



RISK ASSESSMENT OF NUTRIENT DISCHARGES FROM BIOGAS PRODUCTION



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REV. 1

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0 Introduction

Purpose of this report is to assess in how far biogas plants contribute to the eutrophication of the Baltic Sea. Biogas plants in this report are defined as any anaerobic digestion plant except of landfills and gasification / pyrolysis plants. Thus this report will look at biogas plants in the agricultural sector as well as anaerobic digestion of waste and of sewage sludge.

Germany has quite a long tradition in using anaerobic digestion as treatment method for waste water, agricultural fertilizer like dung and slurries and organic residues from food production or catering. Historically the sectors of waste management and waste water treatment have been a municipal responsibility, whilst agriculture has traditionally been a private business in Western Germany and a state-owned cooperatives model in Eastern Germany between World War II and the re-unification in 1990.

It is important to recognize and understand the difference between the municipal and the agricultural sector, because it has a direct effect on responsibilities and developments that are associated with the respective anaerobic digestion and biogas plants.

In the municipal sector data collection, monitoring and control as well as the thrive to become better in terms of nutrient removal has been a continuous process, though large steps were always related to improved legislation (e.g. 3rd cleaning step for phosphorus removal in catchment areas of sensitive water bodies). However, since municipal enterprises provide services of general interest they do to some extent have an inherent interest in emission reduction. In this sector it is common to maintain state of the art in plant technology and plant management which includes adapting the system to new standards.

The agricultural sector on the other hand usually focuses more on food production and the corresponding means to increase crop yields. Whilst this is the sector with the fastest growth in numbers of biogas plants, it can be characterized as much more “hands-on” in terms of planning, construction and operation. In the early years the focus was on feasible, but cheap technology. In the last decade the standards have increased continuously, but it is still not common to think in prevention and state of the art. Since there are different responsible authorities when it comes to permitting agricultural biogas plants, no common biogas plant register has been established. Such an attempt has only been made in the last few years with the resulting register being published in the second half of 2017. Before that, the main source of information is from energy utility companies, which pay the feed-in tariffs. Their information is, however, very cryptic and focuses mainly on power production, which makes it difficult to impossible to extract all relevant data for this report as will be shown later.

In this report chapter 1 define the geographic and informative basis of this study. Section 1.3 describes the different types of sectors in which anaerobic digestion plays a role and tries to describe the existing installations in the German sub-catchment area of the Baltic Sea. Chapter 2 describes digestate utilization and treatment methods of digestate that are common in the different sectors of agricultural biogas plants, waste digestion plants and anaerobic sewage sludge stabilization. Chapter 3 gives an overview over the relevant legislation with regards to planning, construction, operation as well as to using digestate, sewage sludge or reject waters as fertilizer. Chapter 4 shows a risk assessment of nutrient exports with case examples. In chapter 5 this report elaborates on the profitability of biogas / anaerobic digestion plants. Chapter 6 presents some case studies where marketable fertilizer or other products are produced from digestates. This could be interesting approaches for further digestate treatment, but examples are scarce and therefore the examples are from all over Germany. Additionally biogas plants are part of circular economy concepts, which is presented in chapter 7. Chapter 8 shows further solutions for mitigating adverse environmental impacts of biogas plants. Finally chapter 9 refers to the pulp and paper industry in Germany.

1 List of all biogas installations in the country / region in question, divided by feedstock and size + year of deployment (Landfills and gasification not in focus)

1.1 German sub-catchment area of the Baltic Sea

Germany contributes with its watercourses to the Baltic Sea only for a small fraction. As shown in *Fig. 1*, the area is located in the north-eastern part of the country. The drainage basins areas are the ones related to the rivers Schlei/Trave, Warnow/Peene and the German area of the catchment area of the river Oder.(1; 2)

Germany is a federal parliamentary republic which includes 16 constituent states. In the case study the sub-catchment area overlaps the territory of only four states (see *Fig. 2*):(1; 2)

- Brandenburg
- Schleswig-Holstein (SH)
- Sachsen
- Mecklenburg-Vorpommern (MV)

Each state is then divided in districts at municipal level. *Fig. 3* shows the districts of the four states and their overlapping with the Baltic Sea sub-catchments area.(1; 2) The districts of the case study were selected based on these maps.

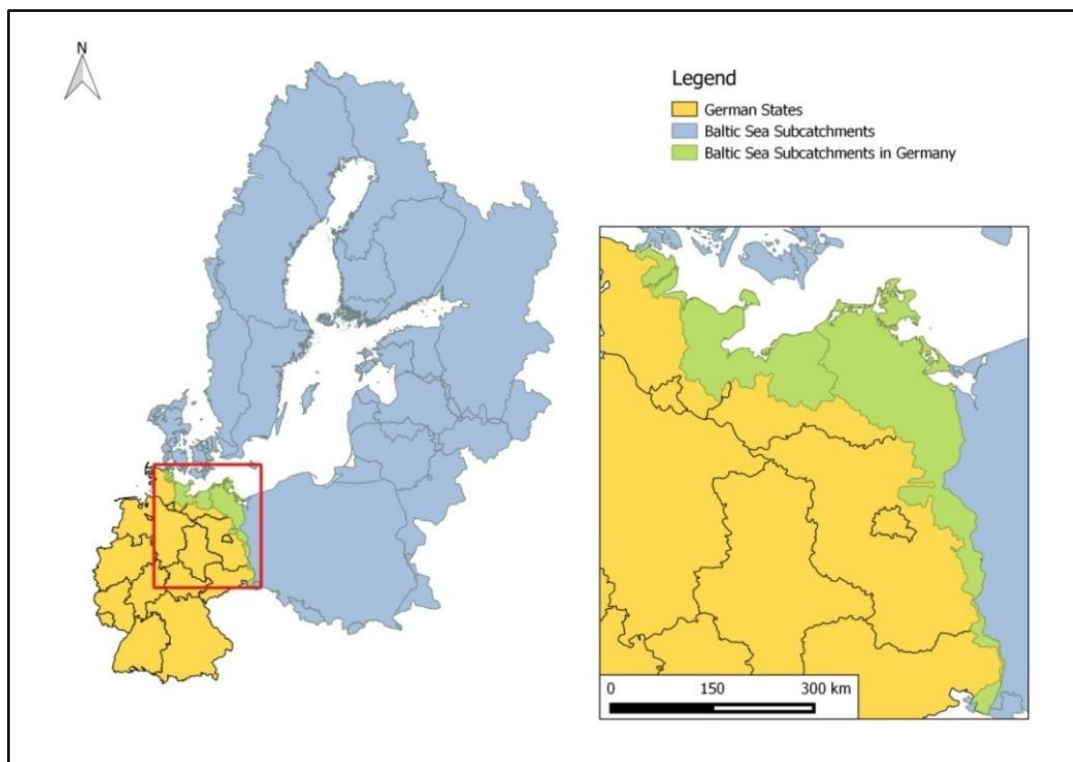


Fig. 1: Baltic Sea sub-catchments in the Baltic Sea Region and in the specific in Germany.(1; 2)

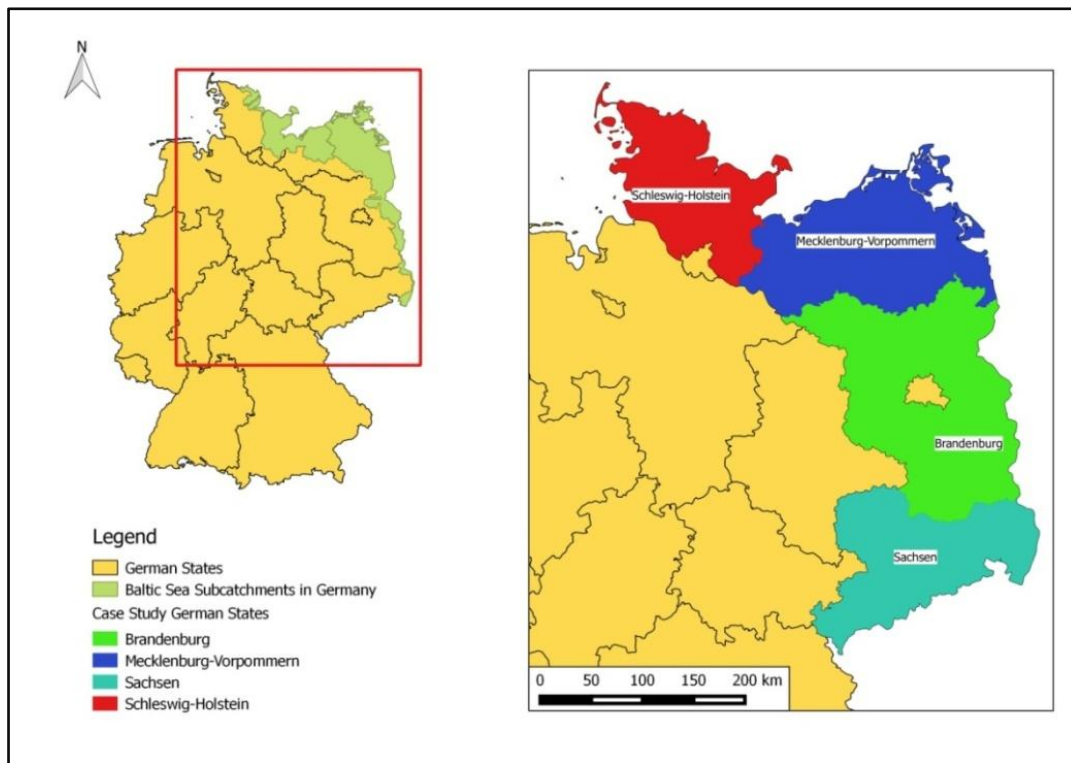


Fig. 2: The German states included in the case study. (1; 2)

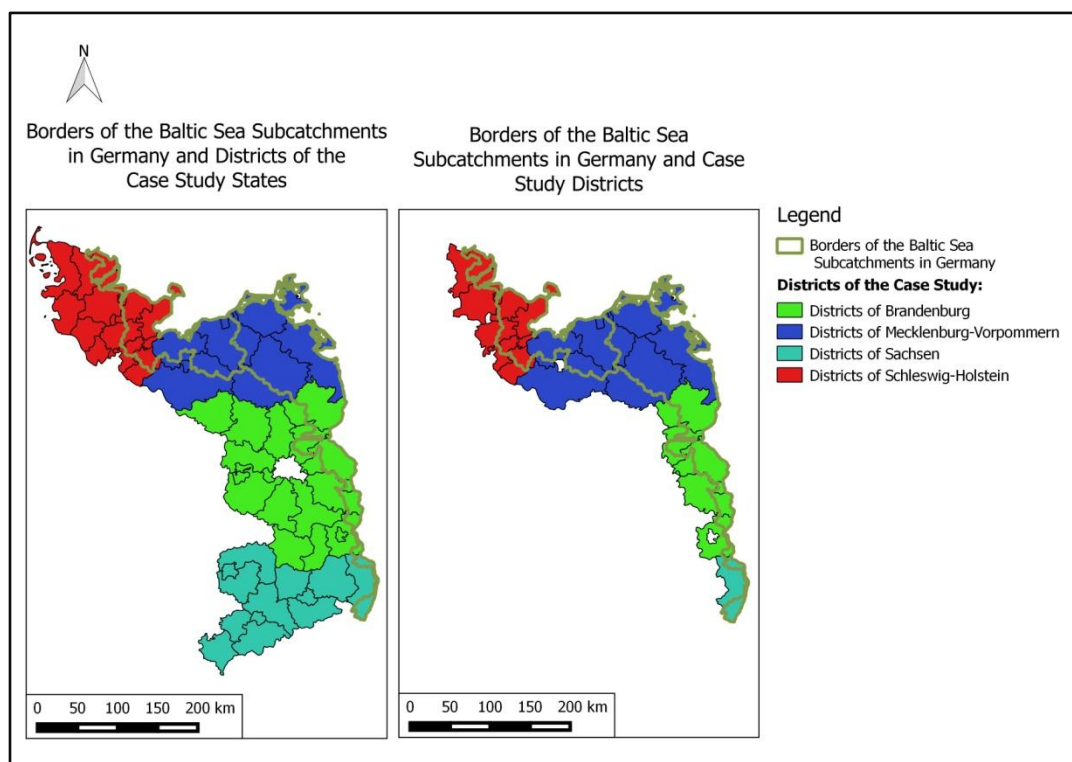


Fig. 3: Selection of the case study districts, based on the area covered by the Baltic Sea sub-catchments. (2; 3)

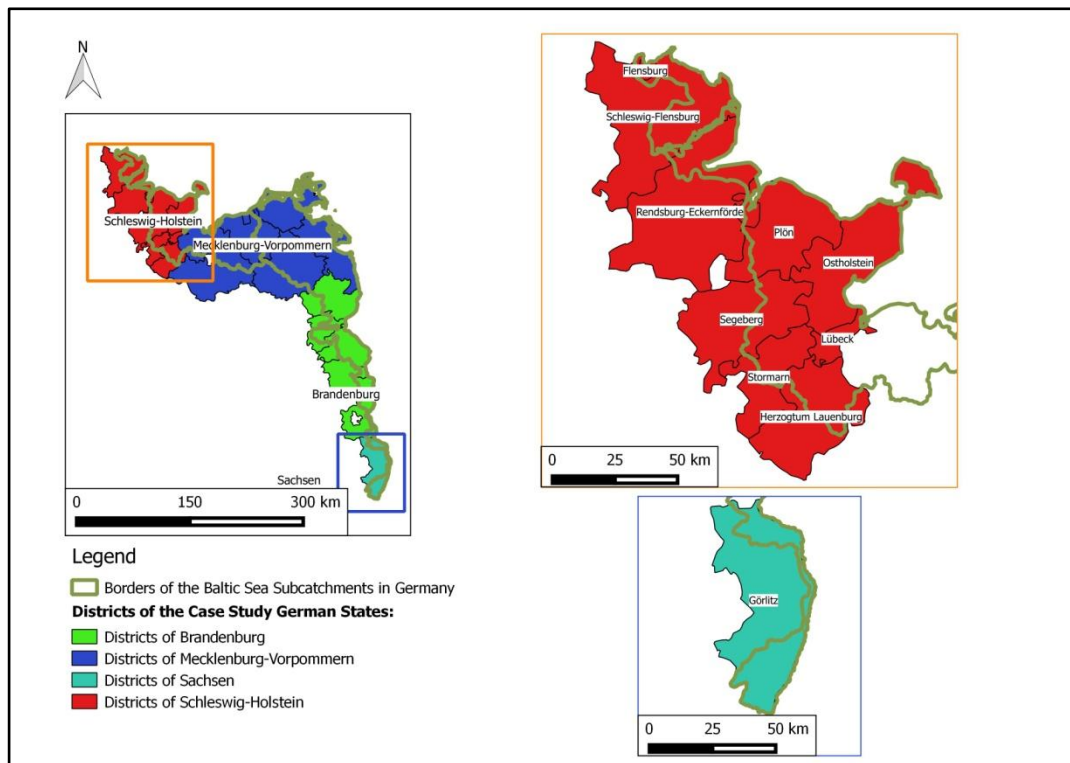


Fig. 4: Maps of the districts in Schleswig-Holstein and Sachsen. (1; 2)

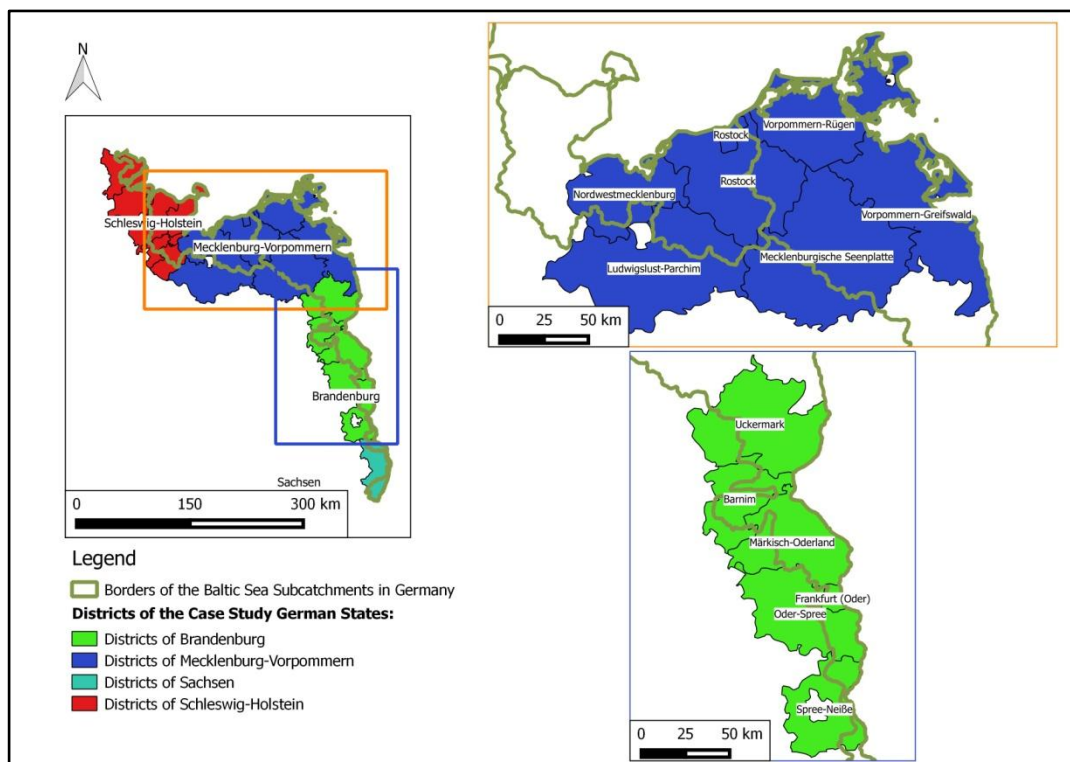


Fig. 5: Maps of the districts in Mecklenburg-Vorpommern and Brandenburg. (1; 2)

1.2 Data sources

There are different available data source regarding the number, location and power of biogas plants. At German level an official national register with all of the plants is not yet present. The record is only done locally at district or region level. Only lately the Ministry of Economics and Energy has started collecting all the information regarding the nationwide biogas situation, but it's a long and complicated task.

The sources used in this study are:

- For **all four states**:
 - **Energie Atlas** (2). This online application shows the total electric power of the biogas plants relative to each district in Germany. The application is updated to 2014.
 - **EEG-Anlagenstammdaten**(4). A register of the renewable energy plants whose compilation started in August 2014 and last update was in July 2017. Starting from 2014, all of the nationwide biogas plants have to register in case of modification of their system. This obligation gave birth to a partial list of the plants present in Germany. In this list both the electric and thermal power are specified for each biogas plant.
- For **Brandenburg**:
 - **List** provided by the *Ministerium für Wirtschaft und Energie des Landes Brandenburg –Referat für Erneuerbare Energieerzeugung* (Ministry of Economics and Energy of the Brandenburg State – Unit for Renewable Energy Production). The list's last update was September 2016. This list specifies the location and the installed electric power of the biogas plants in Brandenburg. (5)
- For **Mecklenburg-Vorpommern**:
 - **Online GIS** (3). The online source specifies the location and the category of the biogas plants, classified by the *Vierte Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes* – the German Emissions Control Act. (6; 7)

As shown in *Fig. 4* and *Fig. 5*, only a fraction of the case study districts is part of the sub-catchment area. Nonetheless the available data from the *Bioenergy Atlas* are relative to the whole district, as shown in *Fig. 9* and listed more in detail in *Tab. 2*, *Tab. 3* and *Tab. 4*. (2; 3) Thus it is only possible to provide rough information regarding the installed capacity in its totality regarding the each whole district.

The partial register *EEG-Anlagenstammdaten* is reported in a table in the *Annex - List of biogas plant*. Some of the plants in the list upgraded to a flexible production. In order to have the necessary electrical power the managers of the facilities changed/replaced the engine in the CHP unit with other ones more powerful. The modified scheme of these plants includes also new gas storage in order to accumulated the biogas while the CHP unit are not running, and thus have the possibility to have a flexible production. Even if the electricity production increases, the total gas and digestate volumes remain constant, thus for the aims of this study what's relevant is the electricity production before the modification. (4)

1.3 Anaerobic Digestion in Germany by sectors and regions

Germany is the European country with the highest number of biogas plants and electric production. Currently there are about 9 000 biogas plants throughout the country (see *Fig. 6*), with a capacity ranging from 7 kW_{el} to 20 MW_{el}, and an average size of about 450 kW_{el}. The main outputs from the plants are: electricity, heat, biomethane and digestate/fertilizer. *Tab. 1* shows some of the important figures that describe the situation of biogas in Germany in 2016.

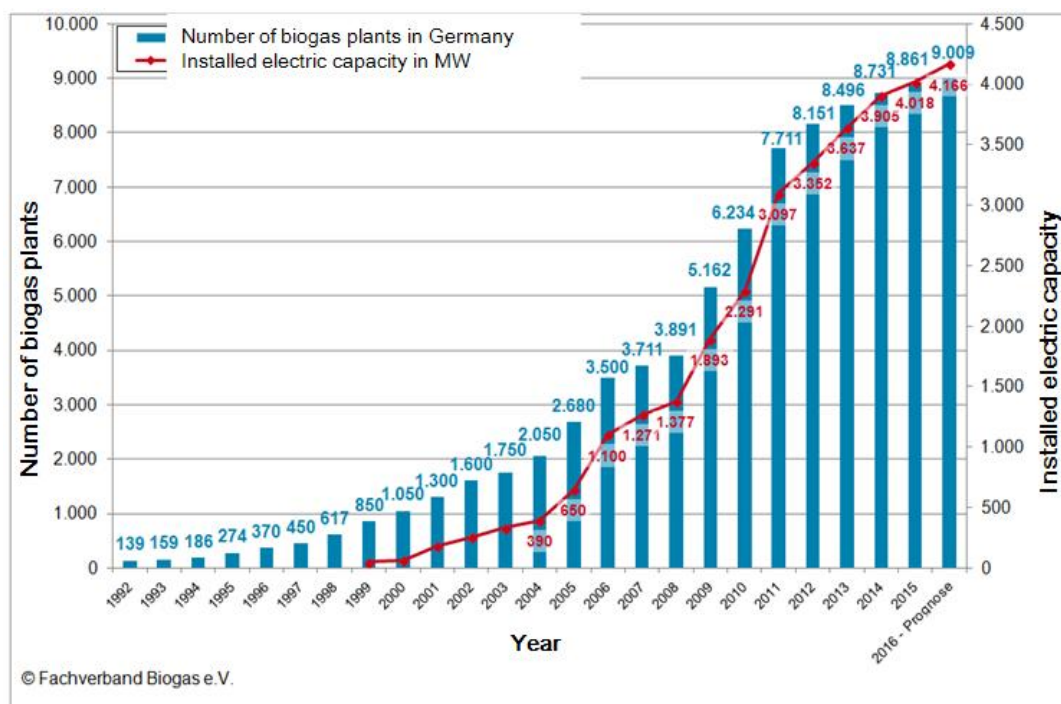


Fig. 6: Cumulated number of biogas plants in Germany.

Amount	9 009 biogas plants
Installed electrical capacity	4 166 MW (~ 4,2 GW) work load; total capacity over 5 000 MW
Power production	27.88 Bil. kWh = Electricity for 8,4 million households
Agricultural area	ca. 1 450 000 ha for biogas
Feed into the natural gas grid	196 Biomethane feed in stations in operation; 5 in construction
Biogas filling stations	100 with 100%, 288 with 10 to 50% biomethane
Turnover in Euro	8,3 Billion
Jobs in the biogas sector	43 000

Tab. 1: Biogas in Germany in 2016.

1.3.1 Agricultural biogas plants

The main feedstock in German biogas plants are manure, energy crops (e.g. corn silage, grass silage, novel plants like *Silphium perfoliatum*), fodder residues and by-products (e.g. beet leaves, cereal debris, ...). As shown in Fig. 7, the agricultural biogas plants are scattered throughout the country. In the northern and southern regions a higher number of biogas plants is located because of the high density of animal husbandry and, consequently, of manure.

