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Statistical Approach for Assessing the Suitability of Substrates for a Biogas Plant

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Abstract: In this paper, we focused on the statistical evaluation of inputs to a biogas plant processing a mixture of kitchen waste and agricultural crops to ensure stable biogas production. The aim of the research was to identify the components of the input substrates that will ensure the maximum yield of CH_4 and the substrates that increase the production of H_2S. By a suitable combination of substrates, it is possible to optimize the production of biogas from the biogas plant. We analyzed a sample of 858 measurements, which were carried out in a selected biogas station for a period of 2.5 years. We were interested in differences in production of CH_4, O_2, and H_2S outputs depending on the composition of inputs. From 17 inputs, 125 substrates were formed. The significance of the influence of individual substrates as categorical variables with the achieved numerical values was assessed by means of ANOVA analysis. Selected substrates were sorted based on CH_4 and H_2S production using graphical methods (bubble graphs) into four quadrants defining the desired and undesired values of the output variables. We identified a total of 20 suitable and 11 unsuitable substrates to produce quality biogas. Sorghum silage substrate was defined as a substrate that significantly increases the proportion of H_2S in biogas.

Keywords: biogas plant; input substrates; biogas; methane production; biowaste

1. Introduction

The use of renewable energy sources is currently a frequently discussed topic. It is generally considered that their main advantage is the reduction in the use of fossil fuels and their environmental impact. The problem of using renewable energy sources is their variability and, therefore, frequent dependence on climatic conditions. Biogas, which is the product of anaerobic fermentation of organic material, has the advantage of being a gas that can be stored in storage tanks and can be used at the time of need. Biogas is used to generate electricity, heat, fuel for cars or in technologies using the synergistic effect of biogas and other energy sources, such as water, wind, sun.

Biogas production in the European Union increased due to encouraging of renewably energy policies. The EU reached production levels of 18 billion m^3 methane in 2015, which is equal to half of the global biogas production. In biogas electricity production, the EU is a leader with more than 10 GW installed output and around 17,400 biogas plants. Half of all biogas consumption was destined to heat generation: 127 TJ of heat and 61 TWh of electricity in 2015 [1]. In the Czech Republic, Denmark, Germany, Italy, Austria and Greece, biogas from anaerobic digesters predominates; meanwhile in Estonia, Ireland, Portugal, and United Kingdom, landfill biogas dominates the market. Biogas from wastewater treatment prevails in few countries, such as Lithuania, Poland, and Sweden [2].

In 2017, 351 new biogas plants were added to the EU. In the countries of the Visegrád Four, the development of biogas plants has occurred, especially in recent years. As of 31 December 2019, there were 574 biogas plants in the Czech Republic with an installed capacity of 367 MW. The amount of electricity produced from these was 2526 GWh and the share of biogas in Renewable Energy Sources (RES) was 22.9%. There are currently 308 biogas plants in Poland and 81 in Hungary; no further data have been found [3,4].

In the last decade, the market for renewable energy sources in Slovakia has grown significantly. This was reflected, for example, in the fact that investments in biogas plants were more strongly promoted, especially until 2013, when 41 were added. In 2014, no station was put into operation, which was caused by the decisions of energy distribution companies. Last year (2019) a call was launched for further biogas plant projects [5].

A total of 108 biogas plants with an output of approximately 103 MW and a planned annual production of 810,526 MWh of electricity are currently connected in Slovakia. Most of these stations have an installed capacity in the range of 0.9–1 MW. The facilities in Badín (7.03 MW, KOMPALA, a.s.), Bošany (2.83 MW, Alternative Energy, s.r.o.), Dubník (AT GEMER, s.r.o.), Rozhanovce, and Plavnica (each 1 MW) have the highest output. For comparison, Germany has about 9000 biogas plants with an installed capacity of about 0.4 MW, which allows them to use waste material more consistently [6,7].

Biogas consists of methane (CH_4) in the range of 50–70% and carbon dioxide (CO_2) at a concentration of 30–50%. Nitrogen (N_2) represents 0–3%, water vapor (H_2O) 5–10%, oxygen (O_2) at a concentration of 0–1%, and hydrogen sulfide (H_2S) at a concentration of 0–10,000 ppmv. Other gases are represented in a small number of ppmv. The exact composition of biogas depends on the type of input substrate. Except for CH_4, all other ingredients are undesirable [8]. The methane energy content characterized by the lower calorific value (LCV) is 50.4 MJ/kg CH_4 or 36 MJ/m^3 CH_4 (at sewage treatment plant (STP) conditions). The higher the CO_2 or N_2 content, the lower the biogas value. For biogas with a methane content of 60–65%, the LCV is approximately 20–25 MJ/m^3. H_2S and NH_3 are toxic, explosive, and extremely corrosive, damaging the combined heat and power (CHP) unit (engine) and metal parts by SO_2 emissions from combustion [9–12]. By desulfurizing biogas, we can extend the life of steel parts of the structure [13]. In addition, bacteria which form hydrogen sulfide compete with methane-forming bacteria for the same substrate [14]. The presence of siloxanes in biogas, even in small concentrations, causes silicone oxides to form sticky residues during combustion, which are deposited in biogas internal combustion engines and in valves causing malfunctions [10].

