BIOH_2POWER WP1: BIOGAS SPECIFICATIONS AND CRITICAL ANALYSIS OF PRESENT SITUATION AND FUTURE PERSPECTIVE FOR BIOGAS PRODUCTION IN ITALY AND PIEMONTE

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SUMMARY: The objective of the Work Package 1 on the frame of the BioH_2Power project is to define biogas specifications, in terms of quantity and quality, to be used as a reference for desulphurizing/reforming processes, on the basis of the real on-field experience of a major Italian biogas-to-energy enterprise. Asja will carry on its involvement in the research project building upon its 10-years experience in the field of renewable energy generation from biogas. The technological know-how acquired since the beginning of its operation allows Asja to define the major critical factors in the treatment and use of biogas generated from anaerobic digestion of organic matter. Therefore, its role in the research program will be to provide effective knowing of the reality of biogas, on the basis of the plants Asja manages every day all over Italy and abroad. Then an identification of the potential sources of biogas will be provided in collaboration with Politecnico di Torino. DISMIC complements the work covering other biogas sources different from landfills.

1. INTRODUCTION

Biogas is a renewable biofuel that may have a significant impact on future energy scenarios. It may be both landfill gas or anaerobic digestion gas from organic fraction of MSW, agricultural waste, industrial waste water, sewage sludge, livestock effluents and energy crops.

Biogas is largely produced in Italy and actually the main part coming from Municipal Solid Waste landfills. Landfill was the main waste disposal in Italy and it will ensure biogas production for at least 20 years.

The actual Solid Waste Management Policy are increasing the amount of separated waste with a gradual reduction of landfill disposing. In this way the separated organic fraction of municipal wastes shall be treated in anaerobic digestors for the production of biogas. This amount may be increased by the use of livestock effluents and energy crops that may be cultivated in the hectares of agricultural land unused at the moment. Actually biogas is generally burned in endothermic engines in order to produce thermal and electric energy.

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The present work exposes the results of the activity carried out within the BioH_2Power feasibility study financing by Regione Piemonte. The main objective of the project lies in the feasibility study of a biogas-fuelled processing system for decentralized electricity and hydrogen production, comprising a power unit based on MCFCs (250 kW) and a hydrogen upgrading section specially tailored for a fuelling station capable of supplying about 20-100 H_2-vehicles per day. The role in the research program is to provide the effective knowing of the reality of biogas.

The objective is to identify some peculiar landfill biogas characteristics that can be considered as a reference in the planning and definition of treatment, desulphurization and utilization technologies. Then a critical analysis of present situation and future perspectives for biogas production in the Province of Torino is carried out in order to identify potential biogas sources of the greatest interest for the implementation of the investigated technology.

2. WASTE MANAGEMENT POLICY

In the last twenty years, source separation has greatly influenced the possibilities of energy production from biogas coming from wastes.

In the eighties MSW (and the assimilable ones) were simply landfilled and in this way some big biological reactors were created, capable of generating large amounts of biogas.

Unfortunately most of this biogas was lost because of faults in the management of landfills or exploitation plants inadequacy.

Table 1. Waste landfill and biogas collected at A.M.I.A.T. (Torino).

Year	*Waste landfilled [t/y]*	*Biogas generated [theoretical] [Nm3 /y]*	*Collection efficiency [%]*	*Biogas collected [Nm3/y]*
1984	341.477	-	-	-
1985	331.321	9.201.821	15,02	1.400.000
1986	356.477	16.477.043	17,00	2.800.000
1987	376.782	23.123.297	17,09	4.148.748
1988	600.536	29.122.845	18,00	5.248.748
1989	636.893	38.395.440	20,03	7.795.543
1990	655.536	47.892.664	20,09	9.995.543
1991	701.117	56.088.872	20,05	11.495.543
1992	650.444	63.585.125	20,00	12.695.543
1993	686.941	68.899.702	20,06	14.195.543
1994	795.582	73.553.126	20,02	14.885.620
1995	715.358	79.910.537	20,06	16.471.081
1996	792.695	83.261.433	22,01	18.437.815
1997	817.782	87.513.649	26,08	23.485.054
1998	759.203	90.924.131	27,06	25.079.948
1999	821.152	92.131.381	33,03	30.702.294
2000	913.637	95.758.072	44,06	42.739.300
2001	873.938	101.232.282	55,00	55.700.00
2002	927.399	104.640.097	56,01	61.800.000
2003	756.178	109.064.443	67,06	73.776.922
2004	699.906	108.587.840	82,04	89.451.792
2005	644.257	106.741.015	85,09	90.662.339
2006	587.865	104.801.442	84,68	88.748.995