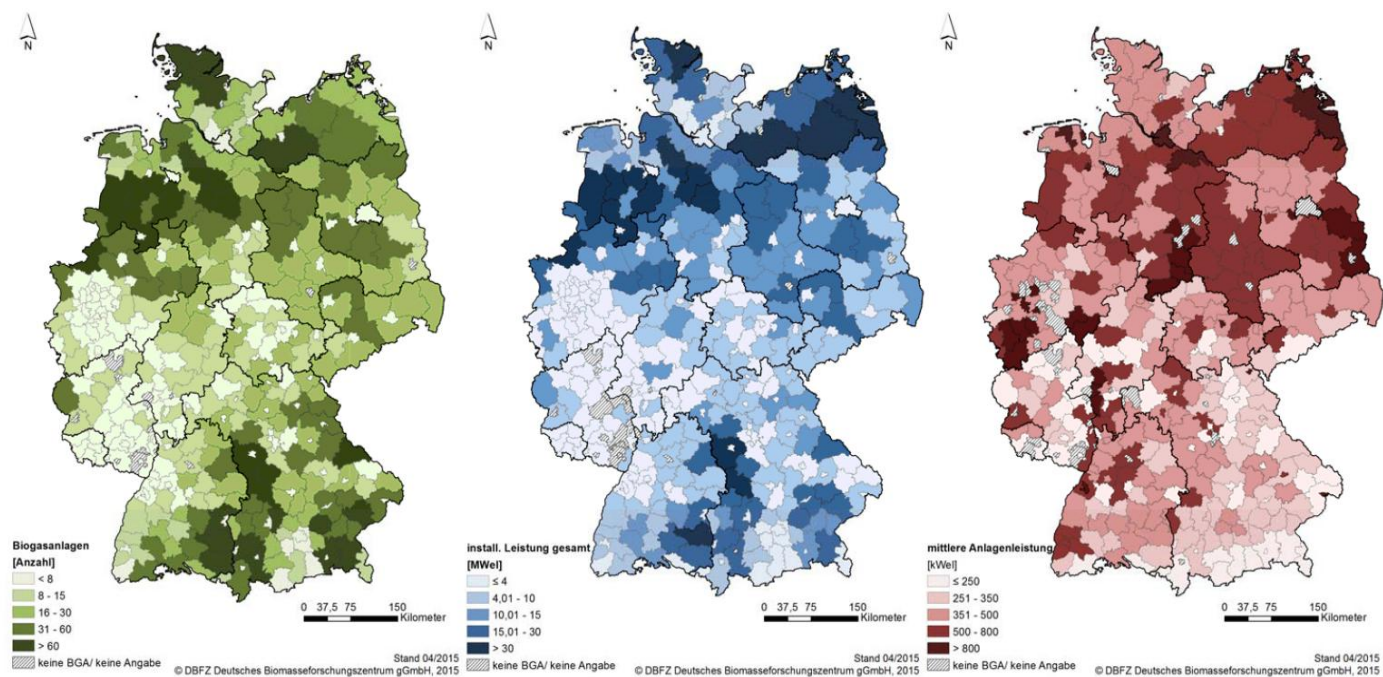


Fig. 7: Agricultural biogas plants (BGP) in Germany. The maps show (in order from left to right): the number of BGP, the total installed electric capacity and the average BGP electric capacity.

1.3.2 Anaerobic digestion of organic waste

In Germany there are about 350 biogas plants whose feedstock is organic waste, 100 of which process biowaste from household, while other 250 use commercial wastes as feedstock. The feedstock include: source separated household organics, catering waste, market waste, packaged waste and residues from food production (e.g. pomace, leaves,...). Fig. 8 shows the location of the biogas plants in this category as of 2014. A more recent map is available online at (8).

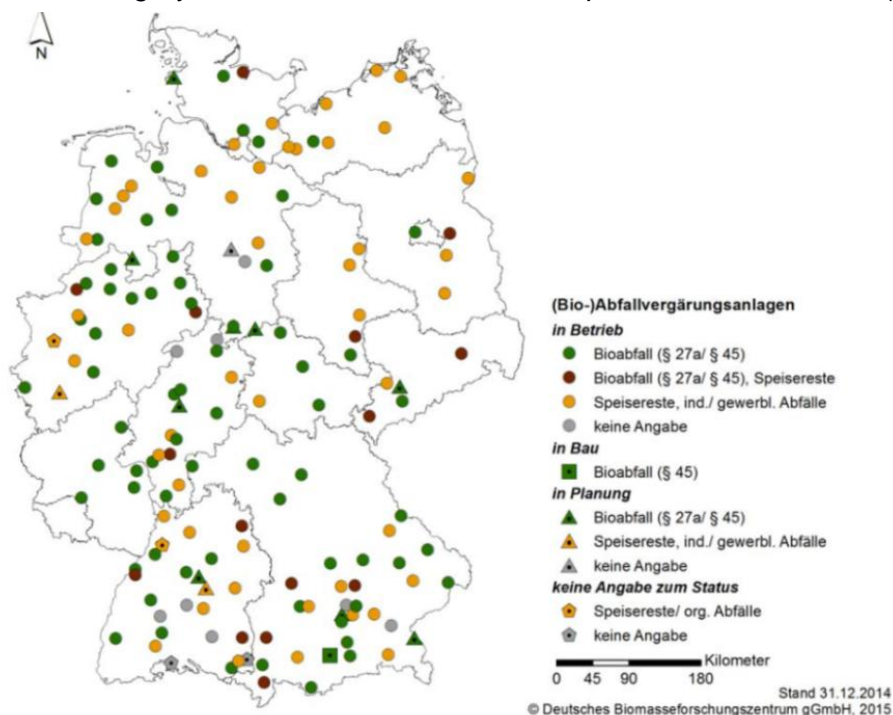


Fig. 8: Biogas plants that use organic waste as a feedstock. Circle: working BGP. Square: BGP in construction. Triangle: planned BGP. As of 31.12.2014.

1.3.3 Anaerobic digestion of wastewater sludge

In 2016 more than 10.000 WWTP were operated in Germany and 1 258 of them were equipped with anaerobic sludge stabilization in digesters (9). In terms of electric power production from the resulting biogas the CHP sizes range between 20 and 700 kW_{el}. The feedstock is mainly wastewater sludge, which is sometimes, but very rarely, combined with organic waste in a co-digestion. With respect to all Germany the digestate from this kind of plants is mainly incinerated, though it varies strongly between the federal states. For the German sub-catchment area of the Baltic Sea section 1.4.2 describes the status quo of waste water treatment and of the sewage sludge use.

Wastewater treatment in Germany fulfills the requirements of the Urban Wastewater Treatment Directive 91/271/EEC both with respect to N- and P-removal. N-removal is usually done through biologic treatment in nitrification and denitrification, while P-removal is predominantly done using precipitation with iron salts, aluminum salts or lime. More detailed information on the applied N- and P-removal in the German sub-catchment area of the Baltic Sea is also described in section 1.4.2.

1.4 Study focus and study area

In this study the focus is on the agricultural plants, because they are higher in number and also represent a more important source of nutrients, since they are smaller facilities whose operators are usually not experts.

Wastewater treatment plants with anaerobic digestion are strictly regulated on their nutrient discharges and phosphate is already commonly eliminated. Thus, wastewater treatment plants with anaerobic digestion will not be analyzed in detail in this study but only mentioned in the following chapters.

Only 11 anaerobic digestion plants of organic wastes (catering wastes, commercial organic waste, green waste, source segregated household organics) are located in the case study area. Their figures are reported in *Annex - List of biogas plant*. (10)

1.4.1 Biogas plants in the German sub-catchment area

Section 1.2 describes the data which was available and used in this report. From this data we aggregated the information on biogas plants in each federal state contributing the Baltic Sea. Due to the fact that there has not been a common and publically available register for anaerobic digestion plants in Germany the available data sources yielded varying information. An example is *Tab. 2*, which shows the two sets of data, from the *Ministry of Economics and Energy of the Brandenburg State* and the *Bioenergy Atlas*. The two show different information. There are different possible reasons:

- the number and/or installed power of the biogas plants has changed between 2014 and 2016,
- the list provided by the *Ministry of Economics and Energy* is not complete because only bigger biogas plants are obliged to register at the Ministry.

It's only possible to have a rough idea regarding the order of size of the installed electrical capacity of the biogas plants in the Brandenburg State. From both sources, data regarding the feedstock are not available, but it's possible to see the number of the plants located in the area. *Fig. 10* shows the location of these plants and gives a visual idea of their installed power.(5)

For the Mecklenburg-Vorpommern State, no specific data regarding the installed power or the feedstock processed in the biogas plants is available. The only available data is classified by the German Emissions Control Act.(6; 7)The classification of the plants of the case study is listed in *Tab. 5* and their location is shown in *Fig. 11*. (7)

Brandenburg			
District	Installed electric power [MW](3)	Number of biogas plants(5)	Installed electric power [MW](5)
Frankfurt (Oder)	3.16	4	2.163
Barnim	7.8	8	5.444
Märkisch-Oderland	29.62	40	22.739
Oder-Spree	19.8	22	12.838
Spree-Neiße	4.8	18	10.955
Uckermark	23.08	45	20.987

Tab. 2: Installed power of the biogas plants in the districts of the case study in the Brandenburg State. (3; 5)

Schleswig-Holstein	
District	Installed electric power [MW]
Flensburg	0
Kiel	0.33
Lübeck	5.45
Herzogtum Lauenburg	14.18
Ostholstein	12.16
Plön	16
Rendsburg-Eckernförde	46.29
Schleswig-Flensburg	76.16
Segeberg	21.55
Stormarn	10.32
Sachsen	
Görlitz	22.84

Tab. 3: Installed power of the biogas plants in the districts of the case study in the SH and Sachsen states. (3)

Mecklenburg-Vorpommern									
District	Installed electric power [MW] (3)	Number of biogas plants – divided by their classification(7)							
		1.15 V	1.16 V	1.2.2. 2V	8.6. 2.1EG	8.6. 2.2V	8.6. 3.1EG	8.6. 3.2V	TOT
Rostock	1.25	0	1	2	1	0	0	0	4
Rostock	27.99	3	5	46	0	0	7	40	101
Ludwigslust-Parchim	60.56	1	0	14	1	3	0	13	32
Mecklenburgische Seenplatte	52.46	0	0	40	2	0	5	44	91
Vorpommern-Rügen	25.79	1	0	17	3	1	2	29	53
Nordwest mecklenburg	20.17	0	0	18	0	2	2	16	38
Vorpommern-Greifswald	32.12	2	2	45	1	3	5	30	88

Tab. 4: Installed power of the biogas plants in the districts of the case study in the Mecklenburg-Vorpommern State. The key of the classification is in Tab. 5. (3; 7)

Code	Classification	Dimensions	Category
1.15V	Production of biogas	≥1.2 million Nm ³ /year of raw gas	Raw gas production
1.16V	Processing of biogas	≥1.2 million Nm ³ /year of raw gas	Raw gas processing
1.2.2.2V	Internal combustion engines or gas turbine plant	1 MW - 10 MW	Biogas total energy
8.6.2.1EG		≥50 t/d	Throughput
8.6.2.2V		10 – 50 t/d	Raw gas production
8.6.3.1EG		≥100 t/d	Throughput
8.6.3.2V		<100 t/d & ≥1.2 million Nm ³ /year	Throughput

Tab. 5: Classification of the biogas plants as in the Vierte Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes.(6)

State	Number of biogas plants	Installed electric power [MW]
Brandenburg	137	88
Schleswig-Holstein	-	188
Sachsen	-	23
Mecklenburg-Vorpommern	407	220
TOTAL		519

Tab. 6: Number and installed power of biogas plant in the case study area.

In order to have more comparable data, during the project meeting in Riga at the end of August 2017, the working group decided to use MWh of primary energy as unit for energy production of the biogas plants. In Germany this kind of data is not available, and the registered production of some of the biogas plants is expressed in installed electric power. In order to have the data in MWh of primary energy, some hypothesis where necessary: the running hours of the CHP unit and its electrical and thermal efficiency. These data have a wide range depending on different factors, among which the plant and the engine. Two sets of data were chosen and a range of energy production values were calculated.

The two chosen sets of values are:

	Running hours [hr/year]	CHP electrical efficiency [%]	CHP thermal efficiency [%]
1st set	7 800	39	52
2nd set	8 000	41	50

From these two sets of data and the values reported in *Tab. 2*, *Tab. 3* and *Tab. 4*, a range of total primary energy produced was calculated. The results are reported in *Tab. 7*. Both the results calculated with the different sets of values are around 10 GWh per annum.

	Total electric energy [MWhel]		Total thermal energy [MWhth]		Total primary energy [MWh]	
	1st set	2nd set	1st set	2nd set	1st set	2nd set
Brandenburg	585 983	601 008	781 310	732 937	1 502 520	1 465 873
SH	1 579 032	1 619 520	2 105 376	1 975 024	4 048 800	3 950 049
Sachsen	178 152	182 720	237 536	222 829	456 800	445 659
MV	1 718 652	1 762 720	2 291 536	2 149 659	4 406 800	4 299 317
TOTAL	4 061 819	4 165 968	5 415 758	5 080 449	10 414 920	10 160 898

Tab. 7: Approximated calculated total primary energy of the biogas production, divided by state.

In conclusion, all the available data are incomplete and do not include all the existing biogas plants present in Germany. Nonetheless, the reported figures give an idea of the considerable number of the plants currently operating.

The following figures visualize the installed electric power in the districts of the federal states contributing to the Baltic Sea. Where the available data made a reference to the location of biogas plants the maps also show this.

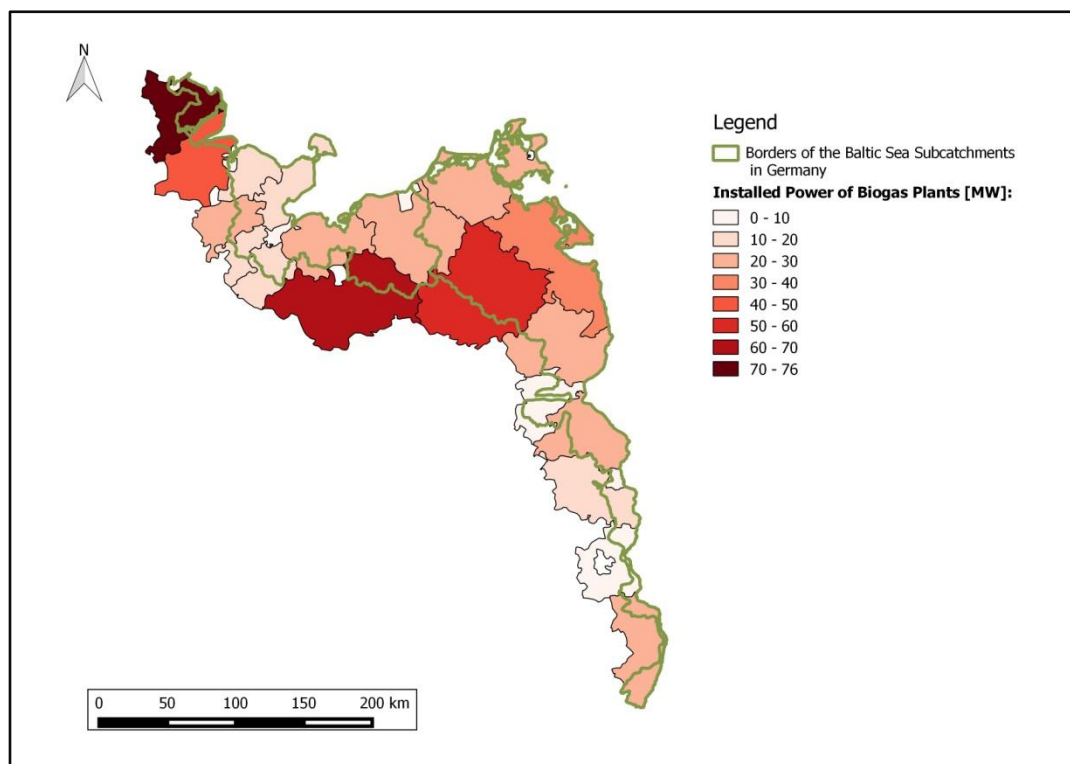


Fig. 9: Installed electric power of the biogas plants in the district of the case study. (1; 2; 3)

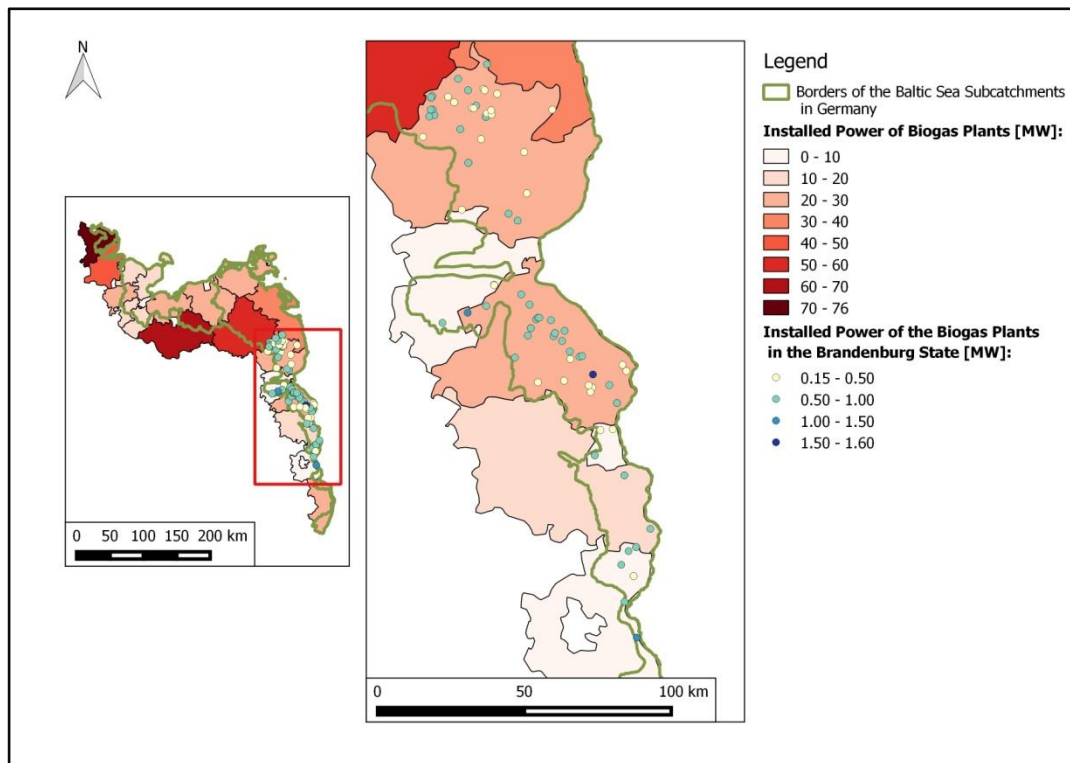


Fig. 10: Biogas plants in the Brandenburg State and in the Baltic Sea sub-catchment area. (1; 2; 5)

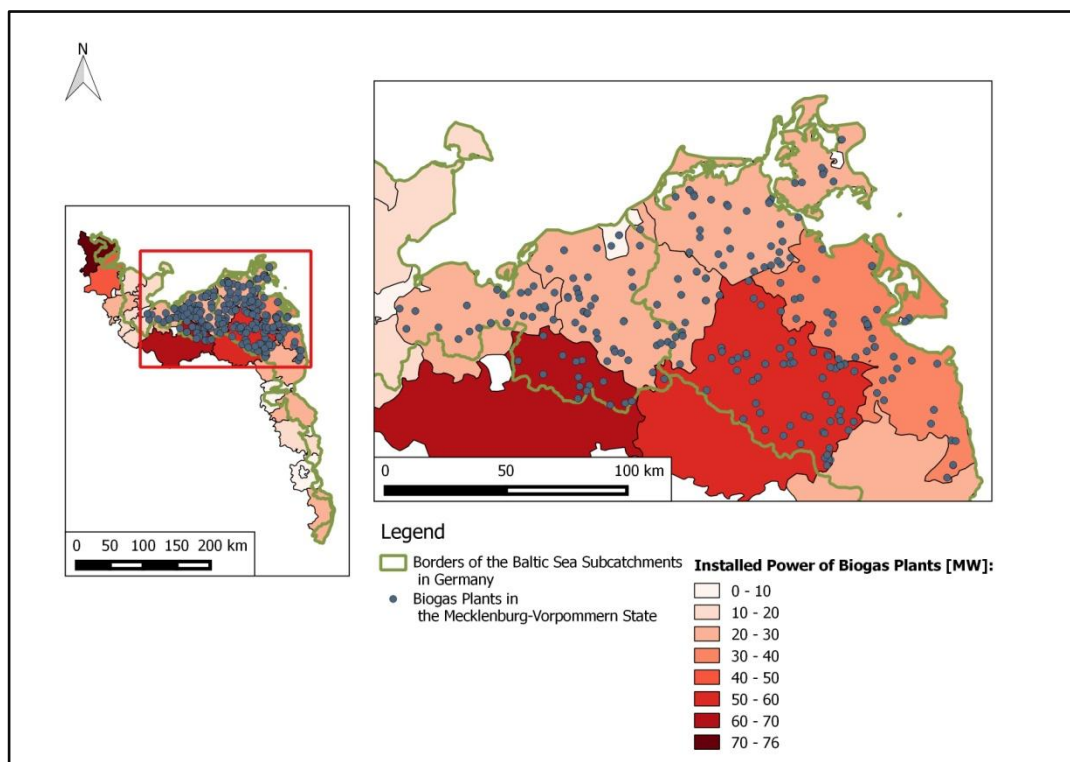


Fig. 11: Location of the biogas plants in Mecklenburg-Vorpommern in the Baltic Sea sub-catchment area. (2; 3; 7)

1.4.2 Wastewater Treatment Plants in the German sub-catchment area

In Germany the main area draining water into the Baltic Sea is located in the federal states Schleswig-Holstein, Mecklenburg-Vorpommern and Brandenburg. Saxony contributes to a smaller extend, both in respect to the area and population. In all states wastewater treatment plants >10.000 p.e. are equipped with tertiary sewage treatment. All states fulfill the requirements of the European Council Directive 91/271/EEC concerning urban waste water treatment. Despite the efforts made to increase the share of population connected to sewers and WWTPs and also to improve the purification capacity it was not possible to reach the standards of very good and good chemical and biological water quality as defined in the European Water Framework Directive 2000/60/EG. Two main reasons were given for this:

1. Diffuse emissions from agriculture
2. High absolute nutrient loads from point sources in regions with high population density (e.g. Berlin and its surrounding area) despite very good reduction rates in the WWTPs.

All federal states in the German sub-catchment area of the Baltic Sea have developed new programs to address issues related to improving the quality of surface water bodies.

The following paragraphs summarize the current situation of waste water treatment in Schleswig-Holstein, Mecklenburg-Vorpommern and Brandenburg. Saxony contributes only to a small share to the Baltic Sea. Since the report on the status quo of wastewater treatment in Saxony (11) from 2017 discusses the matter for the whole state it is more difficult to extract the data needed for the Baltic Sea catchment area. Basically the same applies for Saxony as for the other states presented below – WWTPs with a treatment capacity > 10.000 p.e. are equipped with N- and P-removal technologies.

1.4.2.1 Wastewater treatment in Schleswig-Holstein

Schleswig-Holstein is Germany's most northern federal state and is located between the North Sea and the Baltic Sea. The average population density is 181 inhabitants per km² as compared to the average German density of 230 inhabitants per km². When implementing the Council Directive 91/271/EEC concerning urban waste water treatment into the corresponding state ordinance Schleswig-Holstein declared its coastal waters of the North Sea and the Baltic Sea and the catchment areas of all surface waters to be sensitive areas. Special program have been launched to improve the treatment capacity of WWTPs. In 2013 94,8 % of the state's population, which corresponds to 997 so called "wastewater communities"¹ has been connected to sewers and thus to central WWTPs. In the remaining area, or 119 wastewater communities (the largest having a population of 783 inhabitants) respectively, the wastewater is treated in decentral units.

In 2016 a total number of 787 municipal WWTP with 3,9 Mio. connected people equivalents has been operated in Schleswig-Holstein. In the same year the nitrogen load flowing into the WWTPs was 15.415 t, but only 1.735 t were released into surface waters which corresponds to reduction rate of approx. 88,7 %.

