D4.2 | Report on current and future sustainable biomass supply for biomethane production

Deliverable: Report on current and future sustainable biomass supply for biomethane production

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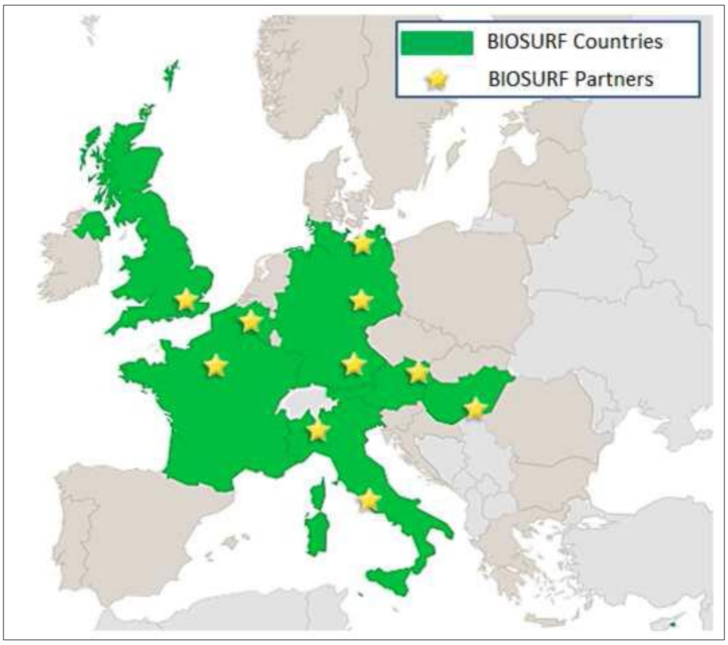
BIOSURF in a Nutshell

BIOSURF is an EU-funded project under the Horizon 2020 programme for research, technological development and demonstration.

The objective of BIOSURF (BIOmethane as SUstainable and Renewable Fuel) is to increase the production and use of biomethane (from animal waste, other waste materials and sustainable biomass), for grid injection and as transport fuel, by removing non-technical barriers and by paving the way towards a European biomethane market.

The BIOSURF consortium consists of 11 partners from 7 countries (Austria, Belgium, France, Germany, Hungary, Italy and United Kingdom), covering a large geographical area, as indicated in the figure on the left.



The intention of the project is:

- To analyse the value chain from production to use, based on territorial, physical and economic features (specified for different areas, i.e., biofuel for transport, electricity generation, heating & cooling);
- To analyse, compare and promote biomethane registering, labelling, certification and trade practices in Europe, in order to favour cooperation among the different countries and cross border markets on the basis of the partner countries involved;
- To address traceability, environmental criteria and quality standards to reduce GHG emissions and indirect land-use change (ILUC), as well as to preserve biodiversity and to assess the energy and CO2 balance;
- To identify the most prominent drivers for CO2-emissions along the value chain as an input for future optimization approaches and to exchange information and best practices all across Europe with regard to biomethane policy, regulations, support schemes and technical standards.

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SUMMARY

Most of the potential biomass feedstocks for the production of biomethane are subject to competitive uses. The studies listed in D4.1 consider theoretical and/or technical biomass potentials in the six European countries: Austria, France, Germany, Hungary, Italy and the United Kingdom. However, some feedstock categories are already in use and are not available for the biogas market. The biomass categories examined here, energy crops, animal waste, other organic waste materials, residues and catch crops, partially compete with the sectors 'feed, fuel and fiber'. The available amount of feedstock is of economic interest and the theoretical and technical feedstock potential was considered in national and international studies. The current use and range and the best utilization pathways (economic and ecological) for the limited feedstocks should be identified, and existing utilization pathways by cascade systems should be optimised.

A huge range of different kinds of biomass usable for biogas and biomethane production is described in this report. The most important feedstocks with respect to their technical potential are energy crops (except for France), animal excrement and straw. These biomasses still have considerable potentials for increased usage as biogas/biomethane feedstocks. The biomass potential of other organic waste and residue materials are lower than the aforementioned substrates. Wastes and residues undergo a revaluation by fermentation and production of biomethane, thus their potential should be fully exploited. All of the aforementioned feedstocks in compliance with official sustainability criteria need to be included when discussing sustainable feedstock supply for biogas plants.

Assuming that farmers and biogas plant operators are respecting "Cross Compliance" and "Best Practice" methods, dedicated energy crops as well as catch crops need to be part of a sustainable substrate portfolio for biogas production. The aforementioned biomass catetegories are renewable but not infinite. The optimal use and combining of all categories is a prerequisite for the efficient use of resources and, hence, for sustainable biomethane production with the potential for further development.

Location and climate primarily determine which substrate mixes are economically and environmentally sustainable, and these should be adapted according to each case.

Political guidelines and the resulting regulations have a great influence on the use of sustainable feedstocks and will stimulate or reduce their future utilization. It is therefore important to base relevant political decisions on scientifically proven facts when evaluating the sustainability and efficiency of available feedstock sources for biogas/ biomethane production.

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1. INTRODUCTION

The expected increase in total biogas and biomethane production and its targeted trade across borders (via the national gas grids) raise the concern of safeguarding the sustainable raw material supply. National biogas registries are being harmonised, to increase, among other things, the traceability and transparency of feedstock use. Furthermore, the project assesses the availability and potential of previously identified sustainable feedstock sources. In this context, sustainability criteria and indicators will be discussed and guidelines on sustainable raw material supplies will be developed.

This report describes selected sustainable feedstock categories including future perspectives and potential for sustainable biomass supply and their current use in biogas plants in six different European countries (Germany, Austria, the U.K., Italy, France and Hungary). Country-specific data were primarily received from representatives of the corresponding national biogas associations. A literature review served as the basis for the consecutive evaluation and comparison of data and has already provided an outlook on the validity of respective feedstock potential for biomethane production in the countries considered.

When talking about feedstock potential, it should be highlighted that the term “potential” actually needs further specification. As shown in the German study “Potentials of biogas production and use” by Scholwin et al. (2014), it is important to distinguish different types of feedstock potential and to do this as accurately as possible. Otherwise, the identified potential might be misleading, which could affect the evaluation of the entire value chain. The term “potential” can be differentiated as follows:

Theoretical potential reflects the total amount of considered waste materials and land area for biomass cultivation

Technical potential takes into account:
- competition in use of food, feed, material, etc.
- ecological restrictions (humus balance, nature conservation sites, biodiversity)
- technical restrictions (losses during the process chain).

Economic potential varies strongly and depends mainly on:
- the political framework
- the energy carrier’s prices
- the development of conversion technology.

Sustainable potential: additionally takes into account
- nature conservation
- resource conservation
- agricultural restrictions (e.g. safeguarding soil fertility)
- other sustainability criteria (GHG savings, ILUC…).

The following figure (fig.1) illustrates the different kinds of potential (Scholwin et al. 2014).

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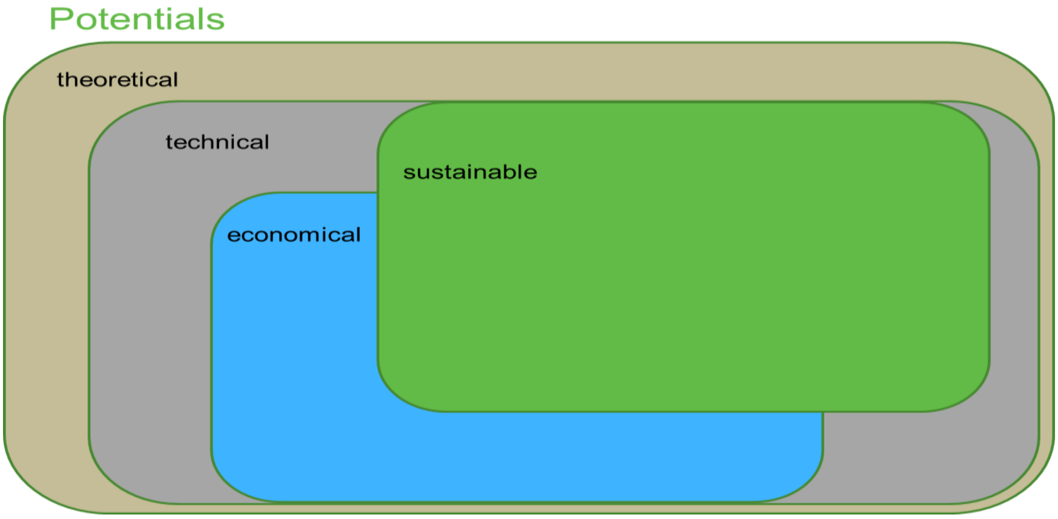

Figure1: Visualisation of the different kinds of potential (Scholwin et al. 2014)

Information about biomass potentials differ strongly between studies (see fig in chapter 4; Monforti et al. 2013). This is a result of the database's quality and survey year, the extent of the parameters considered and their level of detail (different models); the kind of potential (theoretical, technical, economic and sustainable) and the heterogeneous classification of feedstocks in substrate categories. The detailed documentation of the method used and the establishment of methodological standards are strongly recommended in order to better evaluate the indicated figures (Brosowski, Adler, Erdmann, Thrän, Mantau, Mahro, et al. 2015).

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2. SUSTAINABLE BIOMASS

2.1 Definition of sustainability regarding the feedstock supply

When talking about sustainable feedstock sources for biogas and biomethane production, defining the applied criteria is an essential prerequisite for any further assessment. Biomass is regarded as sustainable if it fulfils certain criteria, which have been determined by European and national laws. At the European level, Directive 2009/28/EC "on the promotion of the use of energy from renewable sources" regulates this aspect for the biomass used for the production of biofuels and bioliquids. It prescribes the sustainable production of energy by defining sustainability criteria to be implemented by the European Union member states, starting on 5 December 2010. In the Directive, it is also stated that the Commission will review the inclusion of other biomass applications. This was done in 2010, when a report on the sustainability requirements for the use of solid biomass and biogas in electricity, heating and cooling was adopted by the European Commission. The report makes recommendations on the sustainability criteria to be used by Member States, helping them to develop their own schemes at the national level.

General recommendations were provided to minimize the risk of the developing varied and possibly incompatible criteria at the national level, leading to trade barriers and limiting the growth of the bio-energy sector. The recommended criteria relate to[1]:

- a general prohibition on the use of biomass from land converted from forests, other high carbon stock areas and highly biodiverse areas;
- a common greenhouse gas calculation methodology which could be used to ensure that minimum greenhouse gas savings from biomass are at least 35% compared to the use of fossil sources (rising to 50% in 2017 and 60% in 2018 for new installations) compared to the EU's fossil energy mix;
- the differentiation of national support schemes in favour of installations that achieve high energy conversion efficiencies; and
- the monitoring of the biomass origins, taking into account Cross Compliance requirements for biomass cultivation.

It is also recommended to not apply sustainability criteria to wastes, as these must already fulfil environmental rules in accordance with waste legislation at the national and European level, and that sustainability requirements apply to larger energy producers of 1 MW thermal or 1MW electrical capacity or above.

It was further determined that Member States must submit National Renewable Energy Action Plans in June 2010. Compliance with European as well as the more specific national criteria is necessary to prove the sustainability of produced biomass, which is a prerequisite for reimbursements, tax reductions and to fulfil quota quantities (depending on the corresponding national regulations).

[1] http://europa.eu/rapid/press-release_IP-10-192_en.htm?locale=en

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Since emphasis is put on the requirement of achieving a 35 % reduction of GHG emissions compared to the fossil reference system (natural gas in this case), the following text will focus on this particular sustainability criterion.

In contrast to other biomass-based renewable energy carriers, the production of biomethane/ biogas is not only aligned to one feedstock, but usually demands a substrate mix. Typically from two to five different feedstocks are used in biogas plants.

The advantages of substrate mixes for the biogas process include:

- Substrate mixes generally stabilise the process by providing more balanced nutrient supply for the micro-organisms, increased availability of trace elements, reducing the risk of unilateral pollutant loads; slurry additionally has a buffering effect on the biogas process (higher tolerance of the micro-organisms regarding pH-alterations) and has an improved digestion rate when combined with energy crops.
- Substrate mixes can cause a synergy effect: a well-chosen mix can have higher gas production compared with the digestion of a single feedstock; this is particularly true for feedstocks with low dry matter content or with a high proportion of lignocellulose.
- The use of substrate mixes reduces the risks regarding potential crop shortfalls.
- Improved use of digestate because of the different seeding periods of the feedstocks used and, hence, different possibilities for fertilisation, which reduces the needed storage capacities for the digestate.
- The cultivation of different substrates instead of monocultures increases not only the biodiversity but also the public acceptance of biogas/ biomethane plants.

During the development of sustainability regulations there was no attention paid to the fact that the biogas process is a multi-input process. According to European regulations, it is not allowed to mix the GHG values of the different feedstocks used, i.e. average their values. So far it is necessary to divide the substrate mix into its separate components from every single supplier before starting the sustainability proof of the used feedstocks. This makes the calculation of the corresponding GHG emissions of the process very complex and complicated. It can therefore be stated that there is a strong need for an adapted, more practical calculation method for multi-feedstock processes, which would allow the balancing of the GHG emission values of the different substrates.

The calculation of carbon intensity and GHG emissions covers every step of the value chain, from feedstock production to energy generation. This enables biogas plant operators and other stakeholders to analyse the life cycle emissions from bioenergy using different feedstocks, production processes and transport methods. The biomethane production process can be divided into two different stages that can be evaluated separately: the cultivation and harvesting of the feedstock and the conversion process. Whenever energy crops are used as feedstock for biogas plants, the cultivation and harvesting step is usually responsible for the highest GHG emissions compared with the other stages of the process (Green Gas Grids project 2013). This is, however, only the case when the biogas plant is run according to best practice guidelines. The calculations will show different results, for instance, when the storage tanks for the digestate are not closed.
In contrast, when using manure as feedstock almost no emissions are counted for the feedstock production stage. Consequently, the production of biogas and its upgrading into biomethane becomes the process step that involves most of the total GHG emissions. It must be kept in mind that the use of manure and slurry in AD-plants avoids GHG emissions from the untreated material during storage. However, a much greater quantity of manure and slurry needs to be processed to produce an equivalent amount of biogas compared to the use of energy crops.

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The high proportion of possible GHG emissions during the cultivation and harvest of dedicated energy crops demands careful and sustainable management practices. Farm management practices have a significant impact on the results of the GHG calculation of specific biomethane production value chains and can consequently determine whether the process, or more precisely the used feedstock, is sustainable or not. Using the example of maize cultivation and harvest, the difference between best and worst practice amounts to GHG emissions of over 20 g CO_2 -eq/MJ biomethane (Green Gas Grids project 2013). Considering that the average total emissions of the biomethane production process in this case amounts to approx. 31 g CO_2 -eq/MJ biomethane, it becomes obvious that farm management and feedstock handling have a considerable influence on the evaluation of the whole value chain.

Best practice methods to minimize emissions can be implemented in several key areas, for instance in using digestate as fertilizer for the cultivated crops. The positive effect of using AD digestate as fertilizer includes cost reduction (by replacing mineral fertilizer) and environmental benefits. The nutrient profile and fertilizer value of digestate depends on the feedstock composition. Energy crops generally have higher dry matter content and more favourable nutrient compositions than manure or slurry, resulting in a more concentrated and valuable digestate (Green Gas Grids project 2013).