Table 2. Source separation in Piemonte.

Year	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
Total tons	212.668	294.364	362.503	434.290	506.556	578.259	712000	808.726	903.671	1.002.394
Organic fr. and grass %	19,01	21,09	22,09	24,04	25,07	25,06	27,05	28,09	30,09	32,00
Paper %	39,05	38,07	40,05	37,08	37,00	37,01	35,05	34,06	33,06	32,09
Glass %	17,07	23,03	13,00	11,05	11,09	10,05	11,03	10,07	9,02	9,08
Metals %	3,03	4,02	4,06	5,02	5,00	4,05	3,06	3,01	2,07	2,06
Plastics %	4,05	4,03	4,01	4,02	4,08	5,05	5,09	5,08	4,04	5,03
Food %	6,02	6,01	6,01	5,08	6,06	6,06	8,02	9,00	9,00	8,07
Textiles %	1,06	1,05	1,03	1,01	0,09	0,07	0,06	0,06	0,07	0,06
Others %	8,01	0,00	7,05	9,00	8,01	9,04	7,04	7,03	8,05	8,00

Table 1 refers to the large landfill of A.M.I.A.T. in Torino. In 23 years of activity 15,5E+06 tons of wastes have been lanfilled and 6,5E+08 Nm^3 of biogas collected: more or less 44% of the amount produced according to reliables theories (1). This result originates from the low value of collection efficiency that never exceeded 21% in the first ten years of activity of the landfill and only in 2001 reached 50%.

In recent years collection efficiency had a steady growth till 85%, but since 2003 biogas production began to decrease under the effect of source separation.

In the nineties the best results were achieved with paper (39.5% of source separated wastes in Piemonte in 1998) and other slowly biodegradable materials such as wood (6.2%) and textiles (1.6%); besides, source separation intercepted no more than 15% of wastes and therefore its effect on landfill biogas generation was moderate.

In 2007 source separation in Piemonte has exceeded 45% of wastes and nearly one third is represented by fastly biodegradable materials (Table 2). In spite of the success of source separation of fastly biodegradable fractions, the production of biogas in anaerobic digestion plants is not significantly increased.

This is due to the choice, made some years ago, of directing organic materials to composting plants according to the philosophy of the return of the organic carbon to the soil. Actually the region (and particularly the province of Torino that with 2.266.724 inhabitants represents one half of the whole region) has several composting plants (partly new or lately revamped) that have an overall potentially suitable for the outcomes of source separation. So, the conditions to have significant amounts of fastly biodegradable materials to be destined to biogas production in digesters already exist, but a political revision of wastes management is needed.

3. LANDFILL BIOGAS

The landfill biogas production depends from amount and composition of wastes disposed. For at least 20 years the landfill biogas production can be ensured by wastes disposed. Moreover in many Italian areas, where separated collection haven’t yet reached high rates, landfill remain the main waste disposal. The potential biogas production capacity from municipal solid waste landfills over time will be evaluated as a function of waste typology and time of disposal.

