Deliverable D Action B3

Report on the use of slurry derived fraction in biogas plants for the period September 2018-Sepetember 2019

Executive summary

The B3 action within LIFE DOP project has the aim to highlight if the use of slurry and manure-derived material in biogas plants is possible, effective and if has any counter effects.

The main features to monitor are the quality of feeding mix, the quality of digestate (especially TS and Nitrogen) and of course the general functioning of the plant in relation to the feeding mix.

The main questions for answers are:

- Is the substitution of silage maize with slurry and manure-derived products affecting the general functioning of the biogas plant?
- Is the plant consuming more energy for mixing, and if yes is it a cost-effective action?
- Is the increase of nitrogen and ammonia proper for the plant?
- Is the plant working in stable and balanced condition?
- Is the cost-benefit balance positive for the biogas plant?

Definition

Slurry: livestock faeces. Cattle slurry has average total solids around 9%.

Manure: mix of livestock faeces and straw, average total solids around 18-20%

Shredded manure: Manure subjected to cleaning (removal of stone and metals) and shredding to shorten straw length, in order to be suitable for biogas plant.

Slurry-manure derived fractions: fractions derived from slurry and manure thanks to a specific treatment. Slurry-manure derived fractions are: **Shredded manure**, **Separated Solid fraction of slurry, Cavitated slurry -manure mix.**

Separated solid fraction of slurry: fraction of slurry separated from liquid to be suitable for transport and delivery to biogas plant. An average total solid of this fraction is 16-18%.

Cavitated slurry-manure mix: mix of slurry and manure, which undergo treatment in the prototype device to be realized in the project. The objective of the treatment is to make the materials more suitable for biogas plant , i.e. produce a material with high total solids content, high homogeneity, high digestibility, and pumpability up to 16% of total solids. Foreseen average content of total solids 13-16%.

Materials and methods

Two different anaerobic digestion plants were monitored during the substitution of silage maize with slurry and manure-derived fractions for the production of biogas.

Biogas plant 1: the plant is situated in Pegognaga and has an installed capacity to generate energy of 999kw. The plant is composed by 4 digesters, 2 primary fermenters (2500 m^3 volume each), 1 secondary digester and 1 post fermenter (2500 m^3 volume) for a total volume of 10.000m^3.

The feeding mix is generally composed of silage maize and cattle slurry produced in the farm. The input of the slurry-manure derived fraction in the plant has reached 75% of the total feeding mix. The average temperature of material in the digesters is set at 42°C.

The biogas is used in a CHP (Combined Heat and Power) unit to produce electric energy that is fed in the grid. The biogas is cooled up to 6 °C and the H_2S is removed thanks to air flowing in the digesters.

Biogas plant 2: the plant is situated in Borgo Virgilio and has an installed capacity to generate energy of 999kw. The plant is composed by 3 digesters, 2 primary fermenters (4000 m^3 volume each), 1 secondary digester (4000 m^3 volume) for a total volume of 12.000m^3.

The feeding mix is generally composed of silage maize and cattle slurry produced in the farm. The input of the slurry-manure derived fraction in the plant has reached 80% of the total feeding mix. The average temperature of material in the digesters is set at 45°C.

The biogas is used in a CHP (Combined Heat and Power) unit to produce electric energy that is fed in the grid. The biogas is cooled up to 4-8 °C and the H_2S is removed thanks to air flowing in the primary digesters.

The data were monitored on site (amount of input materials, energy production, digestate production, quality of produced biogas, energy consumption for funning the plant, i.e. mixing and feed loading) and on collected samples analysed in lab.

Samples were analysed according to the standard methods indicated in table 1

Table 1: methods used in the monitoring

Parameter	Method
pH	CNR IRSA n 64 1985
Total Solids (%)	CNR IRSA n 64 1985
Volatile Solids(%ST)	ANPA 2001
Total Kieldal Nitrogen (%ST)	G.U. 180 5 Aug. 1986
Ammonia Nitrogen (mg/l)	CNR IRSA n 64 1985
Total Phosphorus	EPA 1996.
ABP	Schievano et al. 2008

Rsults

Biogas plant 1

Feeding mix of the plant and characterisation of input materials

The inputs of the plant 1 are reported in table 2.