The feedstock to produce biogas in biogas plants is the biomass of organic origin of plant or animal origin. The most commonly used types of substrates are specifically grown biomass (maize, beet, haylage), biowaste from public greenery maintenance, biowaste with households and gardens, food and biowaste from supermarkets, residues from canteens, restaurants and hotels, biowaste from business operations (bakeries, distilleries), breweries, sugar refineries, meat processing plants), farm animal waste (manure, liquid manure, litter), municipal and domestic waste, and sewage sludge [15]. Due to BIO stream in the world, which is growing every day, the volume of biodegradable polylactic acid in waste has increased significantly. Its presence in biowaste could increase biogas production, but with some limitations. The time needed for the maximal biogas production was almost 40 days in thermophilic conditions (separate digesters could be required) and 280 days for mesophilic conditions (which is not acceptable in technical scale) [16].

The operation of biogas plants is overly sensitive to the mix of substrates used. Selection and optimization of the mixture are, therefore, an important task of effectively operating or planning such devices [17]. There are models like the Anaerobic Digestion Model No.1 (ADM1) that allow calculating a good prediction of the biogas plant output based on the substrates used.

Optimizing the operation of biogas plants is and will be one of the major challenges for anaerobic digesting (AD) in the near future. Due to the cost of the substrate, only optimally operated biogas plants will be economically viable [18]. Successful utilization of organic fractions of municipal solid wastes for biogas production is fundamental for process stability in AD and addition of non-activated or activated hydrochars into its reactors improved their digestibility. Activated hydrochars derived from coffee ground biomass in reactor increase biogas production around 5% and are more effective in chemical oxygen demand, dissolved organic carbon and organic acids removal [19]. ADM1 is both exceedingly popular and the latest, most comprehensive mathematical model used to simulate the anaerobic digestion process. ADM1 is a structured model that includes the steps of disintegration and hydrolysis, acidogenesis, acetogenic, and methanogenesis. The ADM1 system is implemented as a differential equation system in the MATLAB® toolbox for modelling, optimizing, and controlling a biogas plant [20]. ADM1 includes a simulation of biogas plant operation, including heat and electricity, as well as models for performance and stability criteria, including costs versus benefits, the stability of substrate degradation processes and operating constraints such as upper and lower pH limits, maximum volatile fatty acidity and total alkalinity (VFA/TA) [21], maximum solids content in the hood and minimum methane concentration in biogas.

Substrate mixtures were also optimized using Genetic Algorithm and Optimization of Particle Swarm [22]. Ziegenhirt et al. [23] used procedures such as Covariance Matrix Adaption Evolution Strategy (CMAES) [24,25] or Differential Evolution (DE) [26] to reduce the number of simulations needed. The parameter optimization tool (SPOT) [27] was also used.

There are also alternative modelling techniques. A rough performance estimate can be determined based on the biogas potential of the substrates used and their associated costs. This additional knowledge can be integrated into the optimization process through the quality of the selected surrogate modelling technique. This approach of integrating different levels of granularity or cost was formerly called multi-fidelity optimization [28].

One of the models is the Kriging, which is a particular model for continuous smooth problems. In addition to its predictive performance, it is often used because it provides an estimate of the local certainty of the model that can be used to calculate the expected improvement (EI) of a new sample [29,30]. Jones et al. [31] introduced this concept to balance usage and exploration in costly optimization, with the term Effective Global Optimization (EGO). Other models include Artificial Neural Networks (ANN), Support Vector Regression (SVR) [32], Random Forest (RF) [33] or Multivariate Adaptive Regression Splines (MARS) [34].

H_2S removal has become an important subject of research in many studies focused on the effective benefits that bring in real conditions of operation of biogas plants (economic, technological, environmental). We know the physical-chemical and biotechnological methods of H_2S removal, however biotechnological ones have become more attractive in recent years due to higher efficiency (> 99%) and lower operating costs, and they do not produce secondary streams [35,36].

Physical-chemical methods include, for example, water scrubbing (at H_2S concentrations 300–2500 ppmv, methane purity is 95–98%), physical organic scrubbing (methane purity is 93–98%), chemical absorption (methane purity is >98%), pressure swing adsorption (PSA, methane purity is 96–98%), and membrane and cryogenic separation (methane purity is 90–96% and 99%) [37].

Biotechnological methods are divided into in situ (addition of H_2 to the liquid phase of the reactor) and ex situ methods (addition of CO_2 and H_2 from an external source with hydrogenotrophic microbes). [36] The purity of CH_4 depends on the type of reactor, raw material, temperature, and retention time, and ranges from 60% (in situ, continuous reactor, chicken manure, 10 days) [36] to 100% (in situ, continuous-flow stirred tank reactor (CSTR), biogas sludge, 38 °C, 20 days) [38].

The influence of control factors on the performance of biogas treatment evaluated by ANOVA was used, for example, by Marin and Vega [39], Armah and Chetty [40], Marin and Carmona-Martínez [41], Jamaluddin [42], etc.