Table 3. MSW total production and separate collection in Italy

	2002		*2003*		*2004*		*2005*		*2006*		*2007*	
	[kton]	*% SC*	*[kton]*	*% SC*	*[kton]*	*% SC*	*[kton]*	*% SC*	*[kton]*	*% SC*	*[kton]*	*% SC*
North	13.632	30,6	13.576	33,5	14.028	35,4	14.175	38,0	14.602	39,9	14.617	42,4
Center	6.594	14,6	6.496	17,0	6.941	18,3	7.230	19,2	7.364	20,0	7.352	20,8
South	9.637	6,3	9.872	6,8	10.181	8,1	10.258	8,8	10.557	10,2	10.579	11,6
Italy	29.864	19,2	29.944	21,1	31.150	22,7	31.664	24,2	32.523	25,8	32.548	27,5

Table 4. MSW disposed in landfill and number of plant in operation in Piemonte

	2002		2003		2004		2005		2006		2007	
	n	Q [t/a]	n	Q [t/a]	n	Q [t/a]	n	Q [t/a]	n	Q [t/a]	n	Q [t/a]
Torino	9	1.089.386	9	912.696	9	737.892	8	776.338	7	686.185	7	611.029
Vercelli	1	20.359	1	7.437	1	5.812	0	0	0	0	0	0
Novara	2	92.449	2	83.224	2	84.219	2	55.265	2	63.468	2	65.424
Cuneo	4	146.049	5	156.320	4	151.378	5	138.078	4	121.581	4	117.923
Asti	1	593	2	639	2	42.162	2	34.228	1	44.475	1	38.356
Alessandria	3	135.261	4	126.980	4	153.567	4	172.357	4	171.813	4	131.908
Biella	1	64.805	2	23.051	1	72.943	1	67.826	1	69.364	1	64.468
Verbania	1	13.332	1	13.420	1	11.649	0	0	0	0	0	0
Piedmont	22	1.562.234	26	1.323.767	24	1.259.623	22	1.244.092	19	1.156.886	19	1.029.108

3.1 Municipal Solid Waste production

Municipal solid waste are the main source of biogas production. The total production of wastes and the rate of separated collection are evaluated in this section on the basis of the data published by ISPRA (Rapporto Rifiuti 2008). The total production and separated collection from 2002-2007 for Italian areas is rappresented in Table 3.

During 2007, 52% of the MSW produced, equivalent to 16.912.000 ton, were disposed in landfills. Lombardia was the Region with the lowest recourse to landfill, with 10%, thanks to the high recourse to incineration. Puglia, Molise and Sicilia with more than 90% of waste disposed were the regions with the higher percentage of wastes disposed on landfills. From 2002 to date the number of landfills in operation were reduced of 175 units, from 552 to the 229 of 2007. But in South Italy landfills remain in any case the main and unique way of waste management.

The actual situation of the Province of Torino was analyzed in detail in order to estimate the future landfills biogas production. In Table 4 are reported the amount of wastes disposed in the last years and the number of landfills in operation in Piemonte. Province of Torino produced more than 50% of the total regional wastes.

3.2 Biogas production model

Biogas production from MSW in landfills over several years is function of different parameters that can influence the kinetic of the anaerobic degradation reaction. Composition of waste, temperature, humidity, disposal, covering materials are only some of the numerous elements that influence the kinetic of biogas production. In a number of countries, landfill operators are required to estimate and report their fugitive methane emissions. Methane is a greenhouse gas with a higher GWP then CO_2, so national lows force operators to burn it in torch or power station. Therefore some countries have developed their own models for the estimation of the fugitive methane.

Different biogas models were developed and implemented to foresee the quantity of biogas giving also an important support to engineers for the dimensioning of plants fed by biogas for the cogeneration of thermal and electric energy.

The models evaluated in this work were selected on the basis of the experiences of Asja in the planning of biogas power plants and a bibliographic research of the most recent development in this field:

- asja model: the method utilized by Asja for biogas plant dimensioning;
- UNFCC tool: a no national model described in the IPCC guideline;
- andreottola-Cossu: developed at the Università di Torino;
- GasSim: a free software utilized for the official method in UK;
- LandGem: software adopted for the US EPA method;
- ADEME: the official method in France.

