Technical Report

Life Cycle Inventories for Biogas and Biomethane Processes

Author
Thomas Kägi, Mischa Zschokke, Fredy Dinkel, Carbotech AG

Zurich, January 2022

–

Contents

1 Introduction

The aim of this report is to summarise all the updates that Carbotech has carried out in the field of biogas over the last two years.

The following biogas and biomethane production types are covered with the present inventories:

- Biogas from bio waste
- Biogas from sewage sludge
- Biogas from agricultural waste (manure)
- Biomethane, purified by amino washing
- Biomethane, purified by pressure swing absorption (PSA)
- Biomethane, purified by membrane technology
- Biomethane, purified, market for gas network
- Biomethane, at user
- Heat, from biogas (manure) at cogen
- Electricity, from biogas (manure) at cogen

The following inventories are already described in Kägi et al. 2021:
- Heat, from biomethan, at boiler…
- Heat and electricity, from biomethan, at cogen….

The annual amount of energy produced with biogas for heat supply amounted to 366 GWh in 2018 (Hafner, 2019). Biogas from sewage sludge accounted for the largest share (223 GWh), followed by biogas from biogenic waste (137 GWh). At 5 GWh, biogas from agricultural waste accounts for only a small proportion of the total amount of energy required for heat generation. In terms of purification technologies, the most biogas was treated with amine washing in 2018 (203 GWh), followed by membrane technology (93 GWh) and PSA technology (55 GWh). 14 GWh are processed otherwise.

The following table shows an overview of the biogas and biomethane mix and methane emissions among the process chain for this update (based on 2018 – 2020 data).

Process	Unit	This update
Biogas from biowaste	g CH4 / kg biowaste input (or 0.1 m3 Biogas unallocated)	1.7
Biogas from sewage sludge	g CH4 / m3 Biogas	14
Biogas from manure	g CH4 / m3 Biogas	5.3
Biogas mix	%	
Biowaste		37%
Sewage sludge		61%
Agriculture (manure)		2%
Biomethane, purified by PSA	g CH4 / m3 biomethane	10.1
Biomethane, purified by membrane techn.	g CH4 / m3 biomethane	4.6
Biomethane, purified by amino washing	g CH4 / m3 biomethane	0.43
Biomethane mix	%	
PSA		15.7%
Membrane technology		26.5%
Amino washing		57.8%
other		n.a.

2 Biogas by anaerobic digestion

2.1 Biogas by anaerobic digestion of manure

2.1.1 Introduction

In addition to the production of biogas, the co-digestion of manure results in a change in the manure so that it has better plant availability after fermentation. However, this positive aspect is associated with higher ammonia emissions during manure application. In the existing inventories, the expected increase in ammonia emissions due to the better availability of nitrogen in the fermentation substrate is also taken into account when applying fermentation substrate using slurry tanks.
Another consequence of fermentation in an agricultural biogas plant is that the use of manure and dung in a biogas plant results in a reduction of methane emissions from manure and dung storage on the farm. These are not assigned to the biogas process as a credit as it is an indirect consequence of the biogas process. This is quite common for a generic database, but in practice it repeatedly leads to incorrect results if the users are not sufficiently aware of this issue. In order to avoid such incorrect calculations and corresponding interpretations, it makes sense to take into account not only the additional ammonia emissions but also the reduction in methane emissions. A more consistent option from the database point of view is that both effects are not assigned to the biogas process, but to the upstream and downstream processes.

Biogas production from manure is therefore modelled anew.

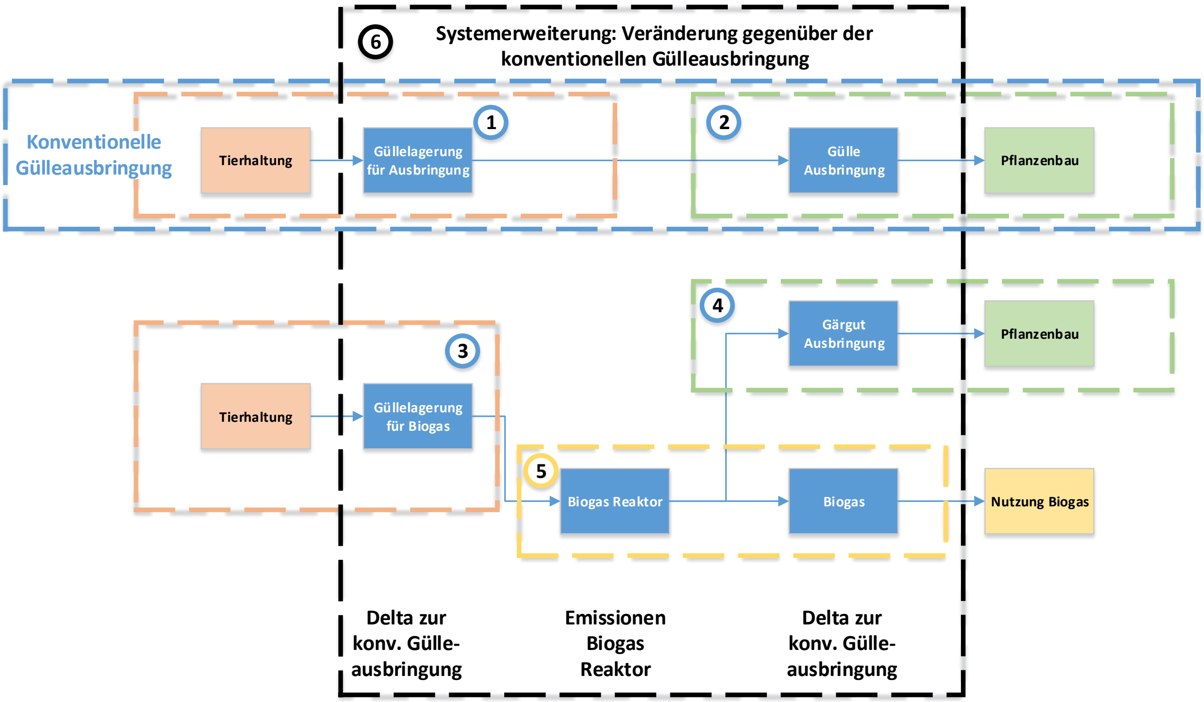
The following figure shows an overview of the composition of the system biogas from manure and the reference system conventional manure handling:

The actual biogas inventory contains the biogas production as well as the post-storage of the manure (5).

Manure storage for biogas (3) differs from conventional manure storage (1) mainly in the storage period, which is considerably shorter.

Manure application (4) differs from conventional manure application (2) mainly in slightly different ammonia and nitrous oxide emissions.

The benefits of biogas production from manure only become apparent when the overall system is taken into account (6). For this purpose, the difference in storage (3)-(1) and the difference in application (4)-(2) are added to the biogas production process (3). On the one hand, this procedure calculates the biogas correctly and, on the other hand, it allows the interested user the necessary comprehensibility or modelling of a specific situation.



2.1.2 Important basic values

Ammonia and nitrous oxide emissions in particular are highly dependent on the nitrogen content of the substrate. Therefore, the relevant nitrogen contents are first defined here and summarised in the following table.

According to the Inspectorate of the Composting and Digestion Industry (2020), the total nitrogen content (Ntot) of digestate is 3.9 kg N/m3 digestate on average. For comparable slurry (unfermented), in addition to the 3.9 kg N, the N losses during biogas production (6.3 g N from 7.7 g NH_3 and 1.4 g N from 2.3 g N_2O / m3 digestate slurry, see chapter 3. 3) and the average ammonia content in the biogas itself (0.05 vol.% according to Ellersdorfer & Harasek (2020) corresponds to 0.39 g NH_3 per m3 biogas or 19.6 g N per m3 substrate). Thus, the total nitrogen quantity (Ntot) of comparable manure (unvergoren) is 3.92 kg N/m3 manure on average.

According to the Inspectorate of the Composting and Digestion Industry (2020), the available nitrogen (Nverf.) is around 2.0 kg N/m3 digestate slurry. The proportion of available nitrogen is higher for fermentation products than for unfermented farmyard manure or substrate. According to the implementation instructions for biogas plants in agriculture(agridea, 2018), the higher nutrient availability for fermentation slurry is around 10 %. In this study, an average increase of 10 % was therefore calculated. With practically the same Ntot content of the slurry and a slightly lower nutrient availability, this results in rounded 1.8 kg Nverf. for slurry.

Tabelle 1: Nitrogen contents of slurry and digestate as used in this study.

	Unit	Average value
Slurry N_{tot}	kg N/m³	3.92
Slurry N_{verf}	kg N/m³	1.83
Digestate slurry N_{tot}	kg N/m³	3.90
Digestate slurry N_{verf}	kg N/m³	2.00

2.1.3 Storage of farmyard manure without fermentation (1) vs. submission for fermentation (3)

Methane emissions

According to Ökostrom (2020), methane emissions from the storage facility are 9.9 g CH4 per m3 of biogas produced. At around 30 m3 biogas per m3 manure input, methane emissions are 301 g CH4 / m3 farmyard manure. Ökostrom shows a 7.49 higher methane emission of the farmyard manure storage than the methane emissions of the biogas plant storage. Thus, the methane emission of the farmyard manure storage is 2,231 g CH4 / m3 farmyard manure. The method for quantifying methane emission reductions from agricultural biogas plants (Ökostrom Schweiz, 2017) served as the data basis for the methane emissions from farmyard manure storage. A cross comparison with top-down data on methane emissions from farmyard manure storage from the Greenhouse Inventory Switzerland (BAFU, 2021) results in 1,060 g CH4 / m3 (25,500 t CH4 per 24 million m3 of farmyard manure). This value is about half as high. In this study, the values from the method for quantifying methane emissions were used, as they appear to us to be derived in greater detail. However, it should be noted here that with a lower reference value for methane emissions, the savings (see Chapter 5) also become correspondingly smaller.

Ammonia emissions

Ammonia emissions from farmyard manure storage (slurry and manure) amount to around 6,900 t NH3-N per year with a farmyard manure quantity of around 24.037 million t per year according to the Agricultural Report(BLW, 2020). The ammonia emissions of farmyard manure storage are thus around 287 g NH3-N and 349 g NH3 per m3 of farmyard manure respectively.

Due to the short retention time of the farmyard manure for fermentation, the ammonia emissions originating from pre-storage are significantly lower. The ammonia emissions from the preliminary storage were calculated according to a study by Agroscope (Dauriat et al., 2012).

NH3 = (17/14) x C(Ntot) x 62% x EF2 x Tau

The amount of ammonia (NH_3) is calculated by multiplying the total nitrogen content (C(Ntot)) by the emission factor for ammonia (EF2) and 62% times the ratio of the retention time to the normal farmyard manure storage (Tau: 14%). 17% of all manure storage facilities in Switzerland are uncovered (https://www.bauernzeitung.ch/artikel/jetzt-muss-der-deckel-drauf-auf-die-guellesilos). With a total N quantity of 3.92 kg and an emission factor of 1.35% for covered storage and 13.5% for uncovered storage, this results in 14 g NH_3 / m^3 of farmyard manure during pre-storage for fermentation.