Concerning the use of dedicated energy crops as feedstock components, the constant improvement of cultivation and feedstock handling methods, as well as advances in plant breeding, help to further reduce GHG emissions during this first step of the biogas production process. For some substrates, however, it is generally more difficult to further reduce GHG emissions. Grass cultures in particular, if not combined with legumes, are characterized by relatively high GHG emissions due to their comparatively high nitrogen, and resulting need for fertiliser.

According to the GHG emission calculation methodology published by the European Energy Directive, Annex V, the agricultural management is allowed to use either measured or aggregated values (DIRECTIVE 2009/28/EC[2]). GHG emissions of the whole supply chain are allocated to the main product and potential co-products (a co-product is one of multiple products coming from the same production process for which the calculation of GHG values takes place). These emissions can then be allocated to the main product and the co-products based on their lower heating values.

No emissions should be allocated to agricultural crop residues, processing residues or waste since these are considered to have zero emissions until the point of their collection. This should also include crops that are not usable for food or feed anymore (e.g. as the result of droughts/ flooding, plant pathogens). Products from a production process that the owner wants to or must dispose of are not considered co-products but waste (DIRECTIVE 2009/28/EC[2]). Consequently, the use of residue and waste materials as feedstock or as a component of the substrate mix makes it easier to comply with the sustainability criteria of the biomethane production process.

[2] DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC:
http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN

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Although the European Landfill Directive (1999/31/EC) obliges Member States to reduce the amount of biodegradable municipal waste that they landfill to 35% of 1995 levels by 2016, in some member states it is still carried out. Landfilling biowaste causes huge amounts of GHG emissions, nutrient leakage and energy losses. The following table shows what anaerobic digestion could deliver from 1 tonne of biowaste that is not landfilled.

Table 1: Anaerobic digestion vs. landfilling: GHG mitigation potential for waste materials (calculations by ARGE Compost and Biogas Association Austria)

		expected emissions from landfilling biowaste	possible energy yield via digesting	avoided emissions by replacement oil (only combustion emissions)	lost nutrients		
	[t FM]	[t $CO_{2\,äqui.}$]	[kWh/kg DM]	[kg $CO_{2\,äqui.}$]	[kg N]	[kg P2O5]	[kg K2O]
biobin	1	1,2	4,5	187,7	2,4	0,8	0,8
garden biowaste	1	1,5	2,5	125,1	6,8	1,7	8,3
Average		**1,4**	**3,5**	**156,4**	**4,6**	**1,2**	**4,5**

The multi-input process in biogas plants allows the use of catch crops, which follows best practice regulations, particularly regarding the preservation of soil fertility and reduction of erosion. In addition, the cultivation of catch crops helps to increase biodiversity and thus avoid monocultures.

Catch crops are not regarded as the main substrates for biogas production so far, as they usually produce lower dry matter yields and therefore lower gas yields per hectare. In some cases, this would even lead to them being rated as not sustainable, since a GHG mitigation of 35 % is not achievable when evaluated as a mono-substrate. This evaluation would deliver the wrong signal to farmers. The use of catch crops as part of the substrate mix should actually be promoted, as their cultivation helps improve soil fertility and conservation, prevents wind and water erosion as well as nutrient leakage, and increases biodiversity. It should also be pointed out that the cultivation of catch crops allows a second usage of the same field, since these crops are cultivated in addition to the main crops.
However, if catch crops that are not hardy are used, it should be taken into account that they may die off during the winter and start to rot before the next main crop is seeded. The University of Vienna and Bioresearch Austria (Badawi 2010) have measured the losses of carbon and nitrogen during this rotting process.

Table 2: Carbon losses during the rotting process of non-hardy catch crops (Badawi et al. 2010)

	Carbon yield at 27.10.2008	**Leakage through winter period**	**Degassing through winter period**	**Total losses**
	[kg Carbon / ha]	[%]	[%]	[%]
Mustard	970	6	42.3	48.3
Non legume mixture	1 286	8.6	47.9	56.5
Legume mixture	1 334	8.7	47.8	56.5
Average		**7.8**	**46**	**53.7**

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Table 3: Nitrogen losses during rotting process of non-hardy catch crops (Badawi et al. 2010)

	Nitrogen yield at 27.10.2008	Leakage through winter period	Degassing through winter period	Total losses
	[kg N / ha]	[%]	[%]	[%]
Mustard	66.9	24.5	37.2	61.7

If the catch crops' growth is used in biogas plants, generally only 70 to 75% of the feedstock's carbon is used for biogas production. The remaining carbon and many nutrients are recovered in the digestate, which is usually brought back to the field, which means that there are many environmental benefits to digesting catch crops.

Besides preventing soil erosion, growing catch crops can bring yet another added value: carbon sequestration in the soil. Consequently, catch crops could deliver about 1500 kg/ha carbon for soil via roots and digestate (Badawi et al. 2010).

Table 4: Carbon sequestration in the soil through catch crop cultivation (calculations by ARGE Compost and Biogas Association Austria)

Carbon sequestration in the soil through cultivation of catch crops and digestion of their growth						
catch crops for biogas	average yield	CO2 for plant growing	digesting		Carbon sequestration in the soil	
	Carbon	total (aufwuchs + roots]	energy yield	digestate		
[ha]	[kg C / ha]	[kg CO_2 / ha]	[Nm³ CH_4 / ha]	[kg C / ha]	[kg C / ha]	kg CO2 / ha]
1	1.193	8.751	903	304	1.498	5.491

Another sustainable feedstock for biogas/ biomethane production is animal excrement, which can be used for commercial energy production on and near farms without competing with the supply needed to preserve the soil fertility of the agricultural land. The material is easy to ferment in biogas plants and the remaining digestate can then be applied as fertilizer on the fields. Some significant advantages of digesting animal excrement – as compared to untreated material - are reduced odour emissions, the homogenization of the substrate, which makes it more readily spreadable, the shifted ratio of phosphorus and potassium and the increased proportion of inorganic nitrogen, which is better adapted to the nutritional needs of crops. Further pathogens and weed seeds are being reduced by the AD process (Insam, Gómez-Brandón, and Ascher 2015).

Digestate is used for closing the nutrient cycles, for the production of renewable energy and offers the option of reducing nitrate impacts in areas with intense livestock farming. Competition for food and feed production is not given (Holm-Nielsen et al. 2009). A further ecological advantage of digestate is the option of concentrating the material, e.g. by pressing. The concentrate can serve as a green fertilizer with increased economic transportability and can extensively provide agricultural land with nutrients while reducing the nitrate impact in areas with intensive livestock farming (Foged, Flotats Ripoll, Bonmatí Blasi, Palatsi Civit, et al. 2012).

At the global level, livestock accounts for 18% of the anthropogenic greenhouse gas emissions (Steinfeld et al. 2006). When untreated or poorly managed, animal manure becomes a major

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source of air and water pollution (see table). The intensification of livestock production has led to the storage of a large volume of animal excrement and the intense spreading of it on agricultural land (Bioteau et al. 2009). Under the aspects of climate protection, the energetic utilization of animal excrement is therefore essential for the reduction of GHG emissions. This can be achieved in many different ways when using it as feedstock in AD plants:

- substitution of fossil fuels by producing renewable energy (biogas/ biomethane),
- avoiding methane emissions from slurry/ manure storage tanks due to the lack of easily degradable organic compounds in fermented excrements (Sommer, Moller, and Pedersen 2001)(Meyer-Aurich et al. 2012)
- reduction of nitrous oxide emissions when applying digestate on the field compared with undigested material (Sommer, Moller, and Pedersen 2001).

Table 5: Emissions from animal excrements (Austrian Agency for Environment(UBA) 2014)

emissions from farm manure: considered is only slurry [source UBA Austria´s national inventory report 2014]										
	Average daily volatile solids excreted (kg) for animal type Vsi	maximum methane producing capacity (m³ per kg of VS) for manure produced by animal type B0i	methane conversion factors for each manure management system by climate region MCFjK	fraction of animal type i´s manure handled using manure systems MS%ijK	annual emission factor (kg) for animal type Efi	CH4 emissions from slurry tanks per animal and year	CO2 equivalent emissions from slurry tanks per animal and year (CH4 is considered)	Nitrogen excretion per animal per year	N2O emissions factor from slurry tanks year expressed in kg N2O-N per kg N excreted	CO2 equivalent emissions from slurry tanks per animal and year (CH4 and N2O are considered)
	[kg VS head^-1 day^-1]	[m³ CH4 kg^-1 VS]			[kg CH4 head^-1 day^-1]	[kg CH4 head^-1 year^-1]	**[kg CO2 equi head^-1 year^-1]**	[kg N head^-1 year^-1]	[kg N2O-N kgNexcreted^-1]	[kg CO2 equi head^-1 year^-1]
dairy cow (4500 kg milk/a)	4,1	0,24	8,7	1	0,06	20,94	**523 kg**	76,62	0,001	559,27
dairy cow (6500 kg milk/a)	4,31	0,24	8,7	1	0,06	22,01	**550 kg**	100,26	0,001	597,14
cattle < 1 year	0,97	0,17	8,7	1	0,01	5,24	**131 kg**	25,70	0,001	142,94
cattle > 1 year	2,16	0,17	8,7	1	0,03	11,66	**292 kg**	53,60	0,001	316,61
swine: breeding sows	0,82	0,45	3,4	1	0,01	4,58	**114 kg**	29,10	0,001	128,11
swine: fattening pigs	0,29	0,45	3,4	1	0,00	1,62	**40 kg**	10,30	0,001	45,31
horses						1,39	**35 kg**	47,90	0,001	57,18
chicken (average of hens and broilers						0,08	**2 kg**	0,52	0,001	2,19
poultry (average of turkeys ducks, gooses...						0,08	**2 kg**	1,10	0,001	2,52
other poultry						0,08	**2 kg**	1,10	0,001	2,47

The leakage of methane and ammonia from biogas plants can be eliminated using technical solutions.

The saved nitrogen loss and the reduced CO_2 emissions depend on the processing technologies and the considered reference systems. Guidelines for the assessment of GHG-emissions and methane conversion factors have been provided by the IPCC (IPCC - Intergovernmental Panel on Climate Change 2006) and were evaluated for cattle and pig slurry in German and Austrian livestock farming (Dammgen et al. 2012), which provides a good basis for further detailed analysis. According to a study that compared 7 livestock manure treatment plants (4 of them with anerobic digestion), comprising 34 technologies, the reduced CO_2 emissions ranged between 0 to 82.5 kg CO_{2e} per m³ treated influent and the saved nitrogen loss ranged between 0.89 and 1.6 kg N_{total} per m³ treated influent (Foged, Flotats Ripoll, Bonmatí Blasi, Schelde, et al. 2012).

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However, the economics might not be beneficial to all farmers, since the methane yield per mass unit of animal waste is comparatively low. Therefore, co-digestion with other substrates (e.g. energy crops, crop residues) is common and their availability near the biogas plant should be included in (future) evaluations. In many cases, only co-digestion of manure with other substrates results in economically feasible manure treatment, due to limited transportability of manure with high water content. This should be considered for the ecological evaluation of energy crop utilisation for biogas production.

2.2 Introduction of chosen sustainable feedstocks for biogas production

As described in the previous chapter there are numerous feedstocks that can be used for the biogas process in a sustainable way. Referring to cultivated biogas crops, management practices and the choice of land in particular determine the crop's sustainability rating.

Obviously, these aspects are not relevant for agricultural residues and other waste materials. Consequently, their use is strongly promoted in order to contribute to renewable energy targets, to mitigate climate change (no GHG emissions until the collection stage) and to reduce competition for resources and land. Used as feedstocks for bioenergy purposes, they are therefore considered a sustainable alternative. As in the previous report (Deliverable 4.1 "Report on data availability of selected raw material categories"), three main residue/waste categories will be of particular interest when evaluating current and estimating future sustainable biomass supply in this report: animal waste (slurry and manure), other waste materials (municipal biowaste and food/feed residues) and biomass residues (agricultural crop residues, by-products from cultivation, harvesting and processing, residues from landscape maintenance and conservation, including pruning material and catch crops).

As described in the previous chapter, and assuming best practice methods and cross compliance regulations are applied, the use of dedicated energy crops as feedstock for biogas/biomethane production is sustainable. The fact that these raw materials are characterised by the highest yield and land efficiency should not be neglected. For this reason, this feedstock category has also been included in BIOSURF's evaluations of sustainability and potential.

When talking about suitable (i.e. sustainable and economically viable) feedstocks for biomethane production, productivity also plays a role. Consequently, not only crop yield and residue/waste availability is of importance but also the corresponding biogas and biomethane yield. The Bavarian Agency for agriculture, for instance, provides a useful online tool summarizing average gas production based on both dry as well as fresh matter, and methane yield of different substrates. It provides a good orientation for biogas plant operators when contemplating new/additional substrate uses. The tool (in German) is available at : http://www.lfl.bayern.de/iba/energie/049711/. Another overview of biogas substrate characteristics in English, which is based on a FNR (Agency for Renewable Resources, Germany) publication (FNR 2010b) can be found in the annex (Table 1a).

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Another overview of selected substrates is given in the following graph, which displays different biogas yield potentials per tonne of fresh matter. Particularly with regard to resource efficiency as an important sustainability criterion, the use of a well-balanced substrate mix, adapted to local conditions, should be supported.

