Generating Electrical Energy from Landfill Gas: an Italian Experience

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Abstract *- The present paper describes an electrical energy generation system that uses the methane gas produced by the biological processes at a controlled landfill as a source of primary energy; this installation is situated in Cà Asprete, in the municipality of Tavullia (Pesaro-Urbino), Italy, approximately 10 km from the town of Pesaro. The plant was officially opened in December 1998. The analysis of the plant begins with a brief description of the systems for extracting the biogas from the body of the landfill and for treating the biogas, and of the electromechanical equipment used to convert said fuel into electrical energy, concluding with the automated system for managing the plant. From the functional standpoint, the biogas plant was analyzed in its three main sections:*

- *biogas collection-aspiration;*
- *treatment and analysis;*
- *conversion into electrical energy.*

The biogas collected is used to fuel two internal combustion engines coupled to two electrical generators, but before it is used at the power plant it is analyzed and treated to improve its quality and consequent energy efficiency.

Keywords - **Renewable energy, Landfill gas, Electrical energy.**

1. INTRODUCTION

Experience in Italy has demonstrated that a ton of urban solid waste contains roughly 200-250 kilos of biologically degradable organic material. In strictly anaerobic conditions, the bacterial degradation of said organic material takes place in four stages, giving rise to the production of landfill gas. Numerous variables affect landfill gas generation and to such a degree that every landfill has a qualitatively and quantitatively different biogas output, depending on the composition of the waste, the humidity it contains, how firmly it is compacted, the covering on the surface area of the landfill exposed to the outside air, and so on - all conditions which influence the ambient conditions in which the bacteria that produce the methane gas proliferate and take effect.

Figure 1 illustrates the composition of the landfill gas in the four chronological stages, clearly showing that a landfill is ripe for the purpose of producing biogas suitable for use as energy after a couple of years and it stops producing said gas after about 15 years.

In the first stage, the material buried at the landfill still contains enough oxygen to enable aerobic biodegradation. Within about three weeks, however, this oxygen is gradually removed in the form of carbon dioxide and, as the oxygen supply fails, the second stage of "acid fermentation" begins.

Said second stage lasts for about the next 60-70 days and consists in the decomposition of substances such as cellulose, proteins and fats into substrates suitable for further biodegradation, finally giving rise to the production of short-chain fatty acids, carbon dioxide and hydrogen. The latter two elements are produced mainly during this stage. The methane-producing bacteria begin to function towards the end of this stage, i.e. once all the oxygen has disappeared.

The third stage lasts 2-3 years and coincides with a process of unstable anaerobic fermentation that features a constant increase in the production of methane and a constant reduction in the carbon dioxide up until the beginning of the fourth stage, which is again anaerobic and is the period during which the landfill produces a constant quantity of methane; depending on the previously-mentioned variables, this period can last for as long as 20-25 years.

2. FEATURES OF THE LANDFILL IN CA'ASPRETE

The controlled landfill where the biogas-fired electrical energy generation system is installed in Cà Asprete occupies a suitable site with a low level of human occupation in the hills about 10 km outside Pesaro (Italy) Fig. 2. This landfill is defined as a category I waste disposal site, in that it is for disposing of urban solid waste, comparable special wastes and biological mud coming from the town's waste water treatment plant. The plant was opened in July 1992 and covers an area of 200,000 m², 120,000 of which will progressively be occupied for the actual burial of waste, while the remaining 80,000 m² are occupied by the generation plant, the offices and the surrounding areas of park.