Table 2: input materials of biogas plant 1

Date	Silage maize	Cattle slurry	Solid fraction of cattle slurry	Cavitated slurry-manure mix	Total input	Slurry-manure derived fraction on total input	maize substitution
	Tons/month	Tons/month	Tons/month	Tons/month	Tons/month	%	
Baseline*	**1500**				**1500**	**0%**	**0%**
10/18	1088	960	0		2048	47%	27%
11/18	1100	880	0	506	1980	44%	27%
12/18	1040	890	0	818	1930	46%	31%
01/19	1072	910	0	996	1982	46%	29%
02/19	856	840	0	805	1696	50%	43%
03/19	945	910	0	1380	1855	49%	37%
04/19	950	880	0	1311	1830	48%	37%
05/19	950	903	150	780	2003	53%	37%
06/19	930	940	370	620	2240	58%	38%
07/19	920	895	380	580	2195	58%	39%

08/19	950	885	460	420	2295	59%	37%
09/19	910	900	510	480	2320	61%	39%

*** only corn silage use**

The materials fed in the digesters where maize, cattle slurry produced nearby the farm and solid fraction of cattle slurry, coming from a longer distance.

The baseline to compare results is the plant when only corn silage is used, i.e. a supply of maize of 18.000 tons/year and a stable energy production of 8.200.000Kwh/year.

The total amount of slurry and manure-derived fraction was equal to 61% of the total feeding mix at the higher level of substitution tested in during the trial.

The addition of slurry derived fractions allows to save almost 503 tons of silage maize for a month considering the base line and the maximal maize substitution of around 40%% achieved last year in this plant.

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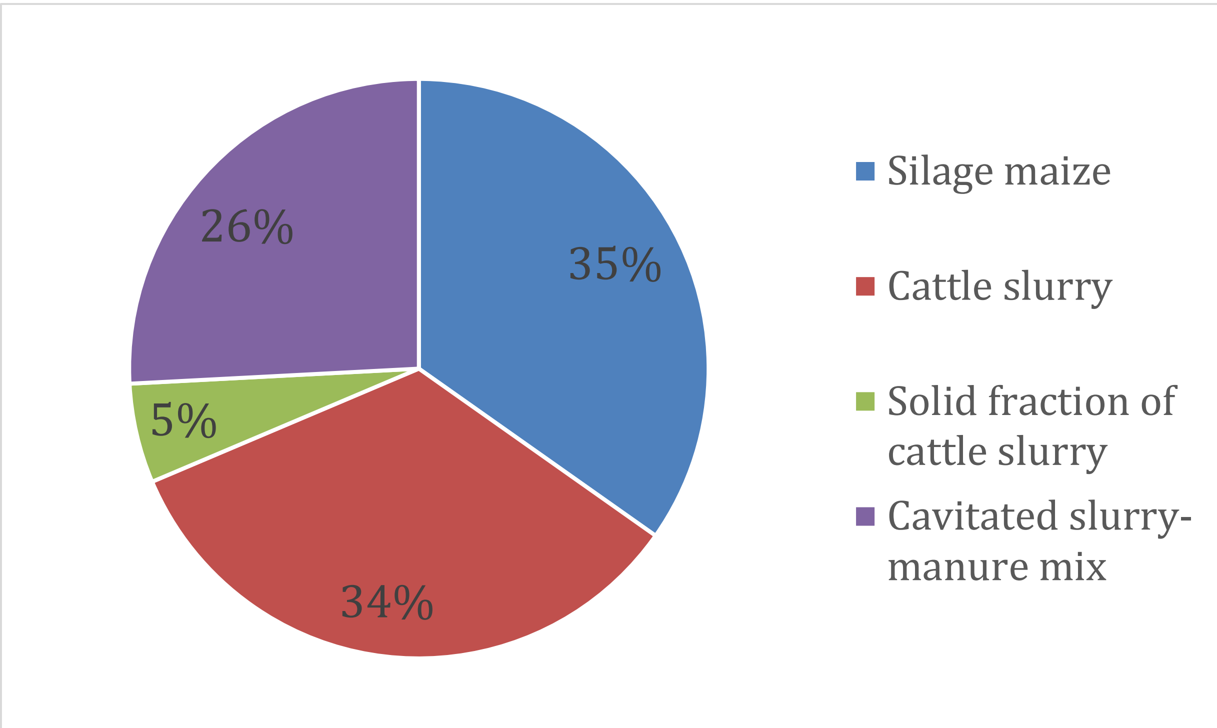

