Waste landfilling in Europe

Energy recovery and GHG mitigation

Sustainable Landfill Foundation

Report

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1. Aim of the study

The aim of this study is to evaluate the opportunities for domestic waste landfilling, regarding energy recovery from landfill biogas (LFG) and greenhouse gas (GHG) mitigation.

The geographical scope is European Union, in particular France, The Netherlands, the United Kingdom, Germany, Spain, Italy, Greece, Poland and Romania.

Focus is made on those 9 countries has they represent 81% of the population of EU-27 and produce 84% of the amount of waste that are landfilled in EU-27.

2. Methodology

2.1 Data used for the review

Data used for this review are mainly based on the sources described below.

2.1.1 Annual European Community greenhouse gas inventory 1990-2008 and inventory report 2010 (EEA)

This report is the annual submission of the greenhouse gas inventory of the European Community to the United Nation Framework Convention on Climate Change.

It presents the greenhouse gas emissions between 1990 and 2008 by individual Member State and by economic sector. It was published by EEA (Environment European Agency) and OPOCE (Office for Official Publications of the European Communities) on May 27, 2010[1].

Annex 2.10 details GHG emissions from the waste sector. The sub-file EC10_SBDT6A.xls gives data for solid waste.

These statistics give in each country and each year from 1990 to 2008:

- Amount of municipal waste landfilled. For some countries, industrial waste are included.
- Methane emissions to the atmosphere
- Methane recovery[2]

In some countries data are detailed by “managed waste disposal” and “unmanaged waste disposal sites” (with a sub-division: deep (>5 m) and shallow (<5m)).

Methodology, tools and estimation models used by member states to report national emissions and waste quantities are detailed in the full report (EU GHG Inventory report 2010.doc), chapter 8.3.1 and 8.2.1.

[1] EEA. *Annual European Community greenhouse gas inventory 1990-2008 and inventory report 2010.* [in line] Brussels : EEA, 27 May 2009. Available in: http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2010

[2] See later for the terminology

2.1.2 Biogas barometers (EurObserv'ER)

BAROMET'ER is the European survey of renewable energy, led by the company EurObserv'ER, and published each year. « Biogas barometer » is built as an enquiry in member states, in order to evaluate the production of biogas per country and per type of production.

Following barometers were used:

EurObserv'ER. *The state of renewable energies in Europe. 9th EurObserv'ER Report*. [in line] Paris : EurObserv'ER, 2009. Available in:

http://www.energies-renouvelables.org/observer/stat_baro/observ/barobilan9.asp

EurObserv'ER. *Biogas Barometer*. Systèmes solaires n°186 [in line] Paris : EurObserv'ER, July 2008. Available in:

http://www.energies-renouvelables.org/observ-er/stat_baro/eufores/baro173a.asp

EurObserv'ER. *Biogas Barometer*. Systèmes solaires n°179 [in line] Paris : EurObserv'ER, May 2007. Available in:

http://www.energies-renouvelables.org/observ-er/stat_baro/observ/baro179_a.asp

EurObserv'ER. *Biogas Barometer*. Systèmes solaires n°173 [in line] Paris : EurObserv'ER, May 2006. Available in:

http://www.energies-renouvelables.org/observ-er/stat_baro/observ/baro186_a.asp

EurObserv'ER data were consolidated by national data. See 2.1.4.

2.1.3 International Energy Agency (IEA) statistics

Part of GHG mitigation calculation done in this report is based on the electrical mix of the country. This is calculated thanks to following IEA databases:

- « Electricity/Heat Data» (2007)

  Available in: http://www.iea.org/stats/prodresult.asp?PRODUCT=Electricity/Heat
- « Balance » (2007)

  Available in: http://www.iea.org/stats/prodresult.asp?PRODUCT=Balances

2.1.4 National data

National data were retrieved from following sources:

- Contacts with local energy agencies and ministries of environment
- An assessment of the implementation of the Landfill Directive in Member States ordered by European Commission and stated by EcoLogic and the Institute for European Environmental Policy. [1]

[1] EcoLogic, IEEP. *A Report on the implementation of Directive 1999/31/EC on the Landfill of Waste*. [in line] Brussels : European Commission, May 2009. Available in: http://ec.europa.eu/environment/waste/reporting/report04_06.htm

- Reports from BIPRO landfill directive assessment project, available in: http://www.bipro.de/waste-events/land/eu-lex.htm

- Fact sheets by country from the European Topic Centre on Sustainable Consumption and Production, available in: http://scp.eionet.europa.eu/facts/factsheets_waste/2009_edition

- An assessment of the RES directive implementation in EU-27 published by the European Renewable Energy Council (EREC). [1]

- BiG>East project. This was used for Romania and Greece. This consortium promotes biogas as renewable energy source and as waste treatment technology in 6 countries from East Europe including Greece and Romania. To access project website : http://www.big-east.eu

[1] EREC. *Reference Document on Renewable Energy Sources Policy and Potential*. [in line] Brussels : 2009. Available in: http://www.res2020.eu/

2.2 Acronyms & Terminology

2.2.1 Acronyms

- ADEME : French national energy agency
- ALEA : Romanian national energy agency
- CH_4 : methane
- DUKES : Digest of United Kingdom Energy Statistics
- EEA : European Environment Agency
- EREC : European Renewable Energy Council
- EU-27 : all European countries
- EU-25 : Europe without Romania and Bulgaria
- EU-9 : the nine countries in the scope of this study
- FIT : Feed-in tariff
- GHG : greenhouse gases
- GUS : Central Statistical Office of Poland
- GWP : Global Warming Potential (equal to & for CO_2 and 21 for CH_4)
- ICPE : French status for industrial facility that may impact environment
- IEA : International European Agency
- ISTAT : Italian national statistics institute
- k_i : methane production rate constant of the fraction i (used in prospective model)
- LFG : landfill gas
- PER 2005-2010: Spanish Renewable Energy Program
- PM_i : Potential of Methane production of the fraction i (used in prospective model)
- MS : member states
- MSW : municipal solid waste
- Mtoe : millions of tons of oil equivalent
- REs : Renewable Electricity sources
- SWD : Solid Waste Disposal facilities
- TGAP : French tax on industrial facilities that may impact environment
- SOeS : French environment statistics services
- WWT : WasteWater Treatment
- GC : Green Certificate market (see 2.2.2 GC market definition)

2.2.2 GC market definition

Green Certificate market is a tool used by government to encourage renewable energy production.

The Green Certificate market is based on a mandatory percentage of renewable energy to be produced by all energy generators. This percentage is decided by government and is increasing yearly. Thus, each energy provider must prove that a certain part of its production is from a renewable source. The evidence is a Green Certificate (GC). So they must get a certain amount of GC each year, depending of the amount of energy they sold during the year. To get those GC they have to either grant those GC by producing renewable energy by themselves or buy GC to renewable energy producers. Each renewable energy producer grants this Green Certificate from authorities for each renewable MWh produced. Thus energy providers that do not produce enough renewable energy by themselves, and so does not grant enough GC compared to government target must buy Green Certificates to renewable energy producers. This makes a GC market and give to the GC a market value.