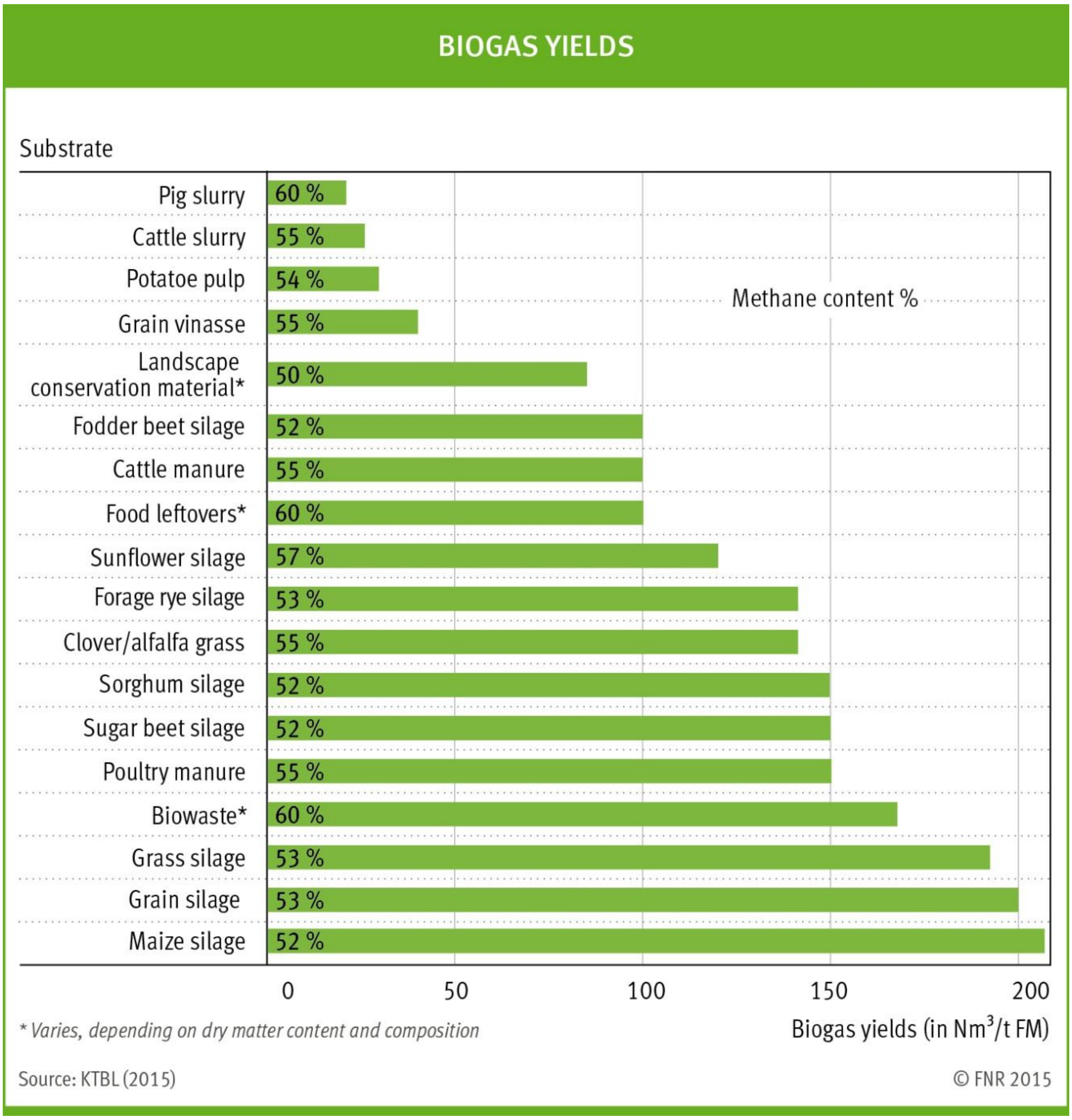

Figure 2: Gas yields of different substrates in agricultural biogas plants (KTBL 2015)

In the following sub-chapters, the aforementioned chosen sustainable feedstock categories are briefly outlined.

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2.2.1 Animal Waste

Animal husbandry results in the production of animal waste, also called agricultural primary residues. The waste can be used as raw material for biogas and subsequently biomethane production. However, only waste from farm animals that are kept in stables can be obtained for energy purposes. Most animal waste from sheep, goats, horses, geese and ducks is not usable for energy applications due to the high proportion of free range systems for these animals (BMVBS 2010). Therefore, most studies of energy potential do not include animal waste from these types of animals. Large quantities of the used animal waste in the EU originates from cattle and pig farming, with lesser amounts from chicken farming. Manure from chickens is typically used in biogas plants, but in limited concentration in a single biogas plant because of its high ammonia content and high proportion of lime due to supplementary feeding (FNR 2010a).

Animal waste can be subdivided into two main groups: liquid and solid waste. “Slurry” is animal waste in liquid form, consisting of more or less solid excrement and urine of domestic animals, possibly including water and/or small amounts of litter. “Manure”, which may be solid or liquid, is a mixture of domestic animal excrement, including animal bedding materials such as straw or chips. “Deep litter” is a result of animal bedding on straw with intervals of straw removal of up to one year, when livestock is removed for grazing or slaughter. The nature (solid or liquid) of animal excrement depends partially on food quality (fresh/liquid fodder, dried fodder). The yields for biogas and methane differ between slurry; manure and “deep litter” and between animal species but also depend on the age of the animal waste (outgassing).

Due to its water content, the biogas and methane yields per volume of fresh substrate are higher for manure in comparison to slurry (FNR 2010a). However, the storage in slurry tanks, the co-digestion with other substrates and the application of slurry in biogas plants is easier due to the flow behaviour (pumpability) in comparison to manure, which needs special filling techniques.

Due to its high water content, the methane yield per mass unit of animal waste is comparatively low and transportation costs are high. Hence, a minimum quantity of animal waste has to be produced on farms that are relatively close to the biogas plants in order to ensure the profitability the AD-unit and the profitability of biomethane production. With an increasing quantity of indoor systems (stables) and farm sizes, the technical/economic potential of animal excrements that can be used/ treated in biogas plants is increasing too. Co-digestion with other substrates (e.g. energy crops, crop residues) is common and their availability close to the biogas plant should be included in (future) evaluations.

In general, theoretical animal waste potentials can be calculated based on animal statistics and the amount of animal waste per livestock unit. The proportion of livestock housing (or availability of animal waste) is considered a good estimate of technical potential.

The analysis of international studies regarding animal waste potentials (see table in BIOSURF’s Deliverable 4.1 (Sternberg, Erdmann, and Kirchmeyr 2015)) is based on data from EuroStat (http://ec.europa.eu/eurostat/data/database) and FAO-Stat (http://faostat3.fao.org/browse/Q/QA/E). Uniform average numbers on livestock housing and the fractions of types of animal waste (solid manure, liquid manure, slurry, deep litter; (Bioteau et al. 2009; KTBL 2015) were applied to all European countries in the studies considered. These average values do not reflect differences between farming systems and livestock patterns in EU countries (http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_livestock_patterns), resulting in rough estimations. The calculation of animal waste potentials could be improved by looking at production systems and animal waste output depending on staple

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systems for each animal category for each country. EuroStat provides the necessary database at the Nuts-2 level.

A higher geographical resolution of animal waste potential was achieved in national studies based on data up to the municipality level from national statistical offices (Sternberg, Erdmann, and Kirchmeyr 2015). However, these studies consider different calculation parameters and therefore are hardly comparable.

To calculate the animal waste potential for biomethane production, it is recommended that economic cut-off criteria be included. The energy content of animal waste is comparably low due to the high water content. Consequently, trading and transportation are not attractive. For these economic and logistical reasons, a minimum number of livestock is required locally to establish animal waste digestion plants (Dalla Longa et al. 2014). Depending on the feed-in tariffs of the respective countries, the minimum size of an economic plant would entail an output of 150-500 m^3/h biogas (Scholwin et al. 2014). However, in Germany, for instance, smaller local plants using primarily manure and slurry are currently supported, which has led to several newly built biogas plants with an output of only 40 m^3/h (75 kWel plants). This is also quite a common size in other countries.

Animal waste potential for the production of biomethane needs to be assessed according to current and future livestock patterns and farm structures (amount of minimum economic quantities of animal waste) at the regional level. Co-digestion with other substrates is commonly used to increase the economic efficiency of biogas plants. The availability of co-substrates (e.g. energy crops, catch crops) at the regional level should be evaluated in future studies, along with the localization of the gas grid to ensure biomethane feed-in options.

2.2.2 Other organic waste materials

Other organic waste materials considered in this paper are defined under the waste framework directive (2008/98/EC) in Article 3, Point 4 as: ‘biowaste’ means biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants.

There are usually several classifications under this definition. The regulation on waste statistics (EC 2150/2002, amended through EC 849/2010) sets out two categories under Section 2 for biowaste: animal and mixed food waste and vegetal wastes. These categories differ sometimes between countries and scientific reports for different reasons including national laws, biowaste collection strategies, statistical requirements, etc.

Although efforts have been made to reduce the amount of biowaste from households in some member states (e.g. Germany, Austria), over the last few years there has still been a considerable amount of biowaste derived from food, feed and beverage production and consumption that cannot be avoided. One of the best options for dealing with this organic waste stream is its treatment and use in a biogas plant producing energy and organic fertilizer.

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It has to be considered that several biowaste streams, mainly from beverage and food processing, are still not on the market as waste streams but as fodder like spent grains, whey, etc. Therefore, these biowaste streams are not included in the available data. In respect of the further development of a sustainable circular economy, the cascade use of feedstock should be encouraged and the use of biowaste feedstock in biogas plants should be the last step. Nevertheless, due to the increasing size of food and beverage production sites and the attractiveness of treating the incurring waste by anaerobic digestion (AD)-plants nearby, an increase in number or size of biogas plants, can be expected

Although some member states have already introduced the separate collection of biodegradable waste, and some member states have also instituted a ban on biodegradable waste in landfills (AT, BE-FL, DE, DK, SE), a huge amount of biodegradable waste in the EU is still landfilled. Through the full implementation of the landfill directive (1999/31/EC) in all member states, which forces the amount of biodegradable waste in landfills to be lowered, we can expect a big increase in separately collected biowaste within the coming years.

Most of the separately collected biowaste from households is currently still treated in compost plants. Due to further regulations and developments in the biogas sector, an increasing amount of biowaste material from this category can be expected for digestion.

2.2.3 Residues and catch crops

The term “residue” comprises very different types of biomass. All of these types, however, are by-products of utilization pathways that were originally not intended to produce bioenergy. Aside from municipal and agro-industrial biowaste and animal excrement, biomass types that were already described earlier, this biomass category also includes crop residues (mainly straw), and residues from landscape maintenance and conservation, including pruning material and catch crops.

Crop residues are parts of the crop that are not harvested during standard agricultural operations. Significant amounts of agricultural residues are generated from agricultural crop production and partially remain in the field after harvest. Residue production depends on a number of factors that include the types of crops, crop rotation, crop mix and agricultural practices. A large annual variation in crop production and consequently in the remaining residues has to be taken into account when making assumptions about the respective potential for bioenergy use. In the EU, there are considerable differences in terms of cultivated area, types of crops and yields due to climate and soil conditions, accessibility and farm practices. Cereals and oilseeds are the most cultivated crops (Scarlat, Martinov, and Dallemand 2010). The availability of residues further depends on their competitive use for other agricultural or industrial purposes. Regarding the preservation of soil fertility, the negative impact from removing the residues can be substantially compensated by using the digestate as fertiliser.

The estimation of agricultural crop residues for bioenergy production requires accurate data on their availability by crop type. Data on crop yields are directly available, while data on their residues are not, since the sole focus of agricultural production has obviously been on the main food/feed

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product in the past. In the meantime, there are many studies that have estimated crop residue availability in the EU.

Straw from cereals, maize and rapeseed production is the main crop residue (figure 3), and is already used for many different purposes. The majority of the available (cereal-based) straw is used for animal housing or remains on the field to guarantee lasting soil fertility. As previously mentioned, the latter is only true if the digestate is not returned to the field, when the straw is used for the biogas process. Further straw is used in heat and power plants as well as for bioethanol production. Sometimes, however, the straw is simply left on the field because economically interesting concepts are missing (or the farmer is not aware of them). This corresponds, for instance, with the findings of a recent study conducted by the German Biomass Research Centre (DBFZ) that revealed that straw still has the third highest potential for additional use in Germany (Brosowski, Adler, Erdmann, Thrän, Mantau, Blanke, et al. 2015). A similar situation is expected in other countries.

The following figure summarizes and presents the average share of crop residues in Europe:

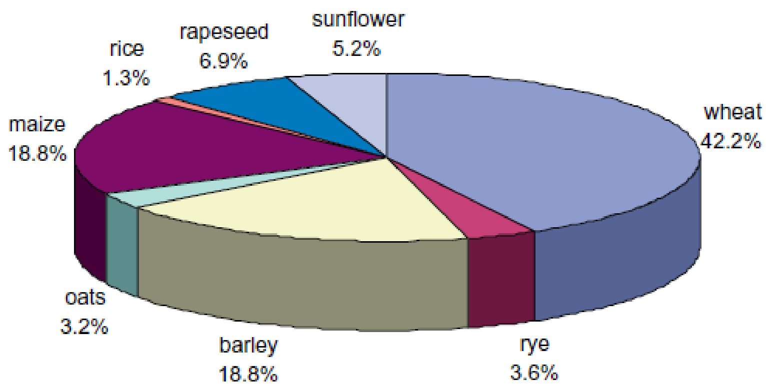

Figure 3: Share of eight crop residues produced in EU-27 (Scarlat, Martinov, and Dallemand 2010)

Landscape maintenance material and pruning residues

There are many other primary residues that can supply biomass for bioenergy, such as cuttings from permanent grasslands which are sometimes found on agricultural lands (in this case usually used for hay or silage production and then in animal husbandry), but which also originate from parks or other recreational areas, nature conservation areas or dykes and abandoned grasslands. Management of abandoned areas through cutting can be beneficial for biodiversity. To a certain degree, human intervention stimulates diversity since it prevents one floristic species from becoming dominant over others. As a consequence, more ecological niches are created for a wider range of species (Khawaja and Janssen 2014). The incurring biomass coming from the named grasslands can then potentially be used as feedstock for bioenergy production.

Woody material from pruning and cutting, which is also part of landscape maintenance, can potentially deliver a large amount of biomass. In certain regions of the EU, plantations of soft fruit,

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citrus, olives and vineyards cover quite a significant area (Khawaja and Janssen 2014). With respect to potential applications for bioenergy production, however, these residues face constraints due to their relatively high cellulosic content and in some cases also the presence of natural biochemical substances, which make the material badly degradable and hamper the digesting process. A pre-treatment is necessary in these cases. Consequently, woody material derived from landscape maintenance can only be used in small amounts for treatment in biogas plants. Therefore, most of the material is currently used to produce woodchips for heating instead or is directly used for thermal processes. There are several processes to treat this kind of biomass physically, chemically or biologically and to convert the material into other primary energy carriers to make the subsequent energetic conversion more efficient. Producing energy through anaerobic digestion is just one of these options (Universität Rostock, Institut für Energetik und Umwelt gGmbH, and Bundesanstalt für Landwirtschaft 2007). However, at present thermochemical technologies seem to be the most efficient conversion technology for material with a high fibre content as compared to biochemical processing. The potential for the use of woody material as biogas feedstock could nevertheless increase if suitable pre-treatment measures are further developed and implemented at an economically viable level.

Roadside verge grass could be another source of biomass supply. The Biomass Futures project provided some estimations on the potential amount of this kind of biomass (Elbersen et al. 2012).The German/ Dutch project “Biores” also found considerable potential for this kind of (residue) biomass. Particularly in countries with limited arable farming like the Netherlands, roadside verge grass presents an interesting alternative to the cultivation of catch crops and their use for the biogas process (Helmer and Böller 2010).

Catch crops represent another alternative for using “residues” for biogas/ biomethane production. Catch crops are sometimes cultivated together with the main crops, but are mostly used to bridge the time in between the cultivation of main crops, when the area would otherwise just consist of delicate fallow land. In this context, catch crops help to prevent water and wind erosion, nutrient leakage and, consequently, soil deterioration. The use of catch crops in biogas plants has been/is being tested in several research projects. The German/Dutch project “Biores”(Helmer and Böller 2010), for instance, found that that a combination of summer rape (seeded until June) and winter cereal supplies good and economically interesting feedstocks for biogas producers. A study conducted by a research team at the University of Soil Science in Vienna (BOKU) further revealed that a mixture of maize, sorghum/millet and sunflower or Sudan-grass and sorghum by itself are achieving promising biomethane yields (Amon et al. 2010). The results of the German research project EVA showed that winter rye (used for whole plant silage) and maize are the most productive “2-crop systems”.

In addition, there is the possibility of cultivating stubble seeds/ covering crops (e.g. wild mustard, cultivated radish and cup plants) after the main crop, which could also be used for the biogas process or as direct fertiliser. Many studies have shown that they generate an ecological and economic added value by fixation of nutrients, reduction of erosion, improvement of the soil’s humus balance, and increased biodiversity.