Nitrous oxide emissions

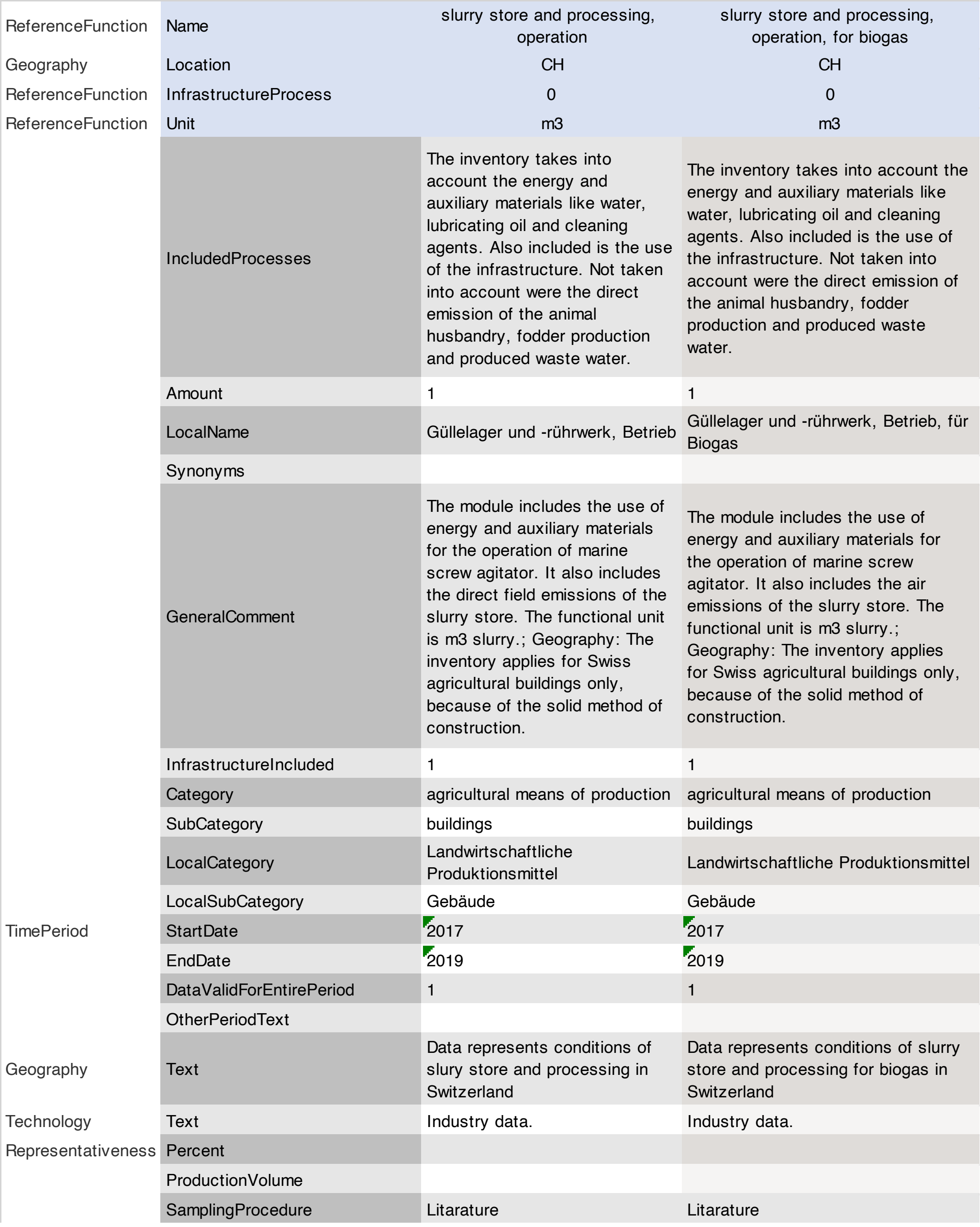
Nitrous oxide emissions from farmyard manure storage are 0.002 kg N_2O-N/kg N according to IPCC Guidelines. With a total N quantity of 3.92 kg, this results in 12 g N_2O emissions.
Due to the short retention time of the farmyard manure for fermentation, the nitrous oxide emissions originating from the preliminary storage are close to zero. The nitrous oxide emissions of the biogas plant including the preliminary storage were calculated according to a study by Agroscope (Dauriat et al., 2012).

$$N_2O = (44/28) \times (C(Ntot) - (14/17) \times ES(NH_3)) \times EF3 \times Tau$$

The amount of nitrous oxide (N_2O) is calculated by multiplying the difference of the total nitrogen content (C(Ntot) and the ammonia emission amount (ES(NH_3)) by the emission factor for nitrous oxide (EF3) times the ratio of the retention time to the normal farmyard manure storage (Tau: 14%).

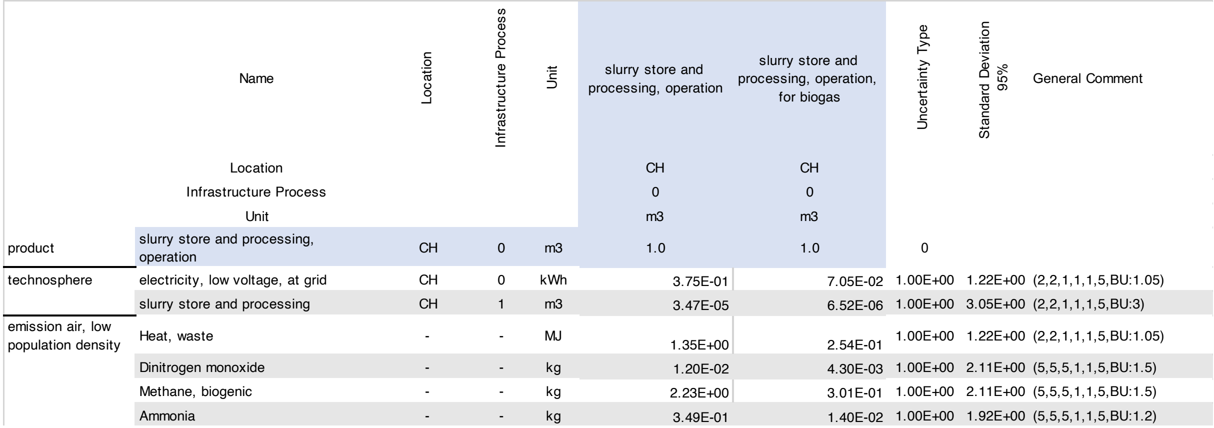
With a total N quantity of 3.92 kg and 14 g NH_3 emissions and a nitrous oxide emission factor of 0.5%, this results in 4.3 g N_2O / m^3 farmyard manure during pre-storage for fermentation.

For the inventory of manure storage and manure storage for biogas, the existing inventory "slurry store and processing, operation" of the UVEK 2018 database was used and the methane, nitrous oxide and ammonia emissions were adjusted accordingly.



ReferenceFunction	Name	slurry store and processing, operation	slurry store and processing, operation, for biogas
Geography	Location	CH	CH
ReferenceFunction	InfrastructureProcess	0	0
ReferenceFunction	Unit	m3	m3
	IncludedProcesses	The inventory takes into account the energy and auxiliary materials like water, lubricating oil and cleaning agents. Also included is the use of the infrastructure. Not taken into account were the direct emission of the animal husbandry, fodder production and produced waste water.	The inventory takes into account the energy and auxiliary materials like water, lubricating oil and cleaning agents. Also included is the use of the infrastructure. Not taken into account were the direct emission of the animal husbandry, fodder production and produced waste water.
	Amount	1	1
	LocalName	Güllelager und -rührwerk, Betrieb	Güllelager und -rührwerk, Betrieb, für Biogas
	Synonyms		
	GeneralComment	The module includes the use of energy and auxiliary materials for the operation of marine screw agitator. It also includes the direct field emissions of the slurry store. The functional unit is m3 slurry.; Geography: The inventory applies for Swiss agricultural buildings only, because of the solid method of construction.	The module includes the use of energy and auxiliary materials for the operation of marine screw agitator. It also includes the air emissions of the slurry store. The functional unit is m3 slurry.; Geography: The inventory applies for Swiss agricultural buildings only, because of the solid method of construction.
	InfrastructureIncluded	1	1
	Category	agricultural means of production	agricultural means of production
	SubCategory	buildings	buildings
	LocalCategory	Landwirtschaftliche Produktionsmittel	Landwirtschaftliche Produktionsmittel
	LocalSubCategory	Gebäude	Gebäude
TimePeriod	StartDate	2017	2017
	EndDate	2019	2019
	DataValidForEntirePeriod	1	1
	OtherPeriodText		
Geography	Text	Data represents conditions of slury store and processing in Switzerland	Data represents conditions of slurry store and processing for biogas in Switzerland
Technology	Text	Industry data.	Industry data.
Representativeness	Percent		
	ProductionVolume		
	SamplingProcedure	Litarature	Litarature

Figure 1: Metadata of slurry store and processing operation.



	Name	Location	Infrastructure Process	Unit	slurry store and processing, operation	slurry store and processing, operation, for biogas	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH	CH			
	Infrastructure Process				0	0			
	Unit				m3	m3			
product	slurry store and processing, operation	CH	0	m3	1.0	1.0	0		
technosphere	electricity, low voltage, at grid	CH	0	kWh	3.75E-01	7.05E-02	1.00E+00	1.22E+00	(2,2,1,1,1,5,BU:1.05)
	slurry store and processing	CH	1	m3	3.47E-05	6.52E-06	1.00E+00	3.05E+00	(2,2,1,1,1,5,BU:3)
emission air, low population density	Heat, waste	-	-	MJ	1.35E+00	2.54E-01	1.00E+00	1.22E+00	(2,2,1,1,1,5,BU:1.05)
	Dinitrogen monoxide	-	-	kg	1.20E-02	4.30E-03	1.00E+00	2.11E+00	(5,5,5,1,1,5,BU:1.5)
	Methane, biogenic	-	-	kg	2.23E+00	3.01E-01	1.00E+00	2.11E+00	(5,5,5,1,1,5,BU:1.5)
	Ammonia	-	-	kg	3.49E-01	1.40E-02	1.00E+00	1.92E+00	(5,5,5,1,1,5,BU:1.2)

Figure 2: Unit process raw data of slurry store and processing operation.

2.1.4 Fermentation in biogas plant (5)

Methane emissions

According to Ökostrom (Ökostrom Schweiz, 2020), the methane emissions of the biogas plant itself, including transports for substrates (without additional charge), are 2.6 g CH4 per m3 of biogas produced. At around 30.4 m3 of biogas per m3 of slurry input, methane emissions are 78 g CH4 / m3 of slurry. Although the subsequent storage of the manure is usually carried out in closed systems, and thus in the ideal case no additional methane emissions are to be expected, it is common to use additional storage when the subsequent storage is full, which is then usually no longer covered. This is particularly the case with longer storage periods. Due to a lack of data, we assume here that half of the manure is stored in additional storage facilities and that half of the maximum permissible residual methane content is emitted as methane. Thus, 0.38% additional methane is produced, which corresponds to an amount of 82 g CH4 / m3 digestate. In total, the methane emissions of the biogas plant including the secondary storage are thus about 160 g CH4 / m3 digestate.

Ammonia emissions

Data for ammonia emissions during biogas production itself or after storage were not known. As an estimate, it was assumed that the ammonia emissions between pre-storage and biogas production including post-storage are in a similar ratio to the reported methane emissions between pre-storage and biogas production including post-storage. This approximation results in about 7.5 g NH3 per m3 of manure.