Feed-in tariff causes a fix price and GC market causes a fix volume. Experts consider GC market is more relevant in country where the technology is well implemented already.

2.2.3 Type of landfill waste considered in this report

Most of landfilled waste reported in this report are municipal waste. However some countries reported also industrial waste to EEA for the GHG inventory report which is the basis of this study. To characterize reported waste quantity we compared EEA figures to EUROSTAT figures that are titled as Municipal Waste (household waste, Commercial &Industrial waste similar to household waste). As a conclusion, the next table report the part of municipal waste reported by EEA GHG Inventory in average over the period 1990-2008.

For instance, 55% of the total amount of landfilled waste reported by France in table 6.A of the GHG inventory are muncipal waste.

Country	% of municipal waste in total landfilled waste reported by EEA GHG Inventory.	Country	% of municipal waste in total landfilled waste reported by EEA GHG Inventory.
FR	55%	ES	78%
DE	91%	GB	40%
GR	99%	PL	100%
IT	94%	RO	98%
NL	15%		

Table 1 : Part of municipal waste in the total landfilled waste considered in this study (i.e reported in GHG inventory).

2.2.4 Terminology about Landfill gas

The following figure explains the main terms used in this report.

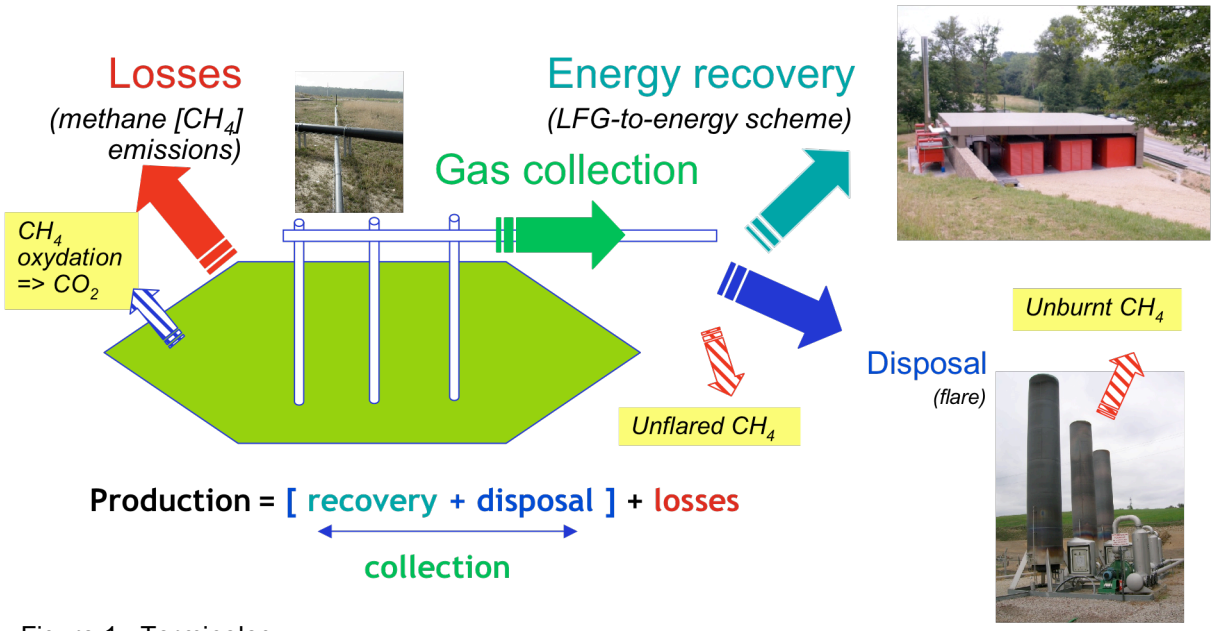

Figure 1 : Terminology

- **Production :** methane produced by anaerobic digestion of biodegradable waste.
- **Gas collection :** quantity of landfill gas collected. The collected gas is then either flared, or converted into energy.
- **Losses :** methane emissions to the atmosphere, due to leakage on gas collection system, or gas escape during the filling phase of the landfill cells.
- **Disposal** : combustion of LFG in flares
- **Energy recovery** : use of LFG in power plants, boilers, furnaces, leachate evaporators, or as natural gas after upgrading.
- **Collection rate** : methane collected over methane production
- **Energy recovery rate** : methane used for energy over collected methane

Production = collected gas + losses

Collected gas = recovery to energy + disposal

A part of non-collected methane is oxidised into carbon dioxide when passing through the cover. A part of collected methane is lost in the gas collection system, or un-flared during flare servicing. Finally, another part of methane is un-burnt in the flare. Oxidised methane is taken in account in some countries (depending on national estimation model) over the period 1990-2008. This implies that Solagro's prospective also takes in account this oxidation in the same way thanks to the calibration phase.

Caution: some publications employ similar terms but not in the same sense. For example, the EEA publication on GHG employs « recovery » for « gas collection », and « emissions » for « losses ». In the present report, « energy recovery » designs only the quantity of LFG used in LFG-to-energy facilities.

2.2.5 Conversion factors

=>	kt CH_4	ktoe	GWh el.	MW el.	Millions of m^3 LFG	kt eq CO_2	kt MSW
kt CH_4	1	1.2	4.8	0.60	2.8	21	20
ktoe	0.84	1	4.1	0.51	2.4	18	17
GWh el.	0.21	0.24	1	0.13	0.58	4.3	4.1
MW el.	1.7	2.0	8.0	1	4.6	35	33
Millions of m^3 LFG	0.36	0.42	1.7	0.22	1	7.5	7.1
kt eq CO_2	0.048	0.056	0.23	0.029	0.13	1	1.0
kt MSW	0.05	0.059	0.24	0.030	0.14	1.1	1

Table 2: Conversion table

Ex : 1 kt of methane is equivalent to 1.2 ktoe. or 4.8 GWh el. or 0.6 MW el. or 2.8 millions m3 LFG at 50% methane.

To simplify, equivalences are given for electricity production with gas motors, which is the standard for LFG energy recovery; obviously, other energy productions are possible, as heat, natural gas, vehicle fuel…

The calculations are done on the following basis:

1 toe = 42 GJ = 11.67 MWh

1 m^3(n) CH_4 = 0.72 kg

1 m^3(n) CH_4 = 9.95 KWh

1 m^3 LFG contains 50% CH_4 (average value)

1 t CH_4 is equivalent to 21 t CO_2 as greenhouse gas

The annual mean power (expressed as MW el.) is calculated assuming a running time of 8.000 hours per year.

