production. It is therefore difficult to assess the exact range limits of the actual energy potential. However, the utilisation of straw in EU for energy production can be clearly seen to hold a great potential for contributing to reaching the targets of the EU renewable energy policies.

3.4 The total energy potentials from animal manure, straw and excess grass

The total estimated energy potential from the different investigated biomass resources in 2030 are presented on country level in figure 7. The detailed numbers can be found in appendix A. In 2030, the total energy potential from these resources over the entire EU28 is projected to range from $1.2 \cdot 10^3$ to

$2.3 \cdot 10^3$ PJ y^{-1}, depending on the availability of the biomass types. The biogas energy potential projected in the scenario representing low substrate availability, corresponds to a doubling of the European biogas production in 2015. France, Germany and the UK were estimated to have the highest energy potentials, corresponding to 300-540 PJ y^{-1}, 250-400 PJ y^{-1} and 90-220 PJ y^{-1} respectively. In the case of Germany, this potential represents a sustainable alternative that could replace or supplement the use of energy maize without reducing the total biogas production. In 2015, the biogas sector in France and the UK produced 20 PJ and 90 PJ respectively [6]. Thus, the assessed agricultural residues represents a significant unutilised potential available for expanding the biogas production.

Figure 7 The total energy potential from anaerobic digestion of animal manure, straw and excess grass for the EU28 member states in 2030

In the majority of the EU member states, straw and manure were estimated to represent the biggest energy potential with a projected production of respectively 440-840 PJ y^{-1} and 670-890 PJ y^{-1}. Grass from permanent grassland and meadows were projected to represent 10-60 PJ y^{-1}. The possibility of using grass from permanent grassland and meadows is of particular interest, as it does not require cultivation of the soil and potentially could prevent the loss of biodiversity on areas that are not being used today. Thus, the use of grass harvested from permanent grassland and meadows can function as: (1) a method for nature conservation, (2) a provider of renewable energy, and (3) a method for recirculating nutrients from the permanent grass areas to cultivated lands via the digestate.

Anaerobic digestion of animal manure can cause many environmental benefits, but due to high concentrations of water in animal manure is it seldom economically feasible to run biogas plants solely on animal manure. The use of co-digestion feedstocks in animal manure based biogas facilities have been largely applied due to the improvement in biogas and methane yields achievable from this scheme [13]. Animal manure, excess grass, and straw were in this study found to be present in the majority of the member states, thus co-digestion of these resources is a possibility, which could enhance the efficiency and economically feasibility of the biogas production.

3.5 Summarizing discussion and perspectives

Based on the European Commission targets that aim for 27 - 30% renewable energy in the total EU energy supply by year 2030, biogas can potentially play a greater role than currently observed if the projected energy potentials identified in this paper are realizable. The estimated residues derived biogas energy potentials correspond to 2-3% of the average gross consumption of energy for the period 2005-2015. Compared to the gross consumption of renewable energy in the EU28 in 2015, the projected potential corresponds to 14-26%.

The estimated energy potential from the use of animal manure, straw and excess grass can represent a significant share of the total future biogas production if the biogas sector continues to develop rapidly. Other resources will, nevertheless, be needed, if the total biogas production is to increase as progressively as seen in the previous decades. The actual development of the biogas sector will strongly be influenced by the regulatory framework for the European biogas producers and is largely still dependent on subsidies today. The availability of the assessed biomass types will furthermore be reliant on future development trends in the EU agricultural sector, as they are residues from the production of crops and products that are currently in demand. Changes in the population size, composition and dietary preferences may reduce the availability of some crops, and create new biomass sources and residues available for energy production. This development will be strongly influenced by the European political situation, thus future changes are challenging to forecast. The need for actions promoting sustainable energy supply are however not likely to decrease due to the challenges which the climate and environment are facing.

Besides the actual availability of the investigated resources, the energy potentials with the use of the investigated biomass will depend on the technological and economic feasibility for the biogas producers when acquiring these biomass substrates. Further technological development and implementation may be required if the biomass resources are to be utilised efficiently. Due to the sustainability approach when using agricultural residues compared to e.g. intensively cultivated energy crops, financial subsidies for efficient use of agricultural residues may be justified. It could stimulate i.e. the development of economic models making private – public partnerships for harvesting natural grasslands or using otherwise waste residues for biogas production become more economically feasible for all partners involved.

A range of uncertainties, as discussed in the previous sections binds the estimated results. The results presented in this study is based on data from Eurostat, which furthermore must be considered to be subject to uncertainty. Eurostat receives and consolidate statistical data from the member states of the EU. It is the responsibility of the member states to verify and analyse their data. Although Eurostat performs comprehensive quality management of the data and the accuracy of the data is assessed to be good, the data will be subject to uncertainty due to i.e. lack of harmonisation in the national statistical methods. The member states have to report the actual national accuracy of the data to Eurostat, however these figures are not published. Nevertheless, it should be noticed that the results are subject to an unknown uncertainty due to this reason.

4 CONCLUSION

The energy potential from manure, grass and straw were projected to range from $1.2\cdot10^3$ to $2.3\cdot10^3$ PJ y^{-1} for the European Union in 2030, depending on the availability of the residues. France, Germany and the UK were estimated to have the highest energy potentials, corresponding to 300-540 PJ y^{-1}, 250-400 PJ y^{-1} and 90-220 PJ y^{-1}. The results show that there is a solid base of agricultural residues well suited for co-digestion present all over Europe, which are ideal alternatives to the use of energy crops. Alone the biogas energy potential projected in the scenario representing low substrate availability corresponds to a doubling of the European biogas production in 2015. Co-digestion of animal manure with grass and straw is a possibility that could enhance the efficiency and economically feasibility the European biogas production in 2030. Further technological development and implementation may be required if the biomass resources are to be utilised efficiently. Acquisition and processing of the assessed biomasses are challenges that need to be addressed if the full potential is to be obtained. Despite the challenges in the acquisition and processing of such biomass resources, energy production based on residues is a more sustainable, secure and economical viable approach for developing the EU biogas sector when considering the potential issues related to sustainability as outlined in this paper.

APPENDIX A

Table A1. The energy potential from anaerobic digestion of animal manure, excess grasses and straw in the member states of the European Union in 2030

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