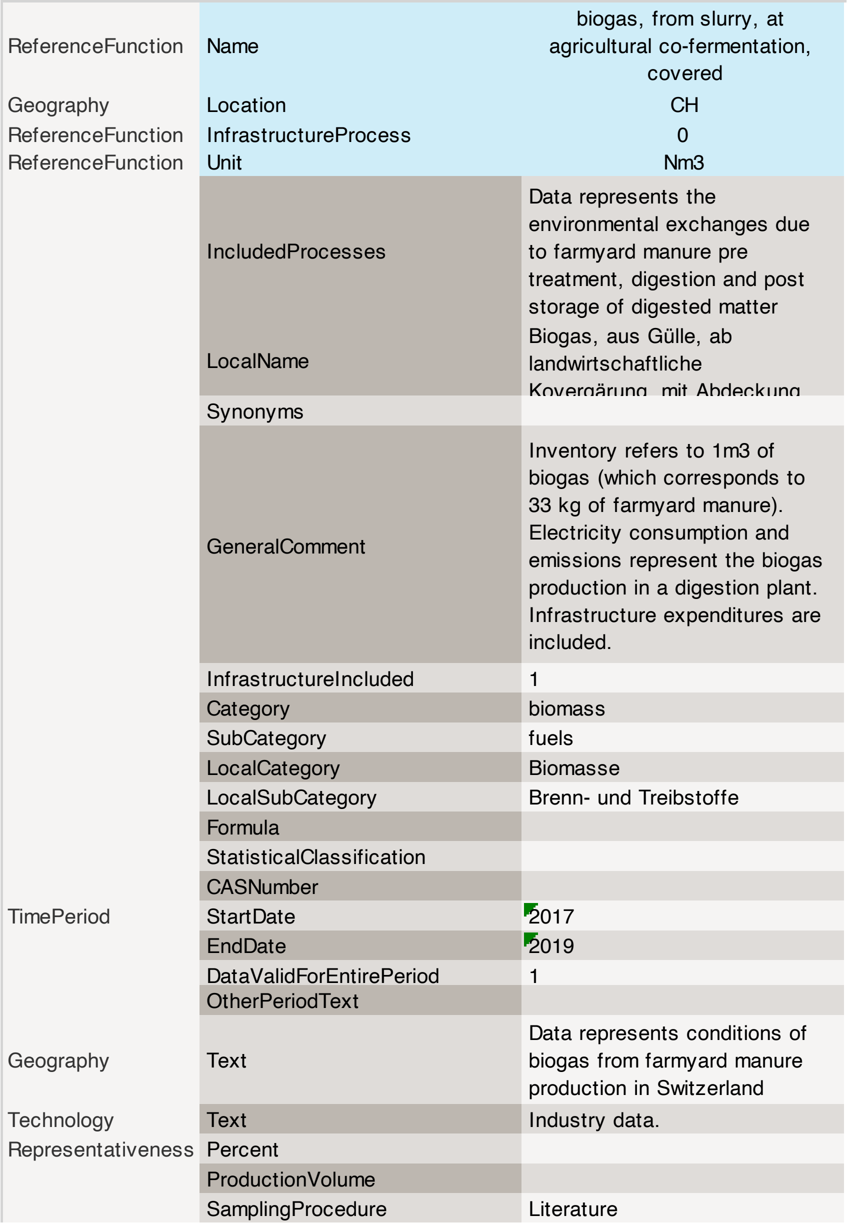
Nitrous oxide emissions

Data for nitrous oxide emissions during biogas production itself or after storage were not known. As an estimate, it was assumed that the nitrous oxide emissions between pre-storage and biogas production including post-storage are in a similar ratio to the reported methane emissions between pre-storage and biogas production including post-storage. This approximation results in about 2.3 g N2O per m3 of manure.

Energy self-consumption of the biogas plants

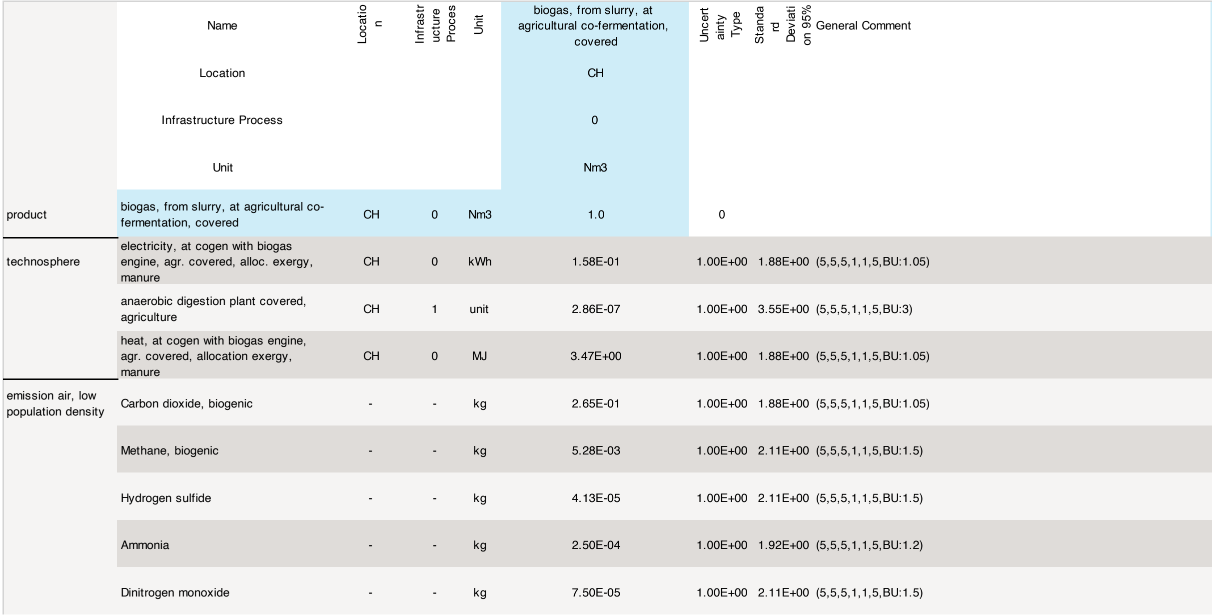
For the operation of the biogas plants, 0.16 kWh of electricity and 3.5 MJ of heat are required per m3 of biogas produced. Agricultural biogas plants, which primarily convert the biogas into electricity, use their own electricity and heat from the combined heat and power plant (CHP) for their electricity and heat requirements. For the electricity demand, the inventory electricity, at cogen with biogas engine, agri-cultural covered, alloc exergy and for the heat demand, the inventory heat, at cogen with biogas engine, agricultural covered, alloc exergy was used. For the correct allocation to heat and electricity of the CHP unit, the exergy approach was used, taking into account the electricity utilisation rate of 33.9 % and the heat utilisation rate of 31.8 % (Anspach & Gysler, 2020).

For the inventory of manure fermentation into biogas, the existing inventory "biogas, from slurry, at agricultural co-fermentation, covered" of the UVEK 2018 database was used and the methane, nitrous oxide and ammonia emissions were adjusted accordingly and the energy consumption of the biogas plants was added.



ReferenceFunction	Name	biogas, from slurry, at agricultural co-fermentation, covered
Geography	Location	CH
ReferenceFunction	InfrastructureProcess	0
ReferenceFunction	Unit	Nm3
	IncludedProcesses	Data represents the environmental exchanges due to farmyard manure pre treatment, digestion and post storage of digested matter
	LocalName	Biogas, aus Gülle, ab landwirtschaftliche Kovergärung, mit Abdeckung
	Synonyms	
	GeneralComment	Inventory refers to 1m3 of biogas (which corresponds to 33 kg of farmyard manure). Electricity consumption and emissions represent the biogas production in a digestion plant. Infrastructure expenditures are included.
	InfrastructureIncluded	1
	Category	biomass
	SubCategory	fuels
	LocalCategory	Biomasse
	LocalSubCategory	Brenn- und Treibstoffe
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2017
	EndDate	2019
	DataValidForEntirePeriod	1
	OtherPeriodText	
Geography	Text	Data represents conditions of biogas from farmyard manure production in Switzerland
Technology	Text	Industry data.
Representativeness	Percent	
	ProductionVolume	
	SamplingProcedure	Literature

Figure 3: Metadata of biogas, from slurry



	Name	Location	Infrastructure Proces	Unit	biogas, from slurry, at agricultural co-fermentation, covered	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH			
	Infrastructure Process				0			
	Unit				Nm3			
product	biogas, from slurry, at agricultural co-fermentation, covered	CH	0	Nm3	1.0	0		
technosphere	electricity, at cogen with biogas engine, agr. covered, alloc. exergy, manure	CH	0	kWh	1.58E-01	1.00E+00	1.88E+00	(5,5,5,1,1,5,BU:1.05)
	anaerobic digestion plant covered, agriculture	CH	1	unit	2.86E-07	1.00E+00	3.55E+00	(5,5,5,1,1,5,BU:3)
	heat, at cogen with biogas engine, agr. covered, allocation exergy, manure	CH	0	MJ	3.47E+00	1.00E+00	1.88E+00	(5,5,5,1,1,5,BU:1.05)
emission air, low population density	Carbon dioxide, biogenic	-	-	kg	2.65E-01	1.00E+00	1.88E+00	(5,5,5,1,1,5,BU:1.05)
	Methane, biogenic	-	-	kg	5.28E-03	1.00E+00	2.11E+00	(5,5,5,1,1,5,BU:1.5)
	Hydrogen sulfide	-	-	kg	4.13E-05	1.00E+00	2.11E+00	(5,5,5,1,1,5,BU:1.5)
	Ammonia	-	-	kg	2.50E-04	1.00E+00	1.92E+00	(5,5,5,1,1,5,BU:1.2)
	Dinitrogen monoxide	-	-	kg	7.50E-05	1.00E+00	2.11E+00	(5,5,5,1,1,5,BU:1.5)

Figure 4: Process raw data of biogas, from slurry

2.1.5 Application of farmyard manure (2) and digestate (4)

Methane emissions

The application of farmyard manure and digestate takes place under aerobic conditions, so that no significant methane emissions are to be expected.

Ammonia emissions

Ammonia emissions from farmyard manure application were calculated using the formula used in ecoinvent inventories to calculate direct field emissions, which is based on the AGRAMON model(Nemecek & Schnetzer, 2011). The formula states that on average 50% of the available nitrogen is emitted as ammonia. This value applies to the conventional application of farmyard manure.

When spreading with a drag hose, the ammonia emission is reduced by about 30% - 35% (Schoop & Fischler, 2020). If a drag shoe or slurry drill is used, the reduction is 30%-60% and around 70% respectively. Since, according to the Direct Payments Ordinance, techniques are supported that have at least the same effect as the drag hose, an average reduction of 35% is calculated in this study.

In Switzerland, 40% of slurry is spread with drag hoses or similar emission-reducing spreading techniques (https://www.sbv-usp.ch/de/veto-zum-schleppschlauch-obligatorium/.) The compulsory use of drag hoses announced by the Federal Council at the beginning of 2020 was approved by the National Council, so that in future a share of approx. 100% of drag hoses can be expected.