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The need to precisely coordinate harvest and seeding times and the reduced duration of growing periods for the chosen crops also bear some risks, which may lead to reduced yields, like shifts of optimal seeding times, inadequate maturation and high ground water use (Eckner et al. 2014). Hence, the combined crops need to have compatible requirements. Temperatures and water supply during springtime nevertheless have the strongest influence on the yields (Eckner et al. 2014).

2.2.4 Energy crops

The use of energy crops has been very restricted over the past years, mainly due to concerns regarding their sustainability and to reduced public acceptance. Several national regulations have limited their use in biogas plants by reducing or cancelling the corresponding incentives, e.g. reimbursements/feed-in tariffs, tax reductions or fulfilling prescribed quota quantities (depending on national regulations).

Nevertheless energy crops, particularly maize, should not be automatically rejected. Its use has many advantages for the biogas process – the main one being its high efficiency with regard to the process. In terms of feedstock sustainability, it seems to be easiest to base the biogas process on residue and waste materials. However, these feedstock sources are finite and already have many competing uses. Even though many efforts have been and still are undertaken to optimise the digestion process, particularly regarding the decomposition of lignocellulosic substances, mostly found in residue materials as well as through plant breeding, energy crops, particularly maize, still remain by far the most efficient biogas feedstock. In combination with waste or residue materials, the process does not only become more effective in terms of energy production but also in terms of economic feasibility. The use of maize in a substrate mix with slurry, for instance, leads to a better digestion of the slurry (higher dry matter content) and can support the profitability of biogas production when only limited amounts of slurry are locally available (Scholwin, Schüch, and Grope 2015).

Energy crops are still the main feedstock for biogas/ biomethane plants in most of the regarded countries. Without their use, existing biogas/biomethane plants could not operate at full capacity and an increase in biogas/biomethane production is not imaginable. According to different studies, residue and waste materials make a valuable contribution to biogas production, but are not considered sufficiently available to fulfil the feedstock needs (Scholwin, Schüch, and Grope 2015); (Brosowski, Adler, Erdmann, Thrän, Mantau, Blanke, et al. 2015). Considering cross-compliance regulations and legal frameworks, the decision regarding which crop is cultivated in which area depends mostly on economics, i.e. the highest expected yields with respect to energy supply.

As briefly described in the previous passage about catch crops, there are many alternative plants that can be cultivated for the biogas process. Nevertheless, maize is the most efficient plant for this purpose (see table 6). In general, all alternatively cultivated plants – depending on local cultivation conditions – are characterised by an increased need for land and higher investments. To improve this situation, ongoing research and development efforts have been undertaken to optimise crops and cultivation methods. Public support of research in the area of energy crop cultivation will

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remain important, particularly for addressing sustainability and efficiency aspects as well as public acceptance.

Table 6: Average yields and energy production of different feedstocks for biogas plants (KTBL 2013; KTBL 2012)

	Yield (t FM/ha)	Methane Prod. (Nm^3/ha)	Energy (kWh/ha)
Maize Silage	40-60	3 956 - 5 934	39 433 - 59 149
Sugar Beet	55-75	3 523 - 4 803	35 112 - 47 881
Sorghum	50-70	3 517 - 4 924	35 059 - 49 082
Cereal Whole Plant Silage	30-50	2 884 - 4 807	28 752 – 47 920
Cup Plant	45-60	2 871 - 3 828	28 616 – 38 155
Sudan Grass	35-55	2 392 - 3 759	23 844 – 37 496
Grass-Legume Mix	30-49	2 251 - 3 711	22 438 - 36 992
Grassland	23-43	2 001 – 3 808	19 946 - 37 959
Rye – Cereal Grains	4.3-6.8	1 390 – 2 179	13 853 - 21 725

Nevertheless, local soil and climate conditions may lead to different results regarding the most preferable crop for cultivation: in areas with low soil quality or inadequate water supply during the growing season, for instance, sorghum is a veritable alternative to maize since it is better adapted to these conditions. Hence, compared to the cultivation of maize, sorghum should be the plant of choice at locations with low ground water supply and less than 600 mm of annual precipitation (Eckner et al. 2014). Another suitable option for dry and warm locations is Sudan grass which has quite a promising potential in the biogas value chain and, under these conditions, can have even better results compared to the cultivation of maize (Roller et al. 2012).

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3. Review of current supply and potential of the determined sustainable biomass feedstocks in the 6 focus countries

Six different national biogas associations are represented in the BIOSURF project. In this chapter the associations will briefly summarise the current status of feedstock use for biogas and biomethane production in their respective countries, provide estimates of further feedstock potentials and describe expected changes in the feedstock supply for biogas plants and their underlying political and regulatory drivers. This has been done for Germany, Austria, the United Kingdom, Italy and France. To describe the situation in Hungary, information from the project GreenGasGrid, “Hungarian Roadmap for the development of the biomethane sector” (2013), has been used. Additionally the Hungarian Biogas Association has provided updated figures for feedstock potentials for biomethane production.

3.1 Germany

At the end of 2015, the German Biogas Association (GBA) reported almost 9,000 biogas plants in Germany with an installed capacity of 4,177 MWel, about 190 of them upgrading biogas to biomethane. Due to the existing framework conditions in Germany, most of the biogas plants are based on digesting energy crops in combination with slurry and manure.

Current biomass supply for biogas plants

In 2015, the German Biomass Research Center (DBFZ) published a study (Schweftelowitz, et.al. 2015) on the use of different substrates. The authors determined a proportion of 52% of energy crops and 43% of slurry and manure as input for the digester based on weight. Only 5% of the inputs are wastes and residues. The share of the digested materials of waste and amounts to 7% of the produced biogas. Energy crops supply 79% of biogas’ energy content, slurry and manure only 14% due to the low energy content of the material.

Focussing on energy crops, the main important feedstock is maize in form of silage. Approximately one million hectares are cultivated with this high yield crop. Further important feedstocks grown on cropland are cereals, using either the grains or the whole plant as silage with 200,000 hectares. Additionally, grass from about 160,000 hectares of grassland is digested in biogas plants. In total, almost 1.5 million hectares of agricultural land is used for substrate supply for biogas plants. That means that less than 10% of the total German agricultural area (17 million hectares) is providing feedstock for biogas.

Most of the existing biogas facilities were constructed before the end of 2011. From 2000 to 2011 the renewable energy act (EEG) promoted the use of energy crops and animal excrement with very high incentives. A bonus for energy crop utilisation was on top of the basic tariff of about 11 ct/kWh. Thus between 400 and 1,400 plants per year, mostly based on agricultural crops, were built in that period.

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Since 2012, a new amendment of the EEG came into force. The government established a new system with requirements regarding efficiency and ecology but in total the feed-in tariffs were reduced. In 2014, the latest amendment of the EEG entered into force. Due to several reasons, such as public protest against rising maize areas and the use of potential food and feed crops for energy production, it was decided not to promote energy crop utilisation with a dedicated bonus anymore. Instead of supporting energy crops, there are currently two special tariffs for small-scale manure plants and for biogas plants digesting waste.

For the future, it can be assumed that the focus for newly installed biogas plants will be animal excrement and waste.

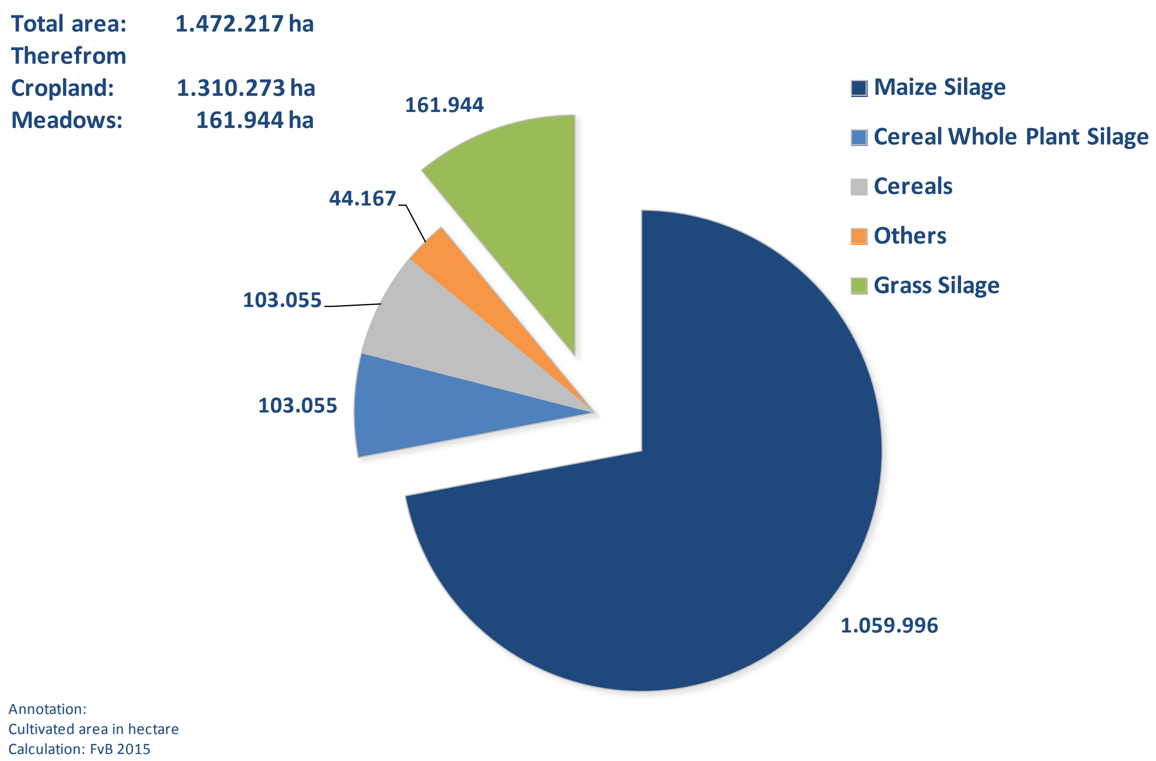

Figure 4: Distribution of energy crops used as feedstocks for biogas plants in Germany, Source: Fachverband Biogas e.V./ German Biogas Association (GBA) own calculation

Currently 190 biogas plants are upgrading biogas to natural gas quality. They have in total a capacity of about 180,000 Nm³/h. About 80% of the energy in the biogas is produced from energy crops.

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Table 7: Biomass utilization in German biomethane plants according to a survey carried out by the German Biomass Research Centre DBFZ, data as of 2013 (Daniel-Gromke et al. 2014)

Biomass resource	Number of biomethane plants [n]	Biomethane volume after upgrading [$m^3_{STP}/h_{biomethane}$]
Energy crops	80	50 375
Energy crops + manure	43	21 555
Energy crops + organic waste	2	980
Organic waste	11	10 968
Organic waste + manure	5	2 185
Sewage sludge	1	650
Sewage sludge + organic waste	1	350
Not specified	1	350
Total	144	87 413

m^3_{STP}/h: volumetric flow rate (STP = standard temperature and pressure)

In Germany, there are over 10,000 wastewater treatment plants in operation, and 1,340 of them produced biogas from sewage (sludge) in 2014. In total they produced 4.6 TWh/a (16.4 PJ/a) biogas; converted into electricity this results in 1.34 TWhel/a biogas (4.8 PJ/a electricity). Compared to 2013, sewage gas production increased by 3.8%. Most of the energy (91%) was used for energy consumption within the wastewater treatment plants (Destatis 2015)[3].

About 1.2 TWh/a (4.5 PJ/a) biogas was produced from landfills in 2013, which is 12% less compared to 2012 (Biogas Barometer 2014)[4]. In Germany the restriction/ban on dumping organic material in landfills has been in effect since 2005. All produced landfill gas originates from organic matter dumped before 2005.

Future potential for the sustainable biomass supply

Although there are already huge numbers of operating biogas plants in Germany, there is a potential for further development (see figure 5 below). The graph shows six categories of materials that can be digested: energy crops, animal excrement, “non-area” renewables[5]/agricultural residues, by-products of food production, biowaste and organic waste from animals. In these groups, materials can be identified that are theoretically digestible but are not used for biogas

[3] Destatis: https://www.destatis.de/DE/PresseService/Presse/Pressemitteilungen/2015/07/PD15_257_433pdf.pdf?__blob=publicationFile

[4] Biogas Barometer 2014, http://www.eurobserv-er.org/biogas-barometer-2014/

[5] „Non-Area” renewables means in this context, plant material that can be used for energy production without competing with food or feed production. Examples are cultivated catch crops, agricultural residues and by-products

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production in practice. Utilization in other pathways might be favoured (e.g. for economic reasons or because of already settled long-term contracts).

Energy crops have the highest theoretical and technical ("realistic") potential for increased production of bioenergy in biogas plants. The German Biogas Association estimates their energetic potential to be about 108 PJ/a (30 TWh/a) electricity. Two-thirds of this potential is already used for energy production or material use. Whether or not this potential is used for bioenergy generation in the future will depend mainly on political decisions (and setting the right incentives). Animal excrement represents the biogas feedstock with the second highest potential, amounting to 38 PJ/a (10 TWh/a), followed by "non-area" renewables like straw, beat leaf, etc. Only minor potentials can be expected from using different kinds of wastes.

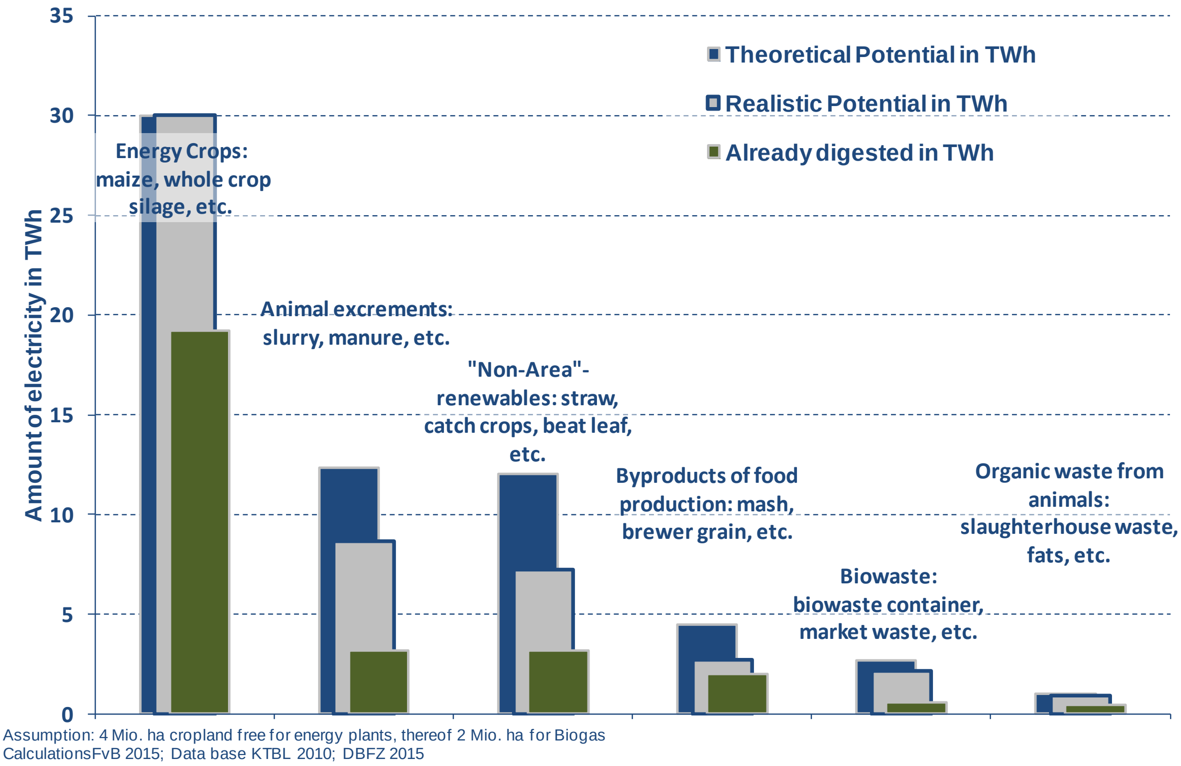

Figure 5: Current used and future energy potential from different feedstock categories for biogas plants in TWh per year

Altogether, about 108 PJ/a (30 TWh/a) electricity is produced in biogas plants in Germany. The theoretical potential amounts to 216 PJ/a (60 TWh/a) and, more importantly, the technical potential to 180 PJ/a (50 TWh/a) according to GBA calculations.

