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Article

Biogas Production Potential from Economically Usable Green Waste

Daniel Pick [1,*], Martin Dieterich [2] and Sebastian Heintschel [2]

[1] University of Freiburg, Zentrum für Erneuerbare Energien, Tennenbacherstr. 4, Freiburg 79106, Germany

[2] Institut for Landscape and Vegetation Ecology, University of Hohenheim, August-von-Hartmann-Str. 3, Stuttgart 70599, Germany; E-Mails: martin.dieterich@uni-hohenheim.de (M.D.); heintsch@mailserver.tu-freiberg.de (S.H.)

* Author to whom correspondence should be addressed; E-Mail: damapi@gmx.net; Tel.:+49-0-761-4894429.

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Abstract: Biomass production for energy purposes on agricultural land competes with food production. This is a serious problem, considering the limited availability of farmland, rising demand for varied food products, demand for more organic crop production resulting in considerably reduced yields per area and the need for more environmentally sound agricultural practices meeting long-term sustainability criteria. Residual land currently not used for agricultural production has been considered a promising resource, but in terms of potentials, difficult to estimate for biomass for use in the energy sector. Biomass potentials associated with "green waste" from residual grasslands were assessed for Schwäbisch Hall County in the Federal State of Baden-Württemberg, Germany. Roadside edges, conservation grasslands subject to low intensity use (landscape maintenance sites), riparian stretches along ditches and streams, and municipal green spaces (public lawns, parks and sports fields) were the area types considered. Data for biomass and biogas yields were either determined through a sampling program or obtained from the literature and through interviews with experts. In an iterative process and distinguishing between theoretical, technical and realized (economic) potentials, unsuitable areas and fractions were subtracted from the theoretical potentials. Theoretical potentials for Schwäbisch Hall County were originally estimated at 21 million m^3 of biogas. The results of the investigation suggest that a very high percentage of the theoretical residual biomass potential cannot be accessed due to various technical, legal, ecological or management (economic) constraints. In fact, in the end, only municipal lawns and green spaces were found to provide suitable substrates. Current use of residual biomass in the model communities did not exceed 0.4% of the theoretical potentials. Provided all residual biomass available under current management practices could be accessed, this would amount to 6.1% of the theoretical maximum potentials.

Keywords: green waste; biogas production; technical, economic and ecological potentials; municipal green spaces; survey methods; biogas yields

1. Introduction

Global warming and the decline of fossil fuels exert pressure on society to use energy more efficiently, to reduce energy consumption and to replace fossil fuels by converting to renewable energy. Both prevention of global warming and replacement of fossil fuels are goals of the German Renewable Energy Act (GREA) [1]. Energy from biomass plays a central role for achieving ambitious CO_2 reduction and sustainability targets. Biomass is particularly important because it can be used flexibly to generate heat, gas, electricity or liquid fuels; it can readily be stored and transported [2]. However, on agricultural plots, biomass production for energy purposes competes with food production. Current crop production based on high intensity agriculture exerts strong pressures on the environment [3,4]. Lessening crop production intensity is a precondition for reducing this pressure. The request for biomass to produce energy, while at the same time reducing production pressures, both translate into more farmland required to satisfy production targets. In the light of this severe competition for space, it is desirable to include previously unused biomass fractions such as waste biomass into new sources for energy production [5].

Grass, cut from residual grasslands, managed for purposes other than the production of feed for livestock, is rarely used as a substrate in biogas fermenters due to low biogas yield, especially from materials that are rich in fiber [6], the associated problem of bulkiness in the fermenter (overloading of the agitator) [7], and problems with the economic feasibility for acquisition of the appropriate materials (harvest from steep slopes and/or small plots, including stretches along streams, lack of suitable equipment). Unlike agricultural crops, residual grassy substrates are not concentrated in one location; they are not well suited to effectively initiate a chain for generating value.

Table 1 depicts estimates the total amounts of various residual materials in Germany and provides a first estimate of necessary subtractions from theoretical potentials. The subject of this article is to assess theoretical potentials and subsequently eliminate fractions that are not ecologically, technically, legally or economically feasible for intensification and harvest, and for subsequent use in energy production. Necessary factors to be addressed when converting theoretical potentials into extractable biogas are depicted. Methods applied for a more detailed determination of potentials include: GIS-based assessments of residual area size; field sampling to verify area (cover by vegetation other than grass, herbs or tall herbs), accessibility (slopes), and specific management regimes (mowing frequency); interviews (actual management practices and equipment); assessment of management and vegetation type-specific biomass and biogas yield (measurements and literature values). The methods described are applied to a model county (overview assessment) and four model communities (detailed assessment) in southern Germany (Schwäbisch Hall County, Federal State of Baden-Württemberg).

Table 1. Estimated biomass available on residual areas in Germany. Only those fractions that can be used with current technology were considered [5].

Residual area type	Weight	Usable
Roadside cut	778.00 t	56%
Private/and public green spaces	638.00 t	73%
Habitat maintenance sites	1.913.00 t	50%

2. Methods

2.1. General Design

A county-wide study was performed in Schwäbisch Hall County (composed of 28 communities) to assess the biomass and biogas yields of cuttings from different residual grasslands, parks and lawns. Four best suited rural communities (maximum residual areas available) were selected for more detailed investigation. The county-wide overview and detailed investigations for the model communities were based on the same methods (GIS based assessments, field investigations and structured interviews based on questionnaires), but differed in the amount of detail.

Assessed residual areas include edges of classified roads (major roads), edges of unclassified roads (minor roads and paths), riparian stretches along streams and ditches, public lawns and sports fields (municipal green areas), and non-production sites managed under conservation contracts (landscape maintenance sites). Management patterns and total area of the different residual area types are summarized in Table 2. Private yards and lawns were not included in the investigation. Cuttings from private yards and lawns can only be accessed through a collection system. Therefore, these potentials depend mainly on the quality of the collection system rather than available area or management practices.