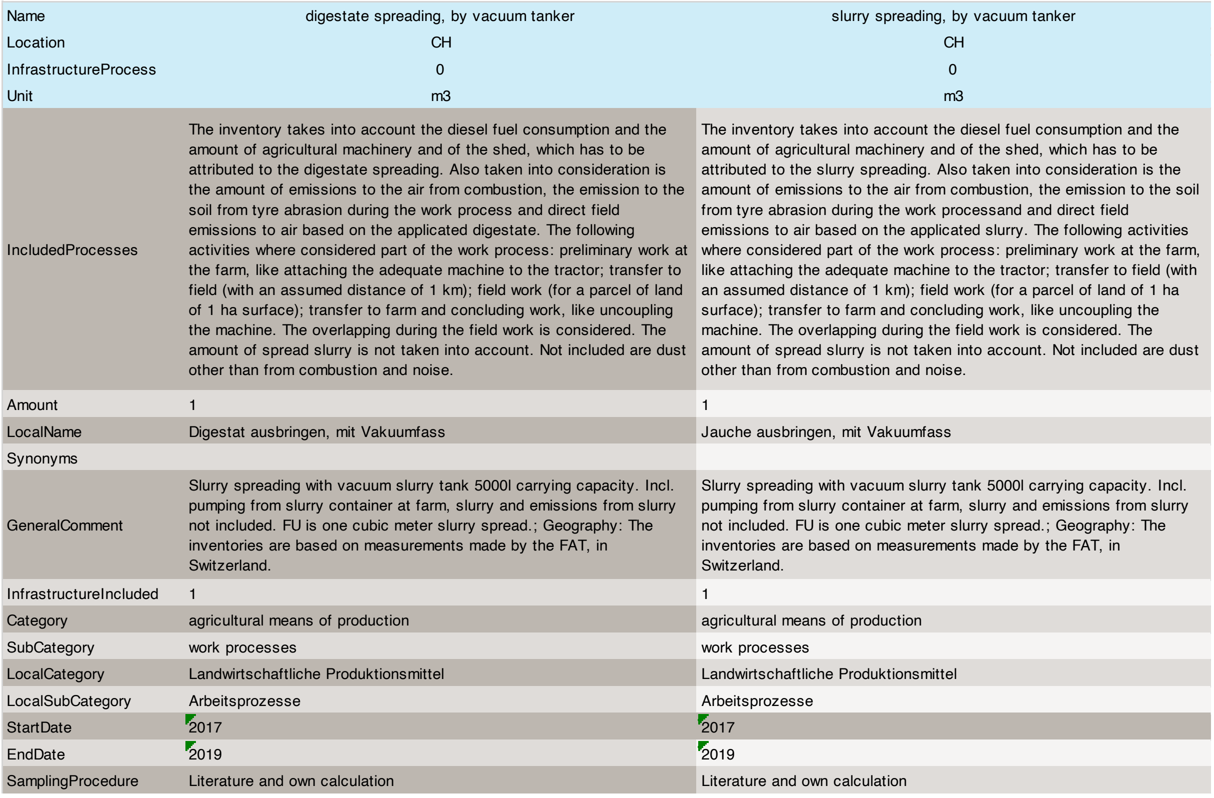
For farmyard manure as a reference, a nitrogen content of 43.92 kg per m3 of farmyard manure was calculated and 1.83 kg of available nitrogen per m3 of farmyard manure and the assumption that 100% will be applied with drag hoses in future. This results in 594 g NH3/m3 of manure applied.

With about 2.0 kg N available for manure and 100 % application by drag hose, this results in 650 g NH3/m3 of manure applied.

Nitrous oxide emissions

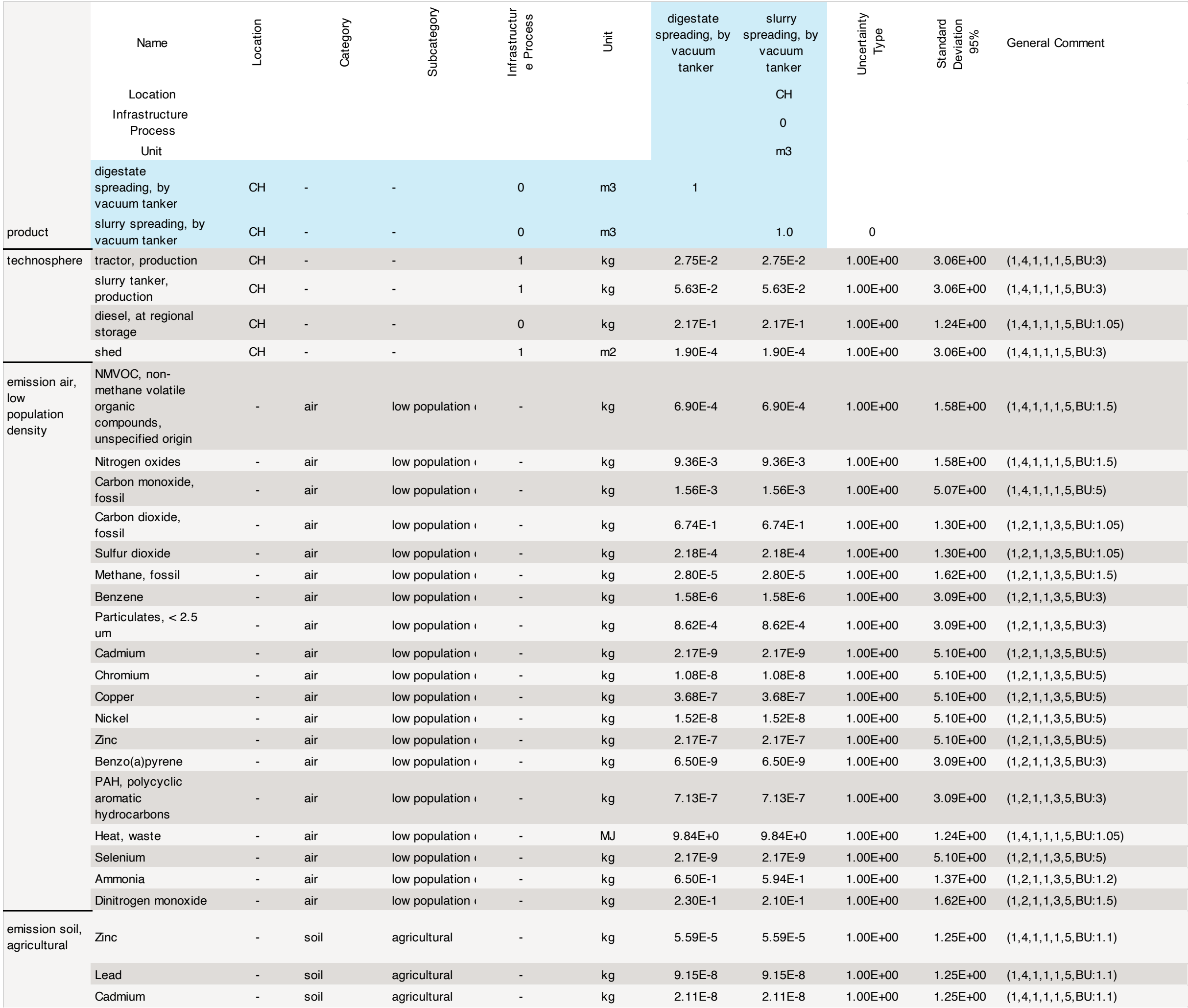
Nitrous oxide emissions from farmyard manure application were calculated using the formula for calculating direct field emissions that is compatible in ecoinvent inventories and IPCC (Nemecek & Schnetzer, 2011). The formula states that 10% of the available nitrogen minus the nitrogen emitted as ammonia is emitted as nitrous oxide.

Using the amounts of available nitrogen and ammonia emissions mentioned in chapter 2.4.2, the following nitrous oxide emissions result:
Farmyard manure: 210 g N2O/m3 Farmyard manure.
Fermentation substrate: 230 g N2O/m3 Fermentation substrate



Name	digestate spreading, by vacuum tanker	slurry spreading, by vacuum tanker
Location	CH	CH
InfrastructureProcess	0	0
Unit	m3	m3
IncludedProcesses	The inventory takes into account the diesel fuel consumption and the amount of agricultural machinery and of the shed, which has to be attributed to the digestate spreading. Also taken into consideration is the amount of emissions to the air from combustion, the emission to the soil from tyre abrasion during the work process and direct field emissions to air based on the applicated digestate. The following activities where considered part of the work process: preliminary work at the farm, like attaching the adequate machine to the tractor; transfer to field (with an assumed distance of 1 km); field work (for a parcel of land of 1 ha surface); transfer to farm and concluding work, like uncoupling the machine. The overlapping during the field work is considered. The amount of spread slurry is not taken into account. Not included are dust other than from combustion and noise.	The inventory takes into account the diesel fuel consumption and the amount of agricultural machinery and of the shed, which has to be attributed to the slurry spreading. Also taken into consideration is the amount of emissions to the air from combustion, the emission to the soil from tyre abrasion during the work processand and direct field emissions to air based on the applicated slurry. The following activities where considered part of the work process: preliminary work at the farm, like attaching the adequate machine to the tractor; transfer to field (with an assumed distance of 1 km); field work (for a parcel of land of 1 ha surface); transfer to farm and concluding work, like uncoupling the machine. The overlapping during the field work is considered. The amount of spread slurry is not taken into account. Not included are dust other than from combustion and noise.
Amount	1	1
LocalName	Digestat ausbringen, mit Vakuumfass	Jauche ausbringen, mit Vakuumfass
Synonyms		
GeneralComment	Slurry spreading with vacuum slurry tank 5000l carrying capacity. Incl. pumping from slurry container at farm, slurry and emissions from slurry not included. FU is one cubic meter slurry spread.; Geography: The inventories are based on measurements made by the FAT, in Switzerland.	Slurry spreading with vacuum slurry tank 5000l carrying capacity. Incl. pumping from slurry container at farm, slurry and emissions from slurry not included. FU is one cubic meter slurry spread.; Geography: The inventories are based on measurements made by the FAT, in Switzerland.
InfrastructureIncluded	1	1
Category	agricultural means of production	agricultural means of production
SubCategory	work processes	work processes
LocalCategory	Landwirtschaftliche Produktionsmittel	Landwirtschaftliche Produktionsmittel
LocalSubCategory	Arbeitsprozesse	Arbeitsprozesse
StartDate	2017	2017
EndDate	2019	2019
SamplingProcedure	Literature and own calculation	Literature and own calculation