In our research, we focused on the statistical assessment of inputs to the biogas plant to ensure stable methane production, because of significant problems with corrosivity of the engine. The aim of our research was to maximize the amount of CH_4 in biogas, minimize the amount of H_2S, and ensure the stability of biogas production to protect the technology of the biogas plant and increase its effectivity and performance. We chose this biogas plant because the operator approached us with a request to assess the impact of feedstock on biogas quality. In Slovakia it is still common practice to install refurbished technologies to reduce investment costs. Cogeneration units used at such biogas plants are extremely sensitive to the increased H_2S content in biogas. This is reflected in the increased corrosivity of machine parts and the need for frequent service breaks of cogeneration units. The operator of this biogas plant does not use a dose optimization calculator. The reason is that the main input raw material is waste from various food operations in the catchment area. This results in a difficult prediction of specific volumes and quantities. Inputs with a positive effect on CH_4 production will allow the operator to replace the input raw material producing larger amounts of H_2S.

2. Methods and Methodology

The analysis itself was performed based on measured data of a specific biogas plant, while the input components of individual substrates were recorded and subsequently the achieved values of CH_4, H_2S, and O_2 were measured. At the beginning, we started from a sample of 858 measurements, which were carried out in a selected biogas station in the period from 1 May 2015–30 October 2017. The data processed the ratio of the input components of the substrate: corn silage, sorghum silage, receiving tank, bread, rye, manure, oil, juniper, haylage, chopped (maize silage), corn cob mix (CCM), pasteurized biodegradable waste, fruit, vegetables, other (1,2,3,4), and the ratio of outputs from the biogas plant in%—CH_4, O_2, H_2S (see Table 1). A total of 73 data were excluded during data validation due to various meter failures and on-site service work.

Table 1. Basic descriptive statistical analysis of research input variables.

Num.	Folder	N	Mean	Std. Dev.	Minimum	Maximum
1	Corn silage/Maize silage [kg]	775	28,358.10	7392.65	1500	39,860
2	Sorghum silage [kg]	155	8258.97	4496.66	1000	17,800
3	Receiving tank [kg]	492	15,634.3	6102.37	1000	34,000
4	Pastry [kg]	191	1155.76	770.8	100	4000
5	Rye [kg]	94	10,245.4	2933.97	1540	17,580
6	Manure [kg]	408	1562.55	571.93	0	2660
7	Oil [kg]	147	276.74	158.13	0	820
8	Juniper [kg]	88	3649.77	2192.42	300	6880
9	Other 1 [kg]	189	3198.52	2868.25	60	15,000
10	Other 2 [kg]	210	1981.86	1890.45	60	20,000
11	Others 3 [kg]	82	1830.00	2535.58	50	10,700
12	Others 4 [kg]	6	2573.33	2009.25	600	6300
13	Haylage [kg]	180	5321.89	2436.56	200	12,000
14	Corn chips silage [kg]	26	27,173.1	8368.92	6000	40,000
15	CCM (Corn Cob Mix) [kg]	23	2135.65	1075.19	1020	4740
16	Pasteurized biodegradable waste [kg]	240	13,727.00	6519.78	0	36,600
17	Fruits/vegetables [kg]	236	2971.50	1341.05	230	6320
#	CH_4 [%]	785	59.53	2.92	43.3	67.5
#	O_2 [%]	781	0.16	0.22	0	5.7
#	H_2S [%]	785	0.10	0.09	0	0.76

Note: # biogas plant outputs.

Within further processing we were interested in differences in production of CH_4, O_2, H_2S outputs depending on the composition of inputs. Since the substrates were composed of 17 components in different structures, we created groups of substrates with the same combination of input variables. The individual input components were numbered from 1–17 and depending on whether the component was present in the substrate, the given number was assigned to the substrate designation, creating 125 substrate combinations (see Figure 1).

The significance of the influence of individual substrates as categorical variables on the achieved numerical values of CH_4 and H_2S was assessed by ANOVA analysis (one-way ANOVA), which was subsequently verified. Our goal was to assess whether there was a statistically significant impact. To verify the results, we supplemented the analysis with a nonparametric Wilcoxon variability test, which confirmed the results of a one-way ANOVA.

Level	Count
Total	858
1-2-3--6-------	88
1--3--6---13----	58
1--3--6-------	43
1--3--56-------	42
1---4-10------16-17	42
1----10------16-17	34
1-2-3--67-------	28
1--3--67---13----	23
1----910------16-17	23
1----------16-17	22
1--3--67-------	19
1---4-910------16-17	18
1-----11-----16-17	14
1--3-4-910-------	13
1--3--910-------	13
1--3--9-------	12
1---4-------16-17	12
1--3--567-------	11
1--3---------	10
1----910-11-----16-17	10
1--3-4-6---13----	9
1---4-910-11-----16-17	9
1----10-11-----16-17	8
1-2-3--678---13----	8
1-2-3--68-------	8
1-2---6-------	8

Level	Count
1--3-4-68---13----	8
1--3--789---13----	8
1----9-11-----16-17	8
1----------16-	7
1-2-3--56-------	7
1--3-4-67---13----	7
1--3--5-------	7
1----9------16-17	7
1--3-4--------	6
1--3-4-678---13----	6
1---4-9------16-17	6
1--3--68---13----	5
1---4-910-11-----16-	5
1---4-9-11-----16-	5
1----56-------	5
----------16-	5
1----10-11------17	4
1----10-------17	4
1-2----------	4
1-2-3-4-6---13----	4
1--3--6789---13----	4
1---4-10-11-----16-17	4
1---4--11-----16-17	4
1----58-------	4
1----910------16-	4
1----9-11------17	4

Figure 1. Substrate combination.