Figure 1: total composition of feeding mix during the last trial period (12 months)

Characterisation of input materials

In table 3 and 4 are reported the biochemical data of the feeding materials

Table 3: average value of chemical characterisation of the biomass fed in the digesters (data from 12 samples)

	pH			**TS (%)**			**VS (%TS)**		
Silage maize	3.8	±	0.62	32.9	±	1.84	95.6	±	2.3
cattle slurry	7.88	±	1.12	6.8	±	0.99	86.1	±	3.3
Solid fraction of cattle slurry	8.4	±	0.57	23.4	±	3.14	84.4	±	4.13
Cavitated slurry-manure	7.68	±	0.93	11.8	±	2.01	85.6	±	8.12

Table 4: average value of chemical characterisation of the biomass fed in the digesters (data from 12 samples)

	TKN (% w.w.)			NH_3 (mgL^{-1})			P (%w.w)			ABP ($NlkgTS^{-1}$)			ABP ($Nlkg^{-1}$)
Silage maize	0.41	±	0.06	118	±	77	0.05	±	0.02	701	±	58	358
cattle slurry	0.39	±	0.08	1612	±	432	0.05	±	0.01	319	±	87	185
Solid fraction of cattle slurry	0.41	±	0.04	1028	±	108	0.08	±	0.02	316	±	95	190
Cavitated slurry-manure	0.36	±	0.05	1529	±	195	0.06	±	0.02	288			170

*ABP: Anaerobic Biogas Potential, for this analysis sample were 11, sampling from September will be available for the next report

Plant Characterization of output materials: digestate

In table 5 are reported the chemical data of digestate

Table 5: digestate characterisation

Date	**TS**	**VS**	**TKN**	**N-NH3**	**NH3/TKN**	**P**
	%	%TS	%	mgL^{-1}	%	%
10/18	**5.7%**	73.31%	0.30%	1722	58.00%	0.04%
11/18	**3.5%**	69.9%	0.41%	2353	58.00%	0.06%
12/18	5.1%	71.7%	0.34%	1903	56.00%	0.05%
01/19	5.6%	68.1%	0.32%	2003	63.00%	0.05%
02/19	6.5%	72.7%	0.30%	1974	65.00%	0.05%

03/19	5.1%	69.0%	0.32%	2004	62.00%	0.05%
04/19	6.7%	73.2%	0.28%	1663	59.00%	0.04%
05/19	6.6%	69.4%	0.28%	1810	64.00%	0.04%
06/19	5.6%	69.2%	0.33%	1831	55.00%	0.05%
07/19	6.6%	68.9%	0.35%	2405	68.00%	0.06%
08/19	6.0%	72.2%	0.36%	2237	63.00%	0.06%
09/19	6.1%	69.4%	0.37%	2199	60.00%	0.06%

Plant functioning data

In table 6 are reported some relevant data on the plant functioning, such as the amount of energy produced, the amount of energy used for running the plant (mixing and feeding) and the Hydraulic Retention Time (HRT), i.e. the average number of days that the feeding materials stay in the digesters.

Table 6: data from plant running: energy production, energy consumption, HRT.