Figure 5: Metadata of slurry spreading



	Name	Location	Category	Subcategory	Infrastructure Process	Unit	digestate spreading, by vacuum tanker	slurry spreading, by vacuum tanker	Uncertainty Type	Standard Deviation 95%	General Comment
	Location							CH			
	Infrastructure Process							0			
	Unit							m3			
	digestate spreading, by vacuum tanker	CH	-	-	0	m3	1				
product	slurry spreading, by vacuum tanker	CH	-	-	0	m3		1.0	0		
technosphere	tractor, production	CH	-	-	1	kg	2.75E-2	2.75E-2	1.00E+00	3.06E+00	(1,4,1,1,1,5,BU:3)
	slurry tanker, production	CH	-	-	1	kg	5.63E-2	5.63E-2	1.00E+00	3.06E+00	(1,4,1,1,1,5,BU:3)
	diesel, at regional storage	CH	-	-	0	kg	2.17E-1	2.17E-1	1.00E+00	1.24E+00	(1,4,1,1,1,5,BU:1.05)
	shed	CH	-	-	1	m2	1.90E-4	1.90E-4	1.00E+00	3.06E+00	(1,4,1,1,1,5,BU:3)
emission air, low population density	NMVOC, non-methane volatile organic compounds, unspecified origin	-	air	low population	-	kg	6.90E-4	6.90E-4	1.00E+00	1.58E+00	(1,4,1,1,1,5,BU:1.5)
	Nitrogen oxides	-	air	low population	-	kg	9.36E-3	9.36E-3	1.00E+00	1.58E+00	(1,4,1,1,1,5,BU:1.5)
	Carbon monoxide, fossil	-	air	low population	-	kg	1.56E-3	1.56E-3	1.00E+00	5.07E+00	(1,4,1,1,1,5,BU:5)
	Carbon dioxide, fossil	-	air	low population	-	kg	6.74E-1	6.74E-1	1.00E+00	1.30E+00	(1,2,1,1,3,5,BU:1.05)
	Sulfur dioxide	-	air	low population	-	kg	2.18E-4	2.18E-4	1.00E+00	1.30E+00	(1,2,1,1,3,5,BU:1.05)
	Methane, fossil	-	air	low population	-	kg	2.80E-5	2.80E-5	1.00E+00	1.62E+00	(1,2,1,1,3,5,BU:1.5)
	Benzene	-	air	low population	-	kg	1.58E-6	1.58E-6	1.00E+00	3.09E+00	(1,2,1,1,3,5,BU:3)
	Particulates, < 2.5 um	-	air	low population	-	kg	8.62E-4	8.62E-4	1.00E+00	3.09E+00	(1,2,1,1,3,5,BU:3)
	Cadmium	-	air	low population	-	kg	2.17E-9	2.17E-9	1.00E+00	5.10E+00	(1,2,1,1,3,5,BU:5)
	Chromium	-	air	low population	-	kg	1.08E-8	1.08E-8	1.00E+00	5.10E+00	(1,2,1,1,3,5,BU:5)
	Copper	-	air	low population	-	kg	3.68E-7	3.68E-7	1.00E+00	5.10E+00	(1,2,1,1,3,5,BU:5)
	Nickel	-	air	low population	-	kg	1.52E-8	1.52E-8	1.00E+00	5.10E+00	(1,2,1,1,3,5,BU:5)
	Zinc	-	air	low population	-	kg	2.17E-7	2.17E-7	1.00E+00	5.10E+00	(1,2,1,1,3,5,BU:5)
	Benzo(a)pyrene	-	air	low population	-	kg	6.50E-9	6.50E-9	1.00E+00	3.09E+00	(1,2,1,1,3,5,BU:3)
	PAH, polycyclic aromatic hydrocarbons	-	air	low population	-	kg	7.13E-7	7.13E-7	1.00E+00	3.09E+00	(1,2,1,1,3,5,BU:3)
	Heat, waste	-	air	low population	-	MJ	9.84E+0	9.84E+0	1.00E+00	1.24E+00	(1,4,1,1,1,5,BU:1.05)
	Selenium	-	air	low population	-	kg	2.17E-9	2.17E-9	1.00E+00	5.10E+00	(1,2,1,1,3,5,BU:5)
	Ammonia	-	air	low population	-	kg	6.50E-1	5.94E-1	1.00E+00	1.37E+00	(1,2,1,1,3,5,BU:1.2)
	Dinitrogen monoxide	-	air	low population	-	kg	2.30E-1	2.10E-1	1.00E+00	1.62E+00	(1,2,1,1,3,5,BU:1.5)
emission soil, agricultural	Zinc	-	soil	agricultural	-	kg	5.59E-5	5.59E-5	1.00E+00	1.25E+00	(1,4,1,1,1,5,BU:1.1)
	Lead	-	soil	agricultural	-	kg	9.15E-8	9.15E-8	1.00E+00	1.25E+00	(1,4,1,1,1,5,BU:1.1)
	Cadmium	-	soil	agricultural	-	kg	2.11E-8	2.11E-8	1.00E+00	1.25E+00	(1,4,1,1,1,5,BU:1.1)

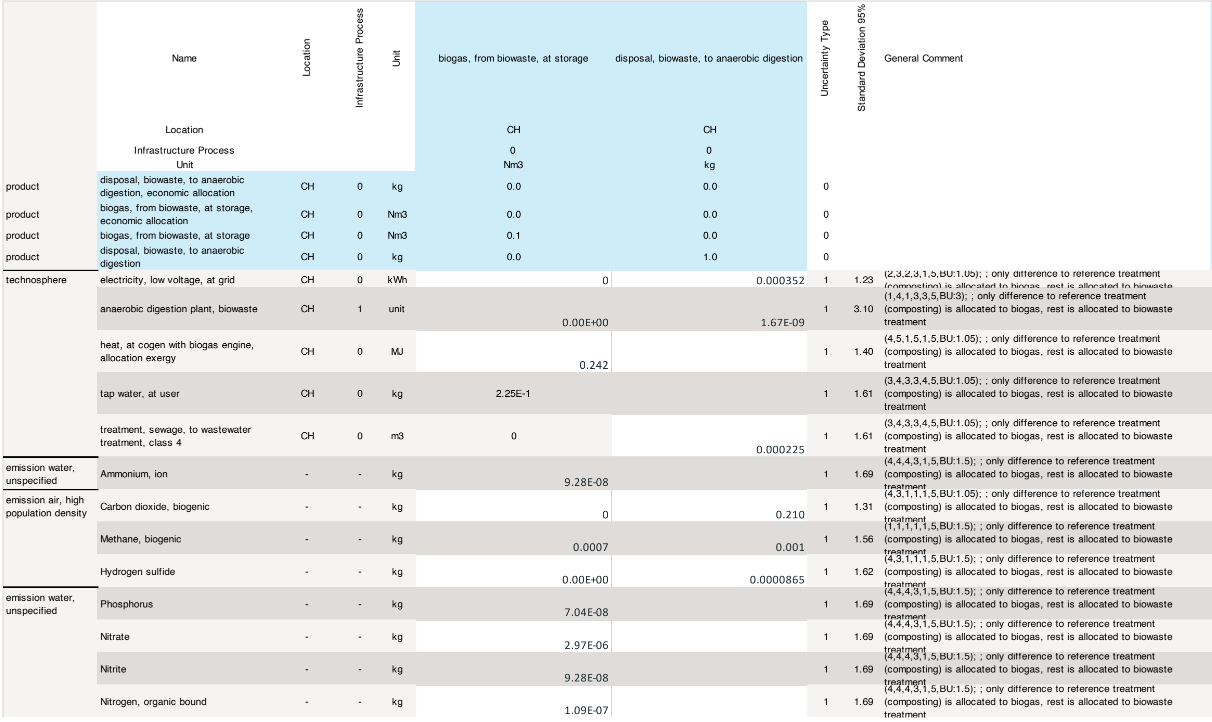
Figure 6: Process raw data of slurry spreading

2.2 Biogas by anaerobic digestion of bio-waste

For biogas from biowaste fermentation, the existing data based on the BFE study from 2012 was used (Dinkel et al. 2012). Electricity consumption and emissions represent the biogas production in a digestion plant. Infrastructure expenditures are included. Methane emissions are based on the sum of pre-storage, fermentation and integrated cogeneration, but without post rotting, which is not common anymore and without purification, which is outside the system boundary of this process (see Dinkel et al. 2012, Tab 4). In order to comply with the requirements of the UVEK and KBOB database, the following allocation approach was implemented: Composting and fermentation are the two viable, legally prescribed options for organic waste treatment. Fermentation is done to additionally produce energy. Therefore, only the difference in efforts and emissions between fermentation and composting are attributed to biogas production. Data for composting as the reference organic waste treatment option are also based on Dinkel et al 2012. With regard to methane, the composting systems shows 1g of CH4 per kg of biowaste. Therefore 0.7g of CH4 is allocated to the biogas production system.

ReferenceFunction	Name	biogas, from biowaste, at storage	disposal, biowaste, to anaerobic digestion
Geography	Location	CH	CH
ReferenceFunction	InfrastructureProcess	0	0
ReferenceFunction	Unit	Nm3	kg
DataSetInformation	Type	1	1
	Version	1.0	1.0
	energyValues	0	0
	LanguageCode	en	en
	LocalLanguageCode	de	de
DataEntryBy	Person	101	101
	QualityNetwork	1	1
ReferenceFunction	DataSetRelatesToProduct	1	1
	IncludedProcesses	Data represents the environmental exchanges due to biowaste pre treatment biowaste digestion and post-composting of digested matter	Data represents the environmental exchanges due to biowaste pre treatment biowaste digestion and post-composting of digested matter
	Amount	0.1	1
	LocalName	Biogas, aus Bioabfall, ab Speicher	disposal, biowaste, to anaerobic digestion
	Synonyms		
	GeneralComment	Inventory refers to 0.1 m3 biogas. Electricity consumption and emissions represent the biogas production in a digestion plant. Infrastructure expenditures are included. Methane emissions are based on Dinkel et al. 2012, Ökobilanzen zur Biomasseverwertung, Tab 4: sum of pre-storage, fermentation and cogen, but without post rotting (not common anymore) and purification (outside the systemboundary). In order to comply with the requirements of the UVEK and KBOB database, the following allocation approach was implemented: Composting and fermentation are the two viable, legally prescribed options for organic waste treatment. Fermentation is done to additionally produce energy. This leads to the following allocation approach: only the difference in efforts and emissions between fermentation and composting are attributed. Data for composting are also based on Dinkel et al 2012.	Inventory refers to 1 kg of biowaste. Electricity consumption and emissions represent the biogas production in a digestion plant. Infrastructure expenditures are included. Methane emissions are based on Dinkel et al. 2012, Ökobilanzen zur Biomasseverwertung, Tab 4: sum of pre-storage, fermentation and cogen, but without post rotting (not common anymore) and purification (outside the systemboundary). In order to comply with the requirements of the UVEK and KBOB database, the following allocation approach was implemented: Composting and fermentation are the two viable, legally prescribed options for organic waste treatment. Fermentation is done to additionally produce energy. This leads to the following allocation approach: only the difference in efforts and emissions between fermentation and composting are attributed.
	InfrastructureIncluded	1	1
	Category	biomass	biomass
	SubCategory	fuels	fuels
	LocalCategory	Biomasse	Biomasse
	LocalSubCategory	Brenn- und Treibstoffe	Brenn- und Treibstoffe
	Formula		
	StatisticalClassification		
	CASNumber		
TimePeriod	StartDate	2016	2016
	EndDate	2016	2016
	DataValidForEntirePeriod	1	1
	OtherPeriodText		
Geography	Text	Data represents conditions of biogas from biowaste production in Switzerland	Data represents conditions of biogas from biowaste production in Switzerland
Technology	Text	Industry data.	Industry data.
Representativeness	Percent		
	ProductionVolume		
	SamplingProcedure	Data provided by factories	Data provided by factories
	Extrapolations	none	none
	UncertaintyAdjustments	none	none

Figure 7: Metadata of biowaste fermentation with the two co-products biogas and disposal service.



	Name	Location	Infrastructure Process	Unit	biogas, from biowaste, at storage	disposal, biowaste, to anaerobic digestion	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH	CH			
	Infrastructure Process				0	0			
	Unit				Nm3	kg			
product	disposal, biowaste, to anaerobic digestion, economic allocation	CH	0	kg	0.0	0.0	0		
product	biogas, from biowaste, at storage, economic allocation	CH	0	Nm3	0.0	0.0	0		
product	biogas, from biowaste, at storage	CH	0	Nm3	0.1	0.0	0		
product	disposal, biowaste, to anaerobic digestion	CH	0	kg	0.0	1.0	0		
technosphere	electricity, low voltage, at grid	CH	0	kWh	0	0.000352	1	1.23	(2,3,2,3,1,5,BU:1.05); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste
	anaerobic digestion plant, biowaste	CH	1	unit	0.00E+00	1.67E-09	1	3.10	(1,4,1,3,3,5,BU:3); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste treatment
	heat, at cogen with biogas engine, allocation exergy	CH	0	MJ	0.242		1	1.40	(4,5,1,5,1,5,BU:1.05); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste treatment
	tap water, at user	CH	0	kg	2.25E-1		1	1.61	(3,4,3,3,4,5,BU:1.05); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste treatment
	treatment, sewage, to wastewater treatment, class 4	CH	0	m3	0	0.000225	1	1.61	(3,4,3,3,4,5,BU:1.05); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste treatment
emission water, unspecified	Ammonium, ion	-	-	kg	9.28E-08		1	1.69	(4,4,4,3,1,5,BU:1.5); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste treatment
emission air, high population density	Carbon dioxide, biogenic	-	-	kg	0	0.210	1	1.31	(4,3,1,1,1,5,BU:1.05); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste treatment
	Methane, biogenic	-	-	kg	0.0007	0.001	1	1.56	(1,1,1,1,1,5,BU:1.5); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste treatment
	Hydrogen sulfide	-	-	kg	0.00E+00	0.0000865	1	1.62	(4,3,1,1,1,5,BU:1.5); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste treatment
emission water, unspecified	Phosphorus	-	-	kg	7.04E-08		1	1.69	(4,4,4,3,1,5,BU:1.5); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste treatment
	Nitrate	-	-	kg	2.97E-06		1	1.69	(4,4,4,3,1,5,BU:1.5); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste treatment
	Nitrite	-	-	kg	9.28E-08		1	1.69	(4,4,4,3,1,5,BU:1.5); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste treatment
	Nitrogen, organic bound	-	-	kg	1.09E-07		1	1.69	(4,4,4,3,1,5,BU:1.5); ; only difference to reference treatment (composting) is allocated to biogas, rest is allocated to biowaste treatment

Figure 8: Unit process raw data of biowaste fermentation with the two co-products biogas and disposal service.