For phosphorus the incoming load in 2016 summed up to 2.480 t. After treatment an amount of 156 t was released to surface waters. This corresponds to a 93,7 % reduction rate.

For COD the reduction rate was 95,9 % and BOD5 requirements from the Urban Wastewater Treatment Directive was met in all WWTPs > 2.000 p.e.

Tab. 8 below gives an overview about WWTP sizes in relation to the kind of wastewater treatment, the number of municipal WWTP in the respective category and the corresponding person equivalents connected to the category.

¹ Wastewater communities were created based on optimal sewer connection and wastewater treatment. They differ from real municipalities or communities.

Fig. 12 and Fig. 13 show the location of WWTPs > 10.000 p.e. in Schleswig-Holstein and in how far the requirements for N- and P-removal are being met.

Capacity of WWTP in terms of People Equivalents	Number of municipal WWTPs	Total number of People Equivalents connected (in 1.000 persons)
Article 7 “Suitable treatment”		
< 2.000 p.e.	605	282
Article 4, Paragraph 1: Secondary Treatment		
2.000 up to 10.000 p.e.	115	321
Article 5, Paragraph 2: Further (Tertiary) Treatment		
10.001 up to 20.000 p.e.	18	177
20.001 up to 100.000 p.e.	42	1.150
More than 100.000 p.e.	7	2.048
Total	787	3.978

Tab. 8: Total load and type of wastewater treatment in relation to WWTP-sizes in Schleswig-Holstein

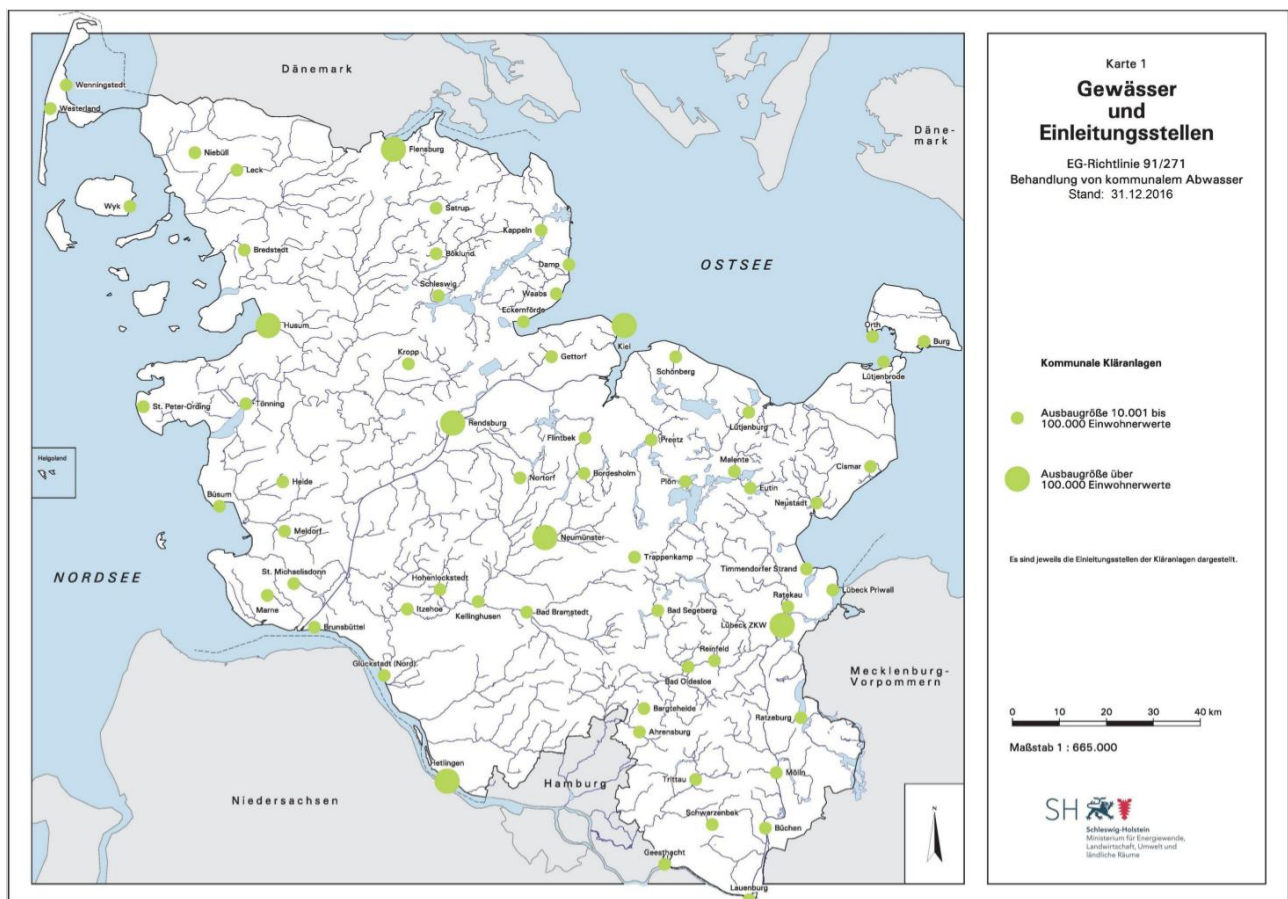


Fig. 12: Waterbodies and waste water discharge points in Schleswig-Holstein

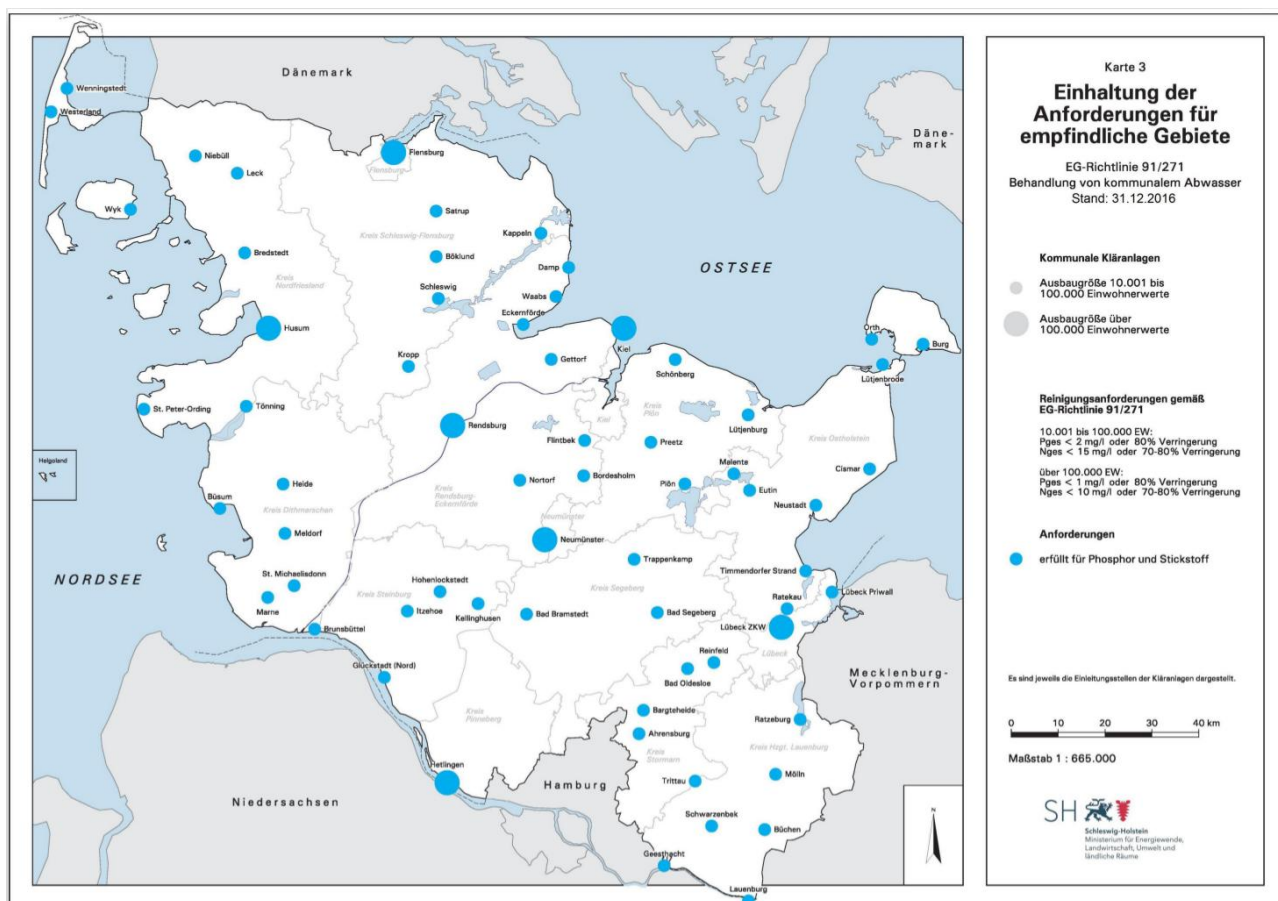


Fig. 13: Nutrient discharge requirements for sensitive areas met (blue colored points meet the requirements for N and P)

All above information is based on the Status Quo report on the treatment of municipal wastewater in Schleswig Holstein from 2017 (12).

1.4.2.2 Wastewater treatment in Mecklenburg-Vorpommern

Mecklenburg-Vorpommern is the German state with the lowest population density with an average of 69 inhabitants per km². Here the definition of wastewater communities plays an important role, because in some areas with a very low population density it is economically not feasible to connect to central sewers and municipal WWTPs. At the end of 2015 90 % of Mecklenburg-Vorpommern's population was connected to central WWTPs. 10 % of the population use decentral small WWTPs or at least have a septic tank that is emptied regularly. Nevertheless Mecklenburg-Vorpommern fulfills the requirements of the Urban Wastewater Treatment Directive 91/271/EEC, meaning that all wastewater communities with more than 2.000 p.e. are connected to sewers and receive basic mechanical and biological treatment. All wastewater communities with more than 10.000 p.e. additionally apply further treatment steps. Overall Mecklenburg-Vorpommern could meet the minimum requirements for discharge concentrations or minimum reduction rates for BOD₅, COD, phosphorus and nitrogen.

At the end of 2016 a total number of 586 municipal WWTPs has been operated in Mecklenburg-Vorpommern, but only 120 plants had a size of minimum 2.000 p.e. (see Fig. 14 and Tab. 1Tab. 9).



Fig. 14. Location of municipal WWTPs in Mecklenburg-Vorpommern with corresponding plant size category

Plant size category (p.e.)	Number		Connected people equiv.	
PSC 1 (< 1.000 p.e.)	428	73,0 %	144.939	4,4 %
PSC 2 (1.000–5.000 p.e.)	86	14,7 %	214.870	6,5 %
PSC 3 (5.001–10.000 p.e.)	21	3,6 %	166.892	5,1%
PSC 4 (10.001–100.000 p.e.)	47	8,0 %	1.820.250	55,4 %
PSC 5 (> 100.000 p.e.)	4	0,7	940.000	28,6 %

Tab. 9: Number and size of municipal WWTPs in Mecklenburg-Vorpommern

The table shows the high number of small WWTPs up to 10.000 p.e. (91,3 % of all WWTPs). They do, however, treat only a relatively small share of wastewater of approx. 16 %. On the other hand a relatively small number of 51 WWTPs treat 84 % of the arising waste water. Hence the treatment quality with respect to nitrogen and phosphorus removal in those large plants is crucial for meeting treatment quality standards.

All WWTPs in this state are equipped with mechanical and biological treatment. 33,6 % of all plants also have a nitrification step, which corresponds to 94,1% of the total treatment capacity. The same applies to further treatment steps like denitrification, phosphorus elimination and filtration. Only about 15-18% of the WWTPs have a phosphorus elimination, but this corresponds to treating the wastewater of approx. 90% of all peoples equivalents (see Fig. 15).

Fig. 16 shows the discharge concentration and treatment efficiency of WWTPs in Mecklenburg Vorpommern in 2015 and 2016 starting with a plant size category of 2.000 p.e.. The column headers from left to right are Parameter, Concentration (Limit value, Mean value, Boxplot), Treatment efficiency (Mean value, Boxplot). The lines from top to bottom are BOD5, COD, Total Phosphorus for two size categories and Total Nitrogen for two size categories.

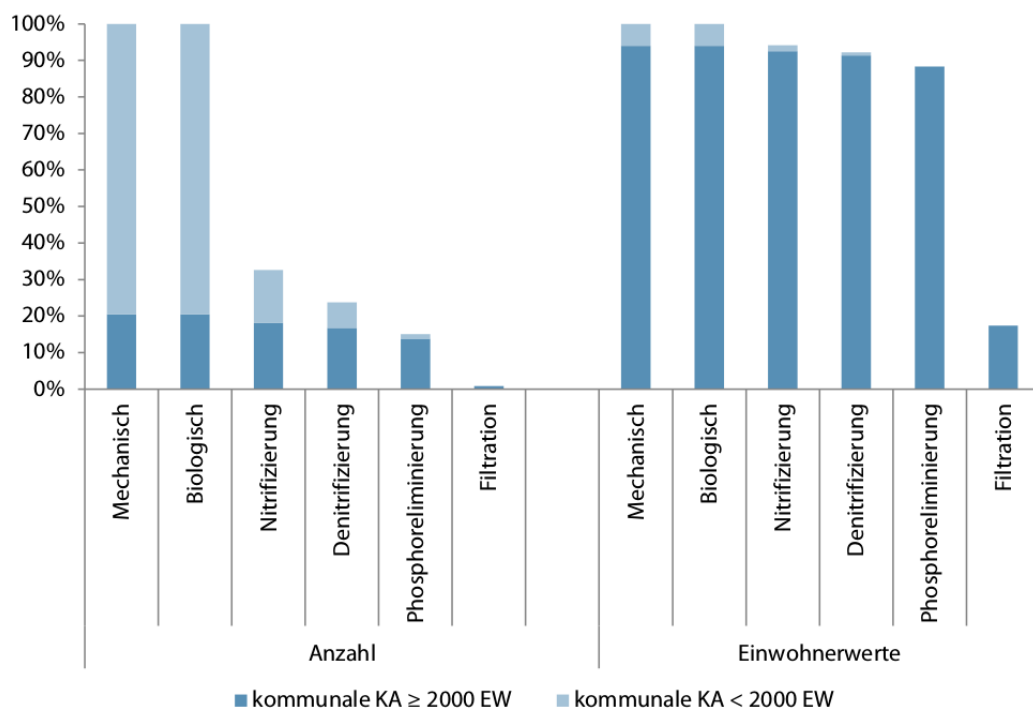


Fig. 15: Share of treatment methods and treatment capacity of WWTPs in Mecklenburg-Vorpommern

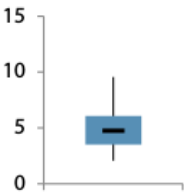
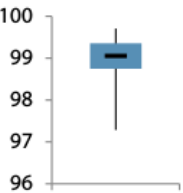
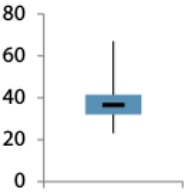
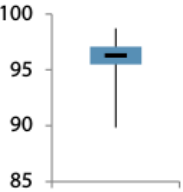
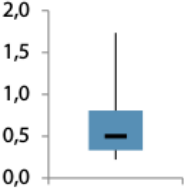
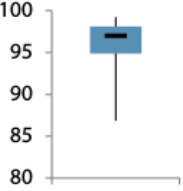
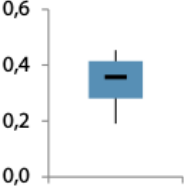
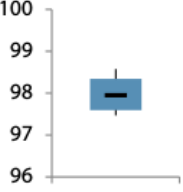
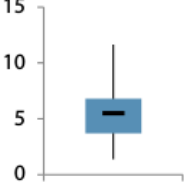
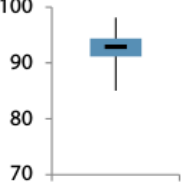
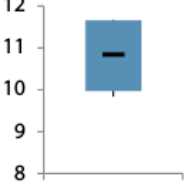
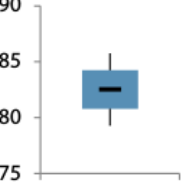
Parameter	Größe	Konzentration			Abbauleistung	
		Grenzwert	Mittelwert	Boxplot	Mittelwert	Boxplot
BSBs	≥ 2000	15 - 25	5,1 mg/l		98,9 %	
	EW	mg/l				
CSB	≥ 2000	75 - 110	38,4 mg/l		95,5 %	
	EW	mg/l				
Phosphor gesamt	10.000- 100.000	2 mg/l	0,7 mg/l		96,1 %	
	EW					
	über 100.000	1 mg/l	0,3 mg/l		98,0 %	
	EW					
Stickstoff gesamt	10.000- 100.000	18 mg/l	5,6 mg/l		92,5 %	
	EW					
	über 100.000	13 mg/l	10,8 mg/l		82,5 %	
	EW					

Fig. 16: Discharge concentrations and treatment efficiency of WWTPs in Mecklenburg-Vorpommern

All above information is based on the Status Quo report on the treatment of municipal wastewater in Mecklenburg-Vorpommern from 2017 (13).

1.4.2.3 Wastewater treatment in Brandenburg

Brandenburg is the state around Berlin. In average the population density is low with 84 inhabitants per km², but varies strongly between urban areas like Potsdam with 891 inhabitants per km² and very rural areas like Uckermark in the Baltic Sea sub-catchment area where the population density is 39 inhabitants per km². This explains why only 88,1 % of Brandenburg's population have been

connected to central sewer systems with municipal WWTPs at the end of 2015. 8,6 % of the population collect their wastewater in septic tanks that are emptied regularly by trucks with the wastewater being treated in central WWTPs. 3,3% of the population treat their wastewater in decentral small WWTPs. At the end of 2015 a total number of 237 municipal WWTPs have been operated in Brandenburg. In the Baltic Sea sub-catchment area twelve plants with treatment capacities between 15.000 and 150.000 people equivalents are located as shown in Fig. 17.

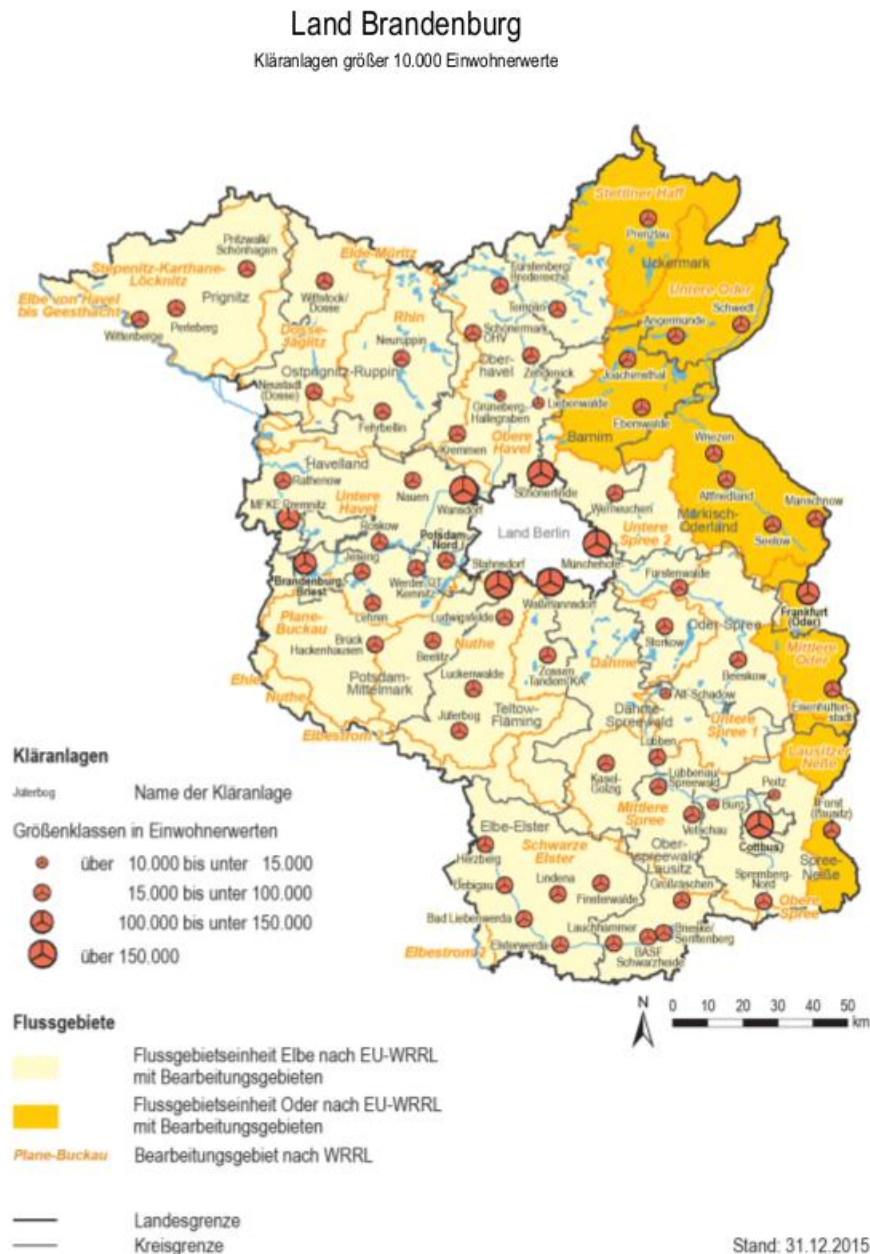


Fig. 17: WWTPs with more than 10.000 p.e. in Brandenburg (dark yellow: Baltic Sea subcatchment area)

Like in Mecklenburg-Vorpommern the majority of municipal WWTPs are small plants that treat only a relatively small fraction of the wastewater whereas the relatively small number of large plants treat the major part of Brandenburg's wastewater. Tab. 10 shows the number of WWTPs per size category at the end of 2015.

Plant Size Category (people equivalents)	Number of Plants (2015)
100 – 2.000 p.e.	108
2.000 – 10.000 p.e.	59
> 10.000 – 100.000 p.e.	62
> 100.000 p.e.	8
Total	237

Tab. 10: Number of municipal WWTPs in Brandenburg according to Plant Size Category

The WWTPs < 2.000 p.e. treat about 2% of Brandenburg's wastewater. The largest 70 plants on the other hand treat 90% of the wastewater in Brandenburg. According to the Urban Wastewater Treatment Directive 91/271/EEC all WWTPs with a treatment capacity of > 10.000 p.e. have been equipped with additional nutrient removal before 2004. However, an increasing number of smaller WWTPs have also been equipped with nutrient elimination technologies. As a result in 99,8 of all wastewater in Brandenburg nutrients like nitrogen and phosphorus have been systematically been removed. The following Fig. 18 and Fig. 19 show the relation between the number of existing WWTPs between 1999 and 2015 grouped by plant size category and the corresponding treatment capacity. Especially Fig. 19 shows the amount of wastewater that undergoes N- and P-removal also in small municipal WWTPs.