In addition to the high variability of the achieved outputs due to the type of substrate, significant differences in the range of the values were found with the calculation of the standard deviation of the outputs according to the substrate. This fact affects the stability in the prediction of biogas and H_2S production. Of the total of 125 substrates, those that achieved relatively stable output values were selected, making it possible to predict outputs with higher reliability. This selection was made by means of the standard deviation indicator, with the substrates having the lowest values of this indicator being selected. This gave 63 substrates. Subsequently, the selected substrates were sorted, based on CH_4 and H_2S production, into four quadrants using graphical methods (bubble graphs) delimiting the desired and undesired values of the output variables. We identified suitable and unsuitable substrates. Finally, by comparing the structure of these substrates, we defined the key components most significantly influencing the improvement/worsening of the outputs.

3. Results

3.1. Analysis of Variability of CH_4 and H_2S Production from Individual Substrates

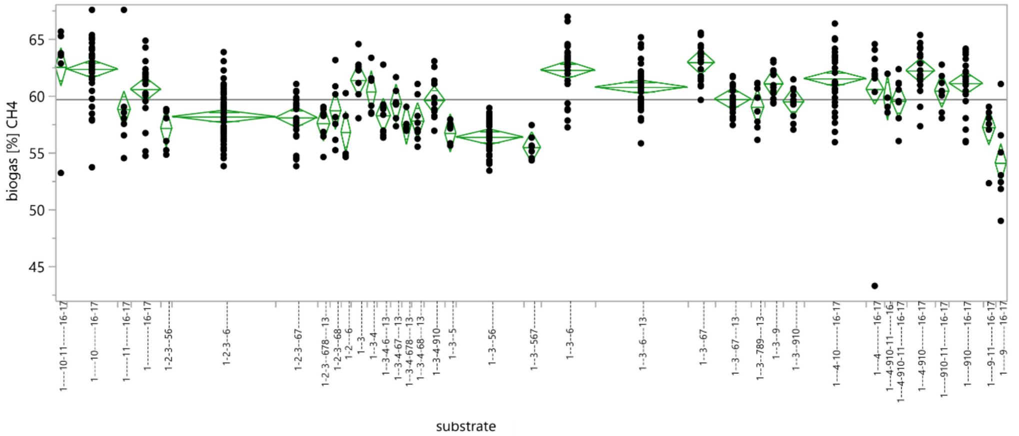
The collected data were first sorted according to the occurrence of the input components into 125 substrates (see Figure 1). Subsequently, the statistical significance of the effect of the substrate on achieving CH_4 and H_2S production was examined.

Analysis of variability of CH_4 production by one-way ANOVA method confirmed statistically significant influence of individual substrates on the achieved values. A statistically significant variability in CH_4 production was demonstrated, with values ranging from 49–67.5% with an average of 59.5% (see Figure 2). This was verified and subsequently confirmed by a non-parametric Wilcox variability test. The subject of further investigation will be the delineation of substrates with above-average values of the investigated indicator.

The analysis of variability also in the case of H_2S production by one-way ANOVA confirmed a statistically significant influence of individual substrates on the achieved values. A statistically significant variability in H_2S production was demonstrated with values ranging from 0–0.75% with an average of 0.1% (see Figure 3). The nonparametric Wilcox variability test also confirmed these findings in this case. The subject of further investigation will be the laying out of substrates with the lowest values of the studied indicator.

Fit Group

Oneway Analysis of biogas [%] CH4 By substrate



Oneway Anova

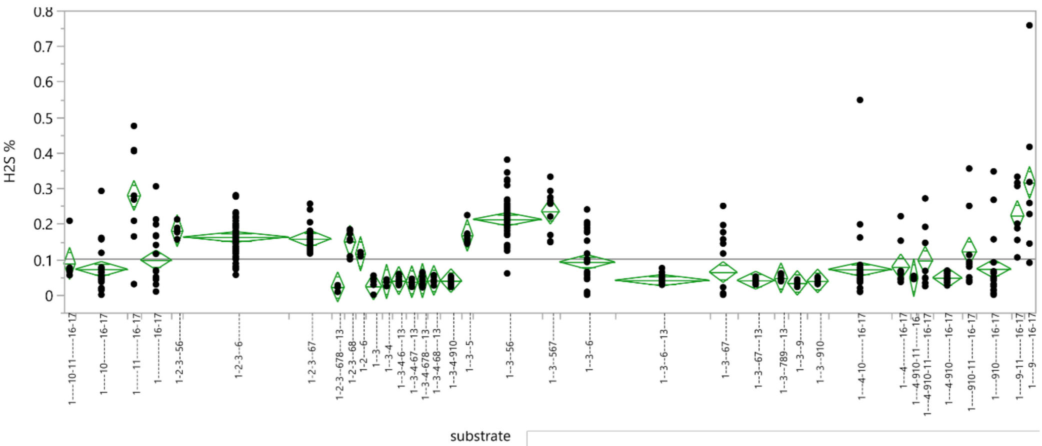
Summary of Fit

Rsquare	0.530312
Adj Rsquare	0.442068
Root Mean Square Error	2.184137
Mean of Response	59.52064
Observations (or Sum Wgts)	785