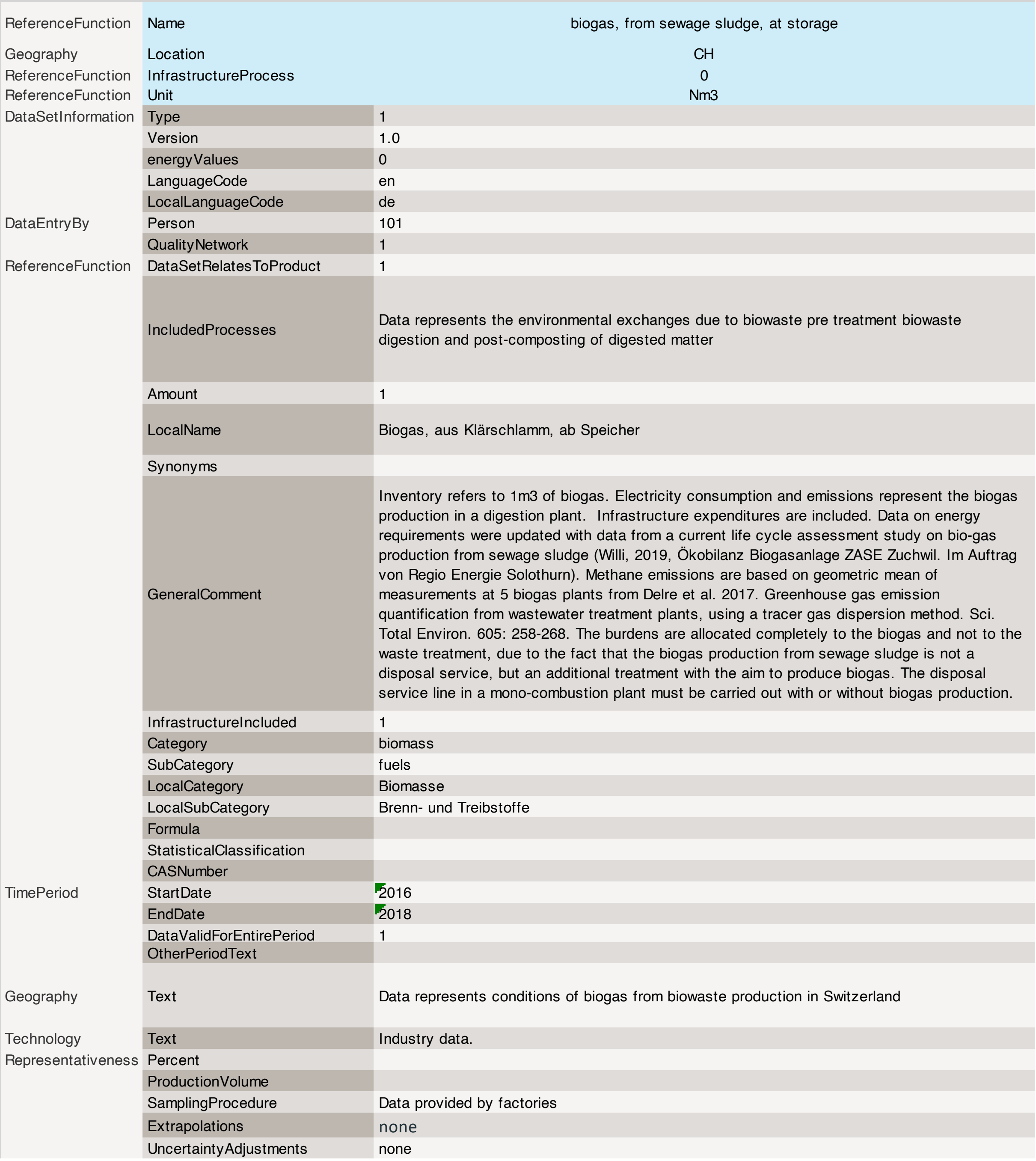
2.3 Biogas by anaerobic digestion of sewage sludge

The inventory is based on the existing inventory anaerobic digestion of sewage sludge. Data on energy requirements were updated with data from a current life cycle assessment study on biogas production from sewage sludge (Willi, 2019). Per m^3 of biogas produced the following energy is used:

- 0.197 kWh of electricity, low voltage, CH market mix
- 3.546 MJ Heat from natural gas.

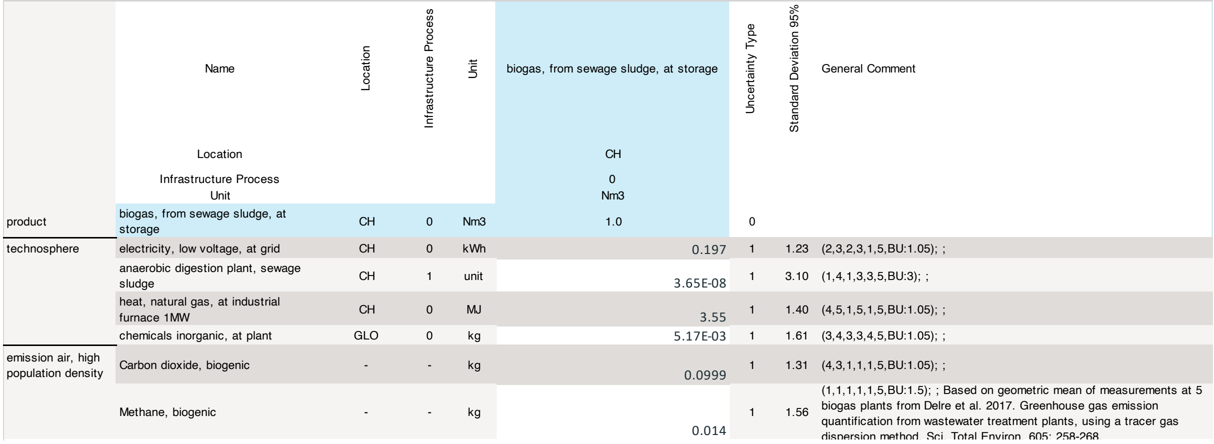
Methane emissions (14g / m3 of biogas) are based on geometric mean of measurements at 5 biogas plants from Delre et al. (2017).

The burdens are allocated completely to the biogas and not to the waste treatment, due to the fact that the biogas production from sewage sludge is not a disposal service, but an additional treatment with the aim to produce biogas. The disposal service line in a mono-combustion plant must be carried out with or without biogas production.



ReferenceFunction	Name	biogas, from sewage sludge, at storage
Geography	Location	CH
ReferenceFunction	InfrastructureProcess	0
ReferenceFunction	Unit	Nm3
DataSetInformation	Type	1
	Version	1.0
	energyValues	0
	LanguageCode	en
	LocalLanguageCode	de
DataEntryBy	Person	101
	QualityNetwork	1
ReferenceFunction	DataSetRelatesToProduct	1
	IncludedProcesses	Data represents the environmental exchanges due to biowaste pre treatment biowaste digestion and post-composting of digested matter
	Amount	1
	LocalName	Biogas, aus Klärschlamm, ab Speicher
	Synonyms	
	GeneralComment	Inventory refers to 1m3 of biogas. Electricity consumption and emissions represent the biogas production in a digestion plant. Infrastructure expenditures are included. Data on energy requirements were updated with data from a current life cycle assessment study on bio-gas production from sewage sludge (Willi, 2019, Ökobilanz Biogasanlage ZASE Zuchwil. Im Auftrag von Regio Energie Solothurn). Methane emissions are based on geometric mean of measurements at 5 biogas plants from Delre et al. 2017. Greenhouse gas emission quantification from wastewater treatment plants, using a tracer gas dispersion method. Sci. Total Environ. 605: 258-268. The burdens are allocated completely to the biogas and not to the waste treatment, due to the fact that the biogas production from sewage sludge is not a disposal service, but an additional treatment with the aim to produce biogas. The disposal service line in a mono-combustion plant must be carried out with or without biogas production.
	InfrastructureIncluded	1
	Category	biomass
	SubCategory	fuels
	LocalCategory	Biomasse
	LocalSubCategory	Brenn- und Treibstoffe
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2016
	EndDate	2018
	DataValidForEntirePeriod	1
	OtherPeriodText	
Geography	Text	Data represents conditions of biogas from biowaste production in Switzerland
Technology	Text	Industry data.
Representativeness	Percent	
	ProductionVolume	
	SamplingProcedure	Data provided by factories
	Extrapolations	none
	UncertaintyAdjustments	none

Figure 9: Metadata of biogas from sewage sludge



	Name	Location	Infrastructure Process	Unit	biogas, from sewage sludge, at storage	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH			
	Infrastructure Process				0			
	Unit				Nm3			
product	biogas, from sewage sludge, at storage	CH	0	Nm3	1.0	0		
technosphere	electricity, low voltage, at grid	CH	0	kWh	0.197	1	1.23	(2,3,2,3,1,5,BU:1.05); ;
	anaerobic digestion plant, sewage sludge	CH	1	unit	3.65E-08	1	3.10	(1,4,1,3,3,5,BU:3); ;
	heat, natural gas, at industrial furnace 1MW	CH	0	MJ	3.55	1	1.40	(4,5,1,5,1,5,BU:1.05); ;
	chemicals inorganic, at plant	GLO	0	kg	5.17E-03	1	1.61	(3,4,3,3,4,5,BU:1.05); ;
emission air, high population density	Carbon dioxide, biogenic	-	-	kg	0.0999	1	1.31	(4,3,1,1,1,5,BU:1.05); ;
	Methane, biogenic	-	-	kg	0.014	1	1.56	(1,1,1,1,1,5,BU:1.5); ; Based on geometric mean of measurements at 5 biogas plants from Delre et al. 2017. Greenhouse gas emission quantification from wastewater treatment plants, using a tracer gas dispersion method. Sci. Total Environ. 605: 258-268.