Table 2. Residual area types included in the analysis and associated management patterns (mowing frequency, fertilization).

Area type	Available area	Annual cutting frequency	Fertilization
conservation grassland	650 ha	1 (−2)	no
roadside edges	1,023 ha	1–2	no
stream edges	357 ha	1	no
public lawns (low intensity)	579 ha	4	no
public lawns (sports fields)		approx. 20	yes

Based on data available from the *Amtliches Topographisch-Kartographisches Informationssystem* (ATKIS) [8] and complemented by field samples, the surface areas of the different residual grassland types and lawns were assessed (see below). The ATKIS is a public system, storing information relating to landscape qualities and land use types. Biomass and biogas yields attributed to different types of residual grassland were obtained from the literature; literature data were complemented by interviews with regional experts. Literature data include as yet unpublished measurements performed in the context of this project and available from the project reports [9–11].

Similar to the methods published by the German Research Center for Biomass (DBFZ) [12], we distinguish between a theoretical, a technical and an actually used or economically usable potential. For our purposes, it was useful to further split theoretical and technical potential into two separate categories and to modify definitions accordingly:

(1). Theoretical potential including all residual areas (TP-all): the biogas yield to be obtained if all available areas could be used for maximum bioenergy output. This corresponds to biomass and biogas yields from intensively used grassland. The theoretical potential is useful as a reference point that can easily be standardized (theoretical maximum).

(2). Theoretical potentials encompassing only accessible areas and considering subtractions from areas and maximum yields resulting from legal restrictions (conservation clauses, protection of surface waters, garbage treatment act) (TP-red): the biogas yield to be obtained if all accessible areas could be used for legally permissible, maximum bioenergy output from grassy substrates.

(3). Technical potentials with optimized machinery (TecP-opt): the biogas yield to be obtained if all accessible areas were managed with the same management intensity as they currently are, but machinery for harvest was optimized, requiring investments in new machinery.

(4). Technical potentials with available machinery (TecP-cur): the biogas yield to be obtained if all accessible areas were managed as they currently are with no investments in new machinery.

(5). Actually used or economically usable potential (AcP): potential that is actually being used or for which interest in use has been expressed under current funding conditions.

All residual areas and associated biomass fractions selected fulfill the criteria for achieving the landscape maintenance bonus under the former German Renewable Energy Act (GREA) [1] in place at the time of the study. This legislation and associated economic potentials have substantially changed under the provisions of the new 2012 GREA.

2.2. Surface Area Determination

2.2.1. Linear Stretches: Classified Roads, Unclassified Roads and Paths, Banks of Streams and Ditches

Available lengths of roads and watercourses were derived for each community, based on publicly available ATKIS data. Urban roads and streams were not considered in the analysis and subtracted from the total available length. Accordingly, due to the presumed lack of grassy banks, forest streams and stream reaches in culverts were not considered in the analysis. Average width of roadside edges and riparian zones was determined over 100 m sampling reaches. In order to obtain available area, total length was multiplied by average width per unit length of road edges or riparian zones [10,11].

In a second step, several corrections and modifications were made to account for different types of potentials. Areas currently not covered by grassy substrates were discarded. A distinction between area utilized and area that could potentially be utilized was made. For a more detailed assessment of management specific biomass and biogas yields, mowing regimes (1 or 2 mowings) were specified relative to available area [10,11].

2.2.2. Landscape Maintenance Sites

The area of non-production nature conservation sites (landscape maintenance sites) and information related to site-specific management was obtained through the county nature conservation authority in charge of administering conservation contracts. Site-specific information concerning the actual cover with grass, management type and slope dependent usability with regular farming equipment was obtained by inspecting plots randomly selected from the pool of available sites [10,11]. This information was needed to assess total grassy area, management specific biomass and biogas yields, and usability with conventional machinery. Based on the information obtained, landscape maintenance sites were divided into 3 utilization patterns:

- pasture land;
- grassland subjected to 1 mow per year including wetland meadows and reed meadows;
- extensively used grassland subjected to 2–3-mowings per year.

2.2.3. Municipal Green Areas

In the county-wide survey, compilation of the surface area covered by municipal green spaces was accomplished based on data available from the State Office for Statistics. The size of different types of municipal green areas (sports fields, parks, school lawns, playgrounds, cemeteries) was added up for each community. For cemeteries, a grass cover of 20% was assumed and the figures from the Office for Statistics were corrected. A random sample of public green areas was inspected to more accurately assess total grass cover, and lawn and park type and management (number of mowings) [10].

In the model communities, all public green areas were visited to verify GIS-based area estimates and to assess management [11]. The information obtained was complemented and specified by interviews with local authorities (see Section 2.3).

2.3. Surveys (Interviews)

2.3.1. Municipal Building Yards (Bauhöfe)

Municipal building yards are charged with managing public green spaces, road edges (especially the edges of unclassified roads) and riparian areas along streams. For the county-wide assessment, the directors of the community-run building yards were interviewed (standardized questionnaires with telephone follow-ups) about management practices, area managed, and the composition, amount and use of the accrued clippings.

In the model communities, a detailed follow-up took place based on one or two face-to-face interviews. In the course of the follow-up, the cartographic representations using cadastral data were updated, either to remove areas no longer belonging to the community or to enter areas newly added to the community. Information on actual management of individual green areas (number of mowings, fertilization), available machinery and personnel, options for the collection of clippings and use in biogas operations, and potentials for technological upgrade was obtained (see Section 2.2.3). Information collected was used to calculate theoretical and technical potential for biomass and biogas yield.

2.3.2. Other Important Officials

In addition, the following important officials were interviewed in order to compile information on available residual areas, management and biomass potentials:

- the director of the county-owned trash management association who is responsible for the recycling centers in many communities and for the public centers which compost grass and woody materials;
- the director of the county road works management division responsible for roadside maintenance along classified roads; the interview was supplemented by visits to 3 of the 5 road maintenance depots to further illustrate management techniques, practices and technical potentials;
- the river maintenance manager based at the Stuttgart regional administration, who is responsible for large river bank and floodplain management in Schwäbisch Hall County, was asked about management and availability of grassland in state owned flooding areas;
- the county administrator in charge of conservation contracts to provide information on the availability of conservation sites for harvesting biomass to be used for biogas production;
- the head of the county farmer's association (Landesbauernverband) to obtain information and perspectives on out-of-production grassland and farmer's willingness to include residual materials in their biogas operations.