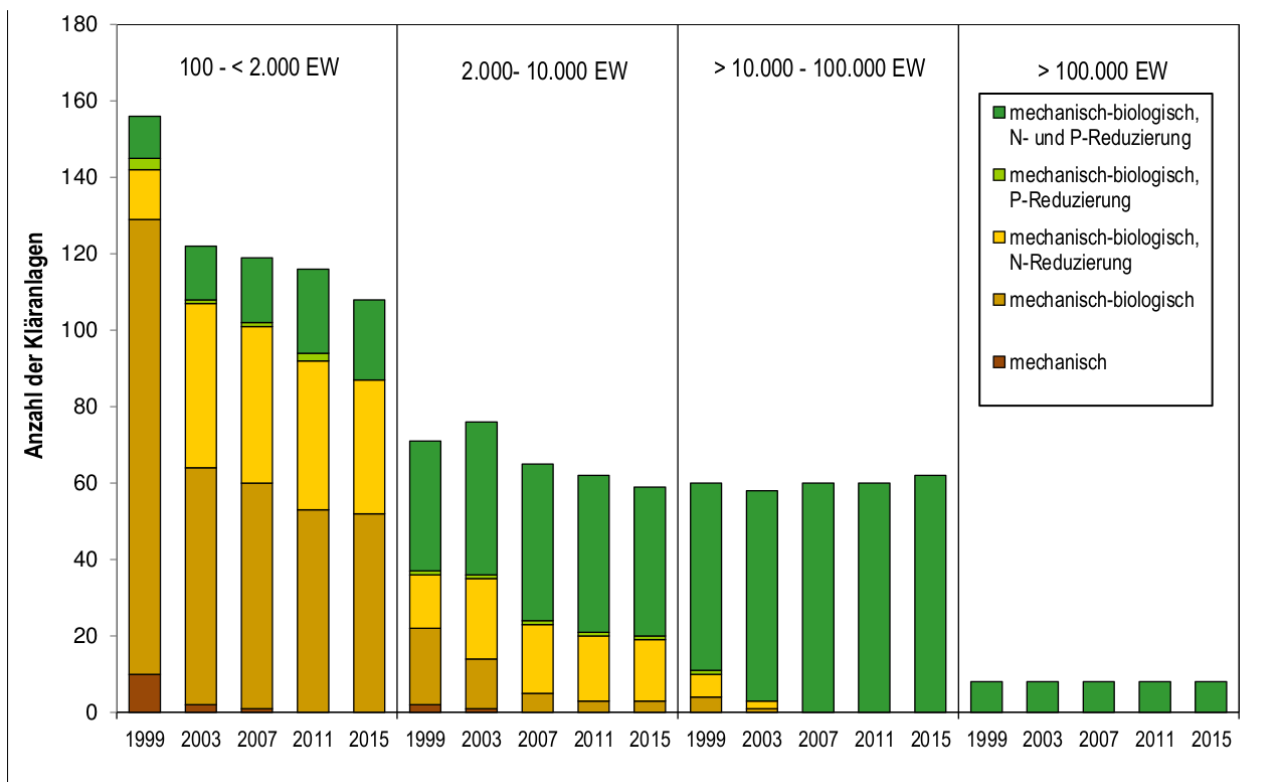


Fig. 18: Number of existing WWTPs in Brandenburg from 1999 to 2015 by plant size category and treatment method (from top to bottom: dark green = mechanic-biologic treatment with N- and P-removal, light green: mechanic biologic treatment with P-removal, yellow = mechanic-biologic treatment with N-removal, light brown = mechanic-biologic treatment, brown = mechanical treatment)

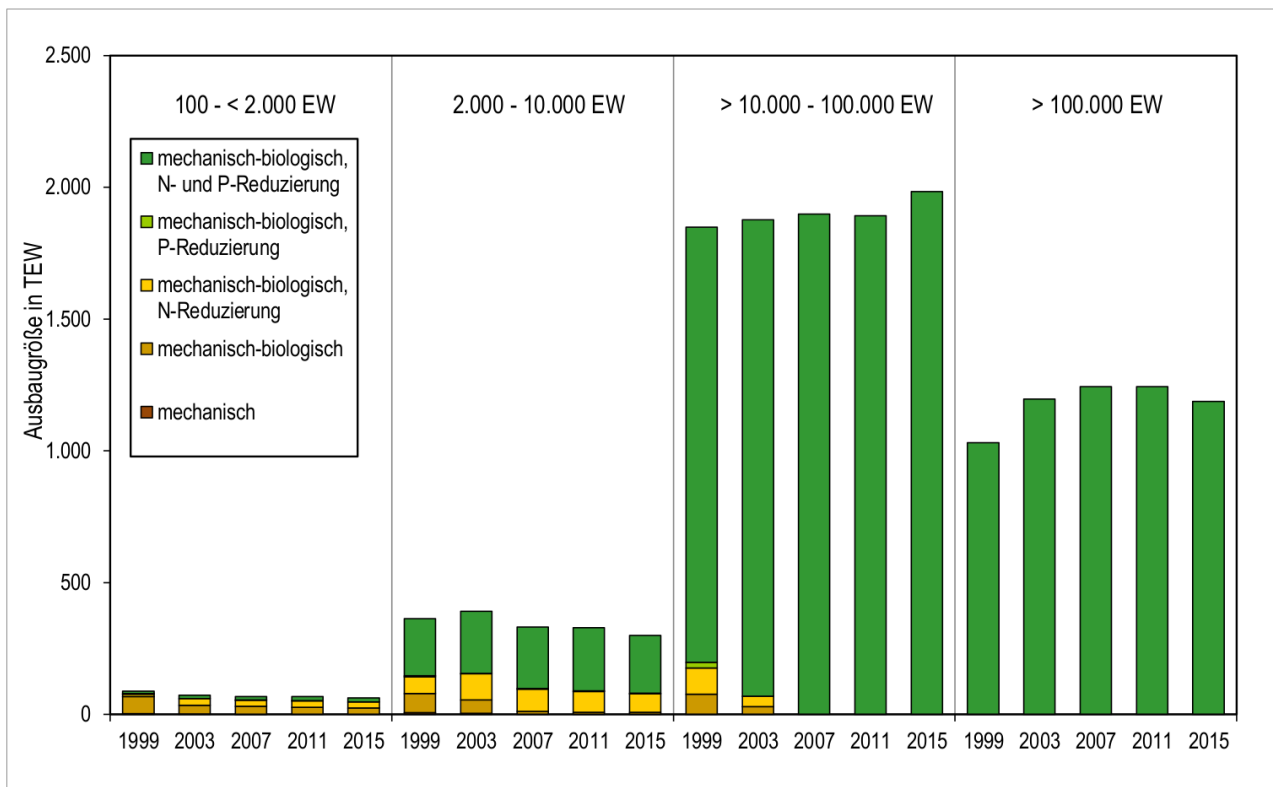


Fig. 19: Treatment capacity in thousand people equivalents from 1999-2015 by plant size category and treatment method

All above information is based on the Status Quo report on the treatment of municipal wastewater in Brandenburg from 2017 (14).

2 Review of treatment methods used for solid and liquid digestate from biogas processes and prevalence of different methods in the country in question

Digestate treatment has become increasingly relevant as an alternative to conventional land application, especially in regions with a combination of a large amount of animal husbandry and many biogas plants which both contribute to the nutrient balance in the soil. This is the case in many regions in Germany.

Digestate treatment is carried out to:

- Save application costs
- Facilitate transportation and nutrient export away from regions with a high nutrient concentration
- Produce marketable fertilizer
- Produce compost
- Reduce the amount of nutrients in the liquid phase
- Avoid the escape of gaseous pollutants into the atmosphere
- Decompose odor intense components
- Deactivate disease germs and weed seeds
- Improve transportability and reduce storage space through liquid removal

(15; 16)

When it comes to digestate treatment, there are **physical**, **chemical** and **biological** methods, which, in many cases, depend on each other. The basic treatment processes are similar for each method: digestate is brought into a solid-liquid separator, producing a solid and a liquid phase. These phases are either treated further or applied directly to the field. The following paragraphs describe the principle functioning of basic and further processing. Whether or not digestate treatment makes sense depends on many factors, especially the need for nutrient exports or the creation of a new business case, because each treatment step involves additional machinery, energy and efforts resulting in increased costs for the final products.

2.1 Physical treatment methods

Physical treatment usually starts with separating **solid matter** from the liquid. This reduces the storage volume for the liquid phase, allows a better fertilizer management and also facilitates further treatment of the solid matter. Further treatment of the solid matter usually includes drying or composting and sometimes pelletizing of the solid phase for the purpose of stabilization and upgrading the former digestate into a marketable product. This produces solid fertilizer, litter and, although very rarely, pellets to serve as fuel in stoves. For the most part, the practice of burning digestate pellets is still subject of discussion and research – especially because of the higher NO_x-emissions in comparison with conventional burning materials. (17)

The **liquid** phase's most popular application is still land application for agricultural biogas plants. If the feedstock has a high dry matter content it is also recirculated within the plant to dilute the feedstock. In this case nitrogen accumulation might be an issue and respective monitoring is needed.

For biogas plants in regions with a high nutrient concentration it might be necessary to further treat the liquid phase because the maximum amount of nitrogen in the soil would otherwise be exceeded. In this case, the methods and targets are twofold:

- Mass reduction, mostly through vaporization or membrane separation techniques
- Extraction of nutrients or other components which allow the remaining liquid phase to be brought into surface waters

In most cases, these targets can only be achieved by lining up multiple processes. This means that the treatment is connected to relatively high efforts and costs.

Further physical treatment methods include ammonia-stripping, drying through evaporation and reverse-osmosis.

2.1.1 Screw press separators and decanter centrifuges

Depending on the digestate properties typical machines used for liquid-solid-separation are screw-press-separators or decanter centrifuges. Screw-press separators are used for fibrous digestate, as the fibres build a press cake that contributes to the result. Non-fibrous slurries, e.g. from anaerobic sludge stabilization or from catering waste digestion, are separated using decanter centrifuges for separating liquids from solids. Often flocculants are needed to achieve an acceptable separation result.

Both the screw press separators and centrifuges represent “state of the art”-technology which means that they are relatively easy to handle and cost efficient in both investment and maintenance.

The liquid phase makes up the majority of the mass, usually between 80 and 90 % of the total input. Further processing of the digestate without any previous separation of the solid and liquid phases is only rarely carried out. (15)

It is not possible to separate or extract nutrients from the digestate with these applications, meaning that the nitrogen will remain in both phases, predominantly in the liquid phase. Phosphorus, however, is predominantly available in the solid phase.

Of these two machines, the screw press separator represents the most energy efficient with a consumption of around 0.4-0.5 kWh/m³ compared to that of the centrifuges 3-5 kWh/m³. *Fig. 20* shows the effect of mechanic separation of digestate with the distribution of mass and contained components. The blue bars represent the liquid and the green bars the solid phase. (17)

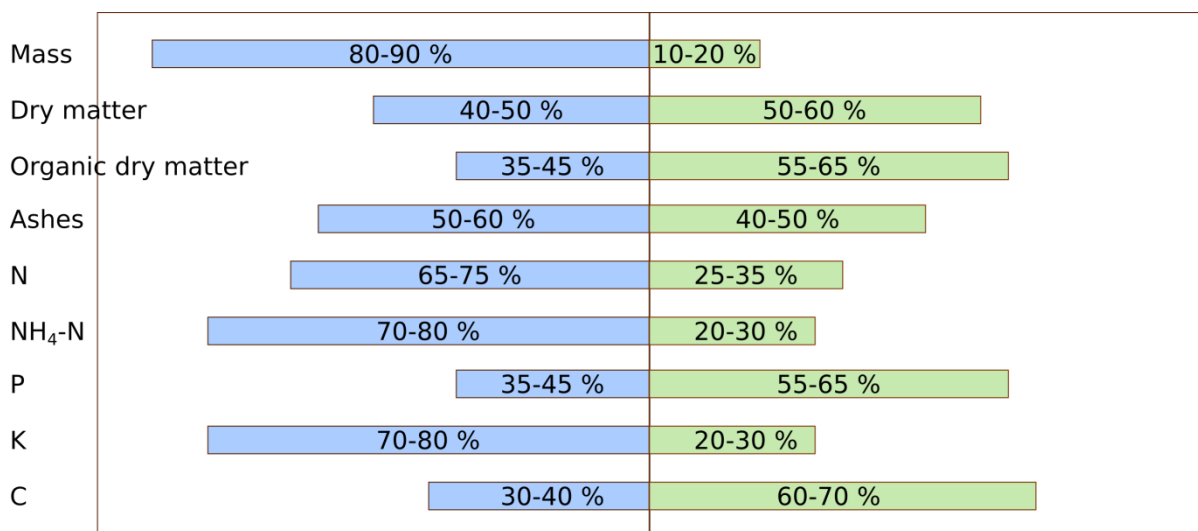


Fig. 20: Composition of separated digestate. (18)

As can be seen in *Fig. 20*, the majority of the total mass and also the nitrogen content of the digestate, both total and organically bound, remains in the liquid phase after separation. This is especially important in regions where nutrient overload, nitrogen in particular, is an issue.

Depending on the severity a subsequent further nitrogen removal – e.g. via stripping (section 2.1.5) – is theoretically possible and easier to achieve.

2.1.2 Belt filters

Using a belt filter for solid-liquid separation of the digestate produces a solid phase with very high dry matter content compared to the screw press separator. It also consumes less energy than a centrifuge. A major downside is the high demand of flocculation products (chemical treatment) which are necessary for a satisfying separation process. It is about two to three times higher compared to the centrifuge and power consumption amounts to 1.5-2 kWh/m³.

2.1.3 Drying through evaporation

After liquid-solid separation further drying might be needed, depending on the final use of the digestate. A wide range of technology is available on the market – ranging from belt and drum dryers to solar-thermal drying in greenhouses. The type of technology applied depends on the sector (e.g. agricultural biogas plants vs. anaerobic sludge stabilization at a WWTP) and the final use of the dried product (e.g. fertilizer vs. fuel substitute). Usually drying is only applied to make the product more worthy for transport.

It is also possible to process the liquid phase using vacuum evaporation. Here the target is also volume reduction by evaporating the water and thus concentrating the nutrients in the concentrate. Often the concentrate is mixed with the separated solids before they are either dried further or spread on the land. The water vapor also still contains nutrients and can only be released into surface waters after yet further treatment.

In any of the two cases a cheap heat source is needed, which is typically the recovered heat from the CHP-unit burning the biogas. Heat leads to increased ammonia evaporation and care has to be taken to recover ammonia in order to prevent venting it to the atmosphere.

The most common use for dried fertilizer is still agriculture, although attempts are being made to market the product to private gardeners. The reduced volume allows exporting nutrients to other regions.

2.1.4 Filtration and reverse-osmosis

If a separation of fine, organic and inorganic digestate components from the liquid phase is desired, **micro- and ultrafiltration** represent an interesting treatment method, especially as a pre-treatment for a following reverse-osmosis. The size of removable particles ranges from 10 µm to 0.01 µm.

During the **reverse-osmosis**, the pre-treated liquid phase is pushed through a semi-permeable membrane to remove suspended solids, organic compounds, colorants, viruses and bacteria from the water. Around 95-99 % of all suspended solids and 99 % of the bacteria can be removed through this method.

2.1.5 Ammonia-stripping

For the purpose of removing ammonia from the liquid phase or to extract it for fertiliser production, the liquid phase of the digestate can be stripped. This means that volatile compounds inside the liquid are pushed out via stripping gas. The volatile compounds enter the gaseous phase through an increase in temperature or a reduction in pressure and are then carried out of the system with the stripping gas. Usually the stripping gas passes an acid washer to remove the ammonia from the gas before it is released to the atmosphere.

2.2 Chemical treatment methods

The digestate is treated chemically for the purpose of extracting nutrients, but also to prepare the digestate or slurry for liquid-solid-separation. For a complete removal of all nutrients, multiple processing steps are necessary. **Flocculation** and **precipitation of the nutrients** are the most

common chemical treatments. This method is effective for phosphate but is not relevant for nitrogen removal. For this reason and for the high costs, the chemical treatment is not commonly used in agricultural biogas plants.

To reduce the nutrient quantity and extract them, iron- and aluminum-salts can be added to the digestate. This causes a **flocculation**, transferring the compounds into an insoluble state allowing the solid flocculants to be removed from the liquid via sedimentation, filtration or flotation. Although this technology represents a safe and reliable practice, it is only rarely used since a market for nutrient fertiliser has to be established and this method only works in line with previous treatments. (15; 17)

2.3 Biological treatment – composting

Aerobic degradation or composting of the solid phase of the digestate after the first mechanical separation is a widely exerted method to produce a valuable and marketable end product. It is usually combined with the digestion of source-separated organic kitchen waste. Since the digestate already underwent anaerobic digestion, the reduced content of carbon-based compounds considerably shortens the aerobic digestion process. This also means that the process temperature is lower compared to composting without preceding anaerobic digestion. Thus, it takes more time for the digestate to be sanitized. In particular the *Regulation on the recovery of biowaste agricultural, forestry and horticultural use soils* (BioAbV) regulates the condition of the composting process in order to be considered also as sanitation of the biowaste. Composting is especially popular in dry digestion biogas plants since the digestate does not need to be separated into a liquid and solid phase, and the BioAbV regulates that the water content should be at least 40%. (19)

2.4 Comparison of specific costs for digestate treatment methods

Naturally the most important criteria for planning and running a digestate treatment line are the investment and operating costs. *Tab. 11* compares net costs for six different method combinations. All numbers of *Tab. 11* represent a rough approximation since the exact costs depend on multiple factors like the type of the transporting machine, the distance from the biogas plant to the fields, the share of the liquid phase in the digestate, the nutrient content and more. (17)

	Direct digestate application	Screw press separation and application	Screw press separation and drying on a belt dryer	Centrifugal separation, ultrafiltration and reverse- osmosis	Centrifugal separation and evaporation	Centrifugal separation, stripping and flocculation
	[€/m ³ Digestate]					
Fixed costs	1.62	2.15	4.01	5.19	3.03	5.07
Energy and operation materials costs	0.29	0.30	3.74	2.77	7.03	3.42
Transportation and application costs	4.42	4.77	4.53	3.17	2.82	2.21
Gross costs	6.33	7.23	12.28	11.13	12.88	10.70

	Direct digestate application	Screw press separation and application	Screw press separation and drying on a belt dryer	Centrifugal separation, ultrafiltration and reverse- osmosis	Centrifugal separation and evaporation	Centrifugal separation, stripping and flocculation
Nutrients (saved fertiliser costs)	-4.40	-4.40	-4.26	-4.40	-4.40	-4.38
Bonus for own heat usage	-	-	-1.23	-	-2.15	-0.88
Net costs	1.94	2.82	6.80	6.72	6.32	5.43

Tab. 11: Comparison of specific costs for digestate treatment methods.(17)

For the biogas plant operator, the most economic solution to treat digestate is the direct application onto the fields, followed closely by the solid-liquid separation using screw presses in combination with land application. Nutrients are mentioned as negative costs because the operator doesn't have to spend money on phosphorus-, nitrogen- and potassium-fertilizer. All processing steps lead to higher costs in comparison with direct application which is why digestate upgrading can only be economically attractive if there is a market for recovered and easily transportable nutrients or if the nutrient pressure on soil is very high. The condition for this scenario is a surplus of nutrients in the region where the biogas plant substrates are produced.

Fig. 21 shows the average distance in km for animal manure and digestate. In the area of study digestate and manure is applied locally or it is transported to a maximum of 10 km radius, meaning that overfertilization is not an issue there.

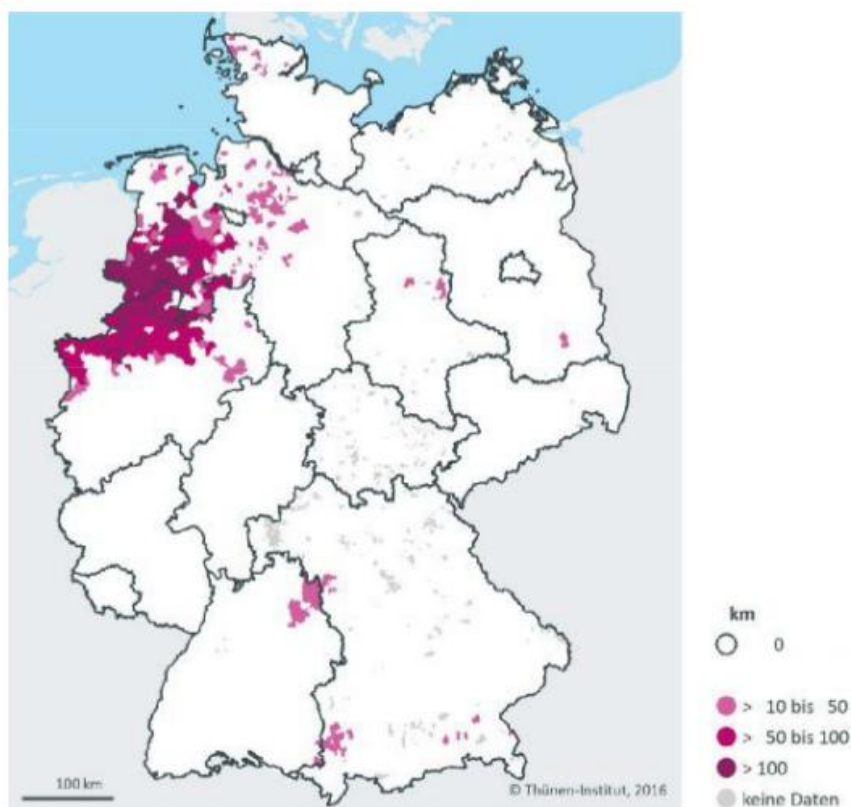


Fig. 21: Average transport distance in km for animal manure (excluding poultry manure) and biogas plant digestate of plant origin. (20)

Tab. 12 summarizes the most common digestate treatment and use for the different biogas plant types.

Most of the above mentioned physical, chemical and biological treatment options originate from corresponding liquid manure and sewage sludge treatment technologies. They are well researched and established methods for these applications, but specific experience regarding digestate treatment is missing. This is still subject of research and, despite the large quantity of possibilities, none of the methods can be called “state of the art” as of now. (17)

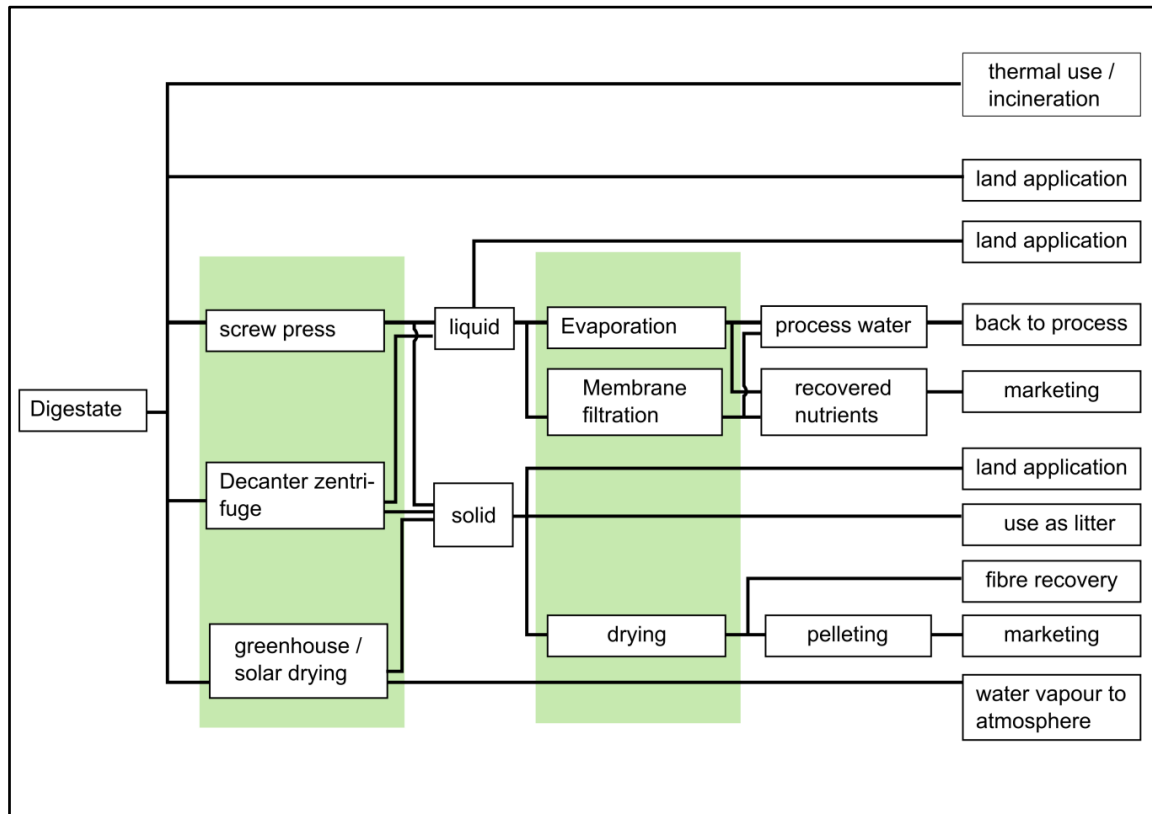


Fig. 22: Most common digestate treatment methods in Germany. (21)

Main feedstock	Most common digestate treatment	Digestate use
Agricultural	Small plants: No treatment	Land application
	Big plants: <ul style="list-style-type: none"> • Screw press • Decanter centrifuge • Drying 	<ul style="list-style-type: none"> • Land application • Pelletizing
Sewage sludge	1. Mechanical liquid/solid separation (circa 50% DM) <ul style="list-style-type: none"> • Screw press • Decanter centrifuge • Chamber filter press 2. Thermal drying (circa 85-95% DM)	<ul style="list-style-type: none"> • Incineration • Land application • Landscaping
Organic waste and industrial by-products	Mechanical separation Composting	Land application

Tab. 12: Most common digestate treatment and use in Germany, divided by biogas plant type.