2.2.6 Population

Regarding graphs that express values per capita, population is considered as constant between 1990-1999. Here are the figures used (Source: EUROSTAT) :

Millions of inhabitant	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
FR	60	61	61	61	62	62	63	63	64	64
DE	82	82	82	82	83	83	83	82	82	82
GR	11	11	11	11	11	11	11	11	11	11
IT	57	57	57	57	57	58	58	59	59	60
NL	16	16	16	16	16	16	16	16	16	16
SP	40	40	40	41	42	42	43	44	44	45
UK	59	59	59	59	59	60	60	60	61	61
PL	39	39	38	38	38	38	38	38	38	38
RO	22	22	22	22	22	22	22	22	22	22
Other MS	96	96	97	96	97	97	97	97	98	98
EU-27	482	483	484	485	487	489	491	493	495	498

Table 3 : Population in Europe

2.3 GHG mitigation with LFG energy recovery

LFG recovery contributes to reduce greenhouse gas emissions by two effects:

- **The first effect : better collection of LFG (methane losses reduction)**

It is a fact that LFG energy recovery gives an economic value to the landfill gas, and therefore the landfill manager is encouraged to produce more. When setting up a LFG energy recovery project, one first task for the landfill manager is to improve the LFG extraction system in order to produce and sell more energy. It is common to increase methane flow by 30% or more.

- **The second effect : substitution to fossil fuels**

Energy recovery from LFG-to-energy plants avoids carbon dioxide emissions (coal, oil and gas thermal plants). Most of biogas is used for electricity production so this second effect varies according to the electrical mix by country. Gas engine efficiency is also taken into account. Results regarding fossil fuels can be found in 1st column of Table 4. Regarding this second effect, for the EU-9, we calculated that 1.7 tons of carbon dioxide is avoided for 1 ton of methane used in a LFG power plant.

The following table details the total GHG mitigation due to the energy recovery of 1 ton of methane. This includes the 2nd effect (substitution to fossil fuel), which varies by country as said before; and the 1st effect (avoided CH_4 emissions due to a better collection rate) - for 3 assumptions: from +10% collection rate to +30%.

The calculation is done as detailed here: for each ton of recovered CH_4, in the first assumption (+10% collection rate) the improvement of the collection rate (due to the energy recovery) leads to a further reduction of 0.1 t of methane to the atmosphere compared to “as usual” LFG management. Using a GWP of 21 for methane, this means that each ton of recovered CH_4 leads to a reduction of 0.1 x 21 = 2.1 t CO_2 eq.

Thus, for the first assumption, the total GHG mitigation in EU9 is 3.8 t CO_2 eq/t CH_4 used in a LFG power plant.

	2nd effect only : Substitution to fossil fuels	Total GHG mitigation *according to different hypothesis for the increase of collection rate*		
		Increase of collection rate		
		+10%	*+20%*	*+30%*
	Avoided t CO_2 eq. / ton of CH_4 used in a LFG - power plant			
DE	2.0	4.1	6.2	8.3
ES	1.7	3.8	5.9	8,0
FR	0.3	2.4	4.5	6.6
NL	1.7	3.8	5.9	8.0
UK	2.2	4.3	6.4	8.5
GE	3.3	5.4	7.5	9.6
IT	1.6	3.7	5.8	7.9
PL	3.2	5.3	7.4	9.5
RO	1.7	3.8	5.9	8.0
EU-9	1.7	3.8	5.9	8.0

Table 4 : GHG mitigation with LFG energy recovery

2.4 Prospective model

For each country of the scope, the amount of landfilled waste, collected biogas, LFG retrieved energy and GHG mitigation during the period 2008-2020 was estimated.

Those estimations use a **Solagro** simulation model similar to the model used by the French national energy agency (ADEME) to report national GHG emissions.

2.4.1 Simulation model used for the prospective

Solagro's model is a model of 1st order and is multi-phase[1] as the ADEME model. Each phase corresponds to a different fraction of waste, depending on the speed of biodegradation. Three different fractions are considered. Each fraction has 2 constants associated with:

- a specific methane generation rate constant ($k_{1,2,3}$), which indicates how fast methane is released by each fraction
- a methane production potential ($PM_{1,2,3}$) that indicates how much methane is released by each ton of waste. This PM depends on the composition of the landfilled waste and on the operating conditions.

The values of the constants chosen for the prospective, before the calibration phase, are similar to constants in the ADEME model as stated in table below. The methane oxidation rate is neglected in those simulations.

k_1	k_2	k_3	% of waste in fraction 1	% of waste in fraction 2	% of waste in fraction 3	Global PM = $PM_1 + PM_2 + PM_3$
0,5	0,1	0,04	15%	55%	30%	88 m^3CH_4/t

Table 5 : Constants used for the estimation model before calibration phase

However those constants are based on theoretical values used in France for municipal wastes. Experts recommend improving the reliability of the results by calibrating model with measured/factual values. Indeed weather conditions, composition of landfilled waste and landfill management differ from one country to another and impact the value of the constants to be chosen. That is the reason why we did a calibration phase using the GHG inventory data in order to find the correct $PM_{1,2,3}$ for each fraction and each country.

The next section describes the method employed to build the prospective, including this calibration step.

[1] The equation is of type: gas production = $PM_1 . e^{-k_1 t} + PM_2 . e^{-k_2 t} + PM_3 . e^{-k_3 t}$