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
substrate	124	3554.8859	28.6684	6.0096	<0.0001
Error	660	3148.4998	4.7705		
C. Total	784	6703.3857			

Figure 2. Analysis of variance of CH_4.



Oneway Anova

Summary of Fit

Rsquare	0.594437
Adj Rsquare	0.518241
Root Mean Square Error	0.063428
Mean of Response	0.100162
Observations (or Sum Wgts)	785

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
substrate	124	3.8918479	0.031386	7.8014	<0.0001
Error	660	2.6552651	0.004023		
C. Total	784	6.5471130			

Figure 3. Analysis of variance of H_2S.

3.2. Selection of Substrates with Stable Production

Based on this, we decided to investigate which substrates achieved the desired values of the output variables (i.e., high CH_4 values and low H_2S values). In more detail, we observed a high variance of values at the level of individual substrates, which reduces the reliability of subsequent deductions.

To increase the accuracy of the following predictions, it was necessary to select from all 125 substrates those that achieved relatively stable output values. This selection was made by means of a standard deviation indicator within each substrate, and the substrates with the lowest values of this indicator were selected. The calculated values were in the interval: standard deviation H_2S < 0; 0.22 >; standard deviation CH_4 < 0; 5.85 > (see Figure 4).

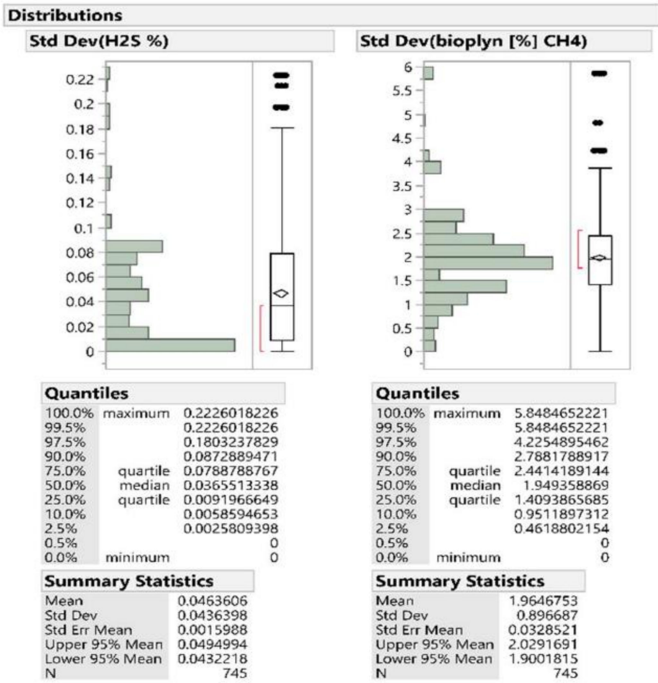


Figure 4. Standard deviation distributions of H_2S and CH_4.

When selecting stable substrates, we chose the standard deviation indicator H_2S, as the values of this indicator are crucial for improving the quality of biogas. The selection limit was set at 0.05, covering more than half of the measurements (see Figure 5). By selecting all substrates with a standard deviation of the H_2S indicator up to 0.05, all stable substrates were marked with a red asterisk; at the same time we can observe how stable the given substrates are in terms of standard deviation CH4, marked with a blue asterisk.

446 measurements from the original 785 were selected. These measurements represent 63 relatively stable substrates. Thanks to the selection, we managed to reduce the standard deviation of H_2S by almost half (see Table 2).

Table 2. Univariate simple statistics after excluding unstable substrates.

	N	Mean	Std. Dev.	Minimum	Maximum
CH_4 [%]	446	59.30	2.39	53.50	65.9
H_2S [%]	446	0.08	0.06	0.00	0.28