2.4. Biomass Potentials

Biomass potentials were calculated based on area and management specific yields. The biomass potentials for meadows and pastures were obtained from references [13,14] (Table 3). To determine a single best value for the calculations, the scatter of the available literature data was reduced by interviews with recognized regional experts (expert survey, Table 3). Due to a lack of, and inconsistency in, published data, and following expert recommendations, biomass yield from lawns and green spaces was assessed, based on an in-depth sampling program in the model communities [9].

Table 3. Potential yield of biomass (dry mass) from grassland types (References [9,11,13,14]).

Grass-cuttings	Biomass range	Biomass average	Experts [references]
1-cut	2–3 t/ha·a	2.5 t/ha·a	Elsäßer [11,13,14]
2–3 cut	4–7 t/ha·a	5.5 t/ha·a	Elsäßer [13,14]
4–5 cut	8–12 t/ha·a	10 t/ha·a	Elsäßer [13,14]
public lawns (low intensity) [1]		3.8 t/ha·a	Thumm [9]
public lawns/sports fields (high intensity) [2]		12.6 t/ha·a	Thumm [9]

[1] 4 mows in 2011; [2] mown weekly.

2.5. Biogas Potentials

Biomass weights were multiplied by a utilization-dependent and substrate-specific gas yield to calculate biogas yields. For grassland other than public green spaces, the corresponding values were obtained from the literature [6,15–17]. Based on the literature survey, values to be used in the calculations were discussed with regional experts (Table 4). Depending on management intensity, biogas yields from grassy substrates vary distinctively. As fiber content increases, yield per unit weight decreases because bacteria-generating methane cannot readily digest hemicelluloses and lignin [18–20].

Table 4. Potential yield of biogas (m^3/t dry mass) from different grassland types. Yields are taken from the literature [6,9,15–17] and from interviews with experts.

Grass-cuttings	Biogas	Biogas average	Experts [references]
1-cut	150–220 m^3/t	185 m^3/t	Öchsner [6,16,17]
2–3 cut	440–480 m^3/t	460 m^3/t	Öchsner [6,16,17]
4–5 cut	330–400 m^3/t	365 m^3/t	Öchsner [6,17]
Golf course (green and fairway)	750–790 m^3/t	770 m^3/t	Thumm, Öchsner [15]
public lawns (low intensity) [1]		644 m^3/t	[9]
public lawns/sports fields (high intensity) [2]		676 m^3/t	[9]

[1] 4 mows in 2011; [2] mown weekly.

Considerable uncertainty was expressed by the different experts about biogas yield from public lawns and sports fields. Therefore, a research program to assess biogas yields from public green spaces was conducted in 2011. A distinction was made between low intensity use (irregularly mowed and unfertilized public lawns) and weekly mowed and regularly fertilized sports fields [9].

3. Results

3.1. Surface Area Potential

Theoretical potentials for area are reported for the actual size of all residual grasslands, lawns and parks that could be used to produce biomass for biogas (Table 5). In order to determine theoretical potentials based on accessible area and technical potentials, a number of subtractions have to be considered. Causes for subtractions include:

- inaccessibility of private property;
- competing use;
- legal restrictions;
- accessibility with conventional equipment.

Table 5. Total and available landscape maintenance area (ha) and necessary subtractions from potentials for biogas production in Schwäbisch Hall County. Potentials are calculated according to interviews and county-wide samples allowing for an assessment of average cover with shrubs and slope (slope as a measure for usability with conventional equipment).

Total area	Area unused (available for biogas)	Bushes and other structures	Total grassland	Special equipment (Slope >25%)	Conventional equipment
650 ha	30 ha	6.6 ha	23.4 ha	13.1 ha	10.30 ha

For the different residual area types, the following subtractions were made from the theoretical potential:

(1). Subtractions from areas under conservation contracts (landscape maintenance areas)

According to the managing administration in Schwäbisch Hall County, out of a total of 650 ha of high conservation value grasslands (landscape maintenance sites), currently only 30 ha are not managed under conservation contracts (grazing or mowing) or threatened by cancellation of these contracts. Only sites currently not under conservation contracts or threatened by contract cancellation satisfy the criteria of lack of competing use and can be considered to be readily available for biogas production. No such area is available in the model communities.

Shrubs and non-grassland obstructions were subtracted from the 30 ha of landscape maintenance sites potentially available for biogas production. Considering technical potentials based on available machinery, steep slopes that can only be harvested with specific equipment were also subtracted from the available area. Based on the county-wide survey, subtractions for shrubs and steep slope amounted to 66% of the total area. Overall, out of approximately 650 ha of landscape maintenance area, only about 10 ha remain to be used for biogas production (Table 5).

The potentials resulting from the abandonment of grassland outside conservation areas remain unclear. We were unable to locate any grassland areas that have gone out of production and are mowed regularly only to obtain area-related subsidies. Specific inquiries asked of agriculture administrations and representatives from the farming community indicate that easy-to-use and productive grassland will not go out of production. Thus, apart from grassland already managed under conservation contracts, the potential for more grassland to go out of production are considered to be very limited or non-existent.

(2). Subtractions from roadside edge areas

Cuttings from roadside edges are currently being mulched. Following requests from conservation groups, suction equipment originally used to recover this biomass has been abandoned to avoid sucking up invertebrates. In addition, residual cuttings from roadside edges raise problems for the spread of pollutants to farmed areas. According to legal provisions in Germany, digestate from biogas produced from roadside edge cuttings must be treated as garbage, at least as long as the biomass is obtained from roadside working crews (mostly biomass from edges along classified roads). This prohibition translates into costly disposal of digestates rather than as usage for fertilizer on agricultural plots. Therefore, under current legal constraints, areas along classified roads cannot be included in any theoretical potentials for biogas production from accessible residual areas.