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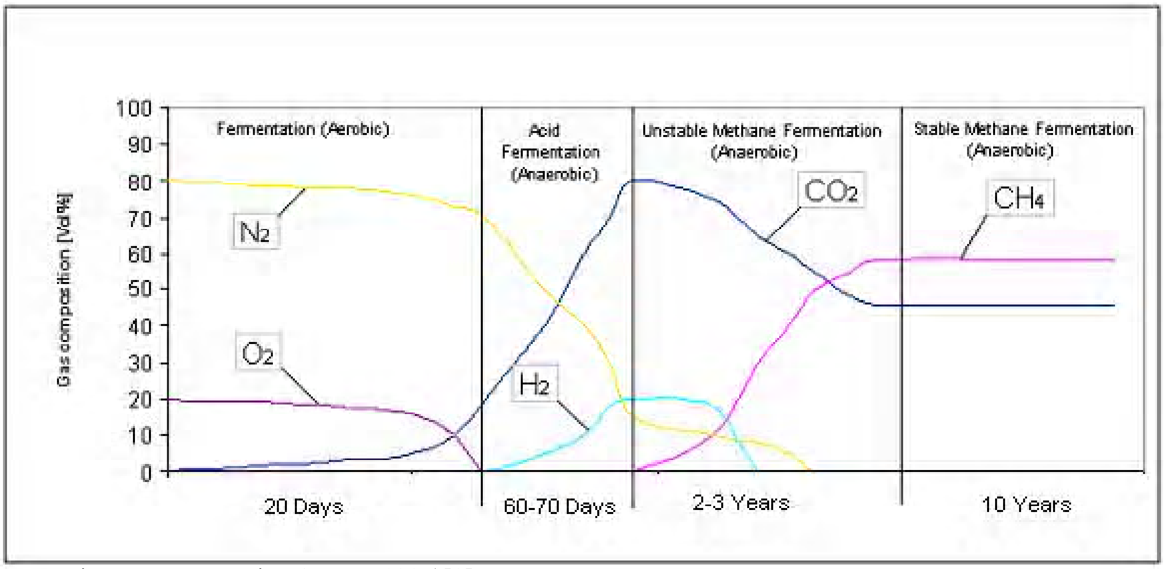

(Source: Environment Protection Agency 1997)[8]

Fig. 1. Composition of the landfill gas in the four chronological stages.

Fig. 2. Geographical location of the town of Pesaro (Italy).

3. LANDFILL MANAGEMENT

The landfill is managed by the local public utility company, ASPES Multiservizi SpA, which has approximately 350 employees and, in addition to collecting and disposing of municipal waste, it also manages the gas, water, waste water, public park and public lighting services.

4. GENERAL FEATURES OF THE BIOGAS PLANT

The plant for generating electrical energy from biogas was in December 1998. Aspes decided on the investment after establishing that the estimated biogas output would be sufficient to enable it to be exploited for energy generation purposes. This decision was also supported by resolutions passed in the early Nineties as part of the Italian national energy plan on the development of renewable energy sources.

Figure 3 shows the main electromechanical equipment installed in the technological area where the gas collected from the wells is fed to the electric generator set. It is worth noting that the gas collection piping existed already, before the electrical energy generation plant had been conceived, because the biogas produced by the landfill had to be disposed of by flaring. Said piping was nonetheless the object of major changes and additions to meet the needs of the new system for exploiting the landfill gas [1], [2].

The biogas is used to fuel two internal combustion engines coupled to two electrical generators: the equipment and machinery were chosen on the assumption of an average biogas flow rate from the landfill of approximately 400 Nm^3 /h, an operating time index around 0.80 (7000 h/year) and a mean heating capacity of the gas mixture assumed from the mean percentages of methane it is predicted to contain (roughly 18840 KJ/Nm^3 53% CH_4).

For the landfill in Cà Asprete, the forecasts for a period of 30 years gave rise to the values for the specific annual and hourly output of biogas shown in Table 1, the quantity of biogas that would actually be collected was also calculated, assuming a collection efficiency of 70% with the plant in operation for 7000 hours/year, as specified at the design stage. The graph below (Fig. 4) confirms the typical trend of the gas production curves.

Table 1. Forecast of production of biogas and utilization of the biogas (2006 estimated)

Year	Production Biogas (Nm^3/h)	Utilization Biogas (Nm^3/h)
1999	823	375
2000	914	305
2001	979	377
2002	1045	350
2003	1136	395
2004	1189	425
2005	1243	452
2006	1305	442