There are not many studies and there exist some uncertainties about the future potential of sewage as feedstock for biogas plants. In a study published by the Federal Ministry of Economic Affairs and Energy, the potential is assumed to be 1 TWh/a (3.6 PJ/a) maximum (Scholwin et al.)[6]

[6] http://www.izes.de/cms/upload/pdf/Meilensteine_2030_Potenzial_Biogas.pdf

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Regarding the use of landfill material, a ban on organic material in landfills (effective since 2005) has been leading to a constant decrease in the production of landfill-based biogas (decrease at a rate of over 10% per year). In the future, the aim is to avoid landfill gas production as much as possible. Organic waste will be treated in aerobic biogas plants, composted or incinerated.

3.2 Austria

Current Feedstock Supply

In 2014, 289 biogas plants with an installed capacity of 80.5 MWel had a contract with the national renewable electricity trade company OEMAG, which is by law the company for trading renewable electricity under the renewable energy act (www.OEM-AG.at). These plants produced 542 GWh/a power and used about 300 GWh/a heat for running their plants, for district heating and for different drying purposes (e.g. grain, wood chips, wood, digestate). Since 2005, 12 biogas plants have been upgrading biogas to biomethane with a total installed capacity of 2.4 MWth/a.

In the 70s and 80s the first Austrian biogas plants were built because of the energy crisis. The feedstock was mainly slurry and some biowaste from nearby restaurants. They used the produced electricity and heat mainly for their own needs on the farm. Special contracts with the power grid owner allowed them to sell the surplus and to receive electricity from the grid at times when their own production was not sufficient. At the end of the last century, the first renewable energy act was put into force and the first plants were built to use energy crops as feedstock. Because of federalism, this was done through one federal guideline law and nine different state laws. In 2002, it was decided to change this situation by developing one federal act for renewable power production (Ökostromgesetz). This act included two feed-in tariff categories for biogas plants. One for biomethane based on feedstocks that are directly derived from agriculture (manure, energy crops, agricultural residues) and one for the use of biowaste as a feedstock for biomethane production. Many plants were designed for the use of energy crops and manure, where the majority of the feedstocks' energy content usually comes from corn silage.

Due to the unexpected rise in grain prices, some plant operators, companies and scientists started to search for alternative feedstocks not directly linked to grain prices. The first research projects on catch crops and the use of corn stover, the residues of maize plants after harvesting the grains, started. One big problem is still that in the last few decades, catch crops were mainly developed to prevent soil erosion without bringing a high yield in a very short period. Additionally, these catch crops are often characterised by very high water content at harvesting time in late autumn. At this time of the year, drying in windrows is nearly impossible. Consequently, the silage was very wet leading to huge losses of silage water and sometimes incorrect fermentation processes in the silo (butyric acid instead of lactic acid). Corn stover, on the other hand, didn´t allow for a good silage process because of too much dry matter content, a bulky consistency leading to compression problems. A solution was to combine these two feedstocks in the silaging process. By using catch crops and corn stover together, it is possible to reach a water content and a density in the silage that allows a good fermentation process.

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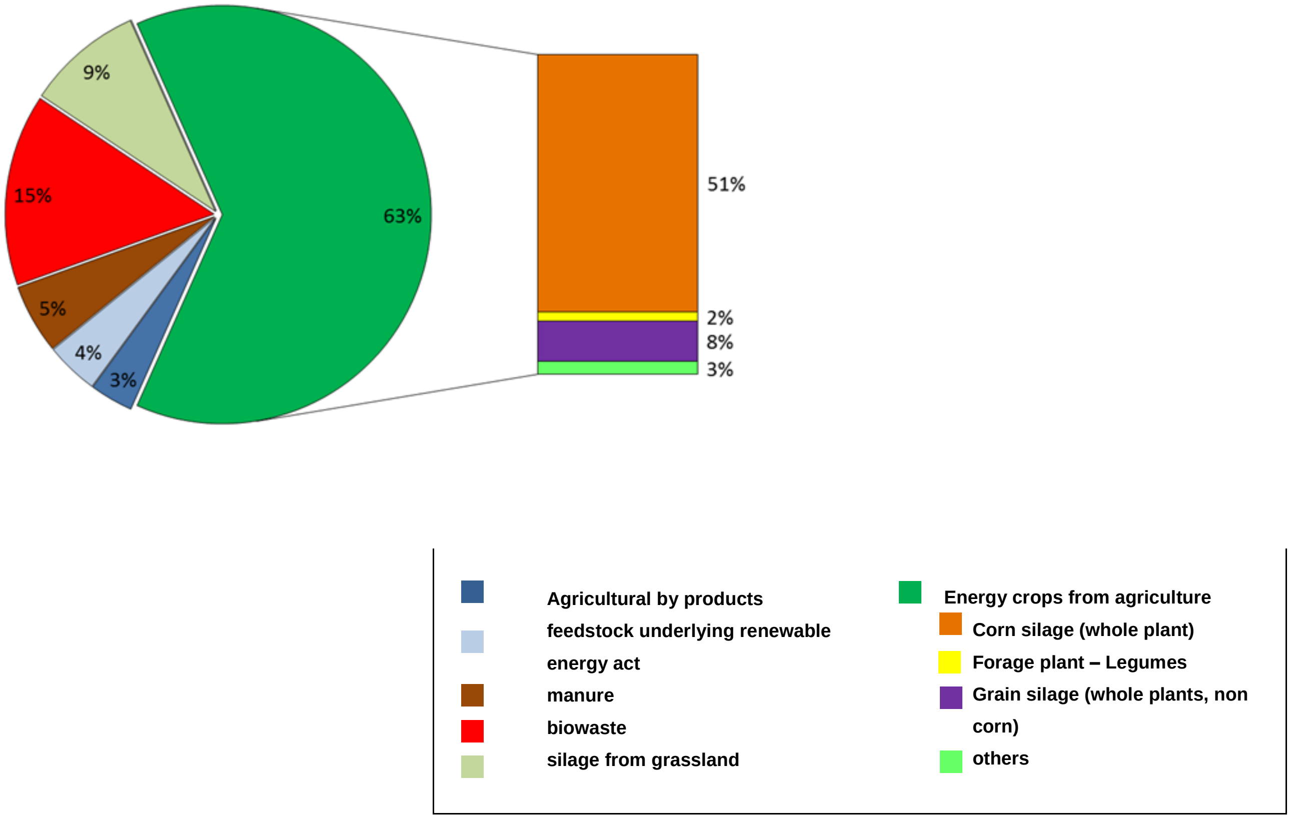

Figure 7: Currently used feedstock in Austrian biogas plants 2014 based on primary energy content (Stürmer et al. 2015)

Future potential for biogas production in Austria

Austria is one of the forerunners for separate collection of organic waste. Beginning in the 80s, Austria started composting and digesting organic waste streams from the separate collection of household, garden and catering waste. Now, in total about two Mio t of organic waste are recorded in the framework of the waste legislation. The Austrian biowaste strategy reports that 1.4 Mio tonnes/a of organic waste are already treated via composting and anaerobic digestion. With further development of the separate collection process, pollution of the organic waste stream will decrease and improve the digestibility of the material. Taking into account that some "organic waste" streams are suitable as fodder or not suitable for digestion at all because of their high lignocellulosic content, the total amount usable for biogas production can be expected as shown in Table 8.

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Table 8: Future potential for biogas/ biomethane production in Austria (calculations by ARGE Compost and Biogas Association Austria)

Future potential for biogas respectively biomethane production in Austria			
			[PJ]
organic waste			2,5
sum from agriculture			23,7
		total	26,2

Currently about 1.35 Mio. hectare arable land are used for crop production and 570 000 ha are used as grassland (multiple cutting) in Austria (Statistics Austria 2014). Depending on market prices, weather conditions etc., the average cultivation of different kinds of arable crops are as follows:

- Maize: 200 000 ha
- Cereals: 570 000 ha
- Rape: 50 000 ha

The animal husbandry figures are:

- Bovine: 1 960 000
- Swine: 2 870 000
- Poultry: 13 900 000

Besides using straw from cereals for the biogas process, the cultivation of catch crops (in addition to their already carried out use for soil preservation measures) for energy production is slowly but constantly increasing. On the other hand, constraints like economics, regional inadequacies or the personal reasons of farmers will limit the possible use of catch crops for biogas production. With regard to the aforementioned possibilities and constraints the share for biogas production is summarised in following table (Table 9).

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Table 9: Future potential for biogas production in Austria (ARGE Compost and Biogas Association Austria)

Future potential for biogas respectively biomethane production in Austria			
agriculture	current land use / husbandry	possible share for biogas production	
	[1 000]	[%]	[PJ]
straw from corn (without silage maize)	200	30%	3,2
straw from winterrape	53	30%	0,6
straw from cereals (without corn)	570	20%	3,2
catch crops	1350	7%	2,8
grassland (multiple cutting)	570	4%	1,1
energy crops	1350	4%	6,9
farm manure from bovine	1960	20%	4,8
farm manure from hogs	2870	20%	0,6
farm manure from poultry	13900	40%	0,5
sum from agriculture			**23,7**

Source for current land use and animal husbandry: Statistics Austria 2014

3.3 United Kingdom

As of October 2015, the UK had 258 operational anaerobic digestion (AD) plants outside of the wastewater treatment sector, 163 of which use predominantly agricultural substrates such as manures, slurries and crops, and 95 of which use mostly food and industrial wastes. There are a further 478 plants under development of which around three quarters are intending to use agricultural feedstocks.

This represents a notable shift from the state of the industry at the beginning of 2014 where there existed more operational waste-fed plants than agricultural facilities and a far more balanced development pipeline. Much of the early industry development focused on the construction of large-scale food waste plants where the benefits of gate fees for feedstock and economies of scale could offset technological risk. As time has passed capital costs have reduced and investors have developed confidence in AD technology, allowing the development of smaller scale systems typically more suited to farm-based sites where feedstock availability is often more heavily restricted. In parallel, accessibility to food waste has reduced as more plants have come online. Combined, these developments have prompted a shift in the UK AD sector away from the use of industrial and commercial wastes towards greater use of agricultural feedstocks.

Food Wastes

This project has received funding from the European Union's Horizon 2020 research and innovation programme.

The UK AD industry is currently estimated to process around 2.3 million tonnes per annum (Mtpa) of municipal, commercial and industrial food waste (Figure 8). In addition, 1.3 Mtpa of “other” wastes (e.g. brewery, abattoir and green wastes) are required by the sector. A further 4 Mtpa of food waste and 2.1 Mtpa of other wastes would be required by the industry if all plants currently under development in the UK complete. However, only around half of these plants can be expected to complete.

Meanwhile, total food waste arisings is estimated at 15 Mtpa by the Waste Resource and Action Plan (WRAP), of which approximately 7 Mtpa is from households, 4 Mtpa is from commercial and industrial sources, 1 Mta is from the hospitality sector and the remaining 3 Mtpa is generated on-farm[7]. While this indicates that significant organic waste volumes remain available for AD in the UK, feedstock accessibility (especially for household waste) remains a major barrier to further industry development. Some progress has been made over recent years to improve access to food waste. Source segregation of food waste became mandatory for many businesses in Scotland under The Waste (Scotland) Regulations 2012. Meanwhile, Northern Ireland banned food waste from entering landfill in April 2015, with separate collections mandatory for Councils from April 2017. In addition, ring-fenced funding has enabled almost all Welsh Councils to provide separate food waste collections. However, in spite of these developments only around half of all UK District Councils currently provide a food collection service for households, with England Councils especially low at below 30%[8]. With current austerity measures enforcing Council cuts to be made across the board, it appears unlikely that further improvements in food waste collection will be made in England for the foreseeable future.

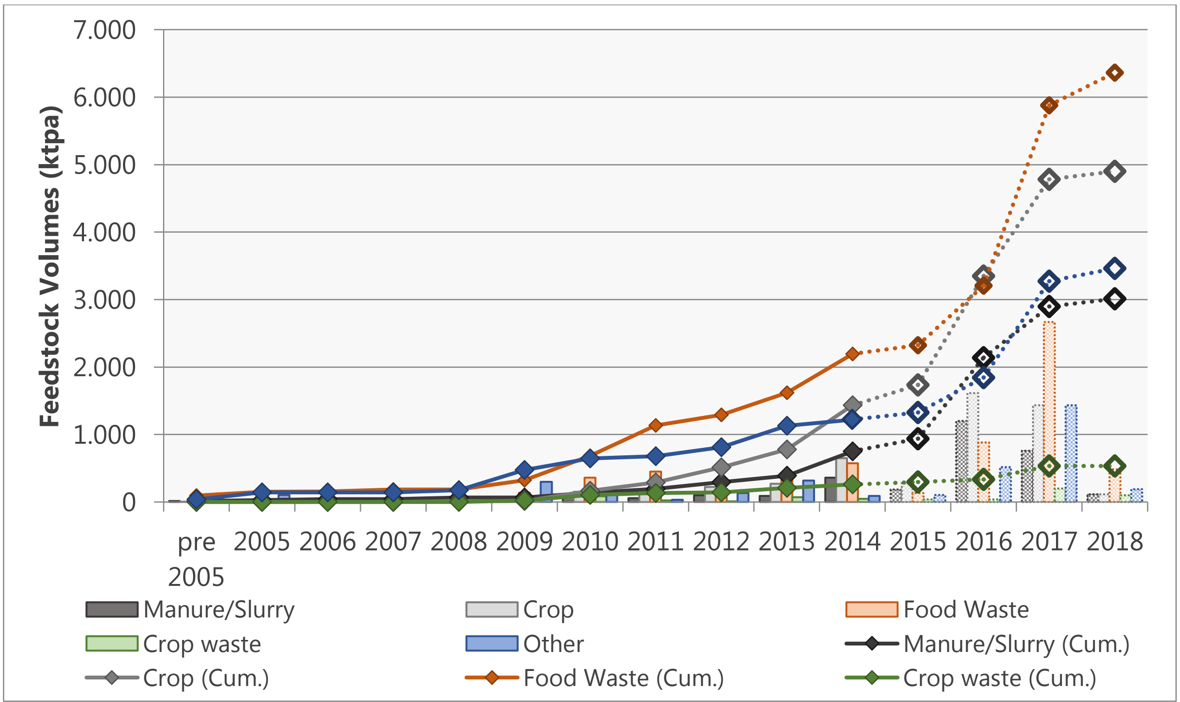

Figure 8. Current and projected feedstock demands of the UK AD sector

[7] WRAP. 2015. Estimates of Food and Packaging Waste in the UK Grocery Retail and Hospitality Supply Chains

[8] Recycling & Waste World. 2014. English food waste collections fall behind Scotland and Wales.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme.