Shrubs and other obstructions comprise approximately 6.5% of the edges along unclassified roads and must be subtracted from the total area available (Table 6). It remains unclear to what extent cuttings recovered from non-classified minor roads could be used for biogas production. These roads are not managed by State/County work crews, but rather by municipal building yards or farmers contracted to do the job. Management by public work crews has been identified as the criterion prohibiting disposal of digestates on agricultural fields. It remains unclear whether this only applies to State/County work crews or municipal work groups and contractors in general.

Even if disposal of digestates from unclassified roads was granted, disposal would require a potentially costly permit and regular testing for pollutants. In addition, operators of biogas plants have expressed concerns about disposed waste in the grassland strips along roads. Furthermore, neither current agricultural nor current public work crew equipment allows for the recovery of such cut. Therefore, these areas do not meet the criteria for current technological potentials (TecP-cur) and at that point at the very latest must be subtracted from the potentially available area. Overall, out of a total of 1.020 ha of grassland along classified roads and unclassified roads and paths, and based on currently available technology, 0 ha are accessible for harvesting biomass to go into biogas production (Table 6).

Table 6. Total and available area along classified and unclassified roads (ha) and necessary subtractions from potentials for biogas production. Potentials are calculated according to county-wide samples allowing for an assessment of available area and mowing frequency. Equipment to collect the cut is currently not available.

Total area	Non garbage area (disposal permitted)	Bushes and structures	Total grassland	Special equipment (Slope >20%)	Conventional equipment
1,023.09 ha	595.30 ha	38.25 ha	557.05 ha	557.05 ha	0.00 ha

(3). Subtractions from residual areas along watercourses

Overall, 357 ha of riparian residual area are available along watercourses for consideration of biomass production in the county of Schwäbisch Hall (Table 7). In most cases, the banks along streams and ditches are privately owned. Therefore, acquisition of cuttings from the banks requires negotiations with a large number of owners. In practical terms, and in the absence of specific programs, privately owned banks along watercourses, therefore, have been subtracted from the potential residual area available for biomass acquisition.

Table 7. Total and available area (ha) along watercourses (streams and ditches) and necessary subtractions from potentials for biogas production. Potentials are calculated according to county-wide samples allowing for an assessment of available area and mowing frequency.

Total area	Publicly managed area (Wasserverband)	Bushes and structures	Total grassland	Special equipment	Available equipment
357.01 ha	33.46 ha	14.09 ha	19.37 ha	19.37 ha	19.37 ha

However, in the model communities, a considerable portion of the stretches along streams, ditches and reservoirs is managed by a municipal water association (Wasserverband Brettach). Management by the Water Association covers approximately 34 ha (Table 7). This allows for coordinated mowing and regular removal of the cutting mainly to prevent clogging of culverts. Based on the county-wide survey, 42% of the area covered by shrubs was deducted from the area managed by the Wasserverband, leaving 19 ha of grassland along watercourses (Table 7). Labor intensive mowing and removal are accomplished by the Wasserverband using small, hand-driven special equipment (hand pushed mower with cutter bar and motor driven rake). The small hand-driven equipment allows for full access to the banks. Therefore, there are no additional subtractions from the available area due to inaccessibility (Table 7). As a result of the Wasserverband activities, some of the riparian grassland in the model community is well maintained and cuttings satisfy the criteria defined for the current technological potentials (TecP-cur).

(4). Subtractions from public green areas

Countywide 580 ha of public green areas have been recorded (sports fields, parks, public lawns) (Table 8). Sample-based assessments indicate that about 30% of the public green areas are actually composed of lawns [10,11]. The total available area of public lawns can be fully included in the technical potentials assuming optimized machinery. While all the green areas can currently be mowed, subtractions must be made for lack of machinery to recover the available cuttings. Based on the interviews in the model communities, we optimistically estimated that suction equipment for recovering the clippings is available for 80% of the relevant public green areas considered (Table 8). The public green area available for recovery of biogas substrates therefore amounts to approximately 145 ha.

Table 8. Total and available area (ha) from public green spaces (sports fields, parks, public lawns).

Total area	Area with shrubs and obstructions	Total grassland area	Area requiring special equipment	Area requiring available equipment (mowing and recovery)
579.60 ha	401.26 ha	178.34 ha	178.34 ha	142.67 ha [1]

[1] Estimate based on interviews in the 4 model communities.

In the analysis of potentials, we did not consider clippings from private lawns that are currently collected in public depositories. There is considerable room for improvement for such collections. However, it is difficult to relate potentials to area or management, as collections will most importantly depend on factors such as willingness to participate or ease of access to depositories rather than the total area occupied by private lawns.

3.2. Biomass and Biogas Yield from Residual Areas–Intensification Aspect

Apart from available area, biomass and biogas yield that can be obtained from residual plots depend on the degree of permissible, desirable and economically feasible intensification. In many cases such intensification is either not permissible (e.g., riparian areas, nature conservation areas) or not feasible in the context of priority management goals (e.g., roadside edges). The potentials for intensification based on the background of legal provisions and feasibility as expressed in interviews by management bodies are outlined below for each of the residual area types.

(1). Areas under conservation contracts

Intensification on lands under conservation contract would contradict the very purpose of such contracts, which is to secure low intensity use (mostly grazing) and associated biodiversity. As a consequence, legal restrictions and associated provisions in conservation contracts prevent intensification and thus, the realization of higher or even maximum biomass and biogas yields from landscape maintenance sites. Restrictions in conservation contracts include prohibition or strict limitation of the use of fertilizer and the number of mowings on such plots. Calculations on technical potentials for biomass and biogas extraction therefore were based on the *status quo* management (Table 9) and according substrate-specific low biogas yields (grassland managed under 1–2 cut regimes, no or minimum fertilization).