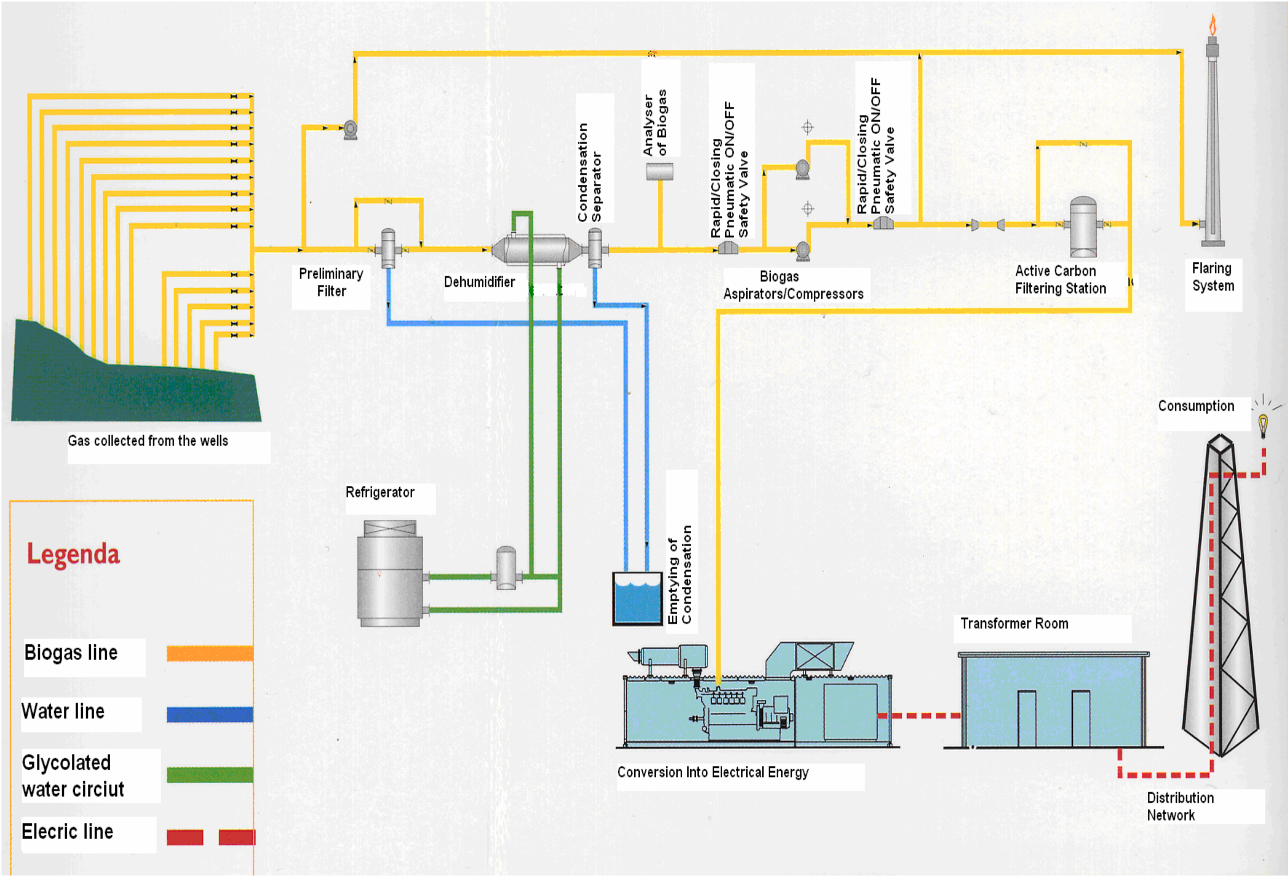

Fig. 3. The main electromechanical equipment installed in the technological area.

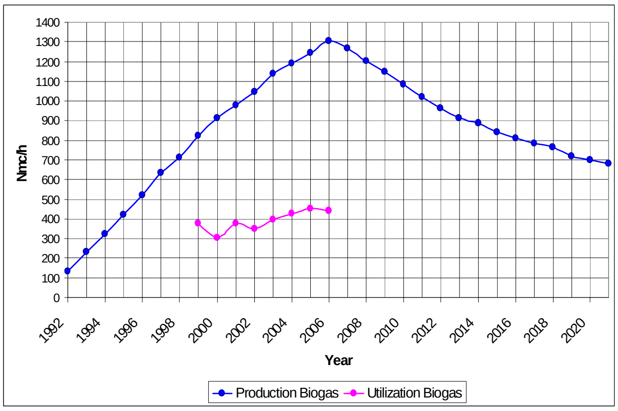

Fig. 4. The typical trend of the gas production curves.