Generally all the models analyzed are based on a first order decay model. Every kind of model use different default parameters that often derived from empirical analysis, typical of local environmental conditions or waste compositions. The principal parameter considered are:

- organic carbon content;
- organic carbon productivity (Lo);
- kinetic of degradation of the organic fraction;
- humidity;
- time of degradation ($t_{1/2}=ln_2/K$ for first order kinetics);
- initial lag time.

The Asja model calculates the annual biogas production on the basis of the amount of waste disposed in landfill in the previous years. Basic hypothesis is that the waste doesn't produce biogas during the first year. Practically the volume of biogas produced is calculated by the sum of the annual productions of biogas, as the product of the amount of waste yearly disposed and a coefficient (function of the waste composition and the year of disposing):

$$P_t = \sum_{j=1}^{t} ptot(t-j) * q(j)$$

$$ptot(t) = \sum_{i=1}^{5} pi = 1{,}868 \sum_{i=1}^{5} Cp_i \times k_i \times e^{-k_i(t-1)}$$

where P_t is the total volume of biogas produced at the year t; *q(t)* is the quantity of waste disposed in landfill at the year t; *t* is the year from the aperture of the landfill in which the production of biogas is calculated; *ptot* is the coefficient of specific production of the waste.

ptot is calculated by the sum of the productivity of five different fractions of the waste. In the Asja model, refered to the typical Italian waste composition, the coefficient are 1^{st} year = 4, 2^{nd} year=12, 3^{rd} = 16,2, 4^{th} =16, 5^{th} =14, ecc.

The other models use a similar approach in the calculation of the biogas production but they start from different hypothesis or use different coefficients calculated in different ways.

Other parameter could also be taken in account, like the type of covertures and the rain infiltration.

3.3 Landfill biogas production

The biogas production was calculated with the Asja model starting from the input data of the MSW disposed on landfill. The amount of savage sludge and Special Wastes assimilated to MSW were also calculated. Moreover, on the basis of the authorized volumes, also the wastes that will be disposed up to the year of closure was considered in the prediction. The amount of biogas producted is refered to the wastes disposed from 2002 up to the espected year of closure.

The landfills considered in this study are that of the Province of Torino:

- AMIAT, Torino
- CIDIU, Pianezza
- SIA Grosso C.se
- ACEA Pinerolo
- CCS Cambiano
- ARFORMA Mattie
- ASA CAstellamonte

The amount of biogas per year productеded in these landfills from the wastes disposed from 2002 to the year of predicted closure is rappresentedin Figure 1 and 2.

3.4 Biogas characterization

The biogas specifications have been defined on the basis of the real on-field experience of Asja, one of the major Italian landfill-gas-to-energy enterprises. Asja has more than 10 years experience in the field of renewable energy from biogas.

Starting from the analysis periodically conducted on the plants that Asja manages all over Italy, the reality of biogas composition was assessed. All chemical-physical gas analysis have been conducted by the laboratory *Programma Ambiente s.r.l.* on samples of biogas collected in all the different landfills where gas capturing and exploitation system is managed by Asja.