2.4.2 Method used for prospective

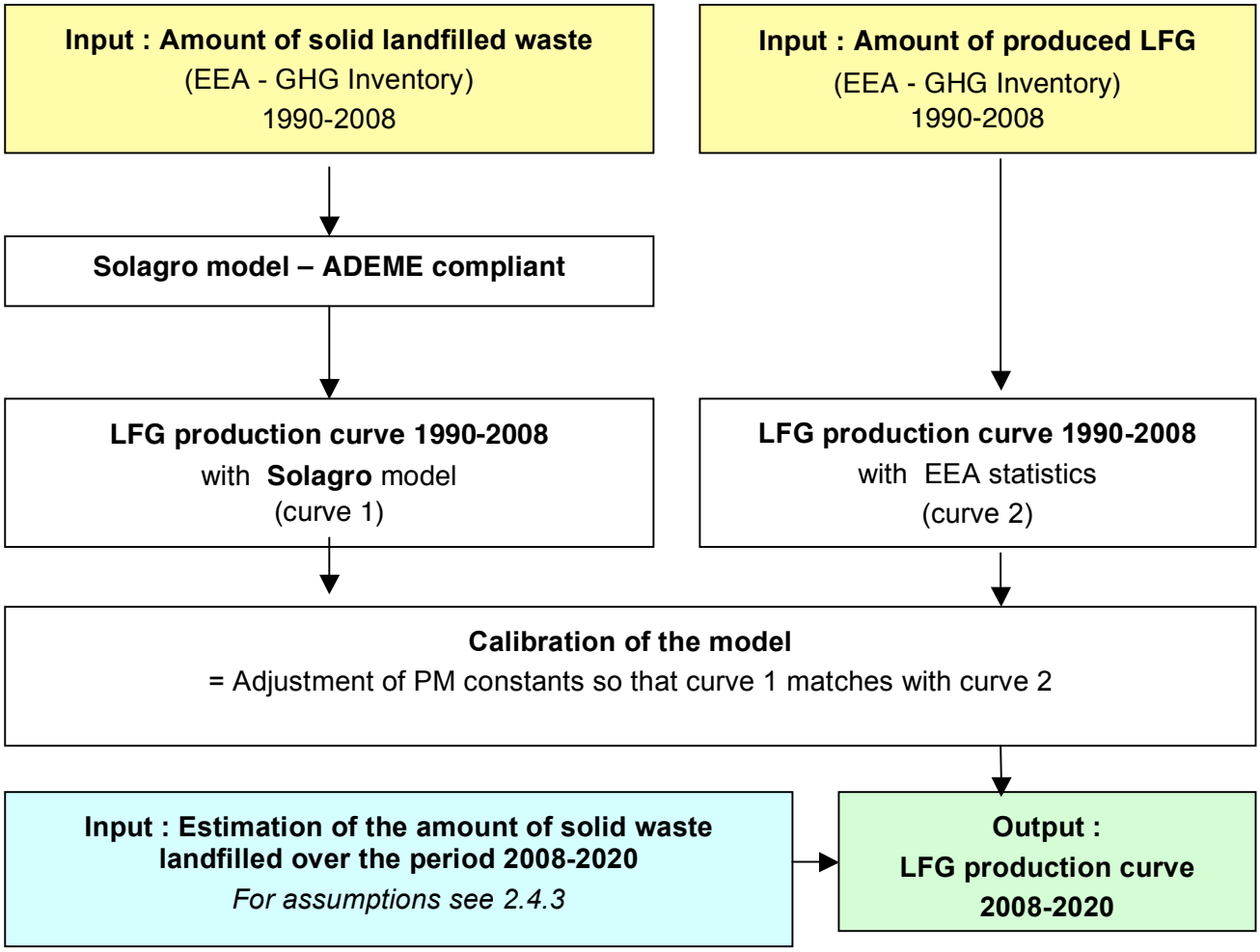

Figure 2 : Prospective model

The EEA's GHG inventory is used to calibrate this model over the period 1990-2008 as it provides the amount of landfilled waste and the correlated biogas production for each year and each country. We simulated the production of biogas over the period 1990-2008, using the amount of waste reported in the GHG inventory and with k constants of Table 5. Then, we adjusted the PM constants of each fraction so that the result of the simulation matches with the methane production of EEA's GHG inventory. k constants are not changed (except for UK and Spain, see Methodology Issues section 2.5.2.1).

Then, the amount of waste that will be landfilled over the period 2008-2020 is estimated following assumptions described in the next section.

Eventually, this estimation model is applied to the estimated amount of landfilled waste in order to get the estimated LFG production over the period 2008-2020.

2.4.3 Main assumptions for prospective

- **Amount of waste landfilled in 2016**

The main assumption is related to biodegradable waste reduction objective of the Landfill Directive 1999/31/EC. The Landfill Directive sets following requirement: the amount of biodegradable municipal waste landfilled in 2016 should decrease by 65% compared to 1995. Municipal waste are defined as household waste and industrial and commercial waste similar to household waste.

The assumption in this document is a median scenario between a “high assumption” and a “low assumption”.

The “Low assumption” is the scenario where all biodegradable and inert waste are reduced in the same proportion and where commercial and industrial waste are also reduced (in case they are considered see 2.2.3 above). This may be caused by a lack of flow separation or by other additional objectives of recycling and reuse given by the waste directive framework.

The “High assumption” is the scenario where no targets are taken into account and trends remain as they are.

Those assumptions have been used in our prospective as follows:

1/ In the last 6 years (2001-2007), the fluctuations of the amount of landfilled waste were calculated (Mt/year). The ratio was linearly reported and led to an estimation of the weight of waste that would be landfilled in 2016. This is the “High Assumption” scenario.

2/ The 65% reduction of landfilled waste compared to 1995 was applied. This led to an other estimation of the weight of waste that would be landfilled in 2016. This is the “Low Assumption” scenario.

Our prospective is then based on an average of the “Low assumption” and the “High Assumption”. The same rules have been applied to all countries. National targets are mentioned if possible in sections dedicated to each country. National targets were compared to our prospective model when possible. They are coherent in a first approach.

For instance for France:

From 2001 to 2007, the amount of landfilled waste decreased by 254 kt per year. This would lead to 20 Mt in 2016 (« High assumption »). The Landfill Directive 1999/31/CE and Grenelle targets (minus 15% of waste landfilled in 2012 compared to 2007), if applied to all kinds of waste, would lead to an objective of 7,6Mt of landfilled waste in 2016. To achieve this goal, the amount of waste should decrease by 1,6 Mt per year (« Low assumption »). Our prospective is based on a median assumption of - 967 kt per year.

- **Energy recovery rate and gas collection rate for the period 2008-2020**

Annual LFG collection fluctuations and annual LFG energy recovery fluctuations were calculated over the period 2003-2008 and the average trend was applied over the period 2008-2020. If LFG collection rate and energy recovery rate did not reach 90% in 2016, then annual fluctuations were modified so that both rates reach 90% in 2016. Those targets are set by Solagro so that they are the highest rate reachable. This target should be considered with caution as this is an ambitious assumption.

For countries that benefit of an extra delay for the application of the landfill Directive, targets were postponed to 2020 in **Solagro**’s prospective (i.e. for Greece, Romania, Poland and the United Kingdom).

2.5 Methodology issues

2.5.1 Caution about gas collection

LFG collection rates stated in this report should be used with caution. Indeed those figures depend on the method used by each country to report the amount of methane collected to EEA.

IPCC guidelines state that reporting landfill gas collection should be based on measured quantities of collected landfill gas. If there are no measurement data available a default value of 20% should be used for collection efficiency.

In many EU countries landfill operators annually report collected amounts of LFG to the competent authorities. Nevertheless many EU member states in their national reports make an estimate of landfill methane emission based on an assumption for collection efficiency. This collection efficiency (against IPCC requirements) is very often higher than 20%. The motivation is that measurements have indicated that higher collection efficiencies occur in reality. It should be noted that most (if not all) of these measurements have been carried out on capped landfill cells with closed chamber measurements. There is consensus among scientist around the world[1] [2] that closed chamber measurements tend to underestimate emission and consequently overestimate collection efficiency. Moreover the measured efficiency only represents the post-operational capped stage of the landfill and only as long as gas collection is active. Landfills also have an operational and a post-operational stage without gas collection. Moreover every country has old landfills without gas collection and recently closed landfills. Sometimes existing regulations did not require gas collection at the time of closure. Therefore the gas collection efficiency found on the capped landfill cannot be considered representative for all landfills in a country. Consequently the gas collection efficiency should not be applied to all landfill gas generated within a country.

The Dutch situation illustrates this clearly. In The Netherlands amounts of gas collected have been measured and reported since the early 1990's. For instance, in 2002, 414 Gg methane was produced on all Dutch landfills [3].This included 3,900 old landfills, some 20 recently closed landfills and some 30 operational landfills. In the same year only 69 Gg methane was collected. This is an average national collection efficiency of 17%. When the data are filtered for landfills with an operational gas collection system, the average collection efficiency increases to around 40%. At the same time it is likely that in specific cells a collection efficiency of 70% is realised.

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for the Sustainable Landfill Foundation, April 2010, http://www.sustainablelandfillfoundation.eu/documenten/100428%20Final%20report%20-%20review%20landfill%20methane%20SLF.pdf

[2] Measurement Technologies for Quantification of Landfill Methane Emissions, Session Report of 6th ICLRS, 9-11 June 2010, Kiroro, Hokkaido, Japan

[3] Greenhouse Gas Emissions in the Netherlands 1990-2002: National Inventory Report, RIVM report 773201008/2004, RIVM, De Bilt, Netherlands.