2.5 Most prevalent method of digestate treatment in Germany

Digestate treatment in the agricultural biogas sector differs very much from the treatment used at wastewater treatment plants. One important reason is that wastewater treatment plants discharge directly into surface water bodies, which are much more sensitive towards nutrients than soil. Despite the theoretically possible treatment methods mentioned above, only a few methods are commonly applied in practice. They differ between agricultural biogas plants / waste digestion plants and wastewater treatment plants.

2.5.1 Agricultural biogas plants and waste digestion plants

In Germany the prevalent use of digestate from agricultural biogas plants is direct land application. Secondly simple liquid-solid separation using screw-presses is applied. This is mainly done to make better use of the existing digestate storage volume, especially if the plant capacity has been increased and the biogas plant is operated at its limit.

Further digestate treatment is currently only feasible for a minority of biogas plants. Especially small and medium sized agricultural plants will struggle to see an economic benefit from further treatment beyond direct land application. The low return-on-investment-rate of only about 5 % per year on the treatment machinery is one of the main reasons. A more refined and waste product oriented bio-economy and further usage for by- and end products of anaerobic digestion could motivate many operators to reconsider. (17)

Only in regions with an excess of nutrients – the pink to dark pink areas in Fig. 21 – farmers invest in technology for further concentrating nutrients. Examples are the cases of Nadu and Sanadur in chapter 6, where biogas plant operators intend to export nutrients from the agricultural sector.

This is, however, not the majority and rather typical for large scale biogas plants. In case of the study region large biogas parks, e.g. Biogaspark Penkun and Biogaspark Güstrow in Mecklenburg-Vorpommern, need digestate upgrading with nutrient recovery. Their substrate producers are numerous and located comparably far away from the plant. Since they are the final users of the digestate, there is a strong economic interest in lowering the transportation costs through weight and volume reduction. By using sophisticated digestate treatment technology they create defined fertilizer products and, to our knowledge, clean water for discharge into surface water. The market for their fertilizer was, however, not identified.

Digestate treatment also has a purpose in biogas plants that digest a large amount of organic waste and industrial by-products. Since both of these plant types, at least for a large proportion, don't obtain their substrates from the fields in their close vicinity, they profit from digestate treatment. To reduce costs for storage, transport and application, a mechanical separation is an easy first processing step. Waste digestion plants also offer fertilizer for agricultural or horticultural use. Because of the feedstock's origin a continuous control and the production of a certified fertilizer with RAL-label (see section 3.2.5) is crucial to convince farmers and private gardeners of the quality and safety of the organic fertilizer. Depending on the feedstock and the applied digestion technology (wet digestion versus dry or solid state digestion) the typical digestate treatment and upgrading ranges from using screw-presses or decanter centrifuges to subsequent drying or even co-composting with greenery waste. Liquid and solid fertilizer is supposed to be applied on land.

For farm scale biogas plants nutrient separation could be interesting in the event of increasing fertilizer costs. But since prices for nitrogen and phosphorus fertilizer have seen a decrease over the last two years, it becomes less and less attractive to extract them from the digestate for further marketing. And with fuel and electricity costs going up in recent years, it is yet even more

expensive to set up and run a treatment line. (22) A new need might arise from stricter fertilizer legislation.

2.5.2 Wastewater treatment plants

Germany as a whole is still diverse with respect to sewage sludge management and final use. Generally three routes exist for using it:

- Thermal use / incineration
- Landspreading in agriculture
- Landscaping material

Which route prevails varies between the federal states and mainly depends on their respective land availability and infrastructure (Fig. 23).

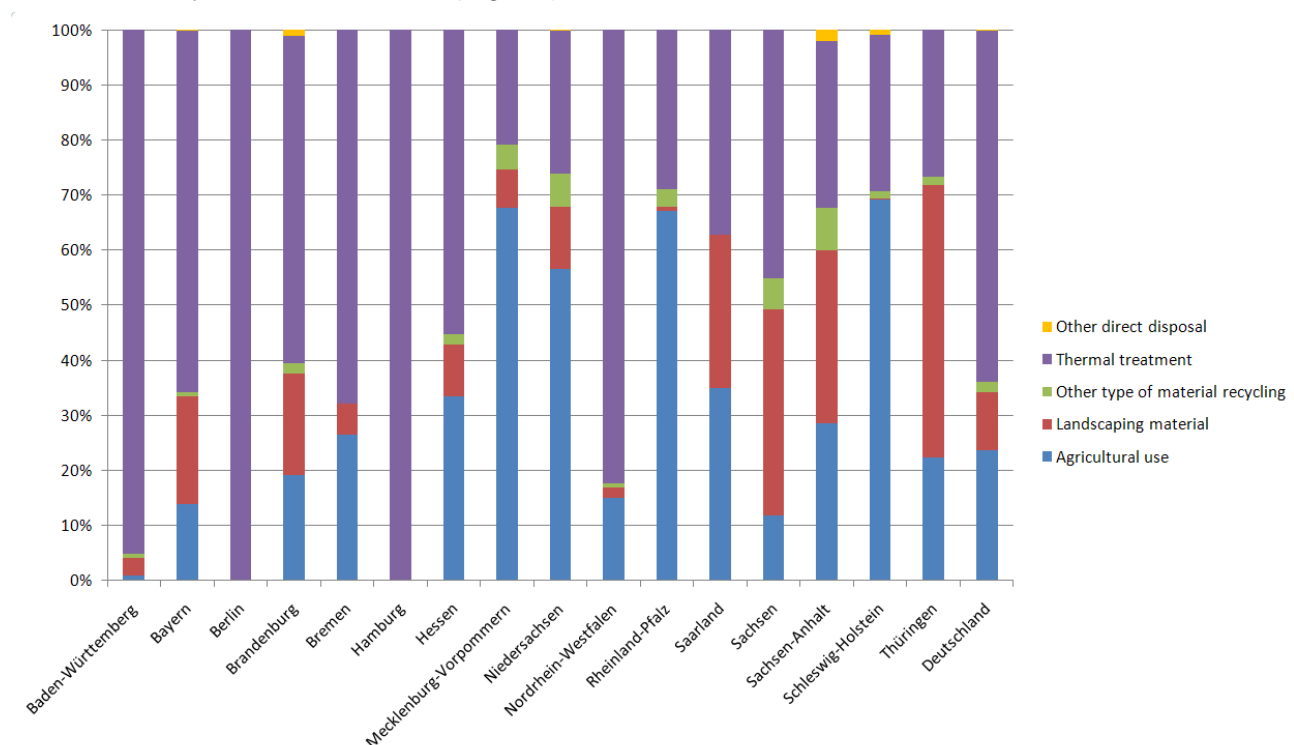


Fig. 23: Sewage sludge treatment and use in 2015 by Federal State (Source:(23) , own presentation)

In average the largest share of Germany's sewage sludge (approx. 64 %) have been incinerated in 2015, whilst approx. 24 % are used in agriculture and 10,5 % are used as landscaping material.

With respect to the study area the land application is still prevalent in the states of Schleswig-Holstein (72 % of the sewage sludge) and Mecklenburg-Vorpommern (88 % of the sewage sludge), whereas in Brandenburg and in Saxony only 17–20 % of the sludge are used in agriculture. The rest is either incinerated or used in landscaping (24).

Prior to releasing the sludge from the WWTP it needs to be dewatered and depending on the final use it will additionally be pressed and dried. Dewatering is mainly done using decanter centrifuges. If flocculants need to be added to increase the separability of the sludge, careful selection is required when the sludge is applied to agricultural land. In that case polymers need to be harmless for the environment.

After dewatering chamber filter presses are typically used to increase the dry matter content of the sludge prior to shipping it to its final destination, e.g. an incineration or gasification plant. In this thermal treatment the digestate is combusted mainly because of increased levels of pollutants that should not end up on agricultural land. The ashes from the process can be recovered and used as a construction material for roads or concrete production.(25)

After separation of the solids the reject water is recirculated back to the inlet of the WWTP. This can lead to nitrogen spikes in the inlet and hence to poor N-removal in the treatment process. This mechanism is known and discussed in literature, e.g. DWA Arbeitskreis "Rückbelastung aus Schlammbehandlung" (26).

Two approaches are under discussion to deal with this matter:

1. Replace batch-wise separation with continuous separation and intermediate storage of reject water in combination with continuous back-feed of reject water. According to (26) this should be the normal case today.
2. Separate treatment of reject water in SBR-reactors.

As of October 2015 a separate treatment of reject waters has been implemented in around 70 WWTPs in western Germany (27), mainly in areas with high population density and possibly WWTPs operating close to their limits. In eastern Germany including the Baltic Sea sub-catchment area no such technology was found during a literature and internet research. One reason could be that WWTPs in east Germany hardly operate at their limit, because east Germany sees a population drain to the west. Compared to the time of construction the WWTPs have been confronted rather with a decreasing than an increasing wastewater volume, especially in the sub-catchment areas in Mecklenburg-Vorpommern and in Brandenburg.

3 Legislative framework and permitting procedures for biogas installations (all relevant laws and permitting practices used both for biogas installations and treatment /disposal of their digestates / reject waters)

3.1 Permitting procedures for German biogas plants

This section targets the permitting procedures in Germany for biogas plants. It gives a general overview, but does not go into details.

In Germany two principle types of permitting procedures exist for biogas plants:

- a) Permitting according to the Construction Law² - this targets *only the construction* of the biogas plant
- b) Permitting according to the Federal Emission Protection Law³ - this targets the construction *and operation* of a biogas plant

Which type of permitting procedure applies depends primarily on the CHP's thermal firing rate, the plant's capacity for raw gas production and the feedstock used. If the thermal firing rate is less than 1 MW, the total annual gas production capacity is below 1.2 Million m³ of raw biogas and feedstock comes from agricultural sources (i.e. manures, dedicated energy crops) the simplified permitting procedure according to the Construction Law is sufficient.

If those limits are exceeded the Federal Emission Protection Law applies. The schematic representation in *Fig. 24* shows the main decision criteria. If it is clear that the permission will be granted based on the Federal Emission Protection Law, a second threshold needs to be taken into account to determine, if a simplified permission procedure or the full procedure including public participation is needed.

Although the permit according to Construction Law is less formal compared to the Federal Emission Protection Law procedure, all relevant sector agencies need to be involved in the process. In this context the applicant is responsible to organize the sector agencies' involvement with exception of the local water authority.

In case of the formal permitting procedure according to the Federal Emission Protection Law the permitting agency acts as a "1-stop shop" which means that they are coordinating the sector agencies.

In any of the cases, emissions into the air and water are one focal point of the authorities as are the veterinary approval in case of manure digestion, worker's health and safety aspects, technical plant safety, digestate use and nutrient application and possibly contracts with third parties showing that enough area is available for nutrient spreading.

Tab. 13 summarizes the basic steps of the permitting procedure under the Construction Law compared to the Federal Emission Protection Law.

Regarding emission control the most important aspects are minimum distances to neighboring housing or industrial areas or odor control and emission control from exhaust gas stacks. With respect to preventing nutrient leaks into the groundwater or surface water bodies biogas plants are required to build a catchment area (e.g. a dam) equivalent to the largest above ground volume of a tank to prevent digester slurry flowing into creeks and rivers in case of a tank failure or technical failure. New biogas plants are additionally required to install leakage detection equipment underneath each tank, in underground slurry pipelines and underneath the silo bunker.

The nutrient management plan is always part of the permitting procedure.

2 Baugesetzbuch (BauGB)

3 Bundesimmissionsschutzgesetz (BImSchG)

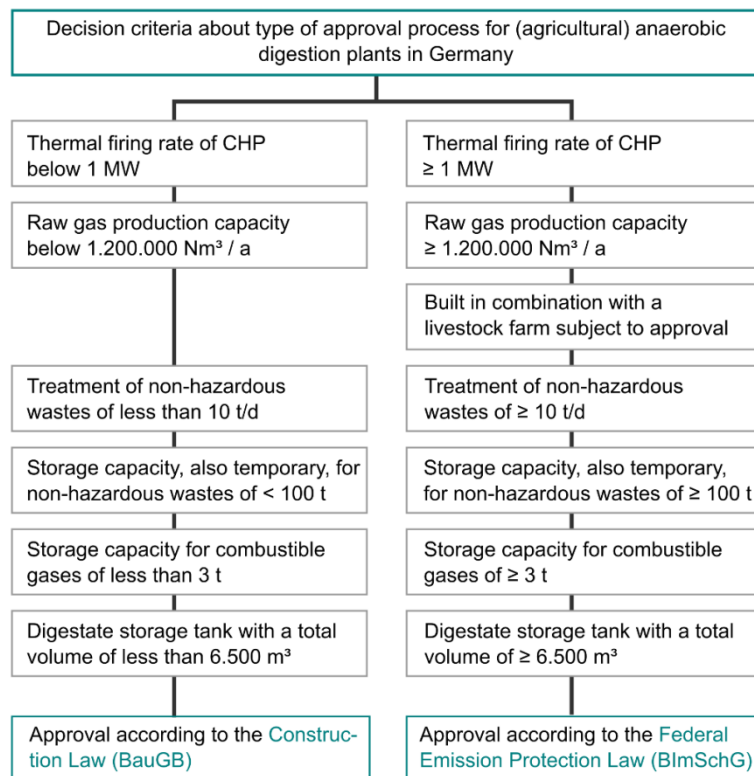


Fig. 24: Decision criteria for selecting the permitting procedure for biogas plants in Germany. (28)

Permitting procedures in Germany		
Construction Law	§19 BImSchG simplified procedure acc. Federal Emission Protection Law	§10 BImSchG formal procedure acc. to Federal Emission Protection Law
	Consulting with authorities prior to application for permit	
Application for permit: a) Application b) Application dossier: Topographic map, Building documents, Technical and operational description of biogas plant	Application for permit: a) Application b) Application dossier: Topographic map, Building documents, Technical and operational description of biogas plant, Schematic representation, Plant installation drawings, Emission forecast, Waste management plan	
		Public announcement
		Public presentation of the application and documents during 1 month
		Public hearing
	Possibly involvement of additional authorities Possibly obtaining an expert opinion for an environmental impact assessment	
	Examination	
	Decision	
	Notification of the decision	
	Possibly objection by applicant	
	Possibly lawsuit at the Administrative Court	

Tab. 13: Overview over German Permitting Procedures for biogas plants. (28)

3.2 Legislation related to digestate treatment and use

The use of digestate is regulated by the fertilizer legislation in combination with hygiene legislation and waste legislation. To which degree the legislation is relevant depends on the biogas plants' feedstock mix (manures, energy crops, organic wastes), on the use of digestate (use on own fields or marketing) and on the degree of post-processing.

3.2.1 Fertilizing Legislation

In Germany the Fertilizing Law (Düngegesetz / DüG) and its regulations govern the manufacturing, the placing on the market and the use of fertilizers, soil improvers, culture media and plant aids. The Düngemittelverordnung (DüMV) (Fertilizer Ordinance) stipulates the regulations for placing fertilizers on the market. It defines fertilizer types with corresponding properties, formulates rules for labeling fertilizers and mentions phytosanitation and disease control. Finally the Düngeverordnung (DüV) (Fertilizing Regulation) fleshes out the usage criteria in accordance with good agricultural practice for fertilizer use like determining fertilizer needs, timing of fertilizer application, buffer strips for surface water bodies, and rules concerning ammonia emission abatement. The Düngeverordnung (DüV) implements the Directive 91/676/EEC into German law. Exempt from regulations of the Düngemittelverordnung (DüMV) are digestates from feedstock that originate from the own farm, like manures or energy crops.

The revised Fertilizing Regulation has come into force since 1st June 2017. It aims at reducing nutrient run-offs and nutrient leakages into surface waters and groundwater. The new modifications that entered into force in June 2017 are necessary to comply with the European Directive 91/676/EEC. National concerns about water protection also led to a stricter regulation. As a matter of fact the water protection agencies in the last years noticed an increase of nutrient concentration in groundwater, relating this growth to the always higher number of biogas plants. Thus these concerns led to the change in the new Fertilizing Regulation.

Important modifications are:

- Manures (slurry and dung) as well as digestates from any kind of anaerobic digestion, composts and sewage sludge are included in the definition of "organic fertilizer". The application of these organic fertilizers on grassland or arable land is limited to $170 \text{ kg N ha}^{-1} \text{ year}^{-1}$. Before this modification the *organic fertilizer* only included digestate originated from animal manure, without taking into account the fraction generated from energy crops
- Extended periods in which no fertilizer can be applied plus more detailed descriptions of the conditions and limits of fertilizing after harvest of the main crop.
- In autumn the maximum amount of N-application is limited to $60 \text{ kg ha}^{-1} \text{ year}^{-1}$ before 1st October depending on intercrops and winter crops. For vegetables, the period ends on 1st December.
- Increased distances for the application of N- and P-fertilizers near surface waters and in sloping sites.
- Reduced control values to determine the difference between nutrient application and nutrient removal by harvest (starting 2020 the limit value is $50 \text{ kg N ha}^{-1} \text{ year}^{-1}$ and $30 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1} \text{ year}^{-1}$).
- A nutrient balance from 2018 of:
 - N: 50 kg ha^{-1} , as 3-year average
 - P_2O_5 : 10 kg ha^{-1} , as 6-year average

The average is calculated over the complete agricultural estate and not for individual fields.

- Modified criteria to determine the storage volume for manures or digestate (min. 6 months, but if more than 3 LSU⁴/ha or limited own area for nutrient application 9 months of storage time needs to be covered).
- Farmers have to calculate fertilizer demand for grassland and arable land separately for nitrogen and phosphorus. Farmers have to provide authorities with those calculations during the permitting procedure and keep bookkeeping in case of controls. In order to achieve a balance between nutrient demand and supply site specific parameters must be taken into account (e.g. nutrient content in the soil, nutrient availability, pH, organic matter content, ...).

The calculations are based on:

- N-demand:
 - the planned crops / crop rotation system per farming unit under average crop yield of the last 3 years
 - N_{min}-level of the soil,
 - humus content
 - N-delivery from organic fertilizer applied in the last year
 - N-delivery from previous and catch crops
- P-demand:
 - expected yield
 - site conditions
 - cultivation conditions and phosphate levels in the soil. Nutrient balances based on a new field-stable-balance.

Every operator has to compile the nutrient management plan and show it in case of control. The plan must describe how the operator intends to deal with the nutrient surplus. In case of land application the operator must have agreements with farmers, who will accept the digestate as fertilizer. The annually plan must be filled in by the 31st of March and must concern the previous year, but the calculations are based on a multi-year management plan. The documentation must be available in case of controls for as long as 7 years after its compilation. The Fertilizer Legislation does not mention the frequency of the monitoring.

The above list is by far not complete, but shows the most relevant changes. In the end those new rules hopefully lead to an increased nutrient efficiency and to reduced leakages and run-offs. On the other hand the categorization of all digestates as organic fertilizers and the corresponding limit of 170 kg N ha⁻¹ year⁻¹ will lead to increased use of mineral fertilizer to cover the higher nutrient demands of intensively managed grass lands, wheat and other crops. Possibly, but this is not clear yet, the regulations regarding increased storage volumes for manures and digestates might lead to the fact that animal slurry is removed from the feedstock mix, because of the relatively high water content and the corresponding relatively low energy content in the slurry leading to adverse effects with regards to reducing GHG-emissions from agriculture.

3.2.2 Hygiene Legislation

Biogas plants that digest animal by-products including farm manure from animal origin are subject to the hygiene legislation and the resulting digestates need to correspond to the hygiene requirements. The European Directive 1069/2009 is transposed into German law by TierNebG and TierNebV. Subject to this legislation are for example catering wastes.

3.2.3 Waste Legislation

If organic waste, especially source separated household waste which is collected in a special (green or brown) bin, is treated in biogas plants, the resulting digestate needs to conform to the Biowaste Ordinance (Bioabfallverordnung / BioAbfV). This ordinance defines maximum amounts of biowaste digestate that can be applied to the soil (depending on the soil type – for agricultural areas, horticultural areas and forested areas) including limit values for heavy metals and nutrients. Regarding the latter, the Fertilizing Regulation must be followed (see paragraph *Fertilizing Legislation*).

The limits are very strict, thus land application of biowaste digestate is very rare.

3.2.4 Sewage sludge ordinance

A new sewage sludge ordinance might enter into force by 1st January 2018. The new ordinance states that the P recovery from sewage sludge is mandatory for all wastewater treatment plants (WWTP) with a capacity of at least 50.000 persons equivalent (p.e.). In Germany these represent around 500 WWTP out of the 9.300 total present in the country.

If the sludge contains more than 20 g of P for each kilo of dry matter of sewage sludge, the P must be recovered. Otherwise the sludge must go into incineration.

The land application of the sewage sludge is allowed only for the WWTP with a capacity under 50.000 p.e.

Every other WWTP will have to fulfill the new requirements, depending on their capacity:

- for WWTP with a capacity > 100 000 p.e. by 2029
- for WWTP with a capacity between 50 000 and 100 000 p.e. by 2032

For P recovery there are two methods:

- chemical precipitation of MAP (magnesium ammonium phosphate)
- sludge treatment in special incinerators and recovery of ashes to fertilizer right after the incineration or separated storage until recovered.

In 2015 in Germany 24% of the sewage sludge was used in agriculture, 10% in landscaping and 64% was incinerated. The sewage sludge management has changed in the last 20 years. In fact in 1998 the values were respectively 32%, 29% and 16%. The remaining amount not covered by either of the categories might have been landfilled in the late 1990s or is listed under “other use” in 2015(23). Land application is expected to half as a consequence of the new fertiliser and sewage sludge ordinances.

3.2.5 Digestate upgrading / processing

In Germany the main application for digested slurry is its application on land in order to use the nutrients in agriculture. While this is not critical in many areas, some “hot-spot” regions suffer from overfertilization and correspondingly higher nitrate levels in the groundwater. In those regions there is a big interest in nutrient export. Also, large biogas plants and biogas plant parks (e.g. Bioenergie Park Güstrow), that are not connected to farms or don’t have enough contracts with farmers for digestate sales, usually need to process digestate into marketable fertilizer products. In Germany the “Bundesgütegemeinschaft Kompost e.V. (BGK)” (Federal Compost Quality Association) is the officially licensed organization by RAL Deutsches Institut für Gütesicherung und Kennzeichnung e.V. (German Institute for Quality Assurance and Labeling (RAL)) to conduct quality assurances for:

- composts
- digestates
- digestates from energy crops

- etc.

It tests and certifies organic fertilizers. Although it is not compulsory to have a RAL-certification for composts or digestates, the RAL-certification is a well known quality label and facilitates the marketing of digestates or nutrient concentrates derived from them.

A RAL-certificate also ensures that the digestate or nutrient product complies with the requirements stipulated in the fertilizer and waste regulations. The labels are shown in Fig. 25.(29)



Fig. 25: RAL certification for different products: compost, digestate, digestate from energy crops and humus and fertilizer from waste water treatment plants. (29)

4 Risk assessment with case examples of installations with potential adverse environmental impacts

At present, anthropogenic nutrient inputs into the Baltic Sea are mainly derived from diffuse sources, the main cause being agriculture. The surplus of nutrients and their concentration into the soil are in fact the main primary causes of the pollution of the waters.(30). Major parts of the assessment are based on studies and models published for Mecklenburg-Vorpommern (M-V) and Schleswig-Holstein (S-H). Brandenburg shares soil properties with M-V, e.g. sandy soils in some parts but also drained wetlands. Therefore the basic results from the reports should be comparable for Brandenburg. The federal state of Saxony has not been included explicitly in this risk assessment, because the catchment area draining into the Baltic Sea is very small. Following are the main nutrients sources.