Table 9. Theoretical, technological and realized (economic) biogas potentials for Schwäbisch Hall County and the four model communities. TP-all—theoretical potential: all available residual area managed for maximum yield (grassland reference); TP-red–theoretical potential: only areas that are actually accessible and intensification that is actually permissible are considered in calculation of yields; TecP-new—technical potential: yield calculated based on current management practices and optimized equipment; TecP-cur—technical potential: yield calculated based on current management and currently available equipment; AcP–actually used or economically usable potential for biogas extraction from residual areas.

Community	**TP-all**	**TP-red**	**TecP-new**	**TecP-cur**	**AcP**
Road-class	3,648,172 m^3	0	0	0	0
Road-unclass	5,074,027 m^3	5,074,027 m^3	642,847 m^3	0	0
Streams	3,043,292 m^3	8,959 m^3	8,959 m^3	8,959 m^3	0
Conservation [1]	4,321,923 m^3	10,823 m^3	10,823 m^3	4,764 m^3	0
Public	4,940,803 m^3	1,516,133 m^3	625,986 m^3	500,774 m^3	nn
County total	**21,028,217** m^3	**6,609,942** m^3	**1,288,615** m^3	**514,497** m^3	**nn**
Schrozberg	1,040,531 m^3	699,484 m^3	107,170 m^3	33,238 m^3	10,560 m^3
Blaufelden	997,083 m^3	578,294 m^3	82,372 m^3	30,208 m^3	0
Gerabronn	465,814 m^3	216,009 m^3	41,690 m^3	26,102 m^3	0
Rot am See	1,034,366 m^3	490,673 m^3	81,125 m^3	33,971 m^3	0
Model total	**3,537,794** m^3	**1,984,460** m^3	**312,357** m^3	**123,519** m^3	**10,560** m^3

[1] Sites under conservation contract.

Adding to the low yields, late mowing will increase the bulkiness of materials and, therefore, lower potentials for those materials to be used in common biogas fermenters (liquid fermentation). Agitators in these fermenters are not designed to handle bulky substrates. As a consequence, no interest was expressed in Schwäbisch Hall County to include additional materials from landscape maintenance sites into current biogas operations. Under current funding conditions, the economic potential therefore is considered to be 0 (Table 9).

(2). Roadside edges

In the interviews, administrations and management bodies expressed a strong desire to minimize vegetation growth along roadsides in order to achieve management goals at least cost. Apart from esthetic considerations, these goals mainly include traffic safety (visibility). Fertilization along roadside edges would cause undesired growth of the vegetation and therefore is contrary to the interests of the road maintenance administrations.

Increased mowing frequency (e.g., 2 or more cuts as a general standard) in order to increase biomass yields is difficult to achieve. Along classified roads, mowing frequency is adapted to available equipment. Therefore, 2-cut management is usually restricted to 3.5 m along the roadside edge. This corresponds to the width of 2 cutter bars usually available with the standard truck based equipment. Mowing beyond the 3.5 m requires contracting out the work or the use of hand-pushed cutter bar mowers and therefore is rather labor intensive. Both solutions usually are considered economically unfeasible. In addition, road management crews in Schwäbisch Hall County and private contractors do not have the suction equipment needed to collect the clippings at their disposition.

Therefore, increasing yields under current conditions is not considered an option along roads even if these areas were accessible. Cuttings from roadside edges currently are not used to generate biogas in Schwäbisch Hall County (Table 9).

(3). Riparian areas

Fertilization as a precondition for effective intensification along streams and ditches would yield undesired nutrient input into the adjacent watercourses and is therefore legally prohibited. The Baden-Württemberg State Water Act requires the establishment of riparian stretches at a width of 10 m from the bank along watercourses. In the riparian stretches, measures affecting water quality (e.g., fertilization) are not permissible. Prohibition does not include agriculture complying with recognized standards ("ordnungsgemäße Landwirtschaft"). The State Fertilization Ordinance for agriculture prohibits fertilization in a 3 m wide riparian strip along watercourses. In exceptional cases (special equipment for targeted application of fertilizer) the zone is reduced to 1 m. Thus, and based on contradictions in legal ordinances, fertilization to increase biomass yields along watercourses may be permissible. However, for environmental reasons and following the precautionary provisions in the State Water Act, such fertilization remains highly undesirable for environmental reasons. As a consequence, we have eliminated potentials to increase grass or silage production along watercourses in the TP-red measure.

In addition, as stated for roadside edges, banks of watercourses are often difficult or impossible to effectively work with standard farming equipment. To exploit these sites would require considerable investment (equipment or labor) in order to harvest low yield/quality materials.

Currently, and likely due to the low biogas yield combined with the bulkiness of the substrates, no interest in the substrates harvested and collected by the Wasserverband has been expressed by biogas producers. Therefore, even cuttings from stream banks readily available through Wasserverband activities cannot be included with the realized economic potentials (AcP).

(4). Public green spaces

Public green spaces in the model communities are mown under the limitations imposed by available machinery and personal. Increasing management intensity is feasible, but would require additional personal and equipment or more contracting with external operations.

Research in the model communities indicates that biogas yields are similar for intensively managed lawns (sports fields) and more extensively managed lawns (school yards, parks) [9] (Table 4). This points to biomass harvested, and therefore mowing frequency, as the lead factor in determining area-specific biogas yields.

For some green spaces such as football fields, frequent mowing and fertilization to provide for a dense turf are indispensable. For other green spaces such as lawns in front of schools or parks, pressures in terms of management are less. Some lawns may even be managed for nature conservation (2–3 cuts). Communities will usually try to minimize investments into management, provided a desired esthetics is granted. Minimizing management means mowing the least possible number of times and, therefore, limits biomass output. Interviews in all the model communities precluded increasing mowing frequency due to a lack of appropriate machinery and personal. Thus, in the model communities, technical potentials with optimized machinery considerably differ from technical potentials achievable with available machinery and personnel.