Bearing in mind that the old landfills and modern landfills in their different stages of development all occur simultaneously it seems unlikely that 70% collection efficiency can be applied for an entire nation. This report has been based as much as possible on officially published data. The Sustainable Landfill Foundation is of the opinion that some of these official data should be approached with consideration of the above. It is not always clear to what kind of landfills (all, recently closed or only operational) the data refer. There could be a huge difference in approach between different countries. Sometimes the data on gas collection efficiency seem unrealistically optimistic.

This is also an indication that in order to really achieve such high landfill gas collection rates stronger incentives than currently available should be provided. Such incentives can range from mandatory bioreactor technology (when biodegradable material is landfilled), to providing guidance for gas collection, to attractive feed-in tariffs for landfill gas to energy projects.

2.5.2 Issues regarding energy recovery

The comparison between different sources shows some incoherencies regarding the amount of energy recovered from LFG. Indeed, when a set of data does not come from a unique source, incoherencies may come from the fact that different conversion factors may have been used. Eventually, national data were used and slightly adjusted depending on trend described in different studies. Following table sum up the sources used.

	2004	**2005**	**2006**	**2007**
FR	Solagro	Solagro	Solagro	(*)
DE	Eurobserver & Ministry of the environment	Ministry of the Environment	Ministry of the Environment	Ministry of the Environment
NL	EcoLogic	EcoLogic	EcoLogic	AgentschapNL
ES	PER 2005-2010(1)	(*)	Ministry of Environment	(*)
UK	DUKES	DUKES	DUKES	DUKES
IT	ISTAT	ISTAT	ISTAT	ISTAT & GES (2)
GR	Eurobserver	Eurobserver	Eurobserver	Eurobserver (3)
PL	GUS	GUS	GUS	GUS
RO	ALEA	ALEA	ALEA	ALEA

Table 6 : Sources used for energy recovery figures

(*): Estimation. When none of the other sources matched with the data obtained previously. We preferred to estimate the data following the trend.

(1): This data is obtained from the total biogas value assuming that 40% of the biogas produced in Spain comes from landfills.

(2): This data is the GES data adjusted to ISTAT set of data.

(3): For Greece, data were retrieved from the CRES and the EREC, however all data show incoherencies so we eventually kept the Eurobserver data, knowing that the range of the energy recovery value is from 25 to 50 ktoe for 2004-2008 and that the activity sector seem dynamic.

2.5.3 Prospective model

2.5.3.1 K constants

For Spain, a mono-phase model was used; meaning only one speed of biodegradation was considered for the total amount of waste. Spanish national GHG inventory was done via a mono-phases model with k = 0,5. Thus for Spanish prospective, we used a unique fraction with k=0,5 and PM=88 m^3CH_4/t as basis model and then calibrated the model as explained before.

For UK, the model did not match to the EEA GHG inventory data as perfectly as for other countries. The methodology section of the EEA GHG inventory specifies that the UK uses a specific model (GasSim) and specific coefficients that make difficult the comparison with other countries (as it is based on cellulose and hemi-cellulose methane potential only). Eventually, the methane rate constants of GasSim were used (k_1 = 0,116 ; k_2 = 0,076 ; k_3 = 0,046) . The global trend was conserved and the data matched exactly for the years 2005-2008.

2.5.3.2 Oxidation

10% to 35% of methane generation may be oxidised through the landfill's covers. This may decrease methane losses (as methane is converted into CO_2). In this study, prospective model is built thanks to a calibration phase based on relation between the amount of landfill waste reported by EEA's GHG inventory and the methane production and emissions reported by EEA's GHG inventory. This implies that Solagro's prospective takes in account oxidation the same way EEA's GHG inventory does. IPPC states recommend a default value between 0% and 10% whereas some searchers states this could be from 10% to 35%. [1]

2.5.3.3 Target on energy recovery and collection rate

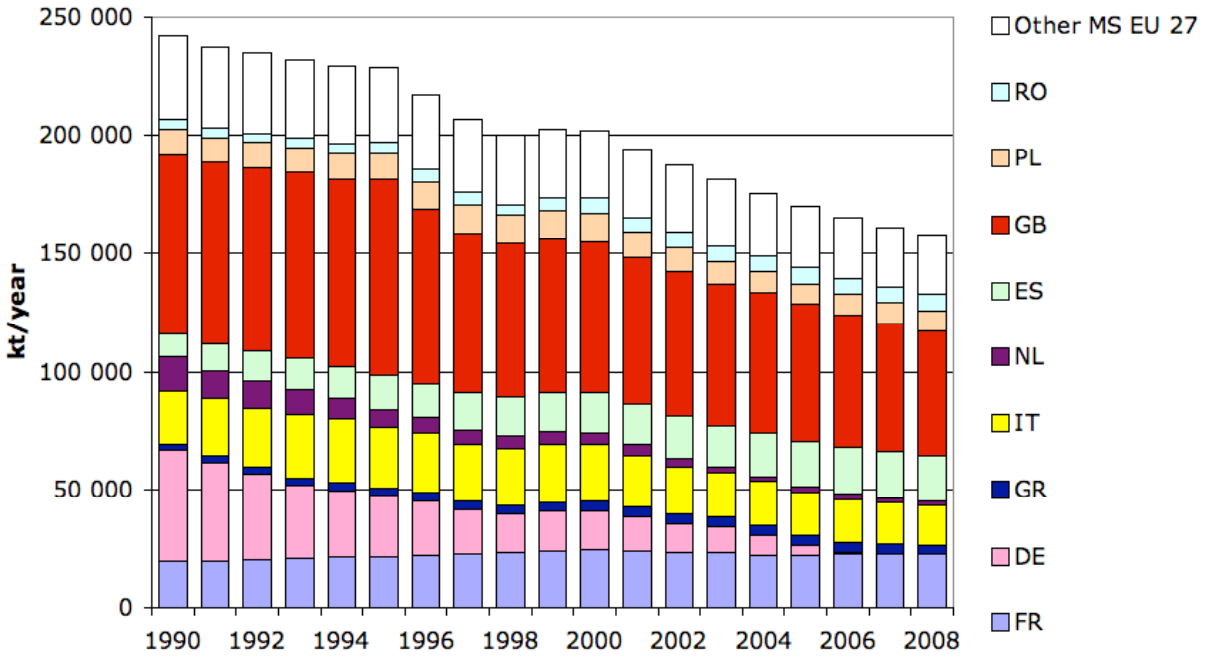
Targets of 90% are chosen in this report for collection rate and energy recovery. Those targets should be considered carefully as they are ambitious assumption.