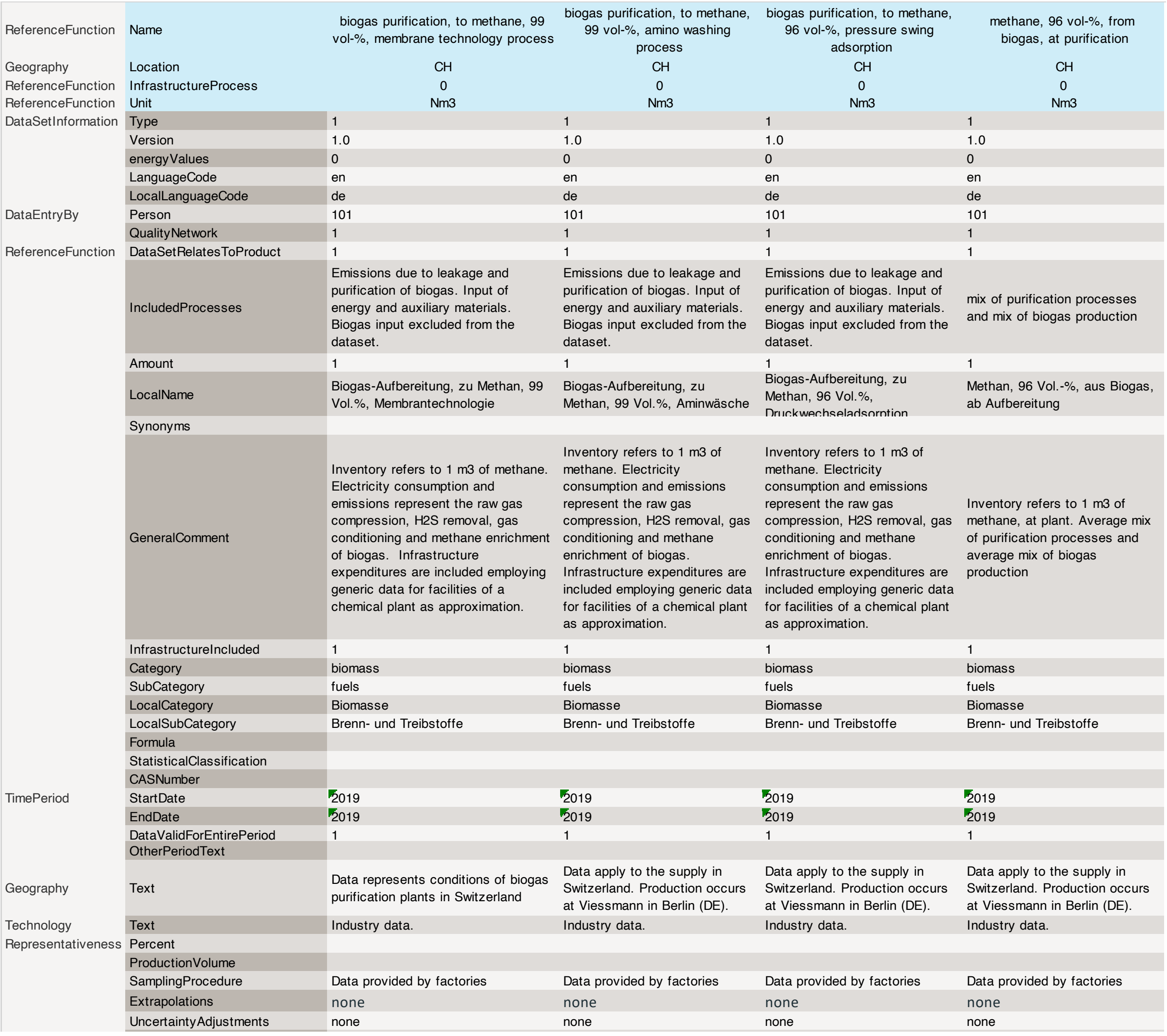
Figure 10: Unit process raw data of biogas from sewage sludge

3 Biogas purification to methane >96%

A biogas purification plant is a facility that is used to concentrate the methane in biogas to natural gas standards. The system removes carbon dioxide, hydrogen sulphide, water and contaminants from the biogas. This purified biogas is also called biomethane. It can be used interchangeably with natural gas.

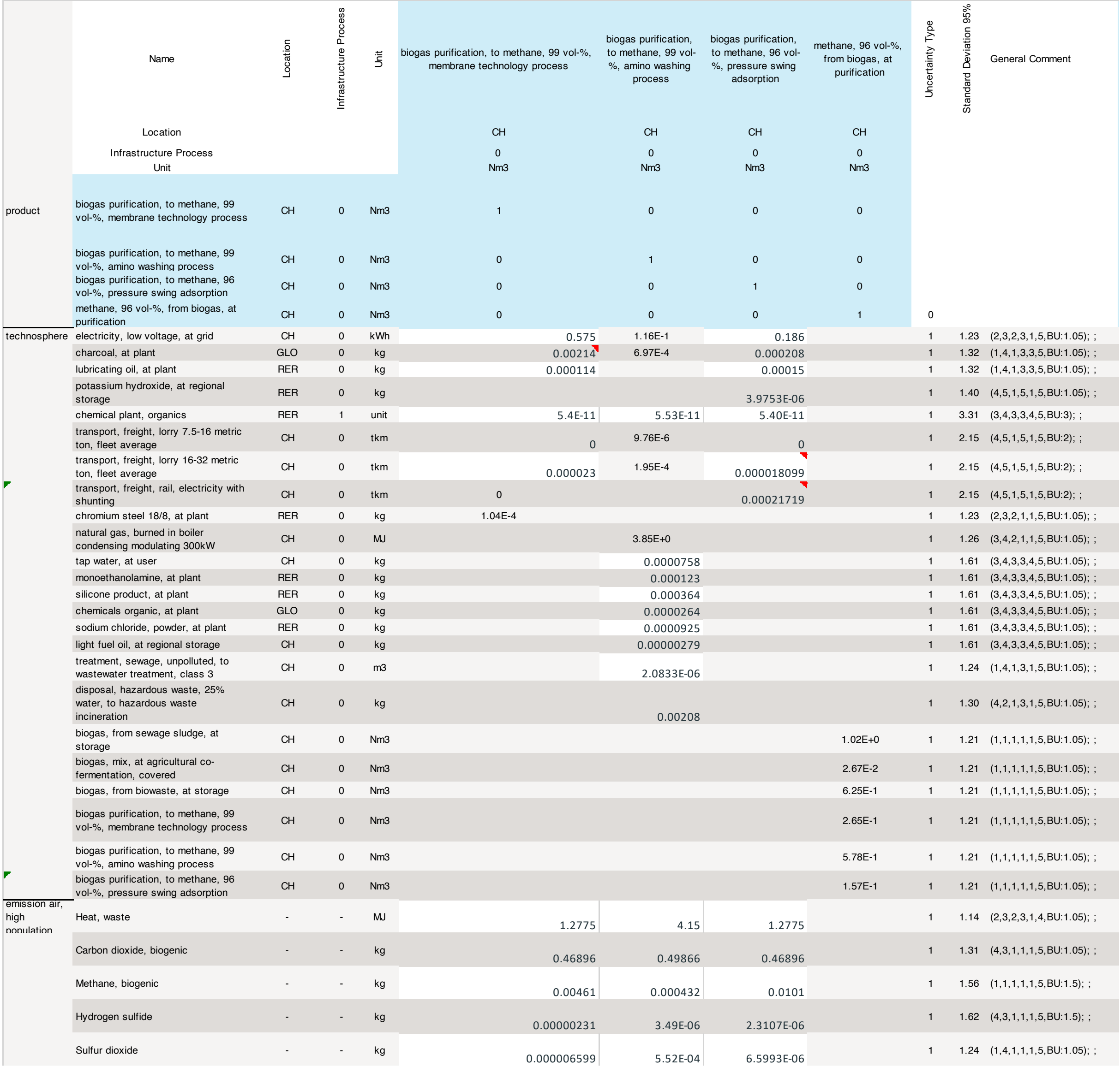
The main components of raw biogas produced from digestion are methane (roughly 60% - 65%) and CO_2 (about 30%) with trace elements of H_2S. It is not high quality enough in order to be fed into the gas pipeline system. The corrosive nature of H_2S alone is enough to destroy the internals of a plant. To avoid this biogas upgrading or purification processes are used whereby contaminants in the raw biogas stream are absorbed or scrubbed, leaving more methane per unit volume of gas. There are different methods of upgrading that are normally used in Swiss purification plants: amino washing, pressure swing adsorption and membrane-based gas permeation systems.

Please note that the following inventories are defined as processing inventories describing the process without the biogas input itself



ReferenceFunction	Name	biogas purification, to methane, 99 vol-%, membrane technology process	biogas purification, to methane, 99 vol-%, amino washing process	biogas purification, to methane, 96 vol-%, pressure swing adsorption	methane, 96 vol-%, from biogas, at purification
Geography	Location	CH	CH	CH	CH
ReferenceFunction	InfrastructureProcess	0	0	0	0
ReferenceFunction	Unit	Nm3	Nm3	Nm3	Nm3
DataSetInformation	Type	1	1	1	1
	Version	1.0	1.0	1.0	1.0
	energyValues	0	0	0	0
	LanguageCode	en	en	en	en
	LocalLanguageCode	de	de	de	de
DataEntryBy	Person	101	101	101	101
	QualityNetwork	1	1	1	1
ReferenceFunction	DataSetRelatesToProduct	1	1	1	1
	IncludedProcesses	Emissions due to leakage and purification of biogas. Input of energy and auxiliary materials. Biogas input excluded from the dataset.	Emissions due to leakage and purification of biogas. Input of energy and auxiliary materials. Biogas input excluded from the dataset.	Emissions due to leakage and purification of biogas. Input of energy and auxiliary materials. Biogas input excluded from the dataset.	mix of purification processes and mix of biogas production
	Amount	1	1	1	1
	LocalName	Biogas-Aufbereitung, zu Methan, 99 Vol.%, Membrantechnologie	Biogas-Aufbereitung, zu Methan, 99 Vol.%, Aminwäsche	Biogas-Aufbereitung, zu Methan, 96 Vol.%, Druckwechseladsorption	Methan, 96 Vol.-%, aus Biogas, ab Aufbereitung
	Synonyms				
	GeneralComment	Inventory refers to 1 m3 of methane. Electricity consumption and emissions represent the raw gas compression, H2S removal, gas conditioning and methane enrichment of biogas. Infrastructure expenditures are included employing generic data for facilities of a chemical plant as approximation.	Inventory refers to 1 m3 of methane. Electricity consumption and emissions represent the raw gas compression, H2S removal, gas conditioning and methane enrichment of biogas. Infrastructure expenditures are included employing generic data for facilities of a chemical plant as approximation.	Inventory refers to 1 m3 of methane. Electricity consumption and emissions represent the raw gas compression, H2S removal, gas conditioning and methane enrichment of biogas. Infrastructure expenditures are included employing generic data for facilities of a chemical plant as approximation.	Inventory refers to 1 m3 of methane, at plant. Average mix of purification processes and average mix of biogas production
	InfrastructureIncluded	1	1	1	1
	Category	biomass	biomass	biomass	biomass
	SubCategory	fuels	fuels	fuels	fuels
	LocalCategory	Biomasse	Biomasse	Biomasse	Biomasse
	LocalSubCategory	Brenn- und Treibstoffe	Brenn- und Treibstoffe	Brenn- und Treibstoffe	Brenn- und Treibstoffe
	Formula				
	StatisticalClassification				
	CASNumber				
TimePeriod	StartDate	2019	2019	2019	2019
	EndDate	2019	2019	2019	2019
	DataValidForEntirePeriod	1	1	1	1
	OtherPeriodText				
Geography	Text	Data represents conditions of biogas purification plants in Switzerland	Data apply to the supply in Switzerland. Production occurs at Viessmann in Berlin (DE).	Data apply to the supply in Switzerland. Production occurs at Viessmann in Berlin (DE).	Data apply to the supply in Switzerland. Production occurs at Viessmann in Berlin (DE).
Technology	Text	Industry data.	Industry data.	Industry data.	Industry data.
Representativeness	Percent				
	ProductionVolume				
	SamplingProcedure	Data provided by factories	Data provided by factories	Data provided by factories	Data provided by factories
	Extrapolations	none	none	none	none
	UncertaintyAdjustments	none	none	none	none