The Schrozberg community has established cooperation with a biogas farmer. Apart from mulching, the community collects clippings from public lawns in a container that is subsequently picked up by the biogas farmer or otherwise deposited in a compost operation. The cooperation requires the farmer to have a specific permit for the use of biowaste in his fermenter. Depending on county administrations, such a permit apparently can be costly. Overall, 163 t fresh mass (FM) of communal grass cuttings are collected every year. Approximately, 80 t FM are picked up by the cooperating farmer to be used in the nearby biogas plant. This amounts to approximately 16% of the total cut available from high and low intensity managed public lawns in Schrozberg (Table 10).

Table 10. Communal grass cuttings in Schrozberg, biomass potentials according to management type (frequency of mowing). For conversion factors used in the calculation see Table 3.

Frequency of cut	Area	Biomass	Conversion factor	Biomass
weekly	7 ha	88.3 t DM	5	441.5 t DM
every 2 weeks	2.6 ha	9.7 t DM	5	48.5 t DM
2-cut	4 ha	22.2 t DM	3	66.6 t DM
total	**13.6** ha	**120.2** t DM		**556.6** t DM

Considerable problems have been encountered in Schrozberg in the attempt to increase the use of cuttings from public and private lawns in the biogas reactor. Problems include the use of effective collection devices (suction devices) for maximizing collection of the materials delivered in rather small fragments (clippings). In addition, even short term storage of the cut is difficult. After just 3 days, due to rotting and associated reductions in biogas yield, the participating farmer considers the cut no longer suitable to be used in the fermenter. This creates logistical problems, further limiting use of the cut both on the part of the community and on the part of the farmer.

3.3. Actually Used or Usable Potentials (Economic Potentials)

Based on current funding scenarios, and apart from the operation incorporating clippings from public lawns in Schrozberg, there was no interest on the part of the county-based operators of biogas plants to include additional residual materials.

Mayors of the model communities were informed about the possibility for the establishment of a 150 KW reactor specifically designed to be run on organic waste and cuttings from communal green spaces. The 150 KW operator was selected as the most cost-effective solution [21]. Based on the economic calculations presented, mayors did not express an interest in building and running such a reactor in spite of recognized positive environmental effects and the existing need for improved treatment or disposal of residual biomass from public and private lawns.

3.4. Summary of Potentials

In Schwäbisch Hall County, a significant increase in actually realized potentials (AcP) through to potentials that can be accessed with currently available technology (TecP-cur) is feasible. Increase would mostly be attributed to effective use of clippings from public lawns and green spaces. Potentials for biogas from residual areas to be accessed with current technology (TecP-cur) amount to about 500,000 m^3 (Table 10). This is only 2.4% of the maximum theoretical potential (TP-all).

If investments in new technology take place (TecP-new), this could be increased to 1,290 m^3 (6.1% of the maximum theoretical potential). The collection of materials from the edges of non-classified roads and paths accounts for more than 80% of the difference between TecP-new and TecP-cur. New technology would mostly encompass suction equipment to more effectively collect the bulky and low biogas yield cuttings. It has to be noted, however, that this does not consider the lack of interest as expressed in the difference between AcP and TecP-cur for bulky substrates in general.

As is expressed in the difference between TecP-new and TP-red, legally permissible intensification offers additional and more profound opportunities to increase biogas yields from residual substrates. Again, the increase is primarily based upon mowings collected along unclassified roads; to a considerably lesser extent intensification of public green areas may increase yields (Table 10). As current roadside and public green space management practices are designed for cost efficiency, changing management would mean an increase in cost for producing what is currently perceived as waste.

The step from TP-red to TP-all could triple theoretical potentials, but would require undesired legal changes in terms of abandoning prime conservation sites (increased yields from conservation sites), spreading pollutants on agricultural fields (permit spread of digestates from edges of classified roads on agricultural fields), increasing nutrient input to surface water (fertilize stream banks) or transforming public green spaces into uniform and regularly fertilized lawns (remove woody vegetation or flower beds from parks).

The county-wide pattern of subtractions from potentials is mirrored in the model communities although the transition from TP-all to TP-red is less pronounced, and mostly due to fewer landscape maintenance sites. The county-wide summary was not suited to fully account for current use of residual biomass in biogas operations. This question was specifically addressed only in the model communities, where current use of residual biomass will yield approximately 10,500 m^3 of biogas, accounting for about 8.5% of the potentials that can be realized with current technology (TecP-cur) and 0.3% of the overall theoretical potentials (TP-all).

4. Discussion

Our study illustrates clear differences between theoretical potentials and factually usable potentials for biogas production from residual grasslands. Competing policy goals resulting in legal restrictions (protection of soils, aquatic resources and biodiversity), actual accessibility of plots and mowings (property and technology factor), and economic considerations cause these distinct differences. In our detailed assessments the technology factor is probably least important for improved recovery of potentials.

According to the administrator-in-charge, in Schwäbisch Hall County, currently only 0.5% of the land under conservation contracts could be available for biogas production. Most of the landscape maintenance sites are grazed under conservation contracts (slopes) or mowed (wetlands). For landscape maintenance sites, significant subtractions for areas theoretically available have to be made to exclude competition for space. Revenue from the grazing operation provides much needed income for livestock keepers that have often cooperated with conservation authorities for a long time. This is particularly true as livestock used for landscape maintenance or derived livestock products often cannot be profitably sold in the market (e.g., sheep products). Apart from competition, from a nature conservation perspective, traditional land use patterns based on traditional species and breeds often provide the best option to deliver desired landscape qualities [22].

Even if more landscape maintenance areas were available provided contracts are not renewed, landscape structure (steep slopes) and lack of potentials for intensification (limits to mowing frequency and fertilization) render these sites unattractive for acquisition of substrates to be used in biogas operations under current funding programs.