5. THE GAS COLLECTION SYSTEM

The system for collecting the gas had to assure a constant flow of the biogas produced by the landfill to the internal combustion engines, also allowing for it to be adjusted to improve the energy characteristics of the final mixture. The path covered by the biogas starts at the vertical wells (be they built during the waste embankment works or drilled at a later date). The gas then flows through horizontal piping to an intermediate manifold which combines the biogas coming from a given landfill lot. From here, another pipe leads to the technological treatment area, pouring the gas into a general aspiration manifold where the biogas coming from the various lots is mixed before it is treated, analyzed and used for energy generation.

The biogas at the landfill in Cą Asprete is currently extracted through 50 wells distributed more or less uniformly over six embankment lots, spaced out on the assumption that each well can collect the gas produced within a radius of approximately 25 m. The layout of the aspiration pipes forming the collection network was assessed in the light of the general layout of each lot (gradient, difference in elevation, roads, arrangement of wells, and so on) and the distance between the wells and the intermediate aspiration manifolds, called stations.

There are two alternative types of biogas collection and transport system, i.e.

- passive aspiration, when the biogas emerges spontaneously due to the positive pressure created in the well due to the ongoing production of gas;
- active aspiration, which involves a forced uptake of the biogas obtained by creating a slightly negative pressure, thus preventing any hazardous emissions into the atmosphere and facilitating the energy recovery.

An active aspiration solution was chosen for the system described here, which uses an aspirator/compressor for each engine. The negative pressure used to aspirate the gas must always be correctly adjusted: the wells normally function with negative pressures of a few mbar; the intermediate stations require negative pressures around 40-60 mbar and the aspiration manifold has a negative pressure created by the two aspirators/compressors of 60-90 mbar. The pressure drop occurring between the aspirators/compressors and the wells is due to linear load losses in the piping, and to the concentrated load losses at the connectors and regulator valves.

6. BIOGAS TREATMENT SYSTEM

The biogas collected from the body of the landfill undergoes a pretreatment to eliminate the substances that can cause damage to, and/or interfere with the aspiration and electrical energy generating equipment. This pretreatment ensures the function efficiency of the waste disposal system and optimizes the energy recovery. It consists of the following components:[4] Fig. 5.

- a preliminary filter;
- rapid-closing pneumatic on/off safety valves;
- a compressed air generator;
- a dehumidifier;
- a refrigerator;
- a condensation separator;
- biogas aspirators/compressors;
- an active carbon filtering station;
- a flaring system.

A brief description of these components is provided below.

Fig. 5. Photo of the technological Area.

Preliminary filter

The first treatment for the biogas is provided by the preliminary filter, which eliminates any particles entrained by the mass of gas. It consists of a stainless steel filter element with a 1000 micron mesh and a filtering surface area of 10000cm^2.

Dehumidifier

The system for drying the biogas to send to the internal combustion engines basically consists of a tube nest heat exchanger connected, via a closed glycolated water circuit, to a refrigerating and air condensing system situated outside the hazardous zone. This dehumidifying treatment is essential to separate the water content from the biogas and, at the same time, it also separates any sulphurous components (the corrosive action of which, even in trace quantities, can have devastating effects on the equipment used to burn the biogas).

Biogas aspirators/compressors

The biogas is aspirated and subsequently compressed to the required pressure by suitable centrifugal multi-impeller equipment situated downstream from the condensation trap. The aspiration/compression work done by the blowers is governed by the computerized control system, based on the inputs it receives from the sensors monitoring the percentage of methane in the gas mixture and its delivery pressure to the internal combustion engines. As for the mechanical features of the impellers, they have a rated capacity of approximately 350 m^3/h and a biogas pressure on the delivery side of around 110 mbar so that, after adding the accidental and line load losses, there is a feed pressure at the engine's inlet of approximately 80 mbar. When there is a pressure drop at the engine's inlet, the system adjusts the turning rate of the blowers with the aid of a frequency converter.

Active Carbon Filter

The final treatment for the biogas is a process of absorption on active carbon in order to ensure the abatement of harmful substances in the biogas, such as siloxanes that - at the temperatures and pressures encountered in the combustion chamber - lead to silica (SiO_2) deposits, particularly around the discharge valve seats, the cylinder heads, spark plugs and discharge manifolds, giving rise to a markedly greater need to service the engine assembly and reducing its useful working life.