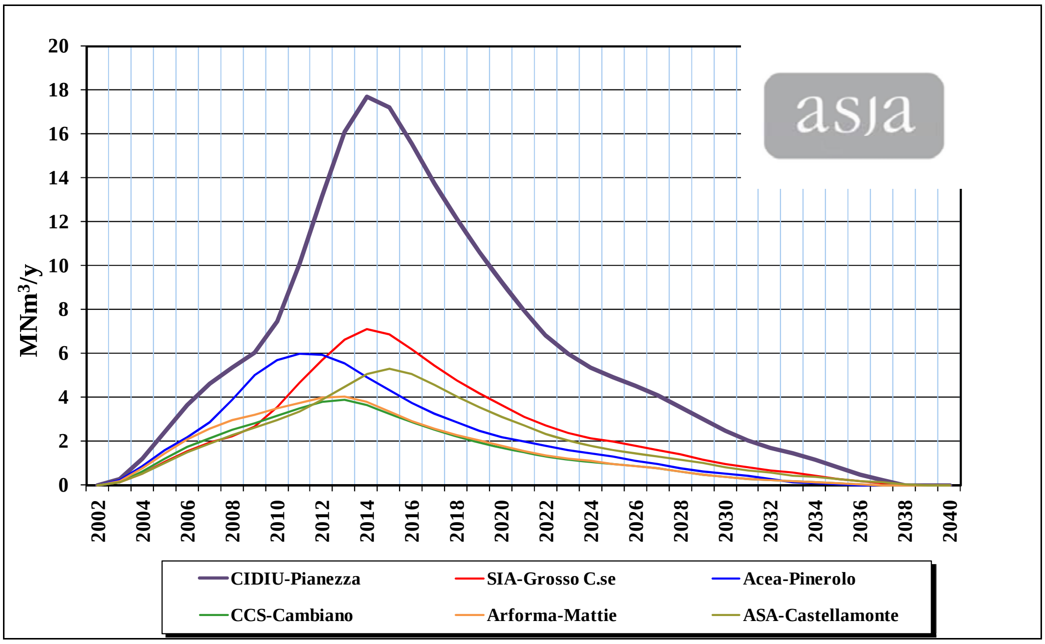


Figure 1. Biogas production by landfills of the Province of Torino

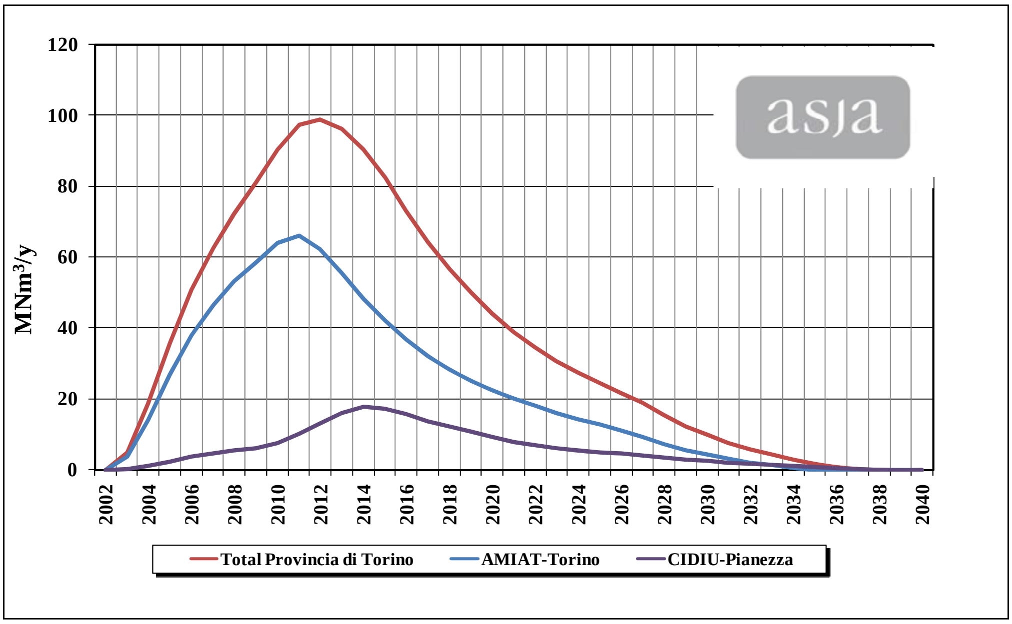


Figure 2. Total landfill biogas production in the province of Torino

Analysis on biogas composition are usually performed every year and in some cases every six months. The landfill gas at the sites where Asja manages the capture system is collected and burned in engines for the production of electric energy. At all sites where analysis are performed, the point of sampling is at the inlet of the power generating sets. Before this point, the biogas has passed through a first section of purification, constituted as follows:

- a primary coalescer where a first separation of the condensate takes place;
- a cooling system which brings gas temperature down to approximately 0-4°C;
- a secondary condensate separator;
- a dry filter to roughly remove residual solids.

After these treatments, biogas at a lower temperature and purified from macroscopic pollutants (like particles and humidity) passes through the blower(s) and is conveyed to the power generating sets.