Surprisingly, we did not encounter any grassland that had recently been abandoned. Studies [23] estimate the expected average of these areas in the Federal State of Baden-Württemberg at 26% by 2015, and more specifically at 28% of the total grassland area in Schwäbisch Hall County. An important reason for the perceived discrepancy between predictions and actual findings might be the accumulation of milk quota in Schwäbisch Hall County, which in fact has one of the highest livestock densities in the State of Baden-Württemberg. High livestock density results in high demand for fodder and mainly grassland. On the other hand, and primarily as a result of biogas operations, demand for agricultural land in Baden-Württemberg is high and may render predictions with respect to future land abandonment uncertain at best.

In the perspective of biogas operators, materials from roadside edges are unfavorable because of pollutants and waste. Pollutants along roads include metals such as copper or polycyclic aromatic hydrocarbons (PAH) that are often highly toxic [24]. The concern that use of biomass from roadside edges will spread pollutants on agricultural soils is warranted. This concern is expressed in legislation that prohibits the use of biogas slurries on agricultural fields, if materials from classified road edges have been used as substrates. Waste (plastic, glass, metals) is of particular concern for biogas operators, because it hampers the fermentation process in biogas plants.

Pollutants might not be a problem for substrates recovered near minor roads and paths closed to public traffic. But even if there are no toxicants and little waste, other problems arise. Cuttings from roadside edges are difficult to collect and cannot be recovered with conventional farming machinery. Rather, the collection of cuttings from roadside edges would require investments into specific suction devices. In Schwäbisch Hall County such suction devices have been abandoned due to nature conservation concerns (Head of County Road Administration, personal communication). Collection of the cut is therefore considered expensive and economically unfeasible. This, in combination with the comparatively low biogas yield from the bulky materials and the lack of specific GREA funding, has prevented requests for such cuttings from non-classified roads to be used in biogas plants and paths usually mowed and then mulched by communal work crews or farmers.

Provided grass along roads can be harvested, there is no foreseeable potential to increase yields by conventional intensification (increased number of cuts, use of fertilizer). Such intensification resulting in enhanced growth would either contradict the management goal for visibility (traffic safety) or the management target of least cost. Least cost management in this case mainly implies that edges have to be mown only twice, preferably only once, in each season. Numbers of personnel, machinery and work schedules are adapted to this situation. Available trucks can accomplish two cuts per year to a width of 3.5 m. Hand driven cutter bar mowers are being used for sites that are cut only once (width of roadside edge >3.5 m). Increasing the number of mowings would require more machinery and personnel.

Ownership structure along streams and ditches prevents the effective use of stream-side biomass. Single plots usually border streams with short boundaries. This equates to a maximum number of plots bordering streams and the subsequent need to communicate with numerous land owners in order to access the sites. Since communities are charged with maintaining so called second-order streams (minor streams); there may be a possibility to have easier access via communal ordinances. We did not examine whether communal ordinances may provide means to facilitate this process. It is, however, doubtful that communities would be willing to interact with property rights in the way described. And, even if the sites were accessible by owner consent, the problem remains of effectively collecting the bulky cut from steep edges and stream banks. Not surprisingly, no interest has ever been expressed in Schwäbisch Hall County in harvesting grassy strips along watercourses and to use these clippings for biogas production.

The Wasserverband Brettach is a specific organizational feature unique to the 4 model communities. The Wasserverband is charged with the maintenance of stream banks and mows the grass on the banks using hand pushed mowers. Cuttings are subsequently collected with hand motorized equipment (Bandrechen). The harvested biomass is currently fed to cattle by a crew member, but could also be used for biogas free of charge. Therefore, in the model communities we included the biomass from stream banks with the technical potentials. However, it has to be noted that there are no potentials for intensification along the watercourses, because this would require the use of fertilizer. For reasons of water quality, use of fertilizer in close vicinity to streams is prohibited und undesirable at distances within the legally protected riparian strip (10 m width along streams).

Under current conditions, only cuttings from public green spaces were found to provide a feasible substrate for biogas production from residual areas. The grassy material is well suited for biogas reactors (mechanically and in terms of biogas yield). And, at least some of the clippings are already collected and then usually have to be deposited. Deposition causes cost (at least for transport, likely transport and volume). Thus, there is a potential for cost reduction on the one hand (communities in charge of public green areas) without causing direct cost for acquiring the biomass on the other (biogas plant operator). Lack of possibilities for simple storage limits the use of the clippings from public green areas. Clippings ideally will be picked up and brought to a biogas reactor at the day of mowing and within 72 hours after mowing at the very latest. Otherwise, rotting will considerably diminish biogas yield. Use therefore is restricted to the growing season (April/May–September/October). Whether mixing of cut from lawns with more bulky materials to allow for production of storable silage could be a viable alternative is unclear. However, such mixing would require considerable logistics and additional processes with associated work time.

Even more cut could be obtained from public green spaces by introducing and optimizing fertilization and increasing mowing frequency. However, this would contradict least cost management and require either additional funds to be invested in park maintenance by communities or an attempt to compensate extra cost by selling the grassy materials to biogas operators. Calculations not considering clippings from private lawns indicate that a 150 KW biogas reactor exclusively operated on feed from public green areas might be profitable under current funding conditions [21]. However, the operation would not be profitable under the provisions of the new 2012 GREA [21]. Mayors of the model communities were presented with the calculations. Considering risks and uncertainties from an economic perspective, the research group was unable to recommend the model and the mayors therefore did not express interest in such a project potentially requiring continued input of communal funding.

Some of our results do not compare well to the estimates provided in Table 1 for the national scale [5]. National estimates for roadside cuts appear to be unrealistically high (56% usable), considering the problems discussed. National estimates for habitat maintenance sites apparently ignore competing use (50% usable), but otherwise may be fairly realistic. Finally, it appears doubtful whether, considering the logistical problems, the estimates for private and public green spaces are achievable (73% usable).

We consider the results presented to be rather robust in terms of general conclusions. Average data on biomass and biogas yields from specifically managed areas used for the calculations will not vary significantly between different geographic regions in Germany and beyond. In terms of area available, there may be more region-specific variation with respect to prominence of nature conservation sites. Southern Germany is a hotspot for species-rich grassland and may harbor more of these sites [25].