Flaring System

As specified by current legislation, it is still essential to be able to collect the gas from the landfill and burn it with a flare - in the event of an excessive production of biogas (which has never occurred to date), or if the electrical energy generation system is out of commission for ordinary or extraordinary maintenance, or due to an alarm condition - in order to avoid the potential hazards deriving from the production of biogas that cannot be used.

7. BIOGAS ANALYSIS

Before it can be used at the electric power generating plant, the gas is analyzed and treated to improve its quality and consequent energy efficiency. A system monitors and analyzes the aspirated biogas to ensure that it is being drawn off properly from the landfill. To be more precise, this procedure involves checking the fundamental characteristic parameters, e.g. CH_4 and O_2; analyzing these values enables the fine adjustment of the regulator valve to ensure optimal plant management. The information sent from the analyzer to the computerized control system is particularly significant because it enables a check on the quality of the biogas so that action can be taken on certain items of equipment for the dual purpose of:

- maintaining a high level of efficiency (e.g. by adjusting the blowers to ensure that the biogas flow maintains an adequate energy content),
- avoiding hazardous situations, e.g. by operating the on/off valve at the biogas treatment system inlet should any explosive mixtures develop).

8. INTERNAL COMBUSTION ENGINES

The assembly comprises two internal combustion engines coupled to two generators capable of delivering a useful electric power corresponding to approximately 1MW, operating for about 7000 h/year. The plant also includes equipment capable of running with a minimum biogas lower heat value (LHV) of 14232 KJ/Nm^3 and a load partialization up to 30% of the maximum power. The units are located inside two soundproofed containers, which also contain the total electronic management (TEM) system and the related control, regulation and safety switchgear. Another two containers alongside house the data acquisition and plant control computer with the related switchboards, the transformer station, the MV grid connection room for transferring the energy onto the public grid, and all the electric equipment for the utilities at the whole plant.[6]

Technical Features

The internal combustion engines are of the water-cooled, supercharged Otto cycle type suitable for operation with landfill gas, while the generators are of the self-excited synchronous three-phase type.[7]

The minimum technical features are as follows:

- mechanical engine power: 485 kW
- electrical power at the alternator terminals: 469 kW
- thermal power delivered to the engine: 1282 kW
- nominal power factor: 0.8
- rated three-phase voltage: 400 V
- rated frequency: 50 Hz
- turning speed: 1500 r.p.m.
- working cycle: 4-stroke Otto
- electrical efficiency: 36.6% at 100% of load approx. 32% at 50% of load
- starter system: electric
- refrigerant fluid: water
- specific biogas consumption: approx. 245 Nm^3/h; constant from 75% to 100% of load
- lubrication: forced
- general engine overhaul:approx. 50,000 h

The internal combustion engine powered with the biogas was chosen in the V-12 cylinder version (at an angle of 60°) with a four-stage lean-mix combustion system, complete with exhaust gas supercharging and mix cooling. The engine is not used to its full potential: it is currently set to operate at 60-80% of its capacity, depending on the conditions of the biogas collected. This fixed value is maintained by the TEM, which monitors and manages all the engine parameters.

Container for Housing the Engine and Fire Fighting System

The generator sets are housed in two soundproofed and forced-air ventilated containers (size 9125 x 2435 x 2585 mm), which also contain the electric switchgear for their management and control. The fan-assisted ventilation is needed to guarantee a maximum ambient temperature compatible with the requirements for operation specified by the manufacturers of the equipment installed, and in any case no higher than 40°C. The soundproofing assures a residual noise level no higher than 60 dB(A) 7 m away from the container, thanks also to the silencers on the outside air intakes and air extractor outlets.

9. GENERATORS

The generators are coupled directly to the engines by means of a joint, and are of the self-excited and self-regulated, three-phase synchronous type with a horizontal axis and no brushes or rings on the excitation circuit. The technical data relating to each of the generators are as follows:

- active power: 0.5 MW
- output voltage: 400 V
- sense of rotation: clockwise (as seen from the coupling side)
- nominal power factor (cos Φ): 0.8
- number of poles: p= 4
- frequency: f = 50 Hz
- turning speed: n = 1500 r.p.m.

The electric line from the plant station is connected to a transformer that interfaces the LV generation system with the MV grid distribution system, raising the voltage from 400 to 20,000 V. The transformer is accompanied by a 30 kVAR 400V power factor corrector; according to the Italian Electricity Board's specifications, the mean monthly power factor at the delivery point must be around 0.9.