4.1 Natural processes

Nitrogen is already produced by natural processes in the soil, so a base concentration is already present. For the Mecklenburg- Vorpommern state (M-V) the average base concentration is between 10 and 40 kg N ha⁻¹. Here the nature of the soil is sandy, so the nutrients are easily transported to the surface waters through runoff. The recommendation is to reach a decrease of diffuse emission of nitrogen by 30 – 50 % and phosphorus by 10 – 20 %. There has been a decrease of the soil concentration of phosphorus in the last decades. However some still contributes to the eutrophication of the Baltic Sea, flowing into creeks and rivers through erosion, drainage and flooding from the agricultural lands. Nowadays only about 25% of the soil of the Mecklenburg- Vorpommern state is oversaturated with phosphorus. In the future a lower percentage is to be expected thanks to the new reduction measures in the latest revision of the Fertilizing Regulation.(31)

4.2 Drainage

The case study area naturally comprises many wetlands, which have been made suitable for agriculture with a system of drainage. This structure has two negative impacts on the nutrients pollution: increase in the run-off and decrease in the travel time for the water that is collected by the drainage to reach the surface waters. Hence, the quantity of nutrients flowing into creeks, small rivers and channels and then to the Baltic Sea increases.(31)

In M-V approx. 65% of the agricultural area is considered as artificially drained. Current studies show the importance of the drainage systems for the N and P total entries. Drainage systems are of great value for agricultural performance, but also present a high risk of nutrient discharges. (31) A solution to this problem could be the use of reactive drainage trenches, which are sections of the drainage system in which the nitrate decomposition is stimulated by the addition of organic substances. Studies from other regions show that reactive drainage can contribute significantly to the nitrate reduction compared to the classic drainage system.(31)

4.3 High livestock density

Since most of the biogas plants in the area of study are agricultural, their number is higher in regions with a high livestock density. In these areas the nutrient cycles are no longer closed because of the large quantities of nitrogen imported as a substrate resulting in the consequentially large volumes of digestate. Biogas production contributes to regionally existing nitrogen surpluses, which are primarily due to concentrated animal husbandry.

More specifically regarding the Schleswig-Holstein state, the study *Entwicklung eines Instrumentes für ein landesweites Nährstoffmanagement in Schleswig-Holstein Braunschweig* shows the direct correlation between the increase in regional nitrogen surpluses and the digestate.(32)

Fig. 26 shows the correlation between intensive livestock and aquaculture with groundwater quality based on the concentration of nitrogen. The groundwater which contains more than 50 mg/l of N is classified as polluted and marked red in Fig. 26. In the case study region the concentration of livestock is not very high (see Fig. 28), so the area where the groundwater exceeds the threshold value of 50 mg N/l is limited. (33)

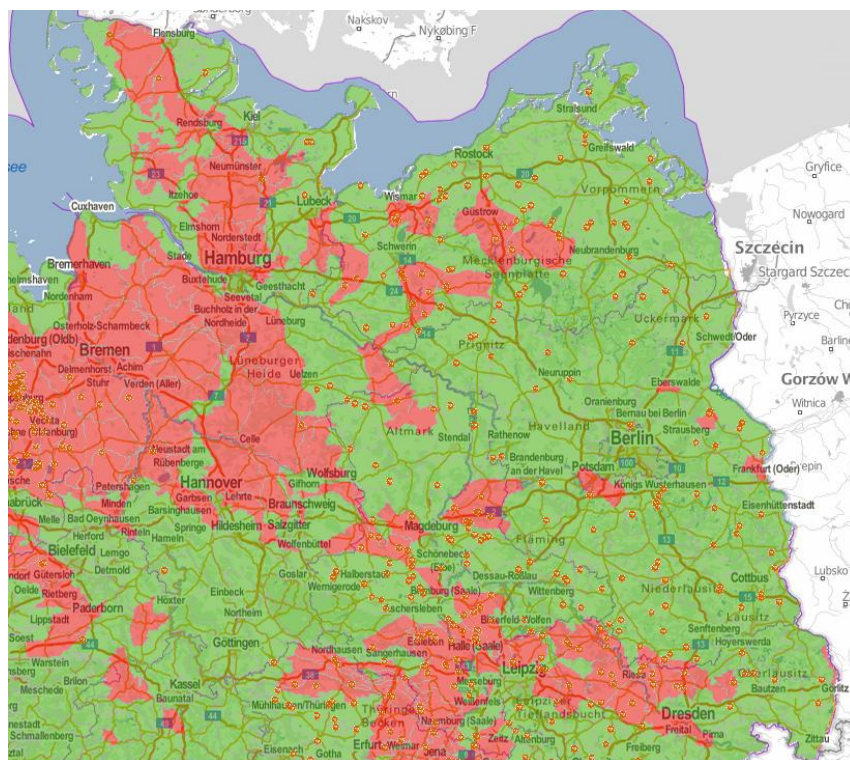


Fig. 26: Intensive livestock and aquaculture (in orange) and groundwater quality (red: bad, green: good). (33)

The case study area is mainly located in former East Germany. When the country was divided this region was socialist. This kind of politics abolished the private property, thus the government took all the lands. Hence the type of farming in socialist Germany was characterised by big areas. After the unification of the country the agriculture style did not change, and kept the particular large scale. This trait is clearly visible in Fig. 27 and Tab. 14.

The correlation large farming and comparably low density of livestock unit, as shown in *Fig. 28*, demonstrate that the risk of nutrient pollution is relatively moderate.

Fig. 29 shows the partial phosphate balance between the input of nutrient as animal manure and output as crops. Higher levels are mainly located in Brandenburg and M-V, in areas corresponding to big cities. In the Baltic Sea region phosphate is not an issue in the soil, that's why the study focuses more on nitrogen.

State	Total farms			Farms with livestock in total		
	Farms	Area	Average area per farm	Farms	Percentage of the total number of farms	Livestock
	[Number]	[ha]	[ha]	[Number]	[%]	[LSU*]
	in 1000					
Brandenburg	5.4	1313.8	243	3.8	70%	540.3
SH	13.3	990.5	74	10.6	80%	1.030.5
Sachsen	6.3	906.6	144	4.6	73%	488.2
MV	4.7	1341	285	3	64%	544.3
Germany	285	16699.6	59	199.2	70%	13.088.8

*The LSU is a standard unit of measure, which is determined by means of the appropriate conversion keys of the different types of livestock, thus allowing a summary of the different types of livestock for comparative purposes.

Tab. 14: Size of the farms in the case study states. The values are relative to the year 2013. (34)

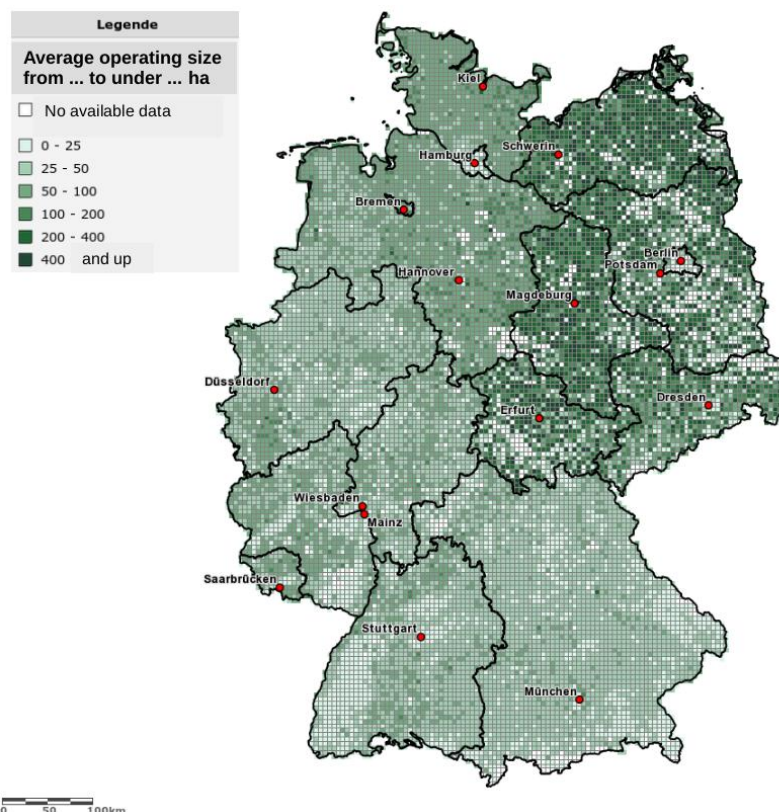


Fig. 27: Average operating size of farming. (35)

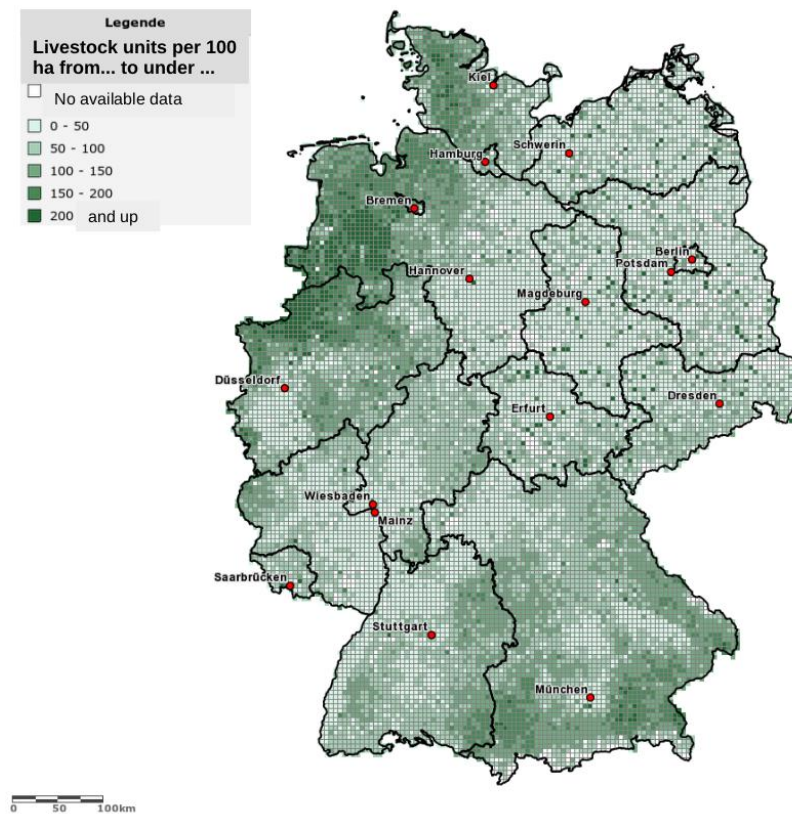


Fig. 28: Livestock unit per 100 ha. (35)

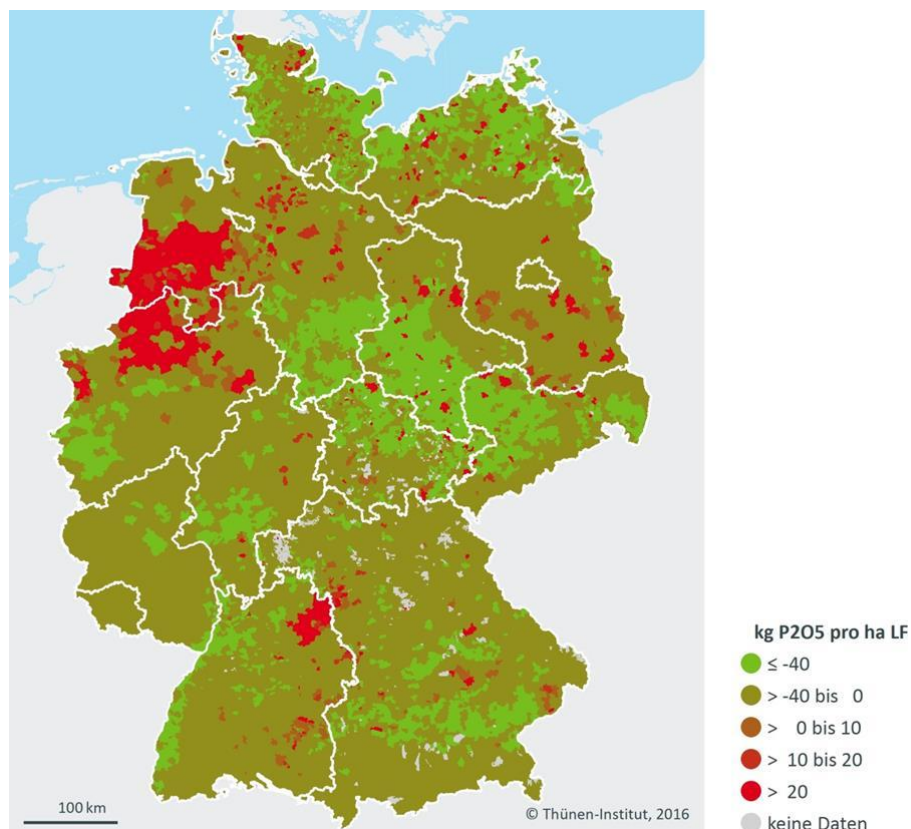


Fig. 29: Partial phosphate balance in kg P₂O₅ ha⁻¹: animal excretion minus export by crops (poultry manure is not included). (20)

4.4 Energy crops

The use of energy crops as substrate of the anaerobic process also contributes to the imbalance between the need of nutrients and their concentration. As a matter of fact this kind of substrate can be transported from longer distances than it's economically feasible for the digestate. Thus it's not convenient to transport the output from the biogas plant (digestate) to the area where the crops are grown: in this way the nutrient cycle is not closed and a new imbalance arises between areas with volumes of nutrients higher than the acceptable limit values (nearby the biogas plant) and others where there is a deficit of them (where the energy crops are grown). In short, some operators deliver significantly more nitrogen to the biogas plants within substrates, than they take back in the form of digestate, which is especially relevant for the very large biogas plant complexes. This indicates a contribution to nutrient accumulation caused by biogas production. (36)

4.5 Fertilizing Regulation

Environmental pollution caused by fermentation residues is also strongly attributable to deficits in the requirements for fertilization. Until the revised Fertilizing Regulation *Düngeverordnung* (DüV) entered into force on 1st June 2017, the definition of organic fertilizer included only the one originated from animal manure. This definition did not take into account the fraction of organic fertilizer produced from the fermentation of energy crops. In Germany between 2004 and 2012 there has been an increasing use of energy crops as substrate in biogas plants, thanks to their high biogas yield, the creation of sufficient to generous feed-in tariffs and unlimited priority feed-in of RE-power. So as a matter of fact the fraction of energy crops in the digestate is often higher than the one of manure. But with the old Fertilizing Regulation the limit of 170 kg N ha⁻¹ year⁻¹ was controlled and calculated only on the substrate fraction that had animal origin, neglecting the quantity of nutrients from energy crops. The latter share was used similar to mineral fertilizer and farmers covered with this share of digestate the demands of crops with higher N-need (e.g. wheat with up to 260 kg N ha⁻¹). Considering that not all nitrogen in the digestate is NH₄-N, but that digestate also contains organically bound nitrogen this practice contributed to overfertilization in some areas of Germany. For a better understanding of the Fertilizing Regulation, see the paragraph *Fertilizing Legislation*.

As mentioned above, the fraction of organic N has not been studied thoroughly – especially not its behavior in the soil and the speed with which the organic-N is made available for the plants. Only recently the possible accumulation of organic-N and its effects has become a topic of interest for academia and policy makers. Its possible accumulation and unknown conversion speed might be critical for the nutrient accumulation and subsequent run-offs or infiltration into the groundwater.

4.6 Storage

Biogas plants contribute to the atmospheric pollution as a new source of ammonia and nitrous oxide. These gases are released into the atmosphere during the application and open storage of the digestate. According to estimations in 2011, only about 50% of the fermentation residues were stored in covered deposits in Germany. On the other side biogas plants are potentially able to contribute to the reduction of nitrous oxide and methane emissions, since the usage of pure manure as fertilizer causes higher emissions. The new Fertilizing Regulation regulates the storage of the digestate, which needs to be covered and gas tight. This new solution will substantially decrease the polluted gas emission from the digestate during its storage. (36)

4.7 Nitrogen farmgate balance

4.7.1 Definition and limit

As a central indicator for the sustainability of farming, the nitrogen surplus was included in the indicator set of the Sustainability Strategy (2002) and the National Strategy for Biological Diversity (2007). The nitrogen surplus is calculated from the difference between the mass flow of nitrogen into agriculture (e.g. chemical fertilizer, animal feed imports, biological nitrogen fixation, and

atmospheric deposition of oxidized nitrogen) and the mass flow of nitrogen in products out of agriculture (marketed animal and plant products).(37)

It is calculated at different scales: national, regional, farm and field level. *Tab. 15* shows the different nutrient balance at various scales in Germany. (38)

Scale	Balance	Data source	Purpose
National	FBgross	Statistical data and estimations	Eurostat: reporting duty Nitrate report: monitoring
	FGB (FBnet+LB)		Agri-Environmental Indicator: Strategy of sustainability/biodiversity
Regional	FBnet (top-down)	FSS data and estimations	Implementation of EU-WFD: emission monitoring
	FBnet (bottom-up)	FADN data, bookkeeping	
Farm	FBnet	Estimations and bookkeeping	Fertilizing Regulation: monitoring Fertiliser planning
	FGB	Bookkeeping	Advisory service Fertiliser planning
Field	SSB	Field record system	Advisory service Fertiliser planning

FGB: FarmGate Balance. FB: Field Balance. LB: Livestock Balance. SSB: Soil Surface Balance. Gross: including gaseous N-losses (NH₃). Net: : without gaseous N-losses (NH₃)

Tab. 15: Data sources and purposes of different nutrient balance at various scales in Germany..(38)

The limit value set by the old Fertilizing Regulation was of 80 kg N ha⁻¹ year⁻¹, while now it has been reduced to 50 kg N ha⁻¹ year⁻¹. Furthermore with the new regulation every farm and biogas plant has to calculate their own nitrogen balance, taking into account the fertilizer need, the plan of crop, the quantity of nutrients already present in the soil, etc..

As shown in *Fig. 30*, the current threshold of nitrogen surplus is exceeded in most of German districts, in particular in the Schleswig-Holstein state, where there is a high concentration of both livestock and biogas plants.(37)

4.7.2 Calculation methods

The nutrient farmgate balance has in itself some uncertainties, based on:

- calculation method
- estimation of yield of N and P in harvested crops
- availability of reliable data regarding the actual use of mineral fertilizer
- absence of reliable data regarding the import/export of manure from/into the Netherlands.

Different nutrient balance calculation methodologies are available. The results differ according to the various methods. *Fig. 31* shows the different results according to three different methods. The Fertilizing Regulation, for example, does not take into account atmospheric nitrogen deposition and gaseous ammonia losses.

Thus, the methodology and the margin of error must be taken into account when comparing results and assessing the nutrient balance situation.

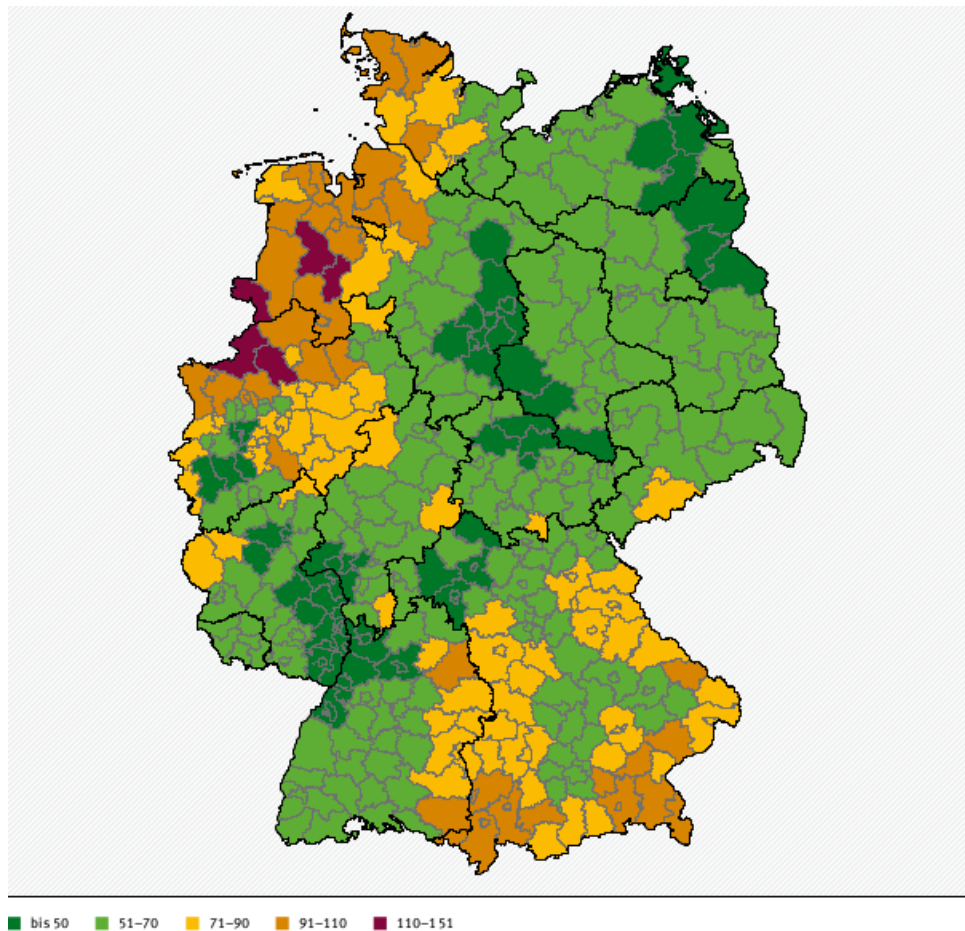


Fig. 30: Distribution of the nitrogen surpluses (mean between 2009 – 2011). (37)

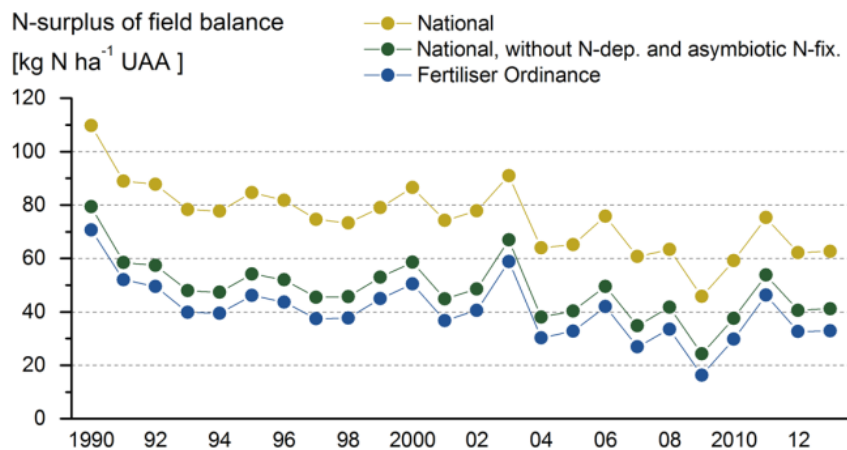


Fig. 31: Nitrogen-surplus of field balance calculated with different methods. (UAA: Utilized Agricultural Area) (38)

4.7.3 Monitoring

As previously stated, Germany is a federal country. For this reason there are many different parties who take part in the data assessment and calculation of nutrient balances, both at state and county level. The monitoring of the nutrient management plans is responsibility of each federal state, but the task is mostly assigned to specialized authorities at lower level. In average only 1 % of farmers are controlled every year. If during the control the management plan is not correct or available, the farmer is at fault and will receive a financial sanction, since this is considered an administrative offence.(38)

4.8 Nutrient reduction model

In 2014 the *Federal / State Committee North and Baltic Seas* (Bund/Länder-Ausschuss Nord- und Ostsee – BLANO) implemented a model whose aim was the nutrient reduction in the Baltic Sea. In the model two main nitrogen pollution sources were identified: from rivers and atmosphere. The two sources have different impact on the Baltic Sea: the one originated from the surface water affects more the coastal region and the atmospheric one influences the nutrient concentration in the central waters of the Sea.(39)

Annually Germany contributes to the eutrophication of the Baltic Sea with a total of 32 700 t of nitrogen divided between 19 700 t from surface waters and 13 000 t as atmospheric pollution.

These data result from observations and measures conducted between 1997 and 2003.