Figure 11: Metadata of biogas purification processes



	Name	Location	Infrastructure Process	Unit	biogas purification, to methane, 99 vol-%, membrane technology process	biogas purification, to methane, 99 vol-%, amino washing process	biogas purification, to methane, 96 vol-%, pressure swing adsorption	methane, 96 vol-%, from biogas, at purification	Uncertainty Type	Standard Deviation 95%	General Comment
	Location				CH	CH	CH	CH			
	Infrastructure Process				0	0	0	0			
	Unit				Nm3	Nm3	Nm3	Nm3			
product	biogas purification, to methane, 99 vol-%, membrane technology process	CH	0	Nm3	1	0	0	0			
	biogas purification, to methane, 99 vol-%, amino washing process	CH	0	Nm3	0	1	0	0			
	biogas purification, to methane, 96 vol-%, pressure swing adsorption	CH	0	Nm3	0	0	1	0			
	methane, 96 vol-%, from biogas, at purification	CH	0	Nm3	0	0	0	1	0		
technosphere	electricity, low voltage, at grid	CH	0	kWh	0.575	1.16E-1	0.186		1	1.23	(2,3,2,3,1,5,BU:1.05); ;
	charcoal, at plant	GLO	0	kg	0.00214	6.97E-4	0.000208		1	1.32	(1,4,1,3,3,5,BU:1.05); ;
	lubricating oil, at plant	RER	0	kg	0.000114		0.00015		1	1.32	(1,4,1,3,3,5,BU:1.05); ;
	potassium hydroxide, at regional storage	RER	0	kg			3.9753E-06		1	1.40	(4,5,1,5,1,5,BU:1.05); ;
	chemical plant, organics	RER	1	unit	5.4E-11	5.53E-11	5.40E-11		1	3.31	(3,4,3,3,4,5,BU:3); ;
	transport, freight, lorry 7.5-16 metric ton, fleet average	CH	0	tkm	0	9.76E-6	0		1	2.15	(4,5,1,5,1,5,BU:2); ;
	transport, freight, lorry 16-32 metric ton, fleet average	CH	0	tkm	0.000023	1.95E-4	0.000018099		1	2.15	(4,5,1,5,1,5,BU:2); ;
	transport, freight, rail, electricity with shunting	CH	0	tkm	0		0.00021719		1	2.15	(4,5,1,5,1,5,BU:2); ;
	chromium steel 18/8, at plant	RER	0	kg	1.04E-4				1	1.23	(2,3,2,1,1,5,BU:1.05); ;
	natural gas, burned in boiler condensing modulating 300kW	CH	0	MJ		3.85E+0			1	1.26	(3,4,2,1,1,5,BU:1.05); ;
	tap water, at user	CH	0	kg		0.0000758			1	1.61	(3,4,3,3,4,5,BU:1.05); ;
	monoethanolamine, at plant	RER	0	kg		0.000123			1	1.61	(3,4,3,3,4,5,BU:1.05); ;
	silicone product, at plant	RER	0	kg		0.000364			1	1.61	(3,4,3,3,4,5,BU:1.05); ;
	chemicals organic, at plant	GLO	0	kg		0.0000264			1	1.61	(3,4,3,3,4,5,BU:1.05); ;
	sodium chloride, powder, at plant	RER	0	kg		0.0000925			1	1.61	(3,4,3,3,4,5,BU:1.05); ;
	light fuel oil, at regional storage	CH	0	kg		0.00000279			1	1.61	(3,4,3,3,4,5,BU:1.05); ;
	treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3		2.0833E-06			1	1.24	(1,4,1,3,1,5,BU:1.05); ;
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg		0.00208			1	1.30	(4,2,1,3,1,5,BU:1.05); ;
	biogas, from sewage sludge, at storage	CH	0	Nm3				1.02E+0	1	1.21	(1,1,1,1,1,5,BU:1.05); ;
	biogas, mix, at agricultural co-fermentation, covered	CH	0	Nm3				2.67E-2	1	1.21	(1,1,1,1,1,5,BU:1.05); ;
	biogas, from biowaste, at storage	CH	0	Nm3				6.25E-1	1	1.21	(1,1,1,1,1,5,BU:1.05); ;
	biogas purification, to methane, 99 vol-%, membrane technology process	CH	0	Nm3				2.65E-1	1	1.21	(1,1,1,1,1,5,BU:1.05); ;
	biogas purification, to methane, 99 vol-%, amino washing process	CH	0	Nm3				5.78E-1	1	1.21	(1,1,1,1,1,5,BU:1.05); ;
	biogas purification, to methane, 96 vol-%, pressure swing adsorption	CH	0	Nm3				1.57E-1	1	1.21	(1,1,1,1,1,5,BU:1.05); ;
emission air, high population	Heat, waste	-	-	MJ	1.2775	4.15	1.2775		1	1.14	(2,3,2,3,1,4,BU:1.05); ;
	Carbon dioxide, biogenic	-	-	kg	0.46896	0.49866	0.46896		1	1.31	(4,3,1,1,1,5,BU:1.05); ;
	Methane, biogenic	-	-	kg	0.00461	0.000432	0.0101		1	1.56	(1,1,1,1,1,5,BU:1.5); ;
	Hydrogen sulfide	-	-	kg	0.00000231	3.49E-06	2.3107E-06		1	1.62	(4,3,1,1,1,5,BU:1.5); ;
	Sulfur dioxide	-	-	kg	0.000006599	5.52E-04	6.5993E-06		1	1.24	(1,4,1,1,1,5,BU:1.05); ;

Figure 12: Unit process raw data of biogas purification processes

3.1 Biogas purification by Pressure Swing Adsorption (PSA)

Pressure swing adsorption (PSA) is a physical process for the separation of gas mixtures under pressure by means of adsorption. The gas is introduced under increased pressure (usually 6 bar to 10 bar) into a fixed-bed reactor which is filled with the adsorbent so that it flows through it. One or more components of the mixture (these are called "heavy components") are now adsorbed. At the exit of the bed, the so-called "light component" can be removed in concentrated form. After a while, the adsorber bed is largely saturated and a part of the heavy component also exits. At this moment, the process is switched over via valves so that the outlet for the light component is closed and an outlet for the heavy component is opened. This is accompanied by a drop in pressure. At the low pressure, the adsorbed gas is desorbed again and can be recovered at the outlet. Two alternately loaded and unloaded adsorbers allow continuous operation. In order to expel the excess of desorbed heavy components from the adsorber bed, a portion of the desired product is rinsed in order to avoid impurities.

The inventory is based on data from the BfE report about biogas production (Stucki et al., 2011). Data for methane emissions during the purification process were updated based on on-site measurements of TISG (Hafner, 2019). He reports mass balanced methane emissions of 1.25% which leads to 0.0101 kg methane per m^3 of purified biomethane. Data for energy use was updated by Hauser (2017). She reported 0.186 kWh of electricity used per m^3 of purified biomethane. All other inputs and outputs were not further updated.

3.2 Biogas purification by Amino Washing

A typical amine gas treating process includes an absorber unit and a regenerator unit. In the absorber, the downflowing amine solution absorbs H_2S and CO_2 from the upflowing sour gas to produce a gas stream free of hydrogen sulphide and carbon dioxide as a product and an amine solution rich in the absorbed acid gases. The resultant "rich" amine is then routed into the regenerator (a stripper with a reboiler) to produce regenerated or "lean" amine that is recycled for reuse in the absorber. The stripped overhead gas from the regenerator is concentrated H_2S and CO_2.

The inventory is based on data from a LCA of a Swiss purification plant using amino washing (Zah & Del Duce, 2014). Data for methane emissions during the purification process were updated based on on-site measurements of TISG (Hafner, 2019). He reports mass balanced methane emissions of 0.06% which leads to 0.43 g methane per m^3 of purified biomethane.

3.3 Biogas purification by Membrane Technology

Membrane-based biogas upgrading systems utilize the different permeabilities of gases through a membrane fibre. As biogas passes through a dense polymeric membrane, CO_2 is prevented from through-flow and removed, while CH_4 passes through. Membrane-based gas permeation systems consume only electrical power, but do not require any chemicals or water. In order to achieve higher methane contents (up to 99% methane) in the final gas, the gas passes through serial groups of membranes. Since membranes are sensitive to water and other impurities in biogas, gas permeation/membrane systems require efficient pre-treatment (especially H_2S and water removal).

The inventory is based on data from a LCA of a Swiss purification plant using membrane technology (Willi, 2019). Data for methane emissions during the purification process were updated based on on-site measurements of TISG (Hafner, 2019). He reports mass balanced methane emissions of 0.64% which leads to 4.6 g methane per m^3 of purified biomethane.

3.4 Purified biogas

The process “methane, >96% by volume, from biogas, at purification (CH)” was used as a basis. The proportions per processing technology were adjusted according to Hafner (2019): In terms of purification technologies, the most biogas was treated with amine washing in 2018 (203 GWh), followed by membrane technology (93 GWh) and PSA technology (55 GWh). 14 GWh are processed otherwise.

4 Literature

agridea. (2018). Wegleitung Suisse-Bilanz. Im Auftrag des BLW.

Anspach, V., & Gysler, M. (2020). Schlussbericht Benchmarking Biogas 2018. Ökostrom Schweiz, Fachverband landwirtschaftliches Biogas.

BAFU. (2021). Entwicklung der Treibhausgasemissionen seit 1990. Retrieved from https://www.bafu.admin.ch/bafu/de/home/themen/klima/zustand/daten/treibhausgasinventar.html

BLW. (2020). *Agrarbericht 2020*.

Dauriat, A., Gaillard, G., Alig, M., Scharfy, D., Membrez, Y., Bachmann, N., et al. (2012). Analyse de cycle de vie de la production centralisée et décentralisée de biogaz en exploitations agricoles. Rapport final. Au nom d'Office fédéral de l'énergie OFEN.

Delre, A., Monster, J., & Scheutz, C. (2017). Greenhouse gas emission quantification from wastewater treatment plants, using a tracer gas dispersion method. http://doi.org/10.1016/j.scitotenv.2017.06.177

Ellersdorfer, M., & Harasek, M. (2020). Entwicklung eines Standard-Konzepts für die Aufbereitung von Rohbiogas zu einem einspeisefähigen Gas. Im Auftrag des ÖVGW - Österreichische Vereinigung für das Gas- und Wasserfach.

Hafner, M. (2019). Biogaseinspeisungen Schweiz 2018: Datenzusammenstellung über die Biogasmengen, Produktionsarten, Aufbereitungsarten und Methanschlüpfe. Schweizerischer Verband für Gas- und Wasserwerke und Technisches Inspektorat des Schweizerischen Gasfaches. TISG / SVGW.

Hauser, M. J. (2017). *Cost evaluation and life cycle assessment of biogas upgrading technologies for an anaerobic digestion case study in the United States - Master Thesis*. Norwegian University of Science and Technology.

Inspektorat der Kompostier- und Vergärbranche. (2020). Auswertungen aus dem CVIS-Analysentool - nur nach Gärgülle ausgewertet. Retrieved from www.cvis.ch

Nemecek, T., & Schnetzer, J. (2011). Methods of assessment of direct field emissions for LCIs of agricultural production systems. Data v3.0 (2012). Agroscope Reckenholz-Tänikon.

Ökostrom Schweiz. (2020). Vergärungsprodukte aus landwirtschaftlichen Biogasanlagen Effizient und nachhaltig düngen mit Gärgülle und Gärmist. Ökostrom Schweiz, Fachverband landwirtschaftliches Biogas.

Stucki, M., Jungbluth, N., & Leuenberger, M. (2011). Life Cycle Assessment of Biogas Production from Different Substrates. Im Auftrag des BFE.

Willi, S. (2019). Ökobilanz Biogasanlage ZASE Zuchwil. Im Auftrag von Regio Energie Solothurn.

Zah, R., & Del Duce, A. (2014). Ökobilanz des Vergärwerks und der Biogas-Aufbereitungsanlage Werdhölzli. Im Auftag von energie360°.