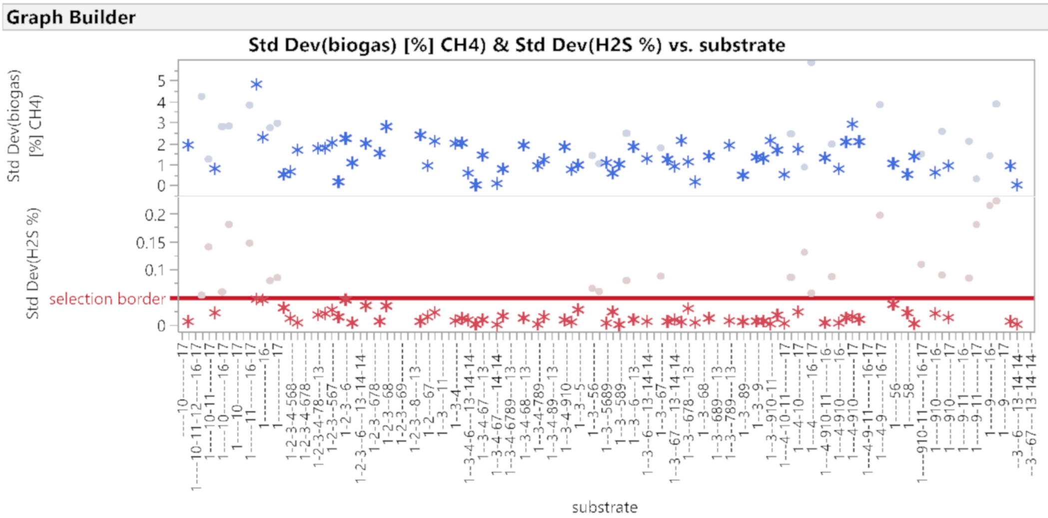


Figure 5. Analysis of the standard deviation of CH_4 and H_2S.

3.3. Assessment of Substrate Quality

Substrate selection presented in the previous analysis was subsequently analyzed for the CH_4 and H_2S output variables achieved (Figure 6). Four quadrants were defined:

I. Quadrant with CH_4 value greater than 60% and H_2S value less than 0.125%.
II. Quadrant with CH_4 greater than 60% and H_2S greater than 0.125%.
III. Quadrant with CH_4 less than 60% and H_2S less than 0.125%.
IV. Quadrant with CH_4 less than 60% and H_2S greater than 0.125%.

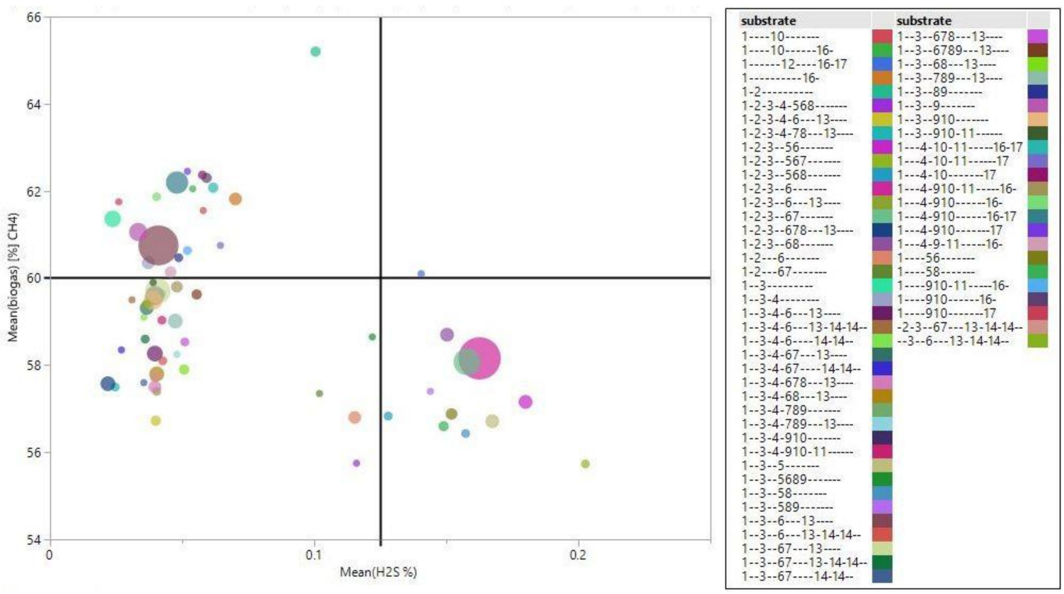


Figure 6. Definition of substrate evaluation quadrants based on H_2S a CH_4.

Our aim was to divide substrates into suitable and unsuitable on the basis of the required values of the output variables. The best quality substrates are those with CH_4 at 60% higher and H_2S below 0.125%, indicated by quadrant I. The least suitable substrates belong to quadrant IV with CH_4 values below 60% and H_2S values above 0.125%.

3.4. Suitable Substrates

On this basis, it was possible to select substrates with the highest quality in our case 20 substrates located in quadrant I (Figure 7). The figure shows the position of the substrates in terms of the achieved values of CH_4 (y-axis) and H_2S (x-axis) production. The size of the bubble expresses the occurrence of such a substrate within the analyzed period of two years. As we can see, the most common substrate was 1-3-6-13, which produced an average of 61% CH_4 and 0.04% H_2S. At the same time, we see here that the best (highest) value of CH_4 was achieved by the substrate 1-2- at the level of 65% and the best (lowest) value of H_2S was achieved by the substrate 1-3-.