10. ELECTRONIC ENGINE CONTROL

The TEM system is designed to manage and electronically adjust the gas combustion process as well as governing the engine-generator assembly, and it can also be used to control auxiliary systems such as the cooling circuit.

The system continuously runs diagnostic procedures, monitoring the electronic circuits and testing the plausibility of the measurement signals recorded at each computer cycle. The processed signals come from analog and digital sensors on the engine and the system's peripheral equipment, enabling an in-depth monitoring of the status of the main components. The section consists of a modular control with a programmable memory and a controller computer that uses the signals it receives to implement all the operating and safety functions of the assembly, i.e.

- automated unit starting and stopping;
- controlling and adjusting of the power demand;
- adjusting the combustion and engine emission;
- saving the measurement data.

The TEM can report any anomalies occurring during plant operation and trigger a generator cutout and engine stoppage in particular circumstances, e.g. when the oil pressure is too low or the engine cooling water temperature is too high, in the event of a cooling circuit malfunction or a low gas delivery pressure.

11. ECONOMIC ASSESSMENT OF THE SYSTEM

The costs of investment per kW_e power installed for the entire landfill gas recovery and utilization system of the plant of Cà Asprete –Pesaro- (Italy) are summarized in the Table 2.

The productivity of electrical energy generation systems powered by renewable energy sources cannot compare with that of a traditional fossil fuel combustion system. In a situation characterized by relatively low running costs but sizable initial investment costs, this type of system benefits from special concessions established by Italian law.

The results achieved so far by Aspes have been more than satisfactory: based on the selling prices agreed with the Electricity Board for the financial years up to December 2006 (when the special rates agreement expires), it will take just three years for the proceeds to cover the investment costs, which is an excellent result. Figure 6 shows the trend of the electrical energy production over the years; note that the second generator went into operation in November 2001 and that the trend is not constant due to variations in the conditions of the biogas collected and to machine stoppages for ordinary and extraordinary maintenance work.

Table 2. Investment costs for landfill gas plant in Euro per kW_e power installed.

Component	Cost in : Euro/kW_e (1)
Suction system	200
Collection system	250
Utilization system	800
Planning & Design	200
Total:	1450

(1): 1 Euro = 1.250 US$

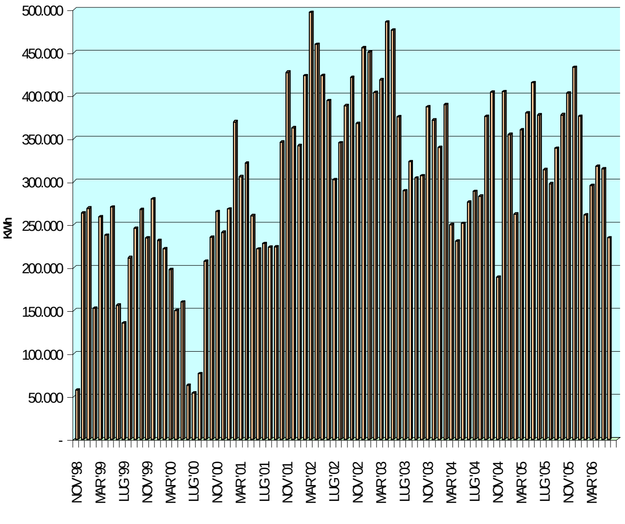

Fig. 6. The trend of the electrical energy production over the years. (from Nov. 1998 to Jun. 2006).

12. CONCLUSION

The experience gained by ASPES in the last seven years at the landfill in Cà Asprete (Pesaro) confirms that collecting and using the biogas deriving from the natural biological processes taking place in an urban solid waste landfill to generate energy represents a valid way to exploit a “waste” renewable energy source. Applying this method to the numerous landfills dotted all over the country, that are now just smelly sources of land and air pollution, can profitably contribute towards alleviating (albeit to a minimal degree) the emergency represented by Italy’s energy bill, while attenuating the environmental impact of the greenhouse gases generated by landfills at the same time.

The above-mentioned experience shows as the revenue from landfill gas recovery is significantly dependent on the type of energy produced. To make landfill gas recovery feasible without state subsidies the produced electricity in Italy should be sold at a price of some 0.090 Euro/kWh_e (0.108 US$/$kWh_e$) or higher.

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