Agricultural Wastes

Agricultural wastes such as manures and slurries remain largely under-utilised by the UK AD sector; of a potential resource of around 90 Mtpa[9] only around 1 Mtpa is used in AD. This is largely because the low biogas yields of these wastes typically make them uneconomical to use as a stand-alone feedstock. Instead, agricultural wastes are more frequently used in relatively small volumes supplemented with high gas-yielding substrates such as crops. Poultry wastes present further issues to AD with their high nitrogen content adversely impacting the health of the digester when used in high volumes.

Despite these barriers, there have been some large (>50,000 tpa) slurry-only facilities that have entered development in the UK over the last year. There have also been several sites that have been developed using front-end systems for reducing the nitrogen content of the feedstock, thereby enabling use of poultry manures in large volumes.

Crops

The use of crop substrates by the UK AD industry has increased significantly over recent years, with total crop demand having doubled from 0.9Mtpa to 1.8Mtpa between October 2014 and October 2015. Despite this rapid growth, current demand equates to around 1.5% of total UK arable land, indicating that at its current scale of development the sector is likely to have only a very minor impact on existing food markets.

Maize and grass silage are the most dominant crops used by the industry, with local growing conditions often dictating which of these is used; plants located towards the South or East of the UK where conditions are drier typically use maize, while those sites towards the North or West often use grass. Maize has proved an excellent rotation crop in the UK for controlling blackgrass although there are some concerns around its contribution towards soil erosion. Outside of these crops, energy beet and rye have proved to be effective feedstocks and have become increasingly used over recent years. Meanwhile whole crop cereals are used on occasion by some projects where growing conditions are favourable.

Future perspectives

Current momentum in the UK AD industry would suggest that over the coming years, the majority of new capacity will be focused on utilising crop feedstock rather than treating wastes. However, UK policy developments could have a very significant bearing on this.

Sustainability criteria were incorporated into the Renewable Heat Incentive – one of the UK's main support mechanisms for AD - as of October 2015. It is possible this could discourage use of crop feedstock to some extent, although it remains likely that the vast majority of crop material would meet the criteria provided reasonable efforts are made to source supply chain data and ensure sustainable cultivation practices are undertaken. Meanwhile, there are early signs that future development of AD support mechanisms will promote greater utilisation of wastes while discouraging use of significant crop volumes. However, there is a great deal of uncertainty over the future of these policies and it remains difficult to predict how feedstock requirements of the UK AD industry will develop in the near future.

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[9] DECC. 2011. Anaerobic Digestion Strategy and Action Plan.

This project has received funding from the European Union's Horizon 2020 research and innovation programme.

3.4 France

Analysis of the sustainable supply of biomass mobilized for the production of biogas in France requires presentation of the French context of the development of anaerobic digestion. The government differentiates between industrial and agricultural biogas plants. Treatment plants for domestic and industrial wastewater fall under the Water Act, whereas the non-hazardous and agricultural waste facilities are classified as “classified installations for environmental protection”.

As of 2016, the support mechanisms for biogas will change and will primarily depend on the proportion of sludge from wastewater treatment (below 50% and above 50%). The specifications of the proportions of wastewater sludge, agricultural effluents and cultures (dedicated, intermediate or “stolen”) are defined in the preparation texts. Under the Law on Energy Transition for Green Growth (LTECV), published on 17 August 2015, the use of dedicated crops for energy purposes is possible under certain conditions, which will be determined by an upcoming governmental decree. The purpose is to allow dedicated crops only if the prevalence of the use of food crops for human and animal consumption is ensured.

Installations using dedicated energy crops can be excluded from receiving public grants, depending on the criteria set by the region. There is a political and societal consensus on the principle of non-competition between food & energy crops. The dedicated energy crops are understood as crops mainly used for energy production, planted as substitutes for food crops or animal feed crops. The agricultural by-products such as straw, chaff, but also catch crops that are cultivated for energy purposes (CIVE) are not regarded as dedicated energy crops.

Today, about 3% of dedicated energy crops are used for biogas production. The French Law on Energy Transition (LTECV) regulates and further reduces their use in biogas plants, while supporting the use of agricultural by-products, intermediate/catch crops for energy purposes. The aim is to further develop and enforce biogas production and anaerobic digestion while avoiding an adverse development regarding sustainability aspects of the process (e.g. imports of biomass, competition for land and with food and feed supply).

In this context, the State and the metropolitan regions (22 in 2015, 13 as of 2016) have expanded their national and regional approaches regarding the available potential for biogas. This potential varies according to region – the most advanced regions have accompanying regional models for the use of renewable energies (at different horizons: 2020, etc.), including field studies on the development potential of anaerobic digestion, resulting in further development plans. The French objective is to accelerate the development of biogas with a national call for proposals (deadline end of 2017) for the completion of 1,500 new biogas plants (623 units are in operation today).

The increase in the number of digesters is expected to enhance biogas production - preferably transformed into biomethane for injection into the natural gas grids. To this end, the government has integrated the prevalence of biomethane injection during the projects’ study phase – for installations over 300 kWe - into their latest regulatory drafts.

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The supply of biogas plants differs according to the typology of the project: in on-farm biogas plants, mainly livestock manure is used as feedstock, centralized biogas plants (territorial plants) on the other hand use primarily diverse effluents. The following table (Table 10) presents the average supply values:

Table 10: Average composition of feedstock of different types of biogas plants (according to Club Biogaz, France)

	Agricultural biogas plant (% of tonnage)	Territorial biogas plant (% of tonnage)
Livestock effluents	64	32
Food industry effluent	9	30
Household biowaste & grass clippings	5	4
Energy crops	3	3
Intermediate crops for energy purposes (CIVE)	8	2
Other input	11	29

Source: ADEME 2015, Supply of means of centralized biogas plants in the park and identified farm.

The development of the biogas sector, particularly of agricultural biogas (on-farm or centralized/collective), promotes the treatment of effluents and agricultural waste, allowing better management of GHG emissions when fertilising, and particularly of nitrogen leakage. In addition, the valuation of energy potential by using the biogas/biomethane in CHP-plants or by injecting biomethane into the gas grid provides additional income for farmers. The potential studies carried out in France are regularly updated (in 2013 for all regions, in 2015 beginning in Aquitaine).

In all regions, the agricultural sector is the main source of methanogen inputs. As an example, the latest study identifies the available proportions of feedstocks for the Aquitaine region: 71 % of livestock excrements (slurry and manure) and 10% by-products of cereals, wine and vegetable cultures. Food wastes, agro-industrial wastes, green residues and sewage sludge represent the remaining feedstock supply. These regional analyses as well as the national data of 2013 confirm that the resources in place allow the continued growth of biogas production, with particular focus on further developing agricultural facilities.

However, the development of anaerobic digestion lies in the use of different products with various methanogen powers and the development of a co-digestion scenario with complex mixtures including manure (cattle, horses, etc.), biowaste hypermarkets and supermarkets (GMS), grass silage, grain, green residues (e.g. grass clippings), sewage sludge and food processing waste (IAA). This development also depends on the proportion of intermediate crops for energy purposes (CIVE) to be authorized in the upcoming ministerial decrees.

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As announced in the Law on Energy Transition for Green Growth (LTECV), the biogas support system will evolve for new biogas plants. Decisions are expected before the end of the year for sewage treatment plants (STEP), facilities for treatment of non-hazardous waste (ISDND) and agricultural and territorial AD plants (< 50% of sewage sludge). For agricultural and territorial AD, the proportion of plants specially grown for the purpose of energy production (CIVE and dedicated energy crops) and food crops (twice as many possible uses) may not exceed 15% in tonnage of inputs following the latest proposals. This limit corresponds to an energy content of about 25%. This mechanism is associated with a financial bonus for the treatment of growing livestock manure - the maximum bonus being reached with 60% of livestock manure in the total input tonnage.

These criteria define the co-digestion or multi-input model promoted in France to develop the biogas industry in competition with other biomass recovery processes (in general) such as direct composting, biomass energy, etc.

In its country analysis, the European "**Green Gas Grid**" project found that 60% of French biogas production came from landfills in 2013. Sewage sludge was the second source of production, accounting for approx. 15% of the biogas produced. The remaining biogas production came from industrial plants, municipal solid waste plants, on-farm plants and centralized plants.(GreenGasGrid 2013a).

At that time on-farm units and centralized units had the fastest rate of growth, with 60 new on-farm plants per year and 10 new centralised units. The relevant figures for the biogas sector in 2013 are shown in the table below (Table 11).

Table 11: Type and number of plants in France 2013 – under specification of used feedstock (GreenGasGrid 2013a)

	Number of plants in operation	***Feedstock (biowaste/ agriculture/ sewage/ landfill)***
*Existing AD biogas **plants in total***	*On-farm~120* *Centralised~15* *Industrial ~ 80* *WWTP 60* *Municipal ~10* *Landfill 245*	*Manure* *Mix of organic waste* *Sewage sludge* *Biowaste* *Landfill material* *Crops and intermediate crops*
*Existing AD biogas **green electricity installations** receiving a feed-in tariff*	*135 green electricity on-farm and centralized AD plants* *? green electricity WWTP and 90 landfills*	
Existing thermo-chemical biogas plants	?	*Forestry wood-chips*
Existing biogas upgrading plants	4	*Landfill/biowaste/ on-farm*
Existing Upgrading plants	3	Biowaste on farm

In early 2013, ADEME published a study of biogas potential for 2030. The purpose was to evaluate the amount of substrates that would be available for the production of biogas. The aim was to use feedstock that was not in competition with food or feed production.

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The resources considered were:
- Household biowaste, waste water and green waste
- Agricultural resources: manure, intermediate crops for energy purposes and crop residues,
- The resources from agro-food industries (IAA) classified by sector
- Biowaste from catering, small businesses, distribution and markets.

Resources were estimated in terms of different rates of production, such as kilograms of food waste per number of meals for restaurants; numbers of cows and pigs in France and their corresponding production of manure; and the production of organic waste by companies (GreenGasGrid 2013a).

Table 12: Biomass potential for biogas production in France in 2030 (ADEME, 2013)

	Resources, tonnes/year Gross production (Fresh Matter tonnage)	**Energy Resources GWh/year LHV**
Household and Green waste	18 600 000	16 600
Sewage treatment plant (waste water)	28 900 000	3 400
Manure	183 100 000	40 500
Intermediate crops	45 300 000	21 600
Crop residues	65 000 000	108 500
Agro-food residues	19 300 000	11 900
Total	**360 200 000**	**202 500**

According the **IEA Bioenergy Country report** (IEA 2015), the vision of the French Environment and Energy Management Agency is to produce 70 TWh biogas annually by 2030 and that 600 biogas plants will be built every year. 50% of the biogas produced will be injected into the grid, 30% will be used to generate electricity and the remaining 20% will be used to produce heat. In 2050, the aim is to produce 100 TWh (IEA 2015).

In France there are 397 biogas plants (September 2015) including 385 power plants and 12 biomethane plants.

3.5 Italy

The last 6 years have been a crucial period for the development of the field of biogas and biomethane. The sector has grown considerably, reaching over a thousand plants with an installed capacity of 1200 MW; in particular, the agricultural biogas sector, according to the latest estimates presented by TERNA for 2014, now has about 1,500 plants installed. 85% are distributed in the

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northern regions and the remaining 15% are distributed among the central and southern regions. Based on these numbers, Italy is the second-largest European producer after Germany, and third in the world after China. The investments made in the last four years were in the range of 35 to 40 billion euro, guaranteeing a significant increase in permanent employment in the sector for over 12,000 employees.

Such a development was possible thanks to the support resulting from the feed-in tariff of Law no. 244 of 2007.

Public incentives for the production of electricity from biogas have provided an important boost to the biogas sector. From 2010 to the end of 2012, years in which Ministerial Decree 18/12/2008, which guaranteed the feed-in tariff of 0.28€/kWel, was in effect, around 600 agricultural installations were made, compared with only 150 made in the three years from 2013 to 2015, during which the rate of the feed-in tariff was decreased.

In December 2012, most of biogas plants were in the range 601-1000 kWel with 598 installed plants accounting for 65.5% of the total installed plants, and an installed electrical capacity of 574 MWel, equal to 82.6% of the total electrical capacity. There were 123 plants in the range 101-300 kW (13.5% of the total number of biogas plants) for 28.6 MW (4.1% of the total electrical capacity).

From '01/01/2013, the date of entry into force of the DM 06/07/2012, the scenario changed: the new decree, as well as having the previously mentioned negative impact on the growth of the sector, has also altered the balance between the different power classes. Small plants (installed power less than 100 kW) increased in importance thanks to stronger incentives and the possibility of building regardless of the mechanism of the "registers" (*.... biogas plants with a capacity up to 100 kW have direct access the incentive mechanisms.... >).*

The last census of the type of biomass used in biogas plants in Italy dates back to 2012, thanks to the work done by the CRPA.

Although the investigation tried to collect more detailed information, it was not possible to collect data for all plants: the coverage of the data is guaranteed for only 59.7% of the total number of plants (representing 67, 2% of the total installed electric power from AD plants). Precisely for this reason, the allocation percentages were reported not considering the class of data not available. Table 13 shows the allocation data between the various classes of materials used for the number of plants and installed electrical capacity.