[1] CHANTON JP. Methane Oxidation in Landfill Cover Soils, is a 10% Default Value Reasonable? . Feb 2009. Available in : http://www.ncbi.nlm.nih.gov/pubmed/19244486

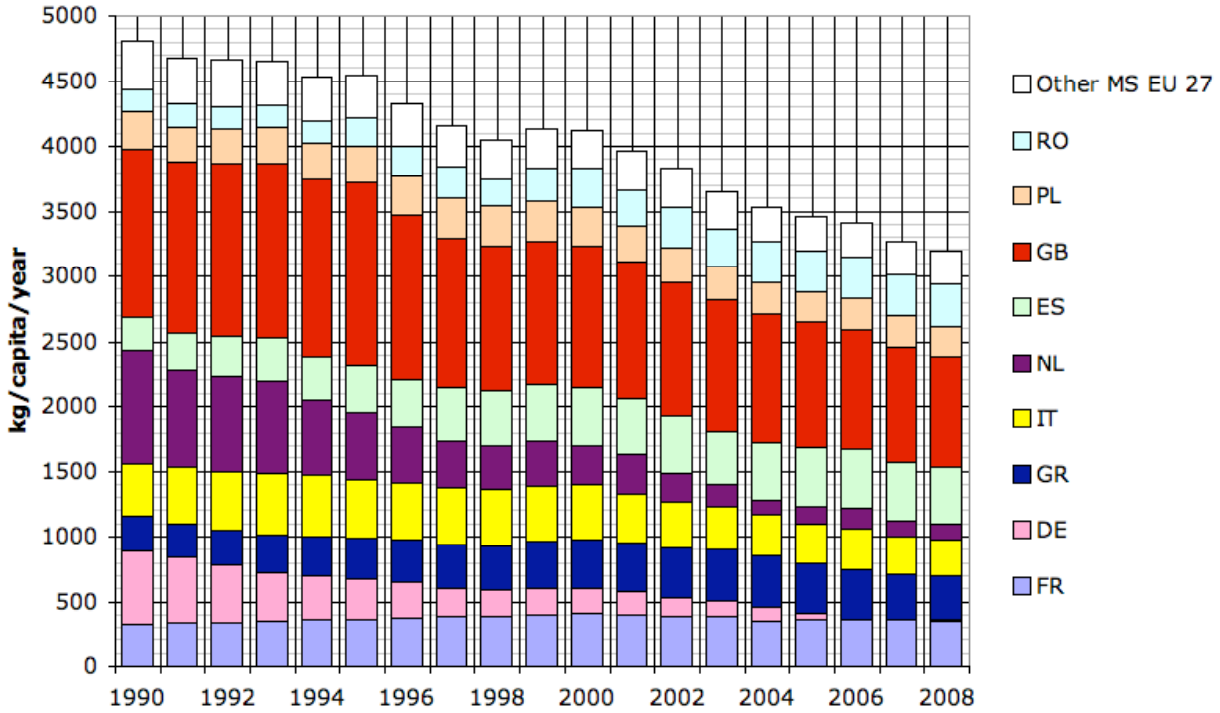
3. Global overview

3.1 Waste landfilling in EU-27

The amount of landfilled waste decreased from 242 to 158 millions of tons in 18 years i.e. -35%.



Graph 1. Amount of solid waste landfilled in EU-27
Source : EEA GHG Inventory 2010 – Table 6A



Graph 2. Solid Waste landfilled per capita in EU-27

Source : Solagro based on EEA GHG Inventory 2010

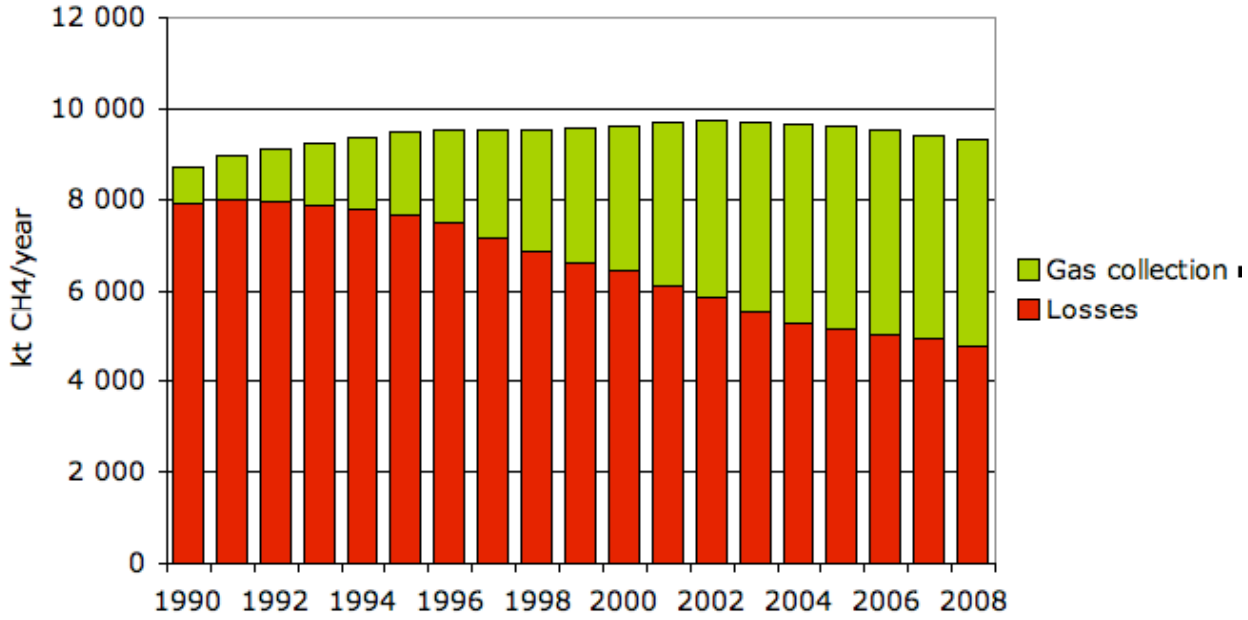
3.2 Methane production, losses, collection