Date	Produced energy	Consumed energy for running	HRT	Methane in biogas	H2S in biogas
	kWh/month	kWh/month	Days	%	ppm
Base line	768550	53909	95	51	180
10/18	613980	55453	105	50	170
11/18	744,200	55220	90	51	212
12/18	741,290	53373	90	50	154
01/19	736,930	54179	84	51	126
02/19	672,310	47868	93	51	167
03/19	727,520	53342	84	50	183
04/19	719,400	50372	82	51	150
05/19	743,070	58108	90	51	160
06/19	716,400	56739	83	53	186
07/19	737,273	58458	87	52	228
08/19	742,946	60126	86	51	168
09/19	713,040	55683	83	52	203

The biogas plant maintained the same average production (1Mw as target electric power capacity). About energy demand to run the plant, data outline that the primary cause for the increase of energy consumption for plant running is related to the ambient temperature and the cooling of the engine during summer time. The average energy demand on an annual basis in 2019 was 7.5% of the total energy production, no significant variation was detected in energy demand due to the use of slurry derived fractions in the feeding mix of biogas plant.

The de-sulfuration system of the plant demonstrated to be able to keep H_2S level within a safe range in the biogas sent to the CHP unit. The biogas composition was around 52% of methane concentration, in the range of that assessed for biogas plant running on energy crop such as maize.

Finally, HRT decreased of only 10%, a value that causes no concern for the stability of process and running of the plant.

Mass balance

In table 7 is reported the mass balance of the inputs and outputs of nutrients in the biogas plants.

Table 7: mass balance of nutrients and total solids load

Date	**Feeding mix TS**	**TKN**	**P**	**S**	**Digestate TS**
	Tons/month	Tons/month	tons/month	Tons/month	Tons/month
10/18	495	8.51	1.31	0.048	86
11/18	441	8.23	1.26	0.044	143
12/18	500	8.02	1.23	0.045	162
01/19	518	8.24	1.26	0.046	198
02/19	552	7.04	1.09	0.042	127
03/19	450	7.70	1.19	0.045	205
04/19	555	7.60	1.17	0.044	201
05/19	546	8.36	1.30	0.048	160
06/19	516	9.41	1.49	0.054	197
07/19	541	9.23	1.46	0.053	178
08/19	531	9.67	1.54	0.054	182
09/19	539	9.78	1.57	0.056	202

Table 8: comparison of critical parameters, baseline VS trial (data at higher maize replacement)

	Baseline	**Test**	**Variation**
Maize	1500	976	-35%
Feeding mix TS	495	546	10%
Digestate TS	152	170	12%
TKN	6	8.48	41%
P	0.9	1.32	47%
HRT	97	88	-9%

The mass balance outline that:

the maximum replacement of maize by slurry derived fraction achieved in this year for the Biogas plant 1 was 35% of the baseline 1 (biogas plant only fed by maize).

The input of total solids in the feeding mix increased by 10%

Total nitrogen and phosphorus input increased compared with baseline. This increase in nutrient input allows to displace these nutrients where needed, i.e. outside the breeding district.

Biogas plant 2:

Feeding mix of the plant and characterisation of input materials

The mass inputs of the plant 2 are reported in table 9.

Table 9: input materials of biogas plant 2

Date	Silage maize	Cattle slurry	Solid fraction of cattle slurry	Manure	Total input	Slurry-manure derived fraction on total input
	Tons/month	Tons/month	Tons/month	Tons/month	Tons/month	%
Baseline only corn silage use	**1500**	**0**	**0**	0	1500	0%
10/18	355	1861	0	1830	4047	91%
11/18	390	1836	0	1840	4066	90%
12/18	368	1825	0	1795	3988	91%
01/19	379	1951	0	1884	4214	91%
02/19	386	1697	0	1717	3801	90%
03/19	372	1843	0	1866	4081	91%
04/19	386	1871	0	1823	4080	91%
05/19	345	1879	0	1797	4022	91%
06/19	390	1783	0	1737	3910	90%
07/19	386	1897	0	1830	4114	91%
08/19	379	1861	0	1901	4141	91%
09/19	372	1843	0	1813	4027	91%

The material fed in the digesters where silage maize, cattle slurry, solid fraction of cattle slurry and manure.

The total amount of slurry and manure-derived fraction was equal to 91% of the total feeding mix at the higher level of substitution tested in the first year of trials. The addition of slurry derived fractions allowed to save up to 1000 tons of silage maize for a month, i.e. a maize substitution close to 70%.