Table 13: Number of biogas plants according to the feedstock categories they use and installed electrical capacity

TYPE OF BIOMASS	n.	%	Mwe	%
only manure	105	17.7	16.3	3.2
manure+ agro-industrial byproducts + energy crops	73	12.3	59.9	11.8
manure+ energy crop	265	44.7	194	38.2
manure+ agro-industrial byproducts	31	5.2	123.9	24.4
energy crops + agro-industrial byproducts	119	20.1	113.9	22.4
data not obtained	401		248.4	
TOTAL	994	100	756.4	100

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62.2% of the plants use the classic co-digestion between manure, agro-products and dedicated crops, 17.7% use only effluent and 20.1% energy crops and/or agro-industrial by-products. Of the latter, 85% exclusively use energy crops. Figure 9 illustrates the distribution of the most frequently used biogas feedstocks and substrate mixes

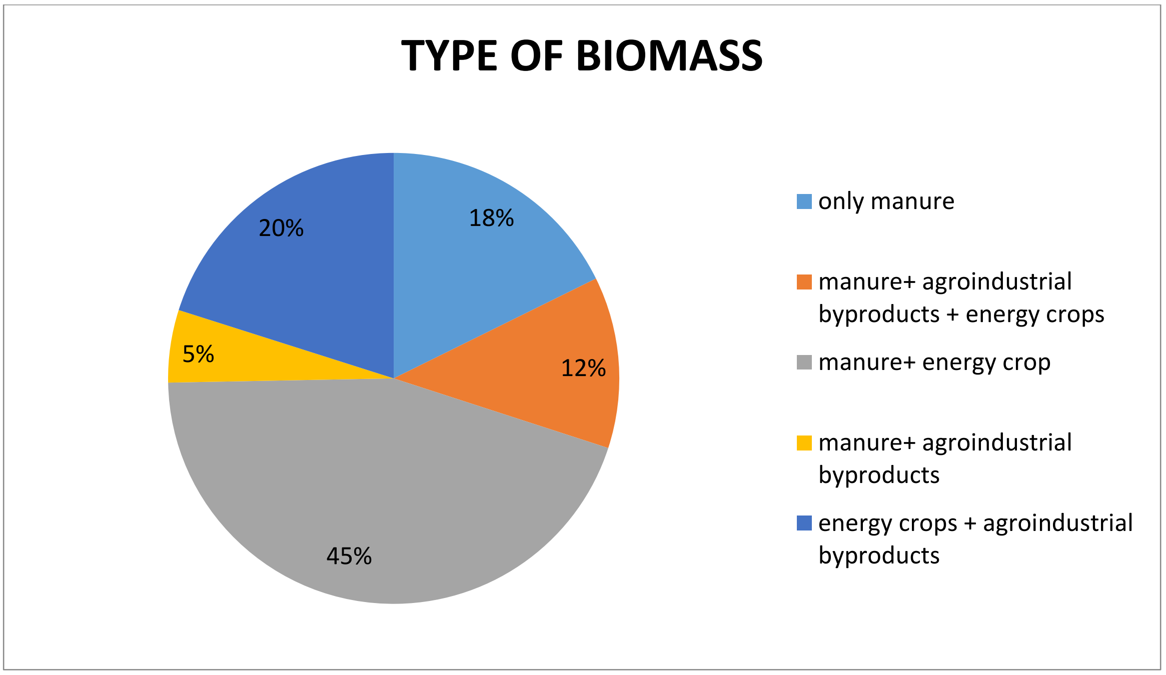

Figure 9: Most frequently used biogas feedstocks and substrate mixes in Italy

The scenario still does not show the effects of Ministerial Decree 2012. On July 6th, 2012, the Ministry of Economic Development, together with the Ministry of Environment and Land&Sea Safeguard and the Ministry of Agriculture, Food and Forestry implemented the decree that consolidated the incentives for renewable energy production, apart from photovoltaic production. The Decree, effective on 11th July 2012, has substantially redefined the incentive scheme for renewable energy production.

The Ministerial Decree of 2012 led to a decrease in the sizes of biogas plants and reduced the percentages of dedicated crops used as a substrate for anaerobic digestion plants. Instead, the use of manure, agro-industrial by-products and waste is encouraged. This tendency will continue in coming years due to a new decree that will promote greater use of manure, waste and by-products.

With regard to the legislation relating to biomethane production (DM 5 DECEMBER 2015), the use of agro-industrial by-products, manure and waste is encouraged by offering a surcharge on the incentive rate. Consequently, a sharp increase in the use of these materials is expected in coming years.

BIOMETHANE POTENTIAL FROM OFMSW (Organic Fraction of Municipal Solid Waste):

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If waste collection was spread throughout the nation, it could generate about 8-9 million tonnes of kitchen waste. If this waste were transformed into biogas, 450 Gm^3 of biomethane could be generated. It is estimated that, with the current generation of "OFMSW",if all the OFMSW was turned into biogas through anaerobic digestion and then upgraded to biomethane, the produced biomethane could feed 80% of the fleets dedicated to the collection of waste. We estimate that the number of biomethane plants that will be realized in the next three years are in the range of 12-20, with an average plant production capacity of 500 m^3/ h of biogas.

Biomass potential in Italy

The Consorzio Italiano Biogas (CIB) has estimated that the production potential of 8 billion Nm^3 of equivalent biomethane will be achieved by 2030 using 400,000 ha land by using the potential of a large proportion of so called integrative biomass, i.e. biomass that does not produce income (but instead has a cost) for farmers. This means:

a) Second harvest crops, (preceding or in succession of feed or food crops)

b) Manure

c) Agricultural by-products

d) Agro-industrial by-products

e) Biomass deriving from bio-refineries

f) Multipurpose crops (crops on land that cannot be easily used for feed purposes)

To reach this production goal it is necessary to increase the land efficiency for biomass production: the average land needed for the first harvest crop to produce one million of Nm^3 of biomethane equivalent (ha/ mln Nm^3 Bio-CH4 eq) is presently 115 ha. This needs to be reduced to 45 ha/ mln Nm^3 Bio-CH4 eq.

Table 14: Biogas/ Biomethane potential in Italy according to feedstock category

Potential of "Biogasdoneright" (biogas fatto bene)						
		2010	2013	2015	2020	*2030*
Biogas From Agricultural Resources						
First harvest Used Agricultural Land (ha)		85.000	200.000	280.000	350.000	*400000*
Land efficiency						
ha/mln Nm^3 Bio-CH_4 eq		140	115	80	60	*45*
ha/Mwel		308	253	176	132	*100*
Biogas from Agricultural Resources						
Billion Nm^3 Bio-CH_4 equivalent		0,6	1,7	3,5	5,8	*8,0*
equivalent Mwel		276	791	1591	2652	*4000*

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Considering the current scenario and the conditions imposed by the new biogas and biomethane regulations, an increase in the use of integrative biomass in the coming years is possible. Based on these assumptions, CIB has provided the following scenario for 2030:

Table 15: Expected developments regarding biogas feedstock supply

BIOMASS FEEDSTOCK FOR BIOMETHANE (PREDICTION)	2015	2020	2025	2030
% First Harvest Crops	59	40	37	35
% Integrative Biomass	41	60	63	65

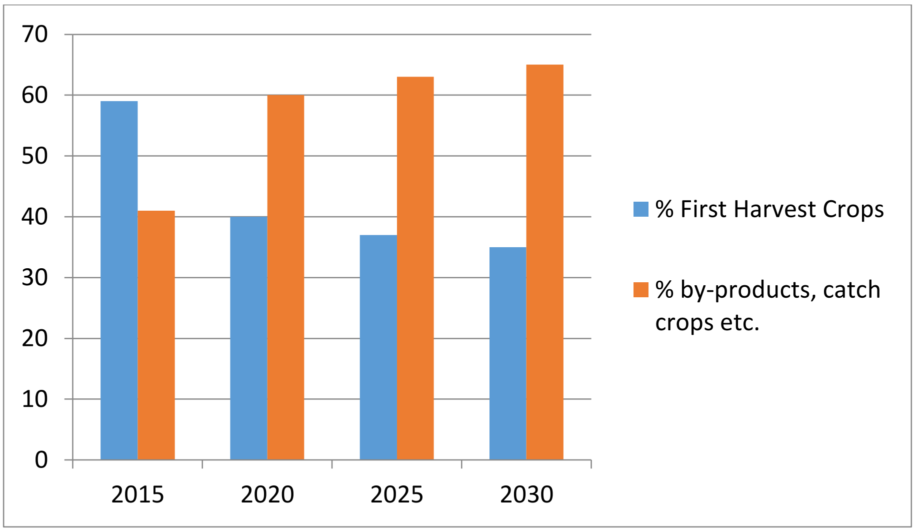

Figure 10: Expected developments regarding biogas feedstock supply

In this way, through digestion of dedicated crops and integrative biomass, biogas development will not occur with a "zero-sum result" [10] using dedicated crops for energy purposes rather than foragers, but by progressively stimulating the entire chain to use "less land to produce more energy, "thus leaving the farm more market outlets: food, feed fiber & energy. Thus, the goal of 8 Gm^3 in 2030 seems adequate in terms of employment of agricultural land and complies with the provisions of the studies so far available.

The results obtained by the Italian biogas association over the past few years unquestionably confirm that these goals are realistic and likely to be achieved both for the increased use of manure and by-products as well as for the reduction of the area needed for the production of biogas feedstocks (dedicated energy crops). This was proven by the study made by the Lombardy

[10] "Zero-sum result" is referring to the mere replacement of forage production with energy crops, resulting in a diversification of market outlets but without an effective increase of the value generated by the farm, excluding incentives.

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Region and Milan Politecnico (http://www.agricoltura.regione.lombardia.it/shared/ccurl/708/163/1713_ecobiogas_ebook_def.pdf).

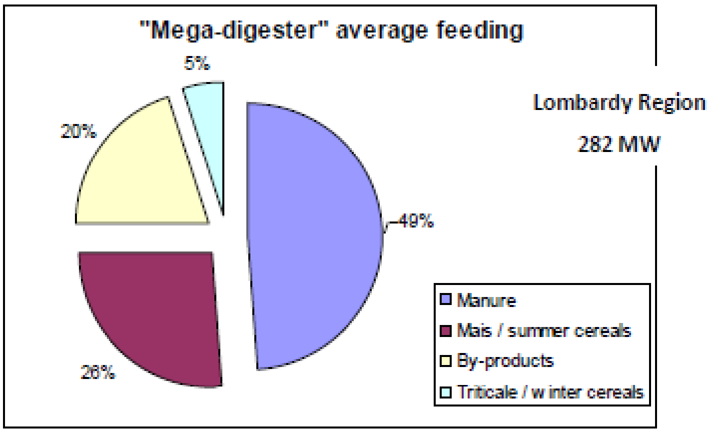

Figure 11: Average substrate mix of biogas plants in Lombardy Region

[Key to above table: Megadigester average feeding of biogas plants in Lombardy Region: manure, summer cereals/corn, Winter cereals/Triticale, By-products]

3.6 Hungary

Current use and available potential of feedstocks for biogas plants in Hungary according to the Roadmap developed by the Green Gas Grid Project (GreenGasGrid 2013b):

The main feedstocks for biogas production by applying anaerobic digestion (AD) can be grouped into three major categories: sewage sludge; agricultural wastes and by-products; and solid organic waste in landfills. The utilization of kitchen and restaurant wastes for biogas purposes is currently negligible in Hungary due to lack of incentives and stringent regulations for the digestate as fertilizer in agriculture.

<u>Waste water sludge</u> (GreenGasGrid 2013b)
In the majority of the large settlements (>5,000 inhabitants) the household waste water is treated and purified by biological methods. This, however, means aerobic treatment in most cases and only about 23-25 waste water treatment facility includes anaerobic degradation (AD) of the sludge in their technologies. The communal waste water is usually concentrated by gravity or mechanical means to 5-10% organic total solid (oTS) content prior to AD. Biogas generation is carried out at mesophilic temperature. Average decomposition of the organic material is 50-60% during the 20-30 days of residence. The methane content of biogas is 60-70%. Thermal, mechanical or chemical pre-treatments are usually not applied for these technologies.

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The total electricity production capacity is 12,567 kW. Biogas is typically utilized locally in combined heat and power (CHP). Both electricity and heat are used within the waste water treatment facility and only a few, large plants feed extra electricity in the grid. The AD of sewage sludge is an economically feasible investment at treatment plants of >10,000 m3/day waste water capacity.

Landfill (GreenGasGrid 2013b)

Communal solid waste of about 4.6-5 million tonnes is generated in Hungary annually. Most of this material is deposited in landfill sites. In addition to small, rural locations there are 80 larger regional landfill sites in the country. Twenty of them collect and utilize landfill gas and their total electrical capacity is 12.7 MW. An additional 40-50 MW capacity is unused today. It is obligatory to burn landfill gas in torches where the gas is not utilized (XLIII./2000 Law on Waste Management). Source-selected household waste collection is virtually non-existent in Hungary except for a few experimental projects. Approximately 30% of the collected solid household waste is biodegradable.

Landfill gas usually contains 40-45% methane and since methane is a greenhouse gas 22-23 times stronger than carbon dioxide, for a sustainable environment it is mandatory to burn the methane.

Landfill gas is seldom used for heat production because the landfill sites are usually far from the settlements. Purification of the gas to biomethane quality is possible and in principle biomethane can be fed into the natural gas grid according to the Law on Natural Gas (XLII./2003). Unfortunately, no incentives and, more importantly, no unequivocal regulation support biomethane feed-in in Hungary. Consequently, electricity is generated from landfill gas where it is utilized. Currently, the total capacity of landfill power is 4 MW, the estimated capacity is >>100 MW.

Agricultural waste and by-products (GreenGasGrid 2013b)

No reliable data are available about the amount of food processing waste in Hungary. Only a small fraction of this biomass ends up in the biogas reactors. Our estimation indicated that at least 100,000 thousand m^3/yr of this kind of material accumulates, which equals to about 25 MW electric capacity if converted to biogas. Unfortunately, the majority of this biomass is discarded in landfills, which is less efficient treatment method for this waste stream. The lack of interest is primarily due to missing incentives and/or regulations promoting the more efficient utilization of biomass.

There are some 40 biogas plants operating with agricultural materials including animal waste and energy plant biomass. Their cumulative electric capacity is 20 MW. As a comparison one has to keep in mind that the total electricity production capacity of Hungary is 9,000 MW and the average utilization is 6,000-6,500 MW.

The main substrate for agricultural biogas plants is animal manure. The number of animals raised in Hungary is dropping radically since 1990, probably due to the fragmentation of animal farms brought about by changes in the political and economic structure.

The most recent trend is the centralization of animal farms and the disappearance of the small ones, which cannot keep up with growing market competition. The novel large animal husbandries generally produce enough manure locally to fuel 500-1,000 kW biogas plants. The manure alone would be sufficient to supply substrate for at least 200 biogas plants of 600 kW capacity.

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Energy crops (GreenGasGrid 2013b)

Energy crops currently do not play a role in the Hungarian AD sector. Nevertheless, the Roadmap developed in the Green Gas Grid project (2013) revealed a promising theoretical approach and considerable available biomass potential for biogas production:

The cultivated land area of Hungary is 4,500,000 ha. In an average year about 16.9 million tons of grains (primarily wheat and corn) is produced. More than half of this quantity is exported as raw grain. If 15% of the agricultural land were used to cultivate dedicated energy plants, the food and feed needs of the country would not be affected, Hungary would just export about one third of the grains exported now. If the biomass gained this way is used for biomethane production, and as a consequence the country needs to import less natural gas, the savings would be equal to the income from grain export. In other words, if Hungary chooses the production of higher value biomethane, the same income would be generated on smaller agricultural land area relative to the current practice of exporting the raw cereal grain.

In total, the domestic biogas potential adds up to 1,600-1,700 MW, which is about one quarter of the total electricity consumption of Hungary.

It should also be emphasized that, in addition to biogas, the biogas facility produces digestate, which is an excellent replacement of the artificial fertilizers widely used in modern agriculture. Since fertilizer manufacturing is a highly energy intensive technology, a considerable amount of additional savings on imported natural gas could be achieved.

More specific and updated figures were provided by the Hungarian Biogas Association (2015):

Based on the availability of different usable feedstock categories for biogas and biomethane production, the Hungarian Biogas Association has calculated the feedstock potential for biomethane production. A more precise breakdown of the different categories, which is the basis for the summary in Table 16, can be found in the annex (Tables 2a - 9a).

Table 16: Biomethane potential in Hungary – summary of all substrate categories

Feedstock categoy	**Technical Potential.**
	PJ/year
Animal excrements	23,8
Primary energy crops	57,3
Catch crops	22,7
Agri by-products (straw)	91,5
Green biomass from land maintenance	3,5
Sewage sludge	3
Landfill & communal waste	2,4
Total	**204,2**

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4. Outlook and Conclusion

This report has given an overview of the evaluation of different feedstocks regarding their sustainable use in biogas plants. It has also presented the situation in BIOSURF's six focus countries (Germany, Austria, the U.K., Italy, France and Hungary), showing their specific approaches of current and predicted future feedstock use in biogas plants.