The model identified the sustainable threshold of the nutrient input into the Baltic Sea as of 21 500 t year⁻¹. Therefore the quantity must be reduced by 11 200 t year⁻¹. The reduction program considers a decrease of 8 600 t year⁻¹ from the surface water source and 2 600 t year⁻¹ from the atmospheric one. The first source is more important for Germany, because, as previously states, it affects the coastal region. The accentuated effect is caused by the nature of the area: close to the coast there are many little islands and peninsulas. This geography limits the circulation of water from these areas to the Baltic Sea, causing a higher and more concentrated eutrophication.

BLANO stated the reduction must be achieved by 2027.(39)

On the other side in 2013, HELCOM (Baltic Marine Environment Protection Commission - Helsinki Commission) stated that the nutrient input from the German side has to be reduced by 2021 of 170 t of phosphorus and 7 663 t of nitrogen (both from water and atmosphere), of which from the Oder river respectively 60 t P and 500 t N.(1)

4.9 Point sources – Accidents

With the more than 9000 biogas plants and long experience, Germany has a long record of more or less serious accidents.

In the last years there have been several events of substrate spilling from the digesters in the states of the case study. Nicola Kabel, spokesperson for the Kiel Ministry of the Environment reported that “Between 2012 and 2017, a total of 104 manure accidents have been registered with biogas plants, where 84 times manure leaked into the soil”. These were caused by different technical problems, e.g. a leaking pipe, non working valve, etc. Prompt actions were taken in order to limit the environmental and economic damages.(40)

As a response to these accidents a new regulation has introduced the mandatory construction of a wall/damn around the biogas plant, in order to limit the flowing of the digestate in case of spillage. The wall has to be big enough to block the flowing of the material from the largest tank volume above ground. This easy solution will prevent the pollution of the area and water around the plant in case of accident.

Nonetheless at present, anthropogenic nutrient inputs into the Baltic Sea are mainly derived from diffuse sources. (30)



Fig. 32: Digestate spilled out of a digester.(40)

4.10 Fertilizer source

In Germany the main source of nitrogen as fertiliser is mineral followed by agricultural residues (manure, straw and agricultural wastes) and digestate only as third origin, as shown in *Fig. 33*. As described in the previous paragraphs, the issue with nitrogen is not attributable only to digestate land application but has instead different origins.

As shown in *Fig. 34*, the main source of phosphate is agricultural residues followed by digestate. In the area of study there are no issues regarding this element according to the sources. No imminent need of further phosphor regulation and reduction is currently needed. (20)

Both *Fig. 33* and *Fig. 34* show that the percentage of nutrient origin from sewage sludge is very low compared to the other volumes. The focus on agricultural residues, digestate and manure of this study is then justified by these proportions. The quantity of nutrient from sewage sludge is going to decrease even more with the new Fertilizing Regulation and the soon to be approved Sewage Sludge Ordinance. With time the P will have to be recycled from sewage sludge and most of the sludge will go into incineration.

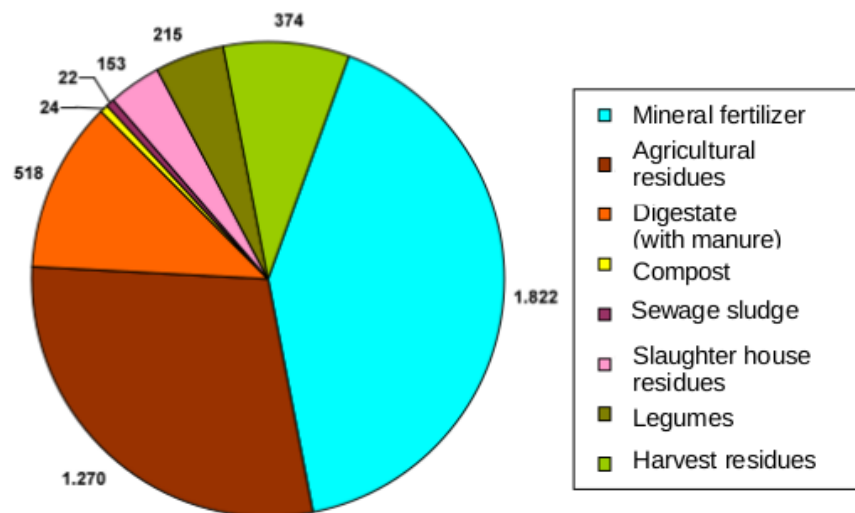


Fig. 33: Source of N as fertiliser in the German agriculture, in 1000 t. (20)

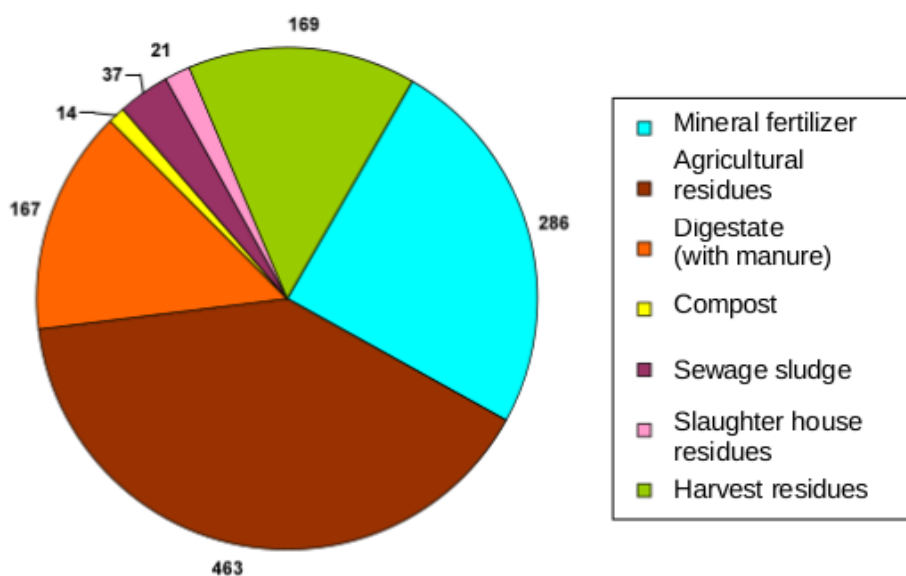


Fig. 34: Source of phosphate as fertilizer in the German agriculture, in 1000 t. (20)

5 Subsidies and profitability (e.g. gate fees, electricity sold out) of production

In Germany the profitability of biogas plants depends on the sector in which the biogas plant is operated. Biogas plants or anaerobic digestion plants in the waste sector base their economic viability on a combination of selling electricity to the grid for a defined feed-in tariff and on gate fees that are being charged for treating the organic waste. In this sector only a small number of 150–170 biogas plants are in operation compared to the agricultural sector and the wastewater treatment sector.

Anaerobic sludge stabilization on **wastewater treatment** plants is financed also by a combination of feed-in tariff and wastewater charges. Additional benefits might come from heat use and thus saving expenditures for fossil fuels. The feed-in tariff for electricity from sewage gas is currently (EEG 2017) 6.49 ct/kWh at max for CHPs up to 500 kW rated electric power and 5.66 ct/kWh for CHPs up to 5 MW rated electric power. Anaerobic sludge stabilization is done in approx. 1250 sewage treatment plants in Germany.

Most of Germany's biogas plants (approx. 9000) are being operated in the **agricultural sector**. They are the most relevant type of biogas plants with respect to nutrient discharges in Germany, firstly because of their high number, secondly because the digestate is generally used as fertilizer and finally because they are operated less professionally than digesters in the waste management and wastewater sector and are more prone to accidents.

Agricultural biogas plants base their profitability mainly on electricity sales to the grid in combination with several bonuses. Bonuses had been designed to encourage either the use of innovative technology, of using the heat generated by the CHP or to pay for the farming, harvesting and processing of energy crops, thus for costs that should in normal farming practices be covered by selling products like milk or meat (if for example corn silage or grass silage is used as animal fodder).

In the last 10-15 years generous feed-in tariffs ensured a continuous growth of the German biogas sector as is shown in *Fig. 35* for agricultural biogas plants. These feed-in tariffs have been granted for 20 years.

Since the beginning of 2017 however, the feed-in tariff system has been modified drastically in Germany. Instead of granting fixed and legally prescribed tariffs, the new EEG determines the tariffs by tender processes for new biogas plants. Additionally there is a defined maximum cap of power that will be recognized per year. For 2017 this is 150 MW. The change in regulation aims to achieve a market more competitive and cost-efficient. The tender system should ensure the continuous expansion of renewable energies and the reduction of their production costs, through a competitive strategy. (41) Existing biogas plants are not subject to the tendering processes as long as their first funding period is still ongoing. If the operator wants to continue biogas production beyond the 20-year funding period he has to participate in the bidding process and can, if successful, qualify for additional 10 years of feed-in tariff, though the tariffs will be considerably lower and bonuses no longer exist. For agricultural biogas plants this is an extreme paradigm shift and it is not clear how many of the existing biogas plants will continue operation after 20 years. As of today and for the future, an intelligent heat use becomes a more and more important part in the economic viability.

Tab. 16 shows the new remuneration of electricity generated from biogas as defined in EEG 2017. The given feed-in tariffs are maximum values. The real value will be defined in the bid. All types of biomass plants can bid in the same round, meaning that also electric power generated from biomass heating plants or wood gas / syngas will participate in the bids. For agricultural biogas plants we expect much lower tariffs than the maximum values defined in EEG 2017 depending on the number of sewage gas plants, waste digestion plants and other biomass plants in the bid round, which either can or need to offer lower prices. The effect on the biogas sector in Germany is not fully clear yet, but starting from 2020 we are likely to see the shut-down of many agricultural

biogas plants under the current framework conditions. While this might be desirable in terms of water protection, it might counteract GHG-emission reduction strategies.

Agricultural BGP			Waste digestion plant		Sewage gas	
	New	Existing	New	Existing	New	Existing
≤ 150 kW	13.32	Maximum of bid round	14.88	At max. the feed-in tariff as before, e.g. 16.00 in EEG 2012	6.49	At max. the feed-in tariff as before, e.g. 6.79 in EEG 2012
≤ 500 kW	11.49	16.90	13.05		5.66	
≤ 5 MW	10.29					
≤ 20 MW	5.71					

Tab. 16: Renumeration of electricity from biogas [ct/kWh] in EEG 2017 without consideration of future depression.

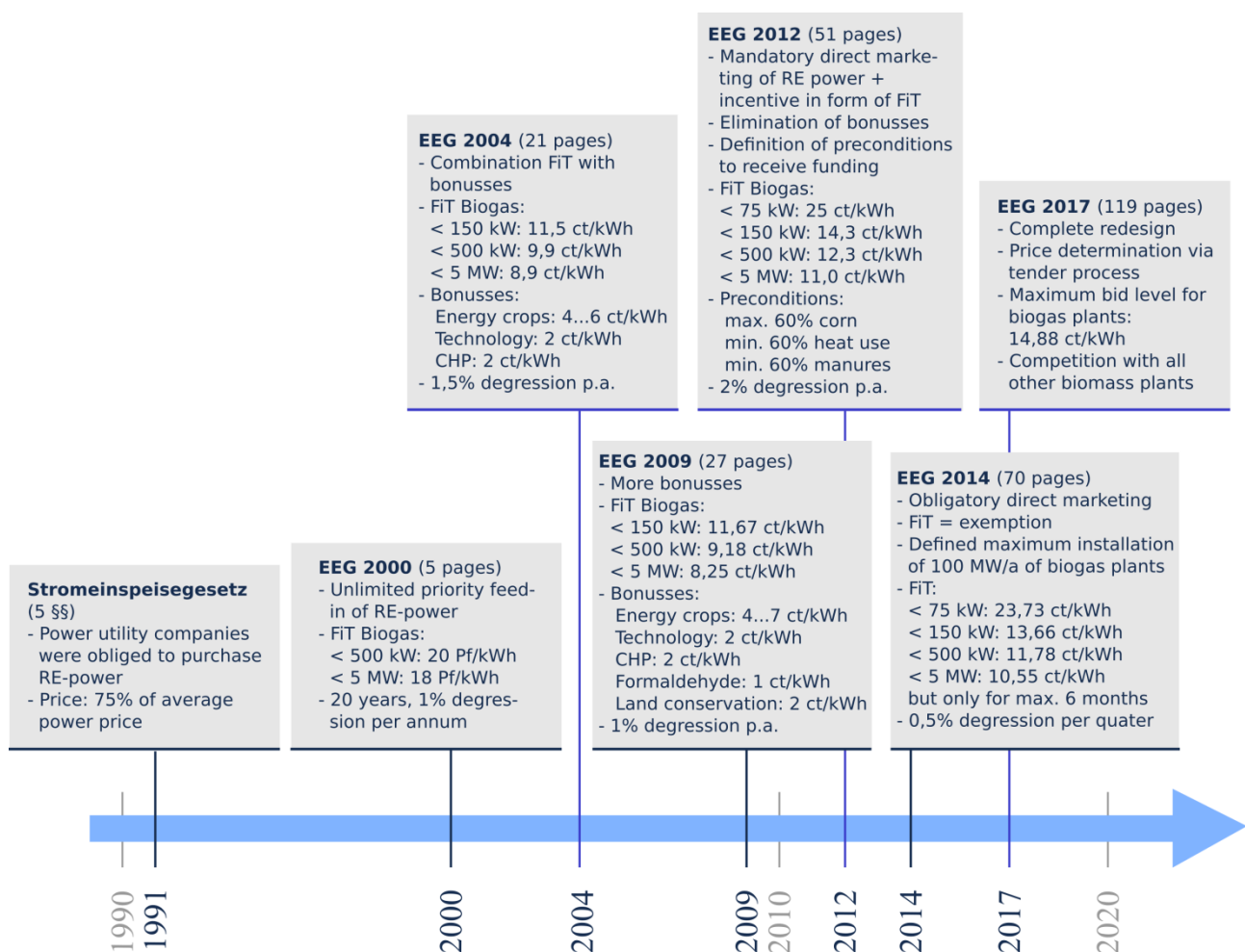


Fig. 35: Overview over German Feed-inTariffs since 1991 for agricultural biogas plants.

6 Case examples (if any) of commercial products from digestates (fertilizers, substrates for industrial processes)

When looking at the nutrient situation in Germany we see regions with excess nutrients and regions with a nutrient demand. Excess nutrients are available in animal farming regions with high numbers of dairy cows, cattle, pigs and poultry (e.g. Vechta-Cloppenburg, Hohenlohe). Pure arable farming areas on the other hand require nutrients (e.g. Brandenburg, southern part of Lower Saxony, Magdeburger & HildesheimerBörde). A typical system for balancing the nutrients between the regions is the so called “Güllebörse”, a manure sharing service. This system also integrates digestate from anaerobic digestion, but not from sewage treatment plants. Farmers and biogas plant operators are part of agricultural cooperatives which manage the sharing service. This system has been used for many years in the agricultural sector, as a solution to the surplus and the demand of nutrients of different farmers. Historically it always has been between private farms and it never included wastewater treatment plant operators. Compared to fertiliser, sewage sludge is regulated more strictly because of its possible content of hazardous substances. Therefore its land application is not common.

Nowadays different “Güllebörse”, in the meaning of various sharing services, are located in the areas with a high nutrient problem: in the Southern and West-north region. The services are not constricted to a specific state, managing the manure and digestate of agricultural regions. This kind of service is not yet present in the area of study.

Depending on the transport distance and the type of excess nutrient liquid-solid separation might be used to divide nutrient streams between liquid phase and biosolids. Long transport distances, however, require a further concentration of nutrients, which is the case in several commercial digester products.

Commercial digester products are a means to concentrate nutrients in order to make them worth transporting. By concentrating and transporting nutrients it is possible to:

- 1) Export nutrient into other (arable farming) regions where nutrients are needed
- 2) Export nutrients into other sectors, e.g. private gardens, orchards, vineyards.

Case examples exist in several regions in Germany. A few are described below. Further examples might exist, but finding them would require more research.

6.1 Case example 1 – Nadu by Agro Energie Hohenlohe GmbH & Co. KG

One prominent example is “Nadu”, a granule fertilizer product from digestate by Agro Energie Hohenlohe GmbH & Co. KG in 74635 Kupferzell-Füßbach. From the beginning Mr. Karle, founder of Agro Energie Hohenlohe GmbH & Co. KG and biogas plant operator, aimed at converting agricultural residues (pig & cattle manure) and residues from vegetable processing (e.g. lettuce leaves, pumpkins) and energy crops into a valuable fertilizer and to find a means to export nutrients.



Today the biogas plant has a continuous power production capacity of 650 kW electric power. After digestion the digestate passes a screw press separator. The solids are brought into a type of greenhouse where they are dried using off-heat of the CHP-units in combination with ventilated warm air from the greenhouse. Finally the dry digestate passes a pelletizer, before the pellets are broken again to form granulates. The “RAL Bundesgütegemeinschaft Gärprodukt” tests the composition of the product and ensures the quality control with the certification process. The mass flow of nutrients during the steps of the process is shown in Fig. 36.

Nadu was originally aimed to be an organic fertilizer for private gardeners. This market was at that time difficult to access, mainly because of the “shelf-logistic” in building supply or gardening supply stores. Mr. Karle made the experience that it is difficult to get a good shelf space and that he found his products after a while moved to a very unattractive area of the shop, whilst the prominent shelves were filled with better known brands. Additionally, the amount of fertilizer sold via those stores did not rise considerably, but his biogas plant continuously produced new supplies. Meanwhile almost all the fertilizer is marketed to wine regions.

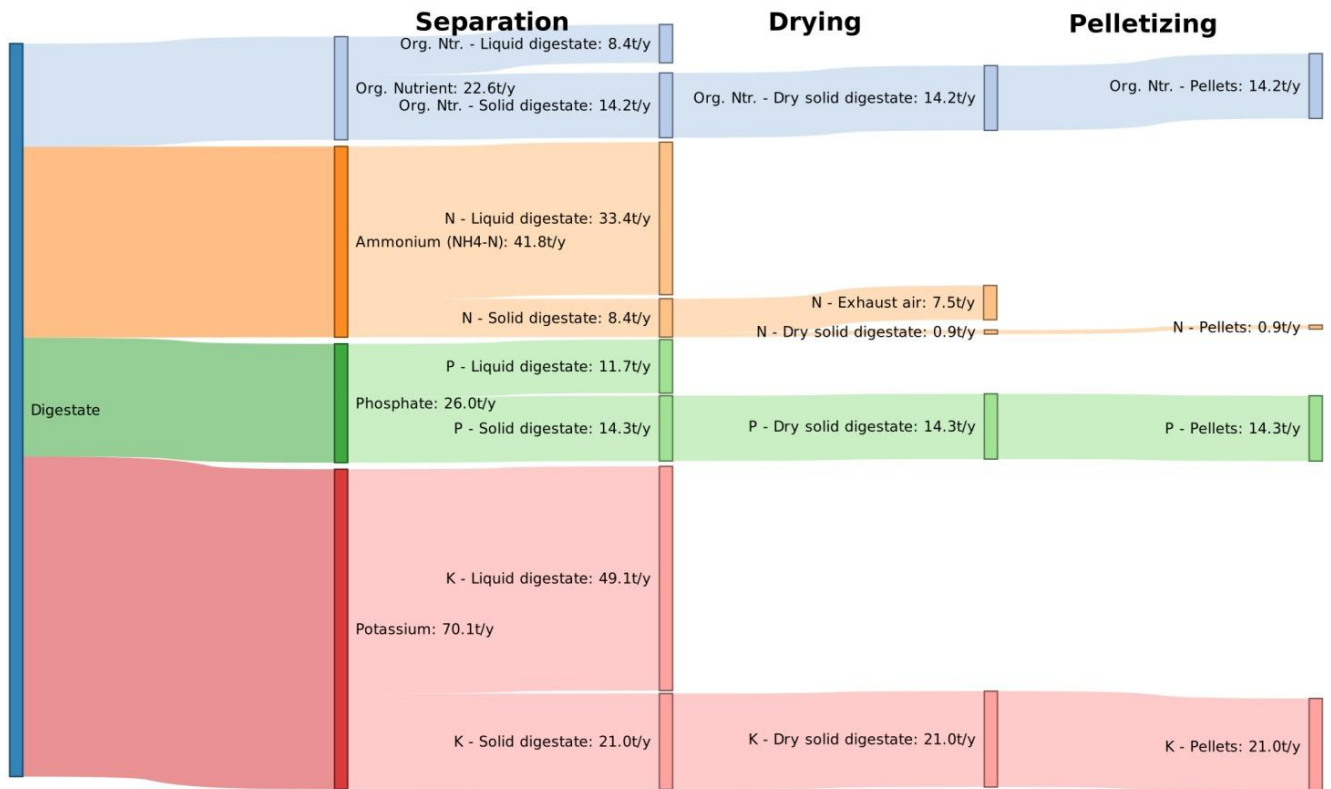


Fig. 36: Mass flow of the nutrients during the different digestate treatment steps of the Nadu pellets. The end products are: liquid digestate and pellets.

6.2 Case example 2 – Sanadur by Saergas GmbH & Co. KG

Another example with about the same approach is Sanadur, an organic fertilizer made from digestates in 48369 Saerbeck. Saerbeck is located in the Münsterland region in western Germany, not far away from the border to The Netherlands. The Münsterland region is strong in animal farming and also in biogas production and is hence prone to overfertilization. Sanadur targets private gardeners and is available at local agricultural trade stores. The biogas plant is operated with 60% of energy crops and 40% of manures. Its continuous power production capacity is ca. 1 MW electric power. The electricity is partly sold locally to households, the rest is sold to the grid. Off-heat is used to dry the digestate.



6.3 Case example 3 – Energiehof Weitenau

Energiehof Weitenau operates a medium-scale biogas plant in 72184 Eutingen-Weitingen in the very south of Germany towards the border to Switzerland. Here, the fertilizer products from digestate are used to optimize the own fertilizer management on the farm. After digestion a separation system separates liquids and solids. The liquids enter a vacuum evaporation unit which:

- a) Concentrates nutrients in a concentrate
- b) Evaporates water and thus reduces the amount of required storage volume
- c) Produces ammonium sulphate solution, which is then crystallized

For the owner of the biogas plant it is important to reduce the number of vehicle movements on the agricultural land, mainly to reduce the ground pressure but partly also to reduce machinery costs. This is possible by concentrating nutrients. Additionally ammonium sulphate is categorised as mineral fertilizer, not as organic fertilizer. By producing a mineral fertilizer from digestate the need to buy mineral fertilizer is considerably reduced. In the light of the new Fertilizing Regulation which limits the amount of organic fertilizer that can be applied to arable land to 170 kg N/ha – regardless of the source of organic matter for biogas production – the ammonium sulphate helps to make the best use of the nutrients contained in the digestate for crops that have a higher nitrogen demand than 170 kg N/ha.



6.4 Case example 4 – FaserPlus

During the BiogasFaserPlus project (2015-2016) a real scale biogas plant model was implemented. This 5 MW_{el} biogas plant uses mainly energy crops and chicken manure as feedstock. The outputs from the different steps are: lime, ammonium sulphate solution and fibers. The first two are used as fertilizers while the latter as material for laminated wood (see Fig. 37). A higher concentration of material from digestate gives a darker tone to the plywood.