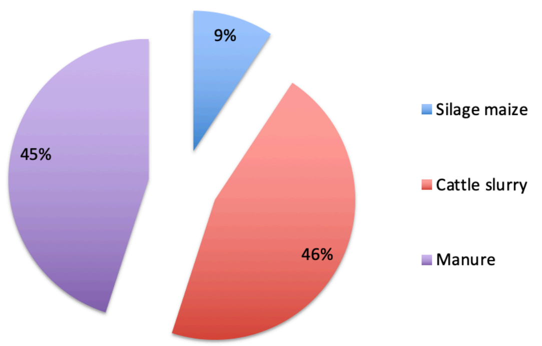

Figure 2: composition of feeding mix in biogas plant 2

Characterisation of input materials

In table 10 and 11 are reported the biochemical data of the feeding materials during the testing period.

Table 10: average value of chemical characterisation of the biomass fed in the digesters (data from 12 samples)

	pH			TS%			VS (%TS)		
Silage maize	3.45	±	0.22	31.8	±	2.12	96.6	±	1.7
cattle slurry	8.19	±	0.16	7.12	±	1.84	84.8	±	4.1
Solid fraction of cattle slurry	8.03	±	0.27	19.3	±	4.87	85.7	±	1.9
Manure	8.12	±	0.32	21.9	±	3.88	86.1	±	4.1

Table 11: average value of chemical characterisation of the biomass fed in the digesters (data from 12 samples)

	TKN (% w.w.)			NH_3 (mgL^{-1})			P (%)			BMP ($NlkgTS^{-1}$)		
Silage maize	0.49	±	0.04	119	±	46	0.07	±	0.02	659	±	64
Cattle slurry	0.36	±	0.03	1846	±	193	0.07	±	0.01	307	±	69
Solid fraction of cattle slurry	0.42	±	0.04	1455	±	294	0.08	±	0.02	335	±	28
Manure	0.44		0.05	1846	±	139	0.08	±	0.02	340	±	73

Plant Characterization of output materials: digestate

In table 13 are reported the chemical data of digestate

Table 12: digestate characterisation

Date	TS	TKN	N-NH_3	NH_3/TKN	P
	%	%	mgL^{-1}	%	%
10/18	9.0%	0.57%	3007	53%	0.57%
11/18	8.9%	0.56%	2815	50%	0.56%

12/18	8.9%	0.57%	3379	59%	0.57%
01/19	9.0%	0.57%	3345	59%	0.57%
02/19	8.8%	0.56%	3673	66%	0.56%
03/19	8.9%	0.57%	3661	65%	0.57%
04/19	8.9%	0.57%	3024	53%	0.57%
05/19	9.0%	0.57%	3289	57%	0.57%
06/19	8.9%	0.56%	3140	56%	0.56%
07/19	8.9%	0.57%	3144	55%	0.57%
08/19	8.9%	0.57%	3184	56%	0.57%
09/19	8.0%	0.58%	3395	58%	0.58%

Plant functioning data

In table 13 are reported some relevant data on the plant functioning, such as the amount of energy produced, the amount of energy used for running the plant (mixing and feeding) and the Hydraulic Retention Time (HRT), i.e. the average number of days that the feeding materials stay in the digesters.

Table 13: data from plant running: energy production, energy consumption, HRT.

Date	Produced energy	Consumed energy for running	HRT	Methane in biogas	H2S in biogas
	kWh/month	kWh/month	Days	%	ppm
baseline	732,193	38295	114	53	135
10/18	723,285	36,776	89	54	178
11/18	741,285	36,987	88	55	276
12/18	718,872	36,894	90	55	145
01/19	752,666	36,482	86	57	209
02/19	701,956	36,026	93	55	134
03/19	739,276	37,590	88	54	133
04/19	736,988	36,773	88	53	175
05/19	711,016	34,801	91	54	166
06/19	712,906	43,905	91	53	231
07/19	740,163	45,584	88	55	221
08/19	752,570	46,348	**87**	55	247
09/19	701,100	41,835	**78**	51	171

The biogas plant maintained the same average production (1Mw as target electric power capacity). About energy demand to run the plant, this year we can detect a sligty increase, that is consistent with the high level of maize substitution (higher amount of material to be mixed and pumped). The de-sulfuration system of the plant demonstrated to be able to keep H_2S level within a safe range in the biogas sent to the CHP unit.