Sustainability

Numerous feedstocks can be used for the biogas process in a sustainable way. Some of the most important sustainability criteria at the European level, which are also used to evaluate the feedstocks for biomethane production, are the mitigation of greenhouse gas (GHG) emissions and the reduction of competition for land, food and feed resources. The other criteria, like not reducing biodiversity and not changing land use if carbon stocks are reduced, should be fulfilled by good agricultural practices and are not a specific biogas problem. Using organic residue and waste materials, these criteria are ideally fulfilled and are therefore strongly promoted by European as well as national regulatory frameworks. In terms of feedstock sustainability, it seems to be the easiest to base the biogas process on residue and waste materials. However, the exclusive use of these materials, even considering their still unused potentials, would not be sufficiently available to meet the feedstock needs of the existing and additional future biogas/biomethane plants since they are also finite and already have diverse competing uses.

Part of this feedstock category is not available for the biogas sector since it is not handled in a very sustainable way. In many countries (e.g. the UK and Italy), food waste is still landfilled because of missing separate food waste collection. This causes considerable GHG-emissions (ca. 1,2 to $CO_{2equiv.}$/t FM), nutrient leakage (approx. 2,4 kg N/ t FM; 0,8 kg P_2O_5 /t FM; 0,8 kg K_2O/ t FM) and energy losses (ARGE Compost and Biogas Association, Austria). Treatment of biowaste in biogas plants would not only almost avoid these losses, but also produce energy. Most of the nutrients remain in the digestate, which can be returned to the field. This again reduces the production and use of mineral fertiliser. An obligation for waste separation would help to tap this still unused potential and mitigate the other detrimental effects of landfilling biowaste.

Animal excrement also proved to have potential for their increased use in biogas plants. Similar to landfilled biowaste, untreated manure and slurry have significant GHG emission when stored in tanks (e.g. approximately 570 kg $CO_{2\ equivalent}$/animal head and year for dairy cows). Again, this can be considerably reduced when used in the biogas process.

Cultivated biogas crops must be taken into account as well and, depending on the management practices and choice of land involved, they can also be considered sustainable feedstocks.

The use of energy crops has been very much restricted in the past few years, mainly due to concerns regarding their sustainability and due to reduced public acceptance. The reduction and, as seen in France, even banning of energy crops as biogas feedstock, is more of a political than a purely rational decision. The country surveys show that there is often a misled public perception about the real proportion of bioenergy crops. Compared to the amount of cultivated food and feed crops they only represent a minor share (e.g. Austria, UK (1.5 %) and Germany (10%)).

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The use of maize, for instance, has several advantages for the biogas process – the main one being the opportunity to make the process highly efficient. Consequently, the needed land area for a specific energy yield is reduced. The use of maize in a substrate mix with slurry also leads to better digestion of the slurry and in some cases energy crops are necessary to achieve economically feasible biogas production of locally limited amounts of manure (Scholwin, Schüch, and Grope 2015). Aside from maize, there are several other usable energy crops with good crop and biogas yields, which can be used for crop rotations to preserve biodiversity. In summary, the use of dedicated energy crops can be regarded as sustainable feedstock for biogas/ biomethane production, assuming best practice methods and cross compliance regulations are applied.

Catch crops represent another group of cultivated sustainable biogas crops. They are mostly used to bridge the time in between main crop cultivation, when the area would otherwise just consist of delicate fallow land. In this context, the same area of land is used twice, which does not only bring the advantage of additional biomass supply (if hardy catch crops are chosen), but catch crops also improve soil fertility and biodiversity and help to reduce water and wind erosion as well as nutrient leakage.

<u>Potential and future developments</u>

The data about national biomass potential provided by the six biogas associations were quite heterogeneous and relied on different assumptions. This makes an overall evaluation and comparison of the available potential of the discussed biomass categories impossible. Research studies in different countries are based on different assumptions, different methodologies and are partly influenced by national incentive schemes. This results in uncertainties when comparing results.

However, further biomass potentials (regarding the discussed feedstock categories) that can be used for biogas and biomethane production were identified in all the countries concerned. This indicates a good and sustainable basis for the further development of the biogas/biomethane sector. The country presentations give a good overview of the different approaches regarding feedstock use for biogas and biomethane production and expected future developments. Again, it can be stated that the choice of substrates is primarily driven by political decisions and financial incentives, as well as by location, agricultural structures and access to specific feedstocks (e.g. food waste).

The different national approaches in the use of feedstock are briefly summarised as follows:

Regarding the controversial use of energy crops, it can be stated that France and Hungary are the only countries (out of the six focus countries), where their use does not play a role in the AD sector, which is in both cases due to national regulatory specifications.

In **France**, for instance, installations using dedicated energy crops can be excluded from receiving public grants. Only 3% of the biogas feedstocks in France are dedicated energy crops and this is further regulated and reduced by law, whereas the use of agricultural by-products, intermediate/catch crops for energy purposes is supported. This might be slightly changed in the future since the latest regulatory proposal suggests a maximum share of 15% of dedicated energy crops for biogas production. In 2013, ADEME (Agency for environment and energy, France),

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allocated the highest technical biomass potential for biogas production to crop residues, followed by animal manure.

In **Hungary**, energy crops currently are not used at all in the AD sector. Nevertheless, the roadmap developed in the Green Gas Grid project (2013) revealed a promising theoretical approach and considerable available biomass potential for biogas production. The Hungarian Biogas Association (HBA) even allocates the highest sustainable biomass potential to energy crops used for biogas/biomethane production (2015). However, this is currently not supported by the Hungarian government, making the use of energy crops not economically feasible. For now, the main feedstocks for biogas production consists of sewage sludge, agricultural waste and by-products, and solid organic waste from landfills. According to HBA, agricultural by-products have the highest technical and economic potential for the production of biogas/biomethane.

In **Italy,** energy crops have been the main feedstock for biogas plants in the past. Driven by respective regulations, this changed slightly in 2012. Since then, increased use of agro-industrial by-products, manure and organic wastes has been pursued. This development will continue and has been supported by respective, recently passed ordinances. Further, the use of agro-industrial by-products, manure and waste for biomethane production is encouraged by applying a surcharge on the incentive rate. Consequently, a sharp increase in the use of these materials as feedstocks for biogas and biomethane plants is to be expected in the coming years.

In **England,** cultivation of energy crops is rapidly increasing, but still has a very small share of total arable land in the U.K. The mainly used feedstocks are food waste, followed by crops and crop residues. In the past few years there has been a shift in the U.K. biogas sector away from the use of industrial and commercial waste towards greater use of agricultural feedstocks. The current development of the AD industry in the UK would suggest that over the coming years, most new capacity will be focused on utilising crop feedstock rather than treating wastes. However, so far it remains difficult to predict how feedstock requirements of the British biogas industry will develop in the near future.

In **Germany** as well as in Austria, energy crops, particularly corn silage, still represent the biggest proportion of the used biogas feedstocks. According to analyses of the biomass potential in Germany it was determined that this feedstock category has even higher, still untapped potential. Animal excrement represents the biogas feedstock with the second-highest potential followed by agricultural residues like straw. Due to recent changes in the German Renewable Energy Law, the use of energy crops is not encouraged. Instead, there are two special tariffs for small-scale manure plants and for biogas plants digesting waste. For the future, it can therefore be assumed that the focus for newly installed biogas plants will be based on using a higher proportion of animal excrement and waste. Whether or not the identified still technically available feedstock potentials, including the one for energy crops, is used for bioenergy generation in the future will mainly depend on political decisions (and setting the right incentives).

In **Austria**, where many plants were designed for the use of energy crops and manure, the use of alternative feedstocks like catch crops or agricultural residues came more into focus when prices for energy crops increased. Analyses of Austrian biomass potential showed that the main feedstock potentials for biogas and biomethane are represented by straw, energy crops and animal excrement.

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It appears that future developments of AD support mechanisms will promote greater utilisation of waste while discouraging the use of significant energy crop volumes. However, the report's analysis has shown that waste and residue materials are not the only feedstocks that can be used sustainably for the biogas process. It is possible to use dedicated energy crops for biogas/ biomethane production in a sustainable manner while respecting nature conservation and biodiversity aspects. There is a considerable overall potential of useable sustainable biomass, but nevertheless it is limited. Therefore, it is necessary to exploit the whole spectrum of identified sustainable feedstock categories and this also means including the available potential of energy crops and catch crops. In some cases, due to process relevant as well as economic constraints, certain feedstock potentials can only be made accessible when combined with energy crops (this is particularly the case for the use of slurry). The energy-specific contribution of an increased use of residue and waste material for biogas production is relatively small compared to the potential offered by energy crops due to their much higher energy content. Hence, it can be summarized that a considerable increase in biogas/biomethane-based energy supply will not be possible when (sustainably produced) energy crops are not included in the feedstock portfolio. This fact should be taken into account when developing relevant political guidelines and the resulting regulatory frameworks, which will have a great influence on the use of feedstocks for the biogas process.

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5. ANNEX

Table 1a: Overview of substrate characteristics (FNR 2010b)

Substrate	DM [%]	VS [% DM]	N[a]	P_2O_5 [% DM]	K_2O	Biogas yield [Nm³/t FM]	CH_4 yield [Nm³/t FM]	Specific CH_4 yield [Nm³/t VS]
Manure								
Cattle slurry	10	80	3.5	1.7	6.3	25	14	210
Pig slurry	6	80	3.6	2.5	2.4	28	17	250
Cattle dung	25	80	5.6	3.2	8.8	80	44	250
Poultry manure	40	75	18.4	14.3	13.5	140	90	280
Horse manure w/o straw	28	75	n. s.	n. s.	n. s.	63	35	165
Energy crops								
Maize silage	33	95	2.8	1.8	4.3	200	106	340
WCC silage	33	95	4.4	2.8	6.9	190	105	329
Green rye silage	25	90				150	79	324
Cereal grains	87	97	12.5	7.2	5.7	620	329	389
Grass silage	35	90	4.0	2.2	8.9	180	98	310
Sugar beet	23	90	1.8	0.8	2.2	130	72	350
Fodder beet	16	90	n. s.	n. s.	n. s.	90	50	350
Sunflower silage	25	90	n. s.	n. s.	n. s.	120	68	298
Sudan grass	27	91	n. s.	n. s.	n. s.	128	70	286
Sweet sorghum	22	91	n. s.	n. s.	n. s.	108	58	291
Green rye[b]	25	88	n. s.	n. s.	n. s.	130	70	319
Substrates from processing industry								
Spent grains	23	75	4.5	1.5	0.3	118	70	313
Cereal vinasse	6	94	8.0	4.8	0.6	39	22	385
Potato vinasse	6	85	9.0	0.7	4.0	34	18	362
Fruit pomace	2.5	95	n. s.	0.7	n. s.	15	9	285
Raw glycerol[c]	n. s.	n. s.	n. s.	n. s.	n. s.	250	147	185
Rapeseed cake	92	87	52.4	24.8	16.4	660	317	396
Potato pulp	13	90	0.8	0.2	6.6	80	47	336
Potato juice	3.7	73	4.5	2.8	5.5	53	30	963
Pressed sugar beet pulp	24	95	n. s.	n. s.	n. s.	68	49	218
Molasses	85	88	1.5	0.3	n. s.	315	229	308
Apple pomace	35	88	1.1	1.4	1.9	148	100	453
Grape pomace	45	85	2.3	5.8	n. s.	260	176	448
Prunings and grass clippings								
Prunings and clippings	12	87.5	2.5	4.0	n. s.	175	105	369

a. N concentrations in digestate, excluding losses in storage
b. wilted
c. Results vary greatly in practice, depending on the method used for biodiesel production

Biomethane potentials in Hungary – overview per feedstock category

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Table 2a: Biomethane potentials in Hungary based on the use of animal excrements

Animal manure + slurry	**No. of heads**	**Methane Potential**	**Technical Methane Potential**
		1000 m^3/year	TWh/year
Cattle	733,000	550,000	5.5
Pig	2,900,000	67,000	0.67
Poultry	38,300,000	45,000	0.45
Total		**662,000**	**6.62**

Table 3a: Biomethane potentials in Hungary based on the use of primary energy crops

Cultivated land	**Used land**	**Technical Methane Potential**	**Technical Methane Potential**
%	ha	1000 m^3/year	TWh/year
1.0	45,200	159,131	1.59
3.0	135,600	477,394	4.77
5.0	**226,000**	**795,657**	**7.96**
7.0	316,400	1,113,920	11.14
10.0	452,000	1,591,315	15.91

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Table 4a: Yield of cultivated catch crops in Hungary

Name	DM	oDM	Share of Methane	Methane yield	Methane yield	Yield	Methane
	%	%	%	Nm^3/to oDM	Nm^3/to FM	to/ha	Nm^3/ha
Helianthus annuus	20	88	55	300	52.8	20	1,056
Secale cereale	25	88	54	325	71.5	25	1,788
Sinapis alba	18	84	56	315	47.6	17	810
Hordeum vulgare	34	93	53	280	88.5	17	1,505
Secale cereale	25	92	53	285	65.6	25	1,639
Triticum x Secale	28	93	53	280	72.9	22	1,604
Raphanus salivus	15	90	52	330	44.6	35	1,559
Phacelia tanacetifolia	11	90	55	300	29.7	40	1,188
Average	**22**	**90**				**25**	**1,394**

Table 5a: Biomethane potentials in Hungary based on the use of catch crops

Cultivated land	Used land	Technical Methane Potential	Technical Methane Potential
%	ha	1000 m^3/year	TWh/year
1.0	45,200	62,988	0.63
2.5	113,000	157,470	1.57
5.0	**226,000**	**314,941**	**3.15**
7.5	339,000	472,411	4.72
10.0	452,000	629,882	6.30

Table 6a: Biomethane potentials in Hungary based on the use of agricultural by-products

	Technical Methane	Technical Methane
	1000 m^3/year	TWh/year
Cereals straw	931	9.31
Corn stover	1,084	10.84
Sunflower stover	473	4.73
Rape straw	53	0.53
Total	**2,541**	**25.41**

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Table 7a: Yields of green biomass from landscape maintenance in Hungary

Green mass yield	to/ha	20.0
Dry matter	%	35.0
Organic dry matter	%	93.0
Biogas yield	m^3/to oDM	580.0
Methane content	%	52.0
Methane yield	m^3/to oDM	301.6
Methane yield	m^3/ha	1,960.0

Table 8a: Biomethane potentials in Hungary based on the use of landscape maintenance materials

Used surface	**Technical Methane Potential**	**Technical Methane Potential**
ha	1000 m^3/year	TWh/year
10,000	19,600	0.20
20,000	39,200	0.39
30,000	**58,800**	**0.59**
40,000	78,400	0.78
50,000	98,000	0.98

Table 9a: Biomethane potential in Hungary based on the use of sewage sludge and landfill

	Volume potential	**Methane potential**	**Methane potential**	**Utilisation present**	**Utilisation present**
	toe/th. citizen	m^3/citizen	TWh/year	TWh/year	%
Sewage sludge	7.20	8.37	0.83	0.23	27.74
Landfill	5.70	6.63	0.66	0.16	24.38

This project has received funding from the European Union's Horizon 2020 research and innovation programme.

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