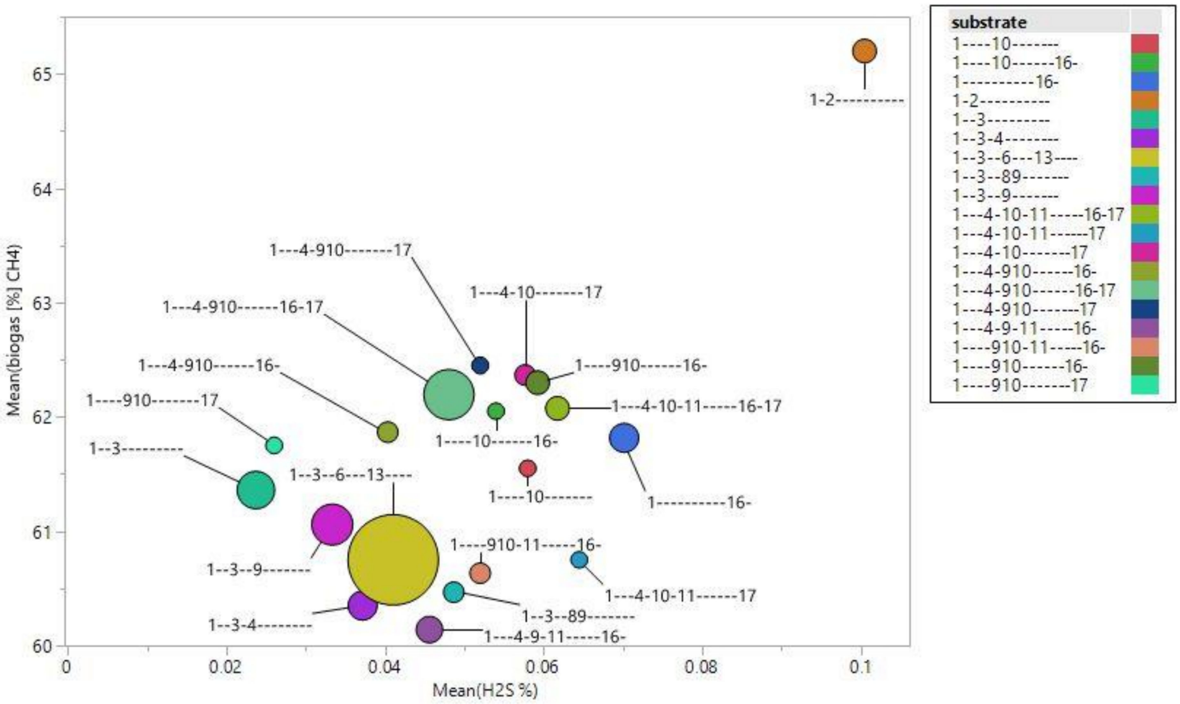


Figure 7. Quadrant I—suitable substrates.

3.5. Unsuitable Substrates

Based on this, we can select substrates of lower quality, in our case 11 substrates located in quadrant IV (Figure 8). The size of the bubble indicates the two most common substrates: 1-2-3-56 and 1-2-3-6-, which reach average values of CH_4 at 58% and H_2S at 0.16%. The worst (highest) values of H_2S were achieved by the substrate 1-2-3-567 with a value of 0.2%, which also achieved the worst (lowest) values of CH_4 at the level of 55.7%.

Subsequently, we dealt with the analysis of individual components of which the substrates thus defined were composed. We found that the selection of stable substrates excluded two components from the analysis: 12-Other 4 [kg] and 14-Corn chips silage [kg], which may indicate that the variability in the achieved values of substrates may be caused by these two components, but this cannot be finally confirmed without further investigation.