Our research demonstrates that detailed multi-scale investigations are required in order to properly assess bioenergy potentials. We consider a need for the development of standardized protocols to evaluate these potentials. In the absence of such standardized and detailed investigations, a precautionary approach should consider the following categories for subtractions from theoretically available potentials:

- land access (ownership and competing use);
- legal provisions restricting intensity of use (overriding environmental concerns);
- a precautionary approach, generally basing calculations on available technologies;
- economic considerations (yield and of cost of collection relative to other substrates) or participation-based indication (willingness to participate).

There are possibilities to use biomass from residual land for energy production. Opportunities to gain energy from sources that are currently considered as waste should be explored and whenever feasible exploited. However, with respect to biogas these possibilities are rather limited and have been estimated at 1.6–3.2% of the total primary energy needs in the state of Baden-Württemberg [26]. In the Baden-Württemberg Biomasse-Aktionsplan a considerable share (up to 41%) of the bioenergy from agricultural systems is attributed to landscape maintenance materials, cuttings from roadside edges and clippings from public green spaces [26]. The discrepancy between the actual data recorded in Schwäbisch Hall County and the political targets for use of residual materials suggests that the potentials for these materials to be used in biogas operations have been vastly overestimated – at least under current funding regimes.

There is strong indication that overestimation of bioenergy potentials has caused passage of unsustainable policies (e.g., biofuel targets). Based on calculations by Rauh and Heißenhuber [27] meeting the national 15% biofuel goal alone would require 50% of the German farmland (farmed fields). Adding the area allocated to biogas production in 2011 (800,000 ha) and ignoring expected biogas expansion in the years to come, would raise this figure to approximately 57% of the farmed area. These figures are not presently under political or public discussion.

Biofuel policies have added an additional demand on the land and caused further intensification of land use. Agricultural intensification tends to create homogeneity at all scales with associated loss of biodiversity [28]. Drivers for such loss include planting of set aside areas with energy crops, turning permanent grassland into arable fields, intensification of grassland use leading to the decline of species-rich grasslands, a more monotonous pattern of use (larger patches, reduced diversity in crop rotation). In addition, at least in Baden-Württemberg, take-up of agri-environment programs and interest in conservation contracts has considerably declined, as compensations awarded cannot keep up with the increased cost of leasing and increased opportunities for higher market value conventional farming products.

A proper assessment of potentials has to precede large scale renewable energy policies and the local establishment of renewable energy operations. This is particularly true for renewable energy to be produced on the basis of limited area and biological/ecosystem potentials. Our research indicates that theoretical potentials should not be taken into consideration for assessments, because of an overriding public interest in other environmental qualities (clean water, biodiversity, minimization of the spread of toxicants on agricultural soils). The public interest in the preservation of these overriding environmental qualities is expressed in legislation or ordinances (conservation ordinances, state fertilization ordinance, state water act).

In environmentally-sensitive areas, intensification is not an option, in spite of offering high theoretical potentials for increased yields. Biomass yields (dry mass) vary between 1.5 t/ha·a from single-cut conservation grassland to 12.6 t/ha·a from intensively managed grasslands and fertilized public green areas. Similarly, biogas yields from residual grasslands vary between 200 m^3/t dry mass from conservation grassland to more than 650 m^3/t from public green spaces and intensively used grassland. In terms of multiplicative effects, this amounts to a 25-fold difference in terms of area-specific biogas yields – 300 m^3/ha from conservation grasslands and 7,560 m^3/ha from intensively managed grasslands, including fertilized public lawns. This difference explains inherent pressures towards intensification, associated with the use of grassland for biogas production. This difference warrants extreme caution when promoting or permitting new biogas operations supposedly founded on primarily using residual materials from conservation sites.

Apart from environmental reasons, intensification on residual areas such as public lawns or roadside edges often faces the obstacle that it is linked to more costly management activities in order to produce more of what is currently considered as waste. This inherent limitation can only be overcome with integrated concepts incorporating “producers” of the substrates (communities and other administrations), potential investors and operators of biogas plants. There is a need to link these parties through long-term contracts. Cooperation may include building facilities specifically suited to handle bulky substrates using dry fermentation techniques that currently do not pose direct competition with less labor-intensive operations, such as liquid fermentation and, if necessary, cover economic shortfalls as compared to more cost-effective operations based on maize from prime agricultural land.

In this context, we also perceive a need for a restructuring of the GREA in order to provide appropriate compensation for increased effort, need for investments and little yield when dealing with substrates from residual areas. There is currently no specific attempt to compensate for effort in the GREA, and compensations for the use of bulky landscape maintenance materials in general have proven to be insufficient as compared to compensations provided for popular liquid fermentation technologies.

We face the problem that putting pressures on ecosystems beyond the effects of climate change may accelerate extinctions and environmental degradation, and thus hamper future ecosystem capacities to adapt to such change. The ability of ecosystems to adapt to environmental change is rooted in biodiversity. In changing environments, biodiversity allows adaptive efficiency of ecosystem services and functions [29]. Despite national or even EU-wide efforts to reduce CO_2 emissions, environmental change appears to be inevitable. There are no signs that efforts at community, state, national or even EU levels can override global trends caused by developed and developing economies to use available fossil fuels as long as these are the cheapest and therefore in the short term the most economic means of producing energy.

Efforts by national governments to positively influence global environmental policies have to be applauded. But, climate change is not the only pressure on ecosystems by far. Other such pressures are under much more direct and fuller control of national, regional and local governments. Such pressures are often linked to land use, and land use intensity in particular [30]. A strong focus for national and regional policies has to be, at least, on not augmenting, ideally even releasing environmental pressures on ecosystems. Development of renewable energy should be evaluated in this context. There has to be a policy focus on responsibilities that can actually be accounted for.

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Conflict of Interest

The authors declare no conflict of interest.

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