A statistic elaboration was conducted on biogas composition data from some selected landfills in Italy where the gas collection system is managed by Asja.

As socio-geographical differences can often cause different waste composition and different biogas specifications, in order to have a standard as homogenous as possible and characteristic of the Piemonte reality, we considered the biogas characteristics from all available Piemonte landfills and from one more close-by:

- Pianezza (TO) – 2007 average flow: 1041 m^3/h,
- Sommariva (CN) – 2007 average flow: 571 m^3/h,
- Mattie (TO) – 2007 average flow: 290 m^3/h,
- Gambolò (PV) – 2007 average flow: 534 m^3/h.

A couple more sites have been taken in consideration as well, because of their particular significancy given by the typical features of large dimension projects and critical concentration of polluting substances:

- Montescarpino (GE) – 2007 average flow: 2579 m^3/h,
- Bellolampo (PA) – 2007 average flow: 2337 m^3/h.

A “typical” landfill gas composition, after capturing and rough pollutant abatement systems, can be defined as in Tables 5 and 6.

Table 5. Typical landfill gas composition as resulting from the analysis.

	CH_4	*CO_2*	*O_2*	*N_2*	*H_2O*	*Siloxanes*	*S*	*Halogens*
Typical	49 %vol	36 %vol	1.5 %vol	12.5 %vol	1 %vol	0.2 mg/Nm^3	155 mg/Nm	18 mg/Nm^3
Max	60.5 %vol	44.3 %vol	3.3 %vol	26.6 %vol	3.7 %vol	1 mg/Nm^3	350 mg/Nm	50 mg/Nm^3

Table 6. Typical landfill gas composition of traces compounds as resulting from the analysis.

	H2S	*Mercaptans*	*H2SO4*	*SO2*	*HF*	*HCl*	*NH3*
Typical	103 ppm	2.4 ppm	1.9 ppm	4 ppm	0.8 ppm	2.2 ppm	15 ppm
Max	215 ppm	27.7 ppm	51.5 ppm	54 ppm	4.4 ppm	16.7 ppm	64 ppm

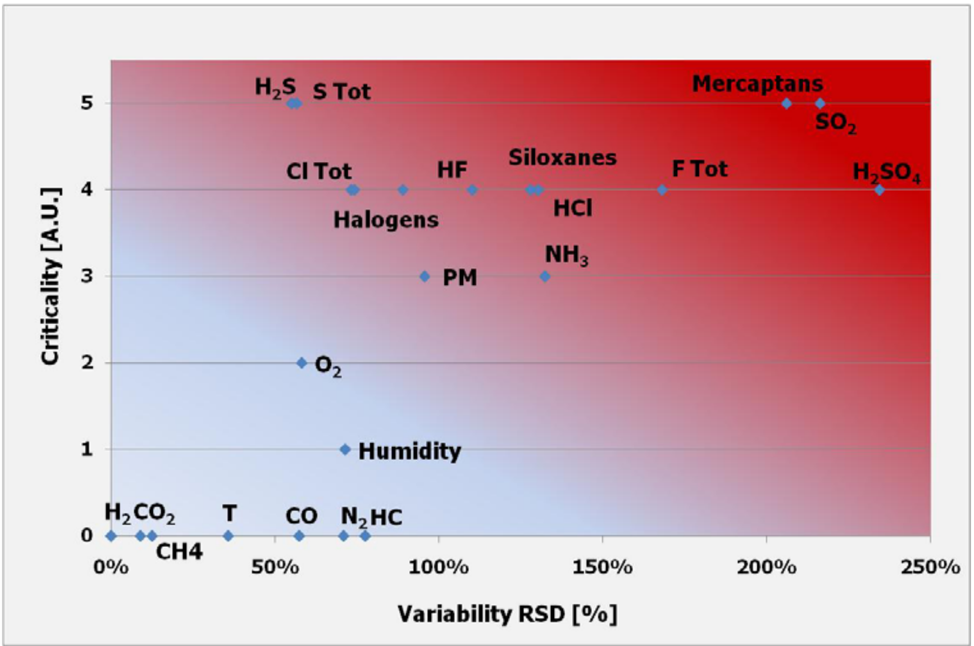


Figure 3. Criticality vs. variability of the biogas pollutants characteristics

For each substance or compound or physical characteristic resulting from biogas analysis, we tried to relate the variability found in the real analyzed cases with its criticality for the BioH_2Power system, set in a scale from 0 to 5 where 5 is associated to the most dangerous compounds and 0 to the innocuous parameters (Fig. 3).