3.2.1 Methane production in EU-27

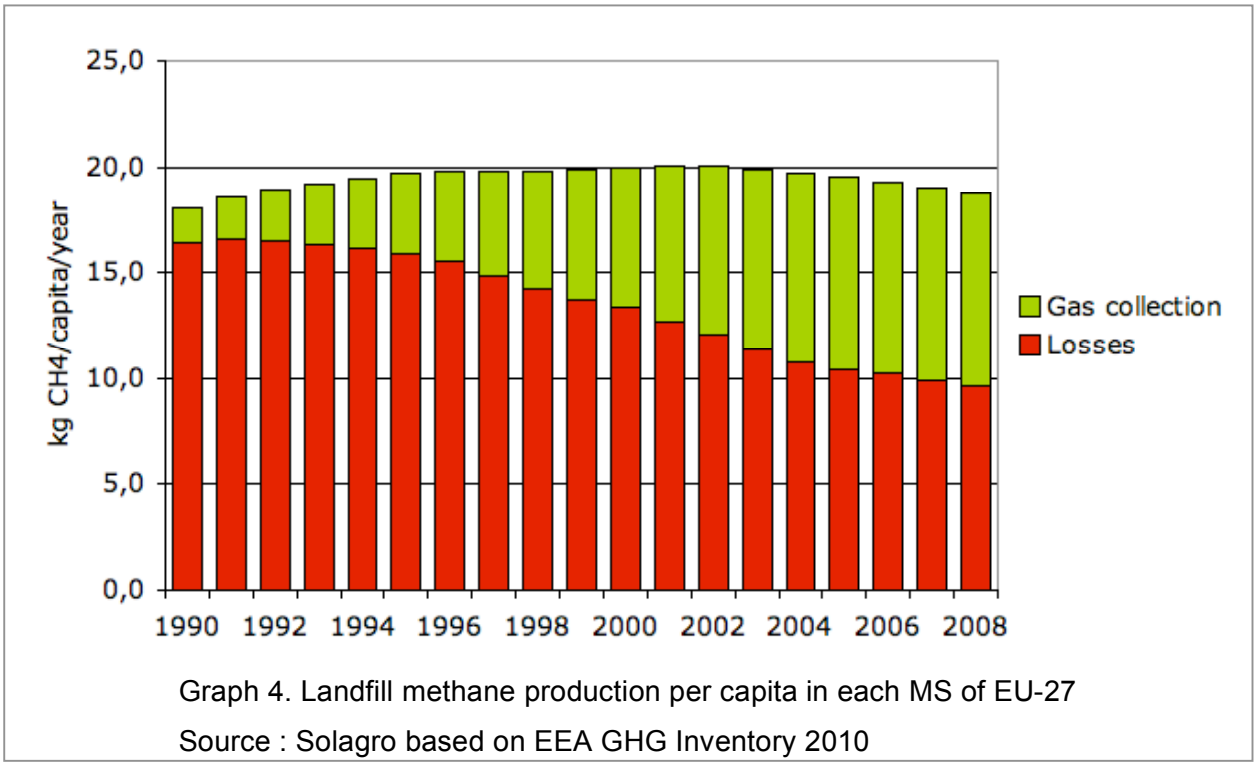
The methane production increased slowly from 8,6Mt in 1990 to 9,7 Mt in 2002.

And then decreased slowly to reach 9,3 Mt in 2008.

This stability, despite the decrease of waste landfilling, is due to the long duration of methane production (several decades after landfilling).



Graph 3. Landfill methane production in EU-27.
Source : EEA GHG Inventory 2010 – Table 6A

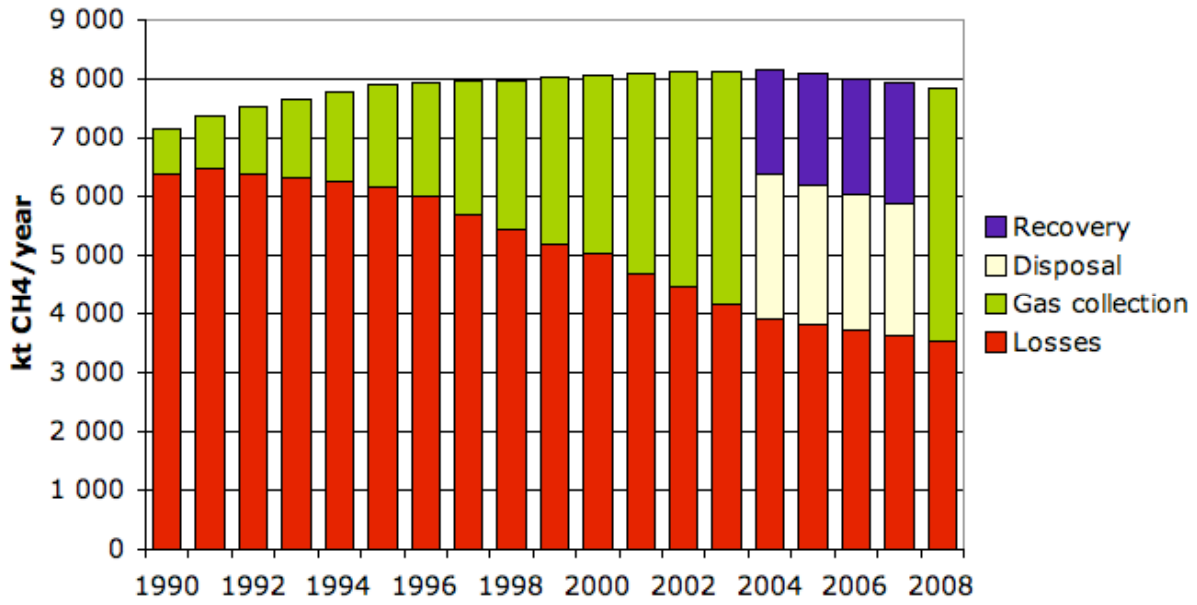


Graph 4. Landfill methane production per capita in each MS of EU-27
Source : Solagro based on EEA GHG Inventory 2010

3.2.2 Methane production in EU-9

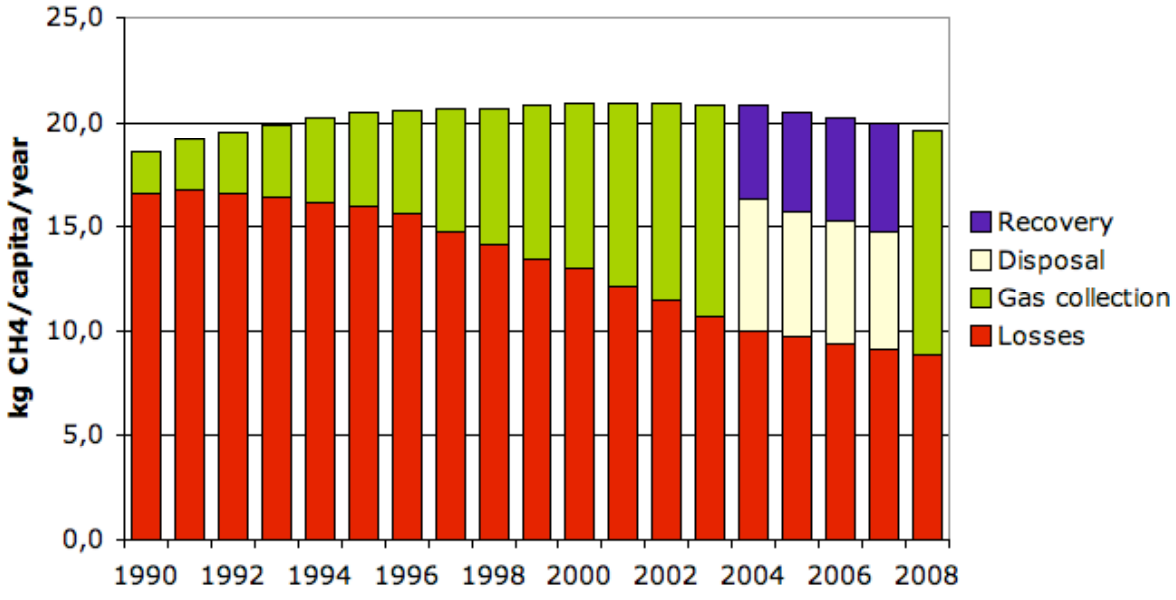
For the 9 countries of this study, the gas production also remains at a stable level: from 7 Mt of methane in 1990, to a maximum of 8.2 Mt in 2001, and decreases slightly to 7.8 Mt in 2008.

For these 9 countries, we have reliable statistics on energy recovery over the period 2004-2007: the collected gas may be therefore divided into “energy recovery” and by difference “disposal” (i.e. flared gas).