Fig. 38 shows the steps of the process in the biogas plant, with the detail of the N content in each input/output. (42)



Fig. 37: Plywood made in the FaserPlus biogas plant. (42)

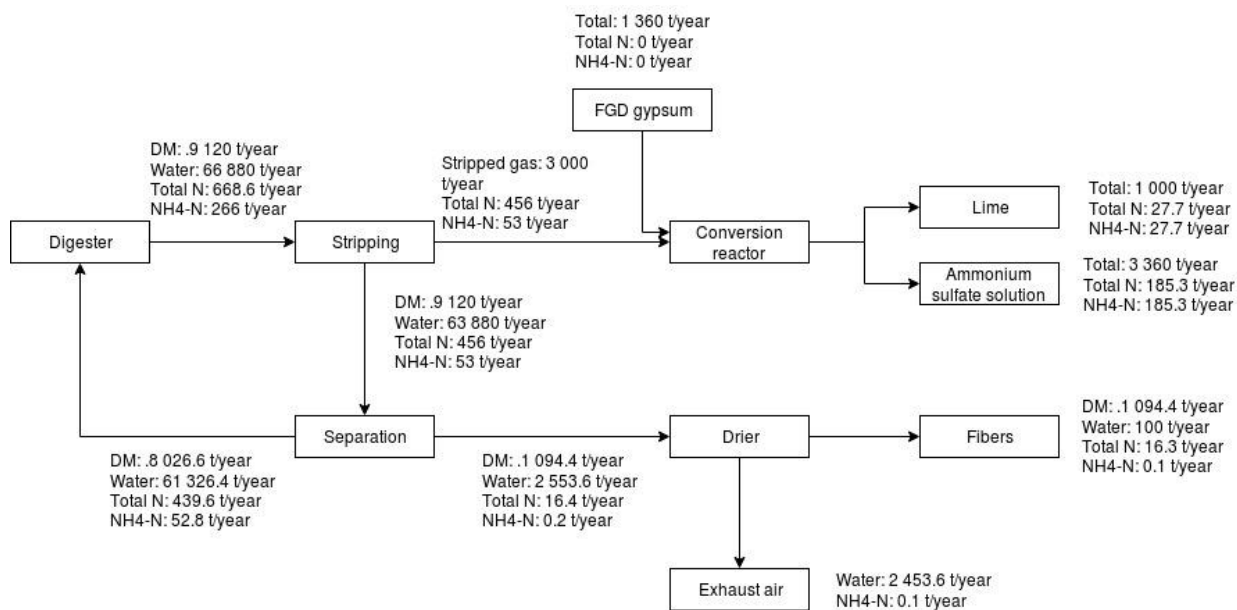


Fig. 38: Process of the FaserPlus biogas plant.

7 Case examples of circular economy, where biogas is a part of a larger chain(e.g. combined chain of closed circle fish farming, use of nutrients in greenhouse vegetables production, biodiesel and biogas production, use of rejects in agriculture)

In Germany biogas plant operators nowadays need to look for cross-sector opportunities to ensure long-term profitability of their business. But also in the past years pioneers have sought new ways to combine biogas plants with other business cases. In many cases a good and relevant heat use is crucial. Approaches range from using exhaust gases in green houses and thus providing the plants with CO₂ for better growth in combination with supplying heat to the green house over combining biogas plants with aquaculture to using residues from grass-fibre production as feedstock for anaerobic digestion.

In the German catchment area of the Baltic Sea there are several projects combining a biogas plant with a fish farm. Especially the state of Mecklenburg-Vorpommern is promoting this business case and supports investors to find good project sites. Usually the synergy is based on heat use. To our knowledge 3-5 of such projects exist in the Baltic Sea catchment area.

The combination of a biogas plant with a greenhouse is not uncommon, though not a real standard combination yet. Examples exist all over Germany, but we are not aware of examples in the Baltic Sea catchment area. Finding example cases in the respective area requires further research.

Very few case examples exist that focus on e.g. fibre production in combination with biogas plants. A prominent example is Biowert GmbH, which serves as best practice example in the bioeconomy sector. They produce fibres from grassland that is not used for any other purpose like dairy farming. Side streams of the fibre production and residues from the process are the feedstock for anaerobic digestion. The digestate is returned to the grass land as fertiliser. Approximately 90% of the value generation comes from fibre production, only 10% from selling electricity to the grid. Biowert GmbH is located in middle-west Germany, thus does not influence the Baltic Sea catchment area. Nevertheless it is an example that indicates future developments in the biogas sector.

8 Solutions and proposals for mitigating adverse environmental impacts of biogas production

Biogas plants per se are neither good nor bad in respect to nutrient run-off or nutrient leakages. They are very comparable to normal agricultural practices. Although digestate contains higher shares of ammonium nitrogen, which binds better to the soil and is quickly available for plants it depends on the individual farmer's fertilising practices whether or not and to which degree digestates contribute to eutrophication.

With respect to sensitive catchment areas or nitrate sensitive regions, permitting authorities might put a higher focus on this topic during the permitting procedure. Also, stronger controls of fertilizing practices and plausibility checks might help to reduce nutrient run-offs and leakages.

In addition to regulatory requirements, the cultivation of substrates should be made more environmentally compatible by means of informational and supportive tools. For example, the low-emission output of fermentation residues or advice on the improvement of nutrient management in maize cultivation can be promoted.

The German state should not only increase the number of nutrient balance controls of each farm and biogas plant, but also provide a service intended to increase the awareness on nutrient management, its consequences and provide practical ways of reducing the connected pollution. It would be very beneficial to strengthen the market for fertiliser products from digestates that are worth transporting. Especially in the light of the high energy demand related to the production of mineral nitrogen fertilisers and the discussion about heavy metals and uranium in mined phosphorus, digestates and products derived thereof have a clear advantage. A strong marketing strategy is needed, including an awareness campaign which aims to enlighten the public about the benefits of this kind of products. It should also educate about the harmlessness of digestate based fertiliser. An important boost to the market would also be retailing digestate products in big store chains, moving the merchandising from numerous small privates to fewer bigger cooperatives. Once the market is launched, longer transport routes of the products will be feasible.

In Germany a revision of the fertilising ordinance has been observed, which restricts fertilising practices from organic fertilisers. To compensate for that, farmers will use more mineral fertiliser. Whether or not this new ordinance contributes to reducing nitrate in the groundwater will be seen in some years.

As stated previously, the new Fertilizing Regulation also sets new rules regarding the storage of the digestate and new emergency measures in case of spilling accidents in the biogas plant, as the surrounding mandatory wall.

Anaerobic digestion has many positive environmental effects and should therefore not be banned because of negative effects in one sector. From our experience, good agricultural practices, responsible farmers and interesting market opportunities for digestate based fertilisers are the most important factors to reduce fertiliser related issues.

9 Pulp and paper industry

Germany is the 4th world producer of paper and board. The industries are organized in an association called VDP – *Verband Deutscher Papierfabriken e.V.* . The German Pulp and Paper Association comprises 150 member companies and a total of 124 production plants. VDP is the largest European paper association and works hand in hand with the Federation of German Industries (BDI). (43)

Fig. 39 shows the location of the pulp and paper industries members of VDP. Most of the plants are in the southern and western regions. Two factors influenced this growth:

- Resources: in the southern and western regions there is higher production of wood compared to the other areas of Germany.
- Industries: in these areas the concentration of industries in general is higher.

In the case study area there are only a couple of industries.



Fig. 39: Pulp and paper industries in Germany, members of VDP. (44)

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13 Annex - List of biogas plant

13.1 Anaerobic digestion of organic wastes, in the case study area

City	Name	Ton through put [t/year]	Inst. electr. Power [kW]	Biogas power [MWh]	Separation	Compost [t/year]	Compost use	Liquid Phase [t/year]	Liquid phase use
Schleswig-Holstein									
Altenholz	Vergärungsanlage Kiel	18,000	536		Yes	20,500	Landscape construction, potting soil	n.a.	Local WWTP
Borgstedt	Bioabfallbehandlungsanlage (BBA) Borgstedt	30,000	1,150		No	16,000	Agriculture, landscape construction	-	
Brandenburg									
Hennickendorf	Biogasanlage Hennickendorf	15,500	610		No	5,000	Landscape construction, other	1,500	Agriculture
Mecklenburg-Vorpommern									
Demen / Kobande	Biogasanlage Demen-Kobande	n.a.	4,000		n.a.	n.a.	n.a.	n.a.	n.a.
Karbow / Vietlütbe	Biogasanlage Vietlütbe	16,000	230		No	-	-	16,000	Agriculture
Kogel	ReFood Kogel	36,000	2,400		No	-	-	n.a.	Agriculture
Malchin	Refood Malchin	58,000	2,042		No	-	-	50,000	Agriculture
Parum	Biogasanlage Parum	50,000	2,100		No	-	-	40,000	Agriculture
Putbus / Pastitz	Biogasanlage Pastitz	76,759	1,250		No	-	-	n.a.	Agriculture
Karft	Biogasanlage Karft	17,250	n.a.	45,000	n.a.	n.a.	n.a.	n.a.	n.a.
Schwerin-Krebsförden	Kompostierungs- und Abfallvergärungsanlage	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

13.2 EEG-Anlagenstammdaten

City or district	Name of the biogas plant	Installed electric power [kW]		Thermal power [kW]
		Before the modification	After the modification	
Sachsen				
Herrnhut, OT Neundorf	Biogasanlage Neundorf		290	674
Großschönau	BGA Sell	190	210	216
Olbersdorf			250	232
Rietschen	Biogasanlage Neuliebel		240	223
Krauschwitz OT Skerbersdorf	Biogasanlage Skerbersdorf		75	70
Brandenburg				
Schenkendöbern			1,068	
Schenkendöbern			75	

City or district	Name of the biogas plant	Installed electric power [kW]		Thermal power [kW]
		Before the modification	After the modification	
Schenkendöbern			75	
Wiesenau	Biogasanlage Wiesenau III		330	339
Frankfurt(Oder)	Biogasanlage Lebuser Chaussee	500	530	593
Jacobsdorf OT Pillgram	K 6732 Am alten Silo		366	403
Gusow	FWE/2014/3922536/ IB Karlshof II		530	436
Lindendorf OT Dolgeln			590	
Vierlinden	Friedersdorf 2	265	250	232
Seelow	Heizkraftwerk Seelow Süd		924	1,326
Seelow	Heizkraftwerk Seelow Nord Krankenhaus		522	804
Lindendorf, OT Dolgeln	Biogasanlage Dolgeln	526	549	546
Vierlinden, OT Worin	Biogasanlage Worin	526	549	546
Gusow	E-Energie Karlshof GmbH		530	436
Neutrebbin OT Altbarnim	Biogasanlage Altbarnim	787	800	801
Neutrebbin OT Wuschewier	Biogasanlage Wuschewier	787	852	838
Podelzig	Podelzig I		998	1,090
Zeschdorf OT Petershagen			340	317
Reichenow / Möglin	Biogasanlage Möglin	876	876	838
Altlandsberg	BGA Gielsdorf	190	210	255
Müncheberg OT Eggersdorf			190	212
Oberbarnim OT Ernhof	Biogasanlage Ernhof	541	530	541
Heinersdorf	Biogasanlage Tempelberg		810	890
Steinhöfel OT Gölsdorf	FWE/2014/3922351/IB	515	530	438
Eberswalde	Heizkraftwerk Nordend		1,999	2,200
Chorin OT Senftenhütte	Schäferlei Piroth GmbH		75	90
Schorfheide OT Schluff	Bioenergie Uhlenhof GmbH & Co. KG - Biogas Schorfheide		765	
Heckelberg-Brunow	KWK Beerbaum		1,026	1,152
Falkenberg OT Krüge	Biogasanlage Krüge	787	800	838
Bad Freienwalde OT Altranft	BGA Altranft		1,274	675
Bad Freienwalde	BGA Bad Freienwalde		1,098	
Wriezen	BHKW Jägerstraße		600	570
Wriezen	BHKW Altkiez		600	570
Wriezen	BHKW Frankfurter Straße		600	570
Gartz / Oder			250	
Wandlitz OT Lanke			75	90
Casekow	Biogas Blumberg		605	536
Nordwestuckermark OT Fürstenwerder	Biogasanlage Fürstenwerder	787	852	919
Prenzlau OT Dedelow	EnDie Hahlweg GmbH & Co. KG	386	475	366
Templin	Biogasanlage Templin	526	549	546
Prenzlau	BGA Blindow		265	
Mecklenburg-Vorpommern				
Altentreptow	Biogas Altentreptow GmbH & Co. KG		549	534
Wolde	BHKW Wolde		1,000	
Cammin	BGA Cammin		340	317
Holldorf/OT Ballwitz			500	
Friedland	Charon Biogas GmbH & Co. KG	600	1,197	
Friedland	Charon Biogas GmbH & Co. KG (Anlage 2)	600	1,197	

City or district	Name of the biogas plant	Installed electric power [kW]		Thermal power [kW]
		Before the modification	After the modification	
Friedland	BGA Eichhorst/Liepen		665	800
Friedland	Biogasanlage		600	
Galenbeck OT Sandhagen	BGA Sandhagen		370	400
Siedenbrünzow OT Vanselow	Biogasanlage Vanselow	800	1,600	803
Warrenzin	BGA Wolkow		311	330
Alt Tellin	BGA I Schweinezucht Alt Tellin GmbH	672	844	859
Bentzin	Biogasanlage der Eising Biogas GmbH		500	537
Bentzin	Biogasanlage der Eising Agrar GmbH		499	537
Alt Sührkow	BGA Milchhof Alt Sührkow		75	
Groß Wüsenfelde			75	
Altkalren	Biogas II		795	621
Altkalen /Lüchow	Bioenergie Lüchow I	500	1,030	924
Walkendorf OT Dalwitz	NaWaRo Dalwitz GmbH & Co KG	537	537	580
Behren-Lübchin OT Wasdow	BHKW Wasdow Trebelhof		75	70
Behren-Lübchin , OT Groß Nieköhr	MAL/3927418/IB		75	
Finkenthal	BGA Finkenthal		515	1,144
Penzlin (Klein Lukow)	Ophelia Biogas GmbH & Co. KG	526	1,197	
Ankershagen	Biogasanlage Ankershagen	526	549	546
Feldberger Seenlandschaft / Lichtenberg	BGA Lichtenberg	400	800	900
Dolgen	BGA Dolgen KG		1,072	
Feldberger Seenlandschaft	BGA 1 Dolgen Thomas Böckermann		536	
Feldberger Seenlandschaft	BGA Gräpkenteich		515	1,144
Krackow	BHKW Krackow		75	85
Woldegk	Rehberg 2	250	500	
Kublank	Biogasanlage Kublank	716	600	604
Lindetal	Biogasanlage Dewitz GmbH		710	406
Woldegk	BGA Pasenow neu		536	
Woldegk	BGA Pasenow alt		250	
Ferdinandshof	Biogasanlage Blumenthal		300	272
Wilhelmsburg OT Mühlenhof	Biogasanlage Mühlenhof		4,800	
Lübs	Biogasanlage Lübs	526	549	546
Boldekow	BGA Zinzow		500	464
Löwitz	BGA Biostrom Schmutgeow		500	580
Bandelin	Biogasanlage Bandelin		360	
Rostock	99301009 BHKW Rostock		1,250	998
Grammow	Bioenergie Grammow GmbH & Co.KG		75	
Dummerstorf	BGA Dummerstorf		373	398
Selpin	BGA Woltow		515	1,144
Bastorf	Biogas Bastorf GbR		75	
Carinerland OT Krempin	Biogasanlage Krempin	230	265	219
Radegast	BHKW Miekenhagen		390	390
Reinshagen	BGA Reinshagen		75	
Tarnow	BGA Tarnow	499	549	450
Rukieten, OT Göldenitz	Biogasanlage Göldenitz		610	354
Güstrow	Heizkraftwerk West 1		280	414
Güstrow	BHKW Wossidloschule Hafenstraße		19	34

City or district	Name of the biogas plant	Installed electric power [kW]		Thermal power [kW]
		Before the modification	After the modification	
Güstrow	BHKW Lange Straße		20	39
Güstrow	BHKW Baustraße		70	115
Güstrow		1,140	1,155	1,160
Zehna	Biogasanlage Zehna	787	800	838
Sarmstorf			75	
Schlieffenberg	BGA Schlieffenberg Aalberts-Krap		1,030	
Schlieffenberg	BGA Schlieffenberg Aalberts-Krap		1,030	
Dolgen am See OT Kankel	Hermann Dechering Biogas GmbH & Co. KG	520	700	599
Laage OT Schweez	Biogas Schweez GmbH		600	654
Laage	Bioenergie Laage		460	490
Ahrenshagen-Daskow OT Ahrenshagen	ADAP Biogas GmbH		590	613
Löbnitz	Biogasanlage		600	
Velgast	Biogasanlage Velgast Trocken	530	550	644
Gremersdorf	BGA Gremersdorf		75	
Preetz / OT Schmedshagen	BioEnergie Schmedshagen		75	90
Oebelitz	Bioenergie Oebelitz GmbH		2,600	600
Grimmen	Mini-BHKW Grimmen		15	30
Wendisch Baggendorf OT Leyerhof	BGA Leyerhof		460	
Süderholz	WLG/3926810/IB + BHKW Grabow (ORC-Anlage)	625	652	702
Süderholz OT Bretwisch	BGA Bretwisch		700	
Süderholz OT Poggendorf	BGA Poggendorf		800	
Süderholz OT Bartmannshagen	Biogasanlage Bartmannshagen		560	581
Sagard	Biogasanlage Sagard (Jasmunder Biogas GmbH & Co. KG)	836	1,385	
Rambin	Biogasanlage Rothenkirchen		400	372
Putbus	BGA Pastitz		1,467	1,979
Neu Schlagsdorf	Walter Huning Biogasanlage Neu Schlagsdorf	526	625	697
Leezen OT Rampe		835	812	728
Grambow	Bioenergie Gut Grambow GmbH & Co. KG		605	549
Demen OT Kobande	BEG Biogaserzeugungs GmbH	800	526	526
Bülow	Biogasanlage Bülow Schulstraße		615	600
Domsühl	W&W Biogas GmbH & Co.KG		530	486
Friedrichsruhe OT Frauenmark	Biogasanlage Frauenmark		265	
Goldberg	HKW Goldberg		526	553
Dabel		536	600	570
Zahrensdorf	Biogasanlage Zahrensdorf		837	852
Neperstorf	Biogasanlage Neperstorf	600	1,005	1,100
Kalkhorst	NBK/3012003/IB + 1-025-092	180	210	200
Zierow	Biogasanlage Zierow	526	549	546
Kalsow	Biogasanlage Kalsow		837	852
Schimm	Biogasanlage Schimm GmbH & Co. KG		720	690
Neuburg-Steinhausen	Biogasanlage Neuburg-Steinhausen		800	803
Hornstorf	Bioenergie Hornstorf GmbH		600	3,000

City or district	Name of the biogas plant	Installed electric power [kW]		Thermal power [kW]
		Before the modification	After the modification	
Moltow			75	99
Schleswig-Holstein				
Lübeck	BHKW MBT 2+3		598	788
Lübeck	BHKW MBT		1,196	1,576
Lübeck			20	40
Lübeck			20	40
Stockelsdorf		160	370	189
Gießelrade			700	644
Krummesse		360	380	406
Scharbeutz			637	503
Luschendorf	BEVL GmbH & Co.KG		450	480
Schashagen			700	
Cismar		550	1,099	1,134
Oldenburg	99700025 BHKW Oldenburg 1		637	779
Oldenburg	99700025 BHKW Oldenburg 3		1,063	1,103
Fehmarn			902	915
Bad Segeberg	99700002 BHKW Bad Segeberg 1		542	998
Negernbötzel	Biogas Heidkaten GmbH & Co. KG		827	820
Blunk	Blumenhof	600	850	862
Bad Oldesloe	BBE-8, Hako-NEU	526	1,427	1,459
Bad Oldesloe	BBE-7, Boltze-NEU	526	1,427	1,459
Wakendorf I		370	770	907
Wesenberg	Denker Biogas GmbH & Co KG	537	1,086	571
Bargfeld Stegen			889	1,029
Bargfeld-Stegen	Bioenergie Gräberkate GmbH & Co.KG		901	903
Mölln			21	46
Mölln			21	46
Mölln			20	40
Klein Zecher		500	1,000	940
Seedorf	BHKW 19		142	207
Klinkrade	Biogas Labenz GmbH & Co. KG		549	530
Lüchow	Biogas Labenz GmbH & Co. KG		600	572
Wentorf	Bioenergie Hack GmbH & Co. KG	400	1,000	1,052
Lehmkuhlen-Trent	Naturenergie Trent GmbH & Co. KG		350	
Wielen			680	634
Honigsee	BGA 1	625	549	578
Honigsee	BGA2	625	549	
Tüttendorf		400	1,200	1,198
Gettorf		400	1,200	1,198
Gettorf			340	317
Martensrade		265	515	438
Köhn			500	464
Lebrade	Bioenergie Lebrade-Rixdorf	550	2,554	2,280
Nehmten		537	697	1,500
Ascheberg	Naturenergie Oha GmbH	252	376	450
Grebin	Naturenergie Oha GmbH	252	376	450
Goosefeld	Bioenergie Marienthal GmbH & Co. KG		889	870
Eckernförde	BHKW Bornbrook III		215	339

City or district	Name of the biogas plant	Installed electric power [kW]		Thermal power [kW]
		Before the modification	After the modification	
Eckernförde	BHKW Ostlandstr.		112	188
Eckernförde	BHKW Gasstr.		238	198
Eckernförde	BHKW Riesebyer Str.		215	339
Eckernfoerde	BHKW Wellenbad		440	542
Eckernförde	BHKW Schiefkoppel/Wegwarte/Sonneneck		400	
Eckernförde	BHKW BEV II		215	339
Eckernförde	BHKW Bornbrook 1		440	542
Eckernförde	BHKW Carlshöhe		70	115
Eckernförde	BHKW BEV I		357	524
Eckernförde	BHKW Pferdemarkt		215	238
Eckernförde	BHKW Hafenspitze		215	238
Goosefeld	Bioenergie Marienthal GmbH & Co. KG		530	400
Bohnert	Bohnert		265	190
Ahlefeld-Bistensee	Bioenergie Ahlefeld GmbH & Co. KG	720	1,820	1,684
Holtsee	BGA Holtsee	717	1,517	1,600
Osterby			630	624
Hasselberg			350	322
Hasselberg			350	322
Kappeln	Satelliten-BHKW	620	1,169	
Boren	BHKW Marxen GmbH		340	317
Süderbrarup			350	322
Süderbrarup			700	644
Süderbrarup		700	1,800	1,164
Süderbrarup		700	1,800	1,164
Süderbrarup		700	1,800	1,164
Pommerby	Petersen & Söhne GbR		265	192
Dörphof	Karlbergfelder Ostseeenergie GbR	150	170	160
Dörphof	Agrarenergie Schuby	800	1,600	1,717
Oersberg			50	73
Stenneshöh	Agrarenergie Messer GbR		265	218
Stenneshöh	Naturenergie Messer GbR		530	436
Stenneshöh	Biokraft Wittkiel e.K.		530	436
Stoltebüll	Bioenergie Messer GbR		536	450
Stenneshöh	Naturenergie Messer GbR		530	434
Stenneshöh	Biokraft Stenneshöh GmbH & Co. KG		550	555
Stenneshöh	Agrarenergie Messer GbR		265	218
Wankendorf	Biogas Löhndorf GmbH & Co KG	526	1,415	1,556
Belau			530	384
Rickling	Bioenergie Hoheluft GmbH & Co. KG		526	561
Rickling	Biogas Fehrenbötöl GmbH & Co. KG		526	545
Schleswig	-		740	800
Schleswig	Biogas Schleswig	1,416	2,585	1,974
Lürschau	Klincker Energie		530	
Lürschau			265	218
Schuby	Biogasanlage Schuby 2	526	1,999	1,910
Schuby	Biogasanlage Schuby 1	526	1,999	1,920
Fahrdorf	Biokraft Wärme Fahrdorf GmbH & Co.KG	600	1,150	1,127

City or district	Name of the biogas plant	Installed electric power [kW]		Thermal power [kW]
		Before the modification	After the modification	
Klappholz	Günther Völkers Energie		75	209
Klappholz		600	1,400	1,379
Brodersby	Nissen Biogas GmbH & Co. KG	1,127	1,126	1,114
Brodersby	Biogas Royum GmbH		250	232
Brodersby	Energiefeld Geel GmbH & Co. KG	363	863	967
Busdorf			591	591
Dannewerk		700	1,589	1,536
Dannewerk	Biogas Schnepfennest GmbH&Co.KG		240	223
Nübel	BGA Brekling II GmbH & Co. KG	400	949	909
Nübel	Biogasanlage Brekling GmbH & Co. KG	550	1,253	1,253
Nübel			700	
Nübel	Bio Wärme Nübel GmbH & Co. KG		400	440
Stolk			75	
Stolk	Biogas Elmholz		250	
Tolk	Satellit	265	250	120
Ulsnis			75	70
Mittelangeln	Biogas Sorgenfrei		250	232
Mittelangeln OT Satrup			250	232
Mittelangeln	Michael Roskothen Energie		340	320
Freienwill	RKR Biogas KG		250	581