The criteria for the assignment of the values of criticality to the analyzed parameters was based on the *Max Value/Admitted level* ratio. This coefficient was calculated through the relation between the max values measured on field and the admitted level, derived from reformer, MCFC or any other equipment requirements, on the basis of Ansaldo experience.

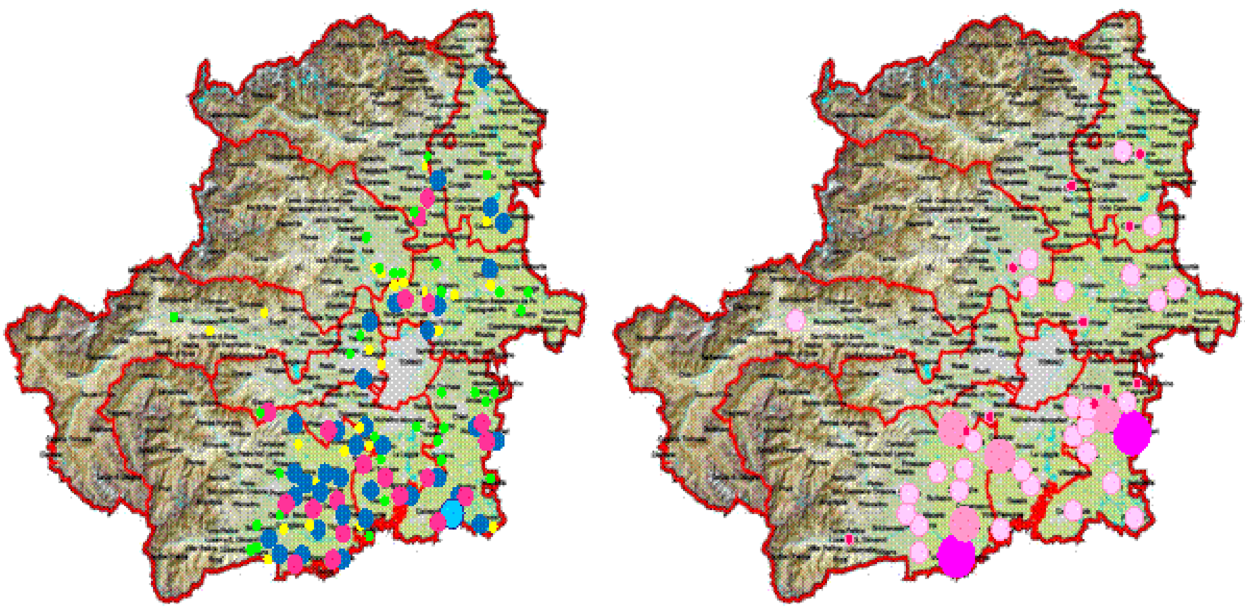
The evolution of any parameter in landfill gas characteristics can be evaluated along the years of life of the landfill and the age of disposed wastes. A variation in the composition of the biogas was estimated on the basis of the analysis of some of the more long-lasting landfills considered in this study, (in this case Gambolò (PV), Pianezza (TO) and Bellolampo (PA)). The concentration of the major pollutants does not appear particularly influenced during the landfill lifetime. A very high variability characterizes the concentration of these compounds and we can't assert that a univocal tendency or clear trend could be observed. As expected, the methane percentage in landfill gas decreases during the life of the landfill. This aspect can be surely correlated with the age of wastes, that is with the historical disposals of wastes along years and in particular with the closure year of the landfill site.