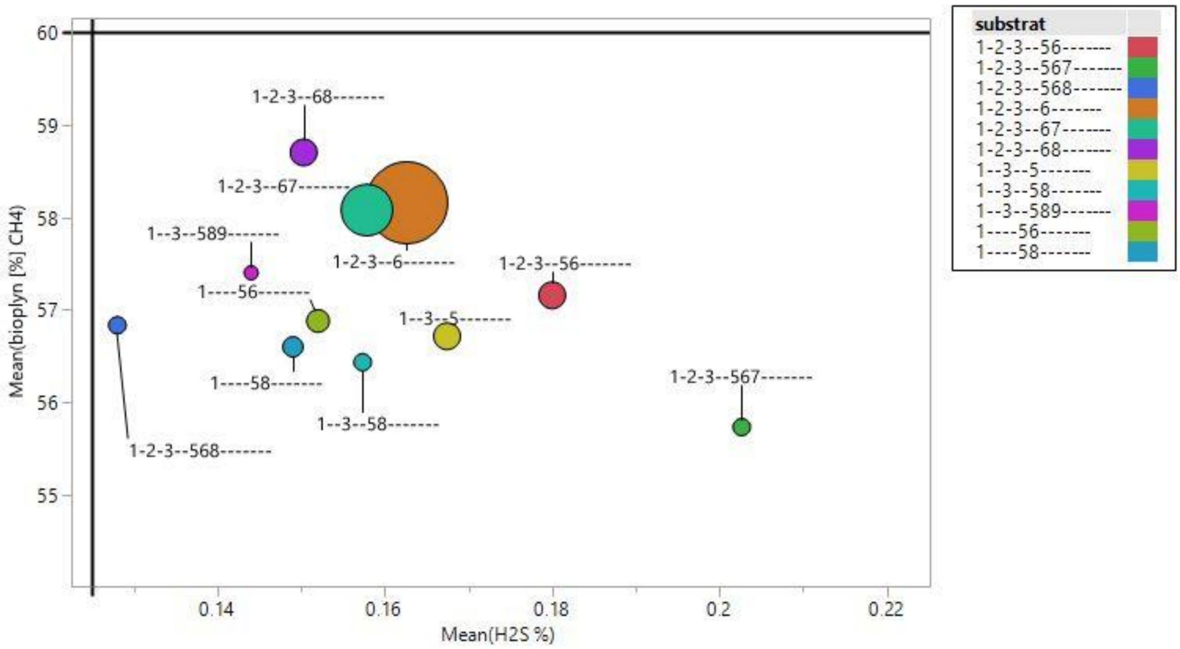


Figure 8. Quadrant IV—unsuitable substrates.

By selecting suitable relatively stable substrates, we found that of the 17 components analyzed, the next four components were not in the substrates:

- 5-Rye [kg]
- 7-Oil [kg]
- 12-Other 4 [kg]
- 14-Corn chips silage [kg]

By examining and comparing the percentage of components of both types of substrates, we came to the conclusion that the most significant difference is in the case of component No. 2-Sorghum silage. For suitable substrates, it was on average 1.29%, but for unsuitable substrates its share reached up to 12.07% (see Table 3).

Table 3. The average proportion of individual components of suitable and unsuitable substrates.

Folder	Mean Suitable Substrates		Mean Unsuitable Substrates	
	[kg]	[%]	[kg]	[%]
1-Corn silage/Maize silage	29,154	61.47%	29,913	56.07%
2-Sorghum silage	404.228	1.29%	6464.32	12.07%
3-Receiving tank	8799.06	18.82%	12,651.5	22.45%
4-Pastry	436.04	0.87%	0	0.00%
5-Rye	0	0.00%	2686.06	5.74%
6-Manure	414.228	0.90%	1634.7	3.01%
7-Oil	0	0.00%	34.5455	0.06%
8-Juniper	133.02	0.26%	229,848	0.49%
9-Other 1	894.698	1.67%	47.2727	0.10%
10-Other 2	585.369	1.21%	0	0.00%
11-Other 3	158.121	0.28%	0	0.00%
12-Other 4	0	0.00%	0	0.00%
13-Haylage	1885.1	3.95%	0	0.00%
14-Corn chips silage	0	0.00%	0	0.00%
15-CCM (Corn Cob Mix)	32.7517	0.06%	0	0.00%
16-Pasteurized biodegradable waste	4503.22	8.12%	0	0.00%
17-Fruits/vegetables	556.705	1.10%	0	0.00%
biogas [%] CH4	61.3047		57.8091	
H2S [%]	0.0453		0.1611	

3-The receiving tank includes: whey, oils and fats, pasteurized restaurant waste, fruit and vegetables, fish, meat, grain, food, chips, pastries, dough, flour.

4. Conclusions

In the presented paper, we analyzed the operating parameters of a biogas plant in terms of the quality of biogas produced from a mixture of kitchen waste and agricultural crops. Based on data obtained over 2.5 years, it was found that the quality of biogas varies significantly. In the research, we used a statistical evaluation of all inputs to the biogas plant in order to identify the impact of individual components on the quality of biogas. Analysis of input variables defined 17 different components entering 125 types of substrates. More detailed analysis confirmed significant differences in the proportion of methane and unwanted hydrogen sulfide in the biogas produced from the investigated substrates. However, due to the nature of the inputs—mixed kitchen waste—a significant dispersion of the achieved outputs was also identified at the level of individual substrates. Within the research, 63 substrates meeting the stability criteria were selected. The result of the analysis is the definition of 20 suitable and 11 unsuitable substrates for the process of quality biogas production in the investigated plant. The influence of component No. 2-Sorghum silage, which is 1.29% on average with suitable substrates, can be considered as a statistically significant result, but with unsuitable substrates its share reaches 12.07%.

The research results show that Sorghum silage in combination with food waste is statistically responsible for the increased share of H_2S in biogas. As only the operating parameters of the biogas plant were analyzed in the research, for more relevant results it would be necessary to verify this fact by longer-term specialized research. Following this, we plan to conduct research aimed at verifying the hypothesis that Sorghum silage increases the share of H_2S in biogas produced from heterogeneous inputs based on food waste. The results of the presented research will be used to determine the composition of the input component of food waste. The used input database makes it possible to determine the composition of the waste depending on the season and the waste supplier. In the laboratory environment CE 642, different proportions of food waste and Sorghum silage will be tested and the amount of H_2S in the produced biogas will be analyzed. The results of the research in the form of critical values will be tested in real operation in order to confirm or reject the hypothesis. If this hypothesis is confirmed, it would be possible to reduce the H_2S content in biogas and reduce the corrosivity of the produced biogas.

Due to the time limits of storage of imported waste, it was necessary to perform a statistical analysis of the impact of substrates used in this biogas plant on the quality of biogas. The results of the analysis will allow the operator to create a logistics plan for the supply of the biogas plant optimizing the quality of production.

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