Finally, HRT decreased of only 32%, but no adverse effects were detected in the digesters and in the biological parameters of samples.

Mass balance

In table 14 is reported the mass balance of the inputs and outputs of nutrients in the biogas plants.

Table 14: mass balance of nutrients and total solids load

Date	Feeding mix TS	TKN	P input	S input in the digester (from biomass)	Digestate TS produced in 1 month
	tons/month	tons/month	tons/month	tons/month	tons
10/18	604	17.17	2.76	0.086	257
11/18	614	17.26	2.77	0.085	258
12/18	598	16.92	2.72	0.084	253
01/19	629	17.87	2.87	0.090	267
02/19	579	16.14	2.59	0.078	242
03/19	614	17.33	2.78	0.085	259
04/19	613	17.30	2.78	0.086	259
05/19	596	17.05	2.74	0.086	255
06/19	591	16.58	2.66	0.082	249
07/19	617	17.44	2.80	0.087	261
08/19	624	17.60	2.82	0.086	**263**
09/19	604	17.09	2.75	0.085	189

Table 15: comparison of critical parameters, baseline VS trial (data at higher maize replacement)

	Baseline	test	Variation
Maize	1500	379	-75%
Feeding mix TS	495	624	26%
Digestate	2386	3696	55%
Digestate TS	190	393	108%
TKN	6.30	17.60	179%
P	0.90	2.75	205%
HRT	114	87	-24%

The mass balance provides some useful information:

The replacement of maize by slurry derived fraction achieved is almost 75%

The total input of solids increased of 26%

Digestate total solid doubled

Total nitrogen input increased almost 3 times the amount that is introduced without any slurry fractions, the same for phosphorus. This increase in nutrient input can be an advantage if there is the possibility to displace these nutrients where needed, i.e. outside the breeding district.

Economic evaluation

The substitution of maize has generated for biogas 1 and 2 this economics:

Table 16: economic data for plant 1

Average maize demand (baseline)	tons/years	18000
Saved maize	tons/month	580
Standard feeding cost in baseline maize	euros/month	67500
Money saved from maize	euros/month	26100
Money spent for slurrry transport, treatment and farmer reward	euros/month	13920
Total saving for biogas plant	euros/month	12180
Total saving for biogas plant respect to baseline	%	18%
Total money for farmers selling manure	euros/month	5220
Money for slurry treatment and trasport	euros/month	8700

Table 17: economic data for plant 2

Average maize demand (baseline)	tons/years	18000
Saved maize	tons/month	1121
Standard feeding cost in baseline maize	euros/month	67500
Money saved from maize	euros/month	50439
Money spent for slurrry transport, treatment and farmer reward	euros/month	26901
Total saving for biogas plant	euros/month	23538

Total saving for biogas plant respect to baseline	%	35%
Total money for farmers selling manure	euros/month	10088
Money for slurry treatment and trasport	euros/month	16813

By the point of view of technical evaluation, process parameter and production, the synthesis of relevant criteria to be taken into account is reported in table 18

Table 18: technical criteria to evaluate the use of slurry derived fraction in digesters

Parameter	Criteria for positive assessment	Biogas plant 1	Biogas plant 2
Energy demand increase	<5-7% of baseline	Not detectable	Not detectable due to
Stability of process	Yes	yes	yes
Increase in digestate volume	<30%	17%	40%
Increase in the amount of nitrogen	To be evaluated	Almost 2 fold increase	3 fold increase
Concentration of ammonia in digesters	< 3000 mg/l	<3000	Sometimes >3000
Stop of running due to maize substitution with slurry and manure-derived fraction	No	No	No
Savings compared with maize		18%	Almost 35%

The substitution of silage maize with slurry derived fractions in the two biogas plants was

Feasible by the point of view of the technical parameters in plant running (table 15)

Economically valuable for biogas plants and farmers, as the expenses for slurry treatment and transport allowed in any case significant savings for biogas plants and new income for farmers.