4. ANAEROBIC DIGESTION

The total production of biogas in the Province of Torino could be integrated with the utilization of livestock effluents, agricultural wastes and energy crops in anaerobic digestion plants. Cattle and swine manure are the more significant effluents at a local level. In Figure 6 are rappresented the farming in the province of Torino. Grounding on Figure 6 the major production of livestoks effluents is concentrated in the south-east area of the province (12-ACEA, 14-COVAR, 13-CCS). In these areas of country there are the bigger livestock breedings.

The hypotetic total production of biogas from the digestion of these effluents was than calculated. The tatal quantity of biogas results in 119.965.822 Nm^3/anno. In this production the percentage attributable to cattle manure is 92%. Moreover the production from poultry farm effluents was considered negligible for the province of Torino.

Very interesting results also the possibility of integrate this production of biogas with the anaerobic digestion of agricultural products. Particular interest is actually address to “energy crops” that is specific coltures producted to be converted in energy. In the province territory the more practicable energy coltures are silomaize, sorghum, rye and grass. These productions can be interesting, considering that actually 20.227 hectares of land is unused. Silomaize is the more efficient colture for biogas production. One ton of silomaize produces 225 Nm^3 of biogas. The whole unsed area could produce annually 340,653,600 Nm^3 of biogas derived from the anaerobic digestion of 1,520,775 ton of vegetable materials.



a) b)

Figure 6. Cattle (a-• 5000<heads<10000, •1000<heads<5000, • 500<heads<1000, •dairy cow 1000<head<5000, • dairy cow 500<capi<1000) and swine(b-•10000<head<30000, •5000<head<10000, •1000<capi<5000, •capi<1000) breedings in the province of Torino.

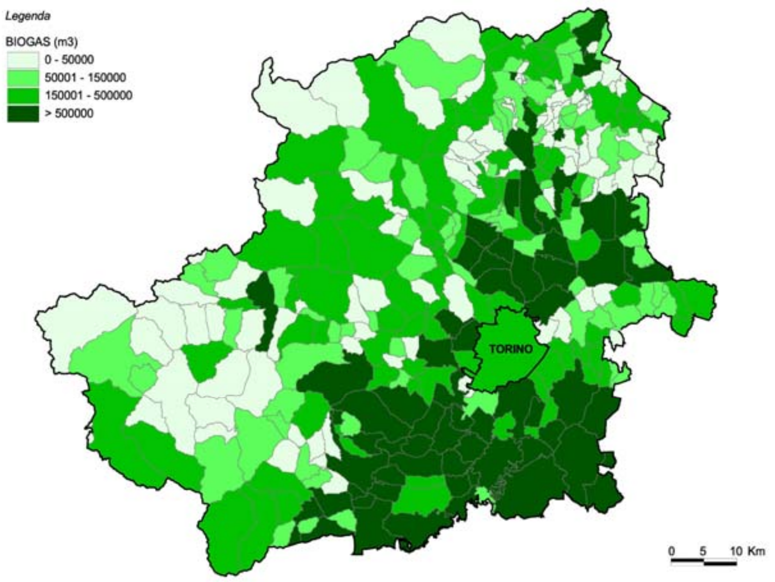


Figure 7. Biogas production from livestock effluents and energy crops in the province of Torino.

Starting from the exposed considerations, in Figure 7 the total biogas production from livestock effluents and energy crops is rappresented. The most interesting areas for the realization of anaerobic digestion plants is located at south and north areas of the province. In a correct pianification, the realization of one or more plants in these areas, collecting the effluents, could be profitable.

5. CONCLUSIONS

An investigation of the peculiar biogas characteristics was conducted upon the experience of Asja in the production of energy from landfill biogas. A set of historical data collected in landfill managed by Asja was analyzed in order to achieve the typical composition of biogas with particular attention to the main pollutants identified as dangerous for the BioH_2power system.
The total landfill gas available for the implementation of the technology in the province of Torino was estimated basing on the production models and the management policy of wastes. Other sources of biogas was finally evaluated with attention to livestock effluents and enrgy crops.

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