Graph 5. Landfill methane production in EU-9

Source : Solagro based on EEA GHG Inventory 2010 & National data



Graph 6. Landfill methane production per capita in EU-9

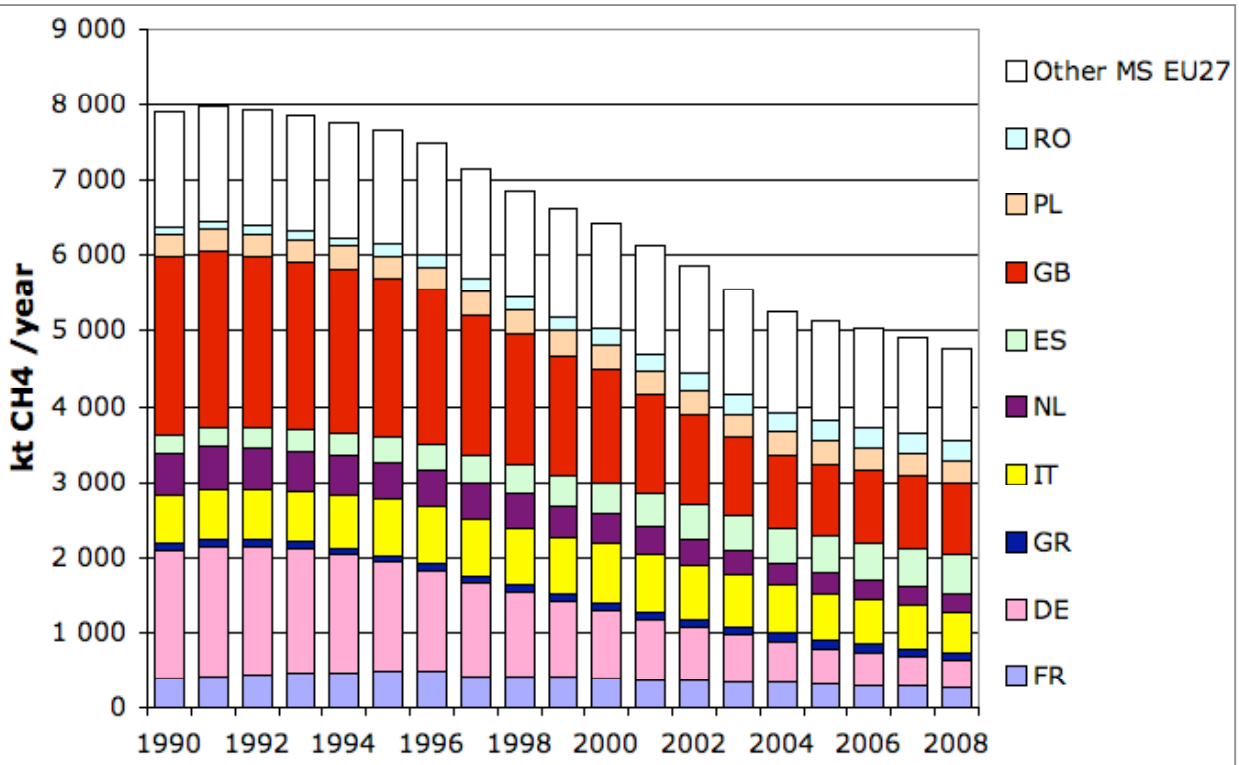
Source : Solagro based on EEA GHG Inventory 2010 & National data

3.2.3 Methane losses in EU-27

Due to improvement of gas collection, methane losses decreased from 7.9 Mt of methane in 1990 to 4.7 for the EU-27 in 2008 (and from 6.3 to 3.5 Mt for the EU-9), i.e. - 40% (- 45% for the EU-9).

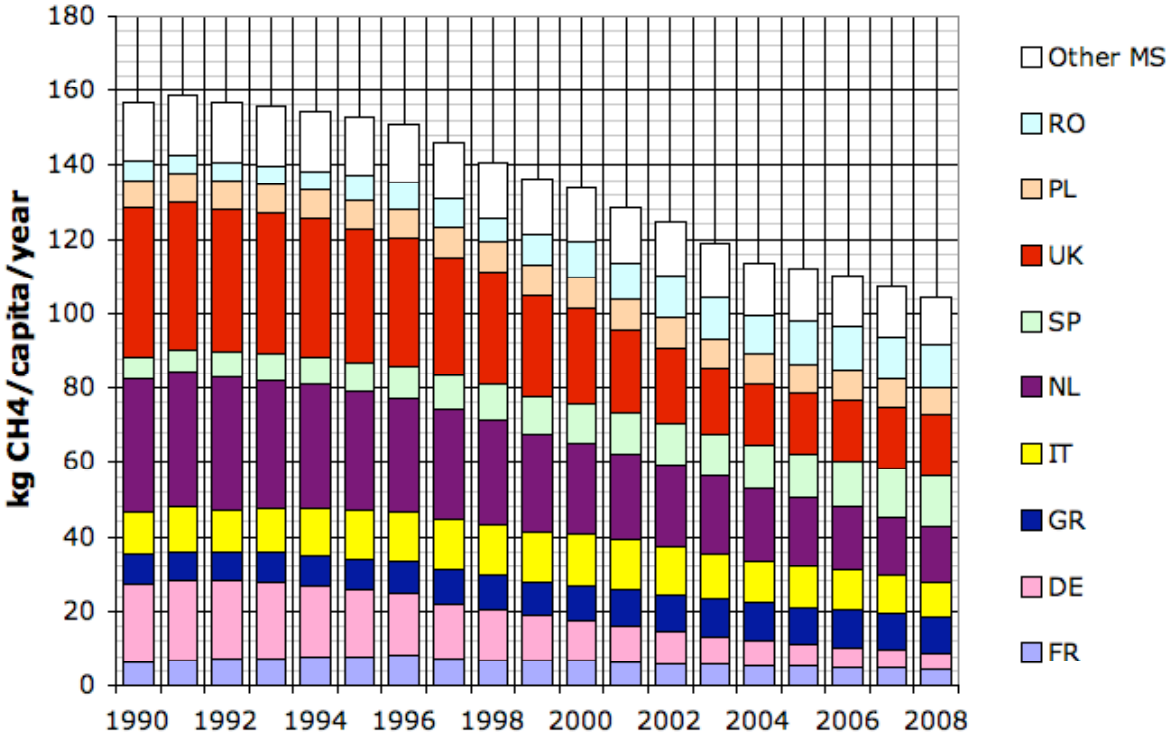
The difference (2.8 Mt of CH_4) is equivalent to 58 Mt of CO_2 per year avoided.

Total GHG annual emissions in EU-27 are 4.6 Gt CO_2 eq which correspond to 9 t CO_2 eq per capita. Therefore, the reduction of methane losses from landfills in European Union is equivalent to the total GHG emissions of 6.5 millions people. This data may be compared to the population of London (7.5 M inhabitants) or the population of the Denmark (5.5 M inhabitants).



Graph 7. Landfill methane emissions (lost) in EU-27
Source : EEA GHG Inventory 2010

Here are methane emissions per capita in each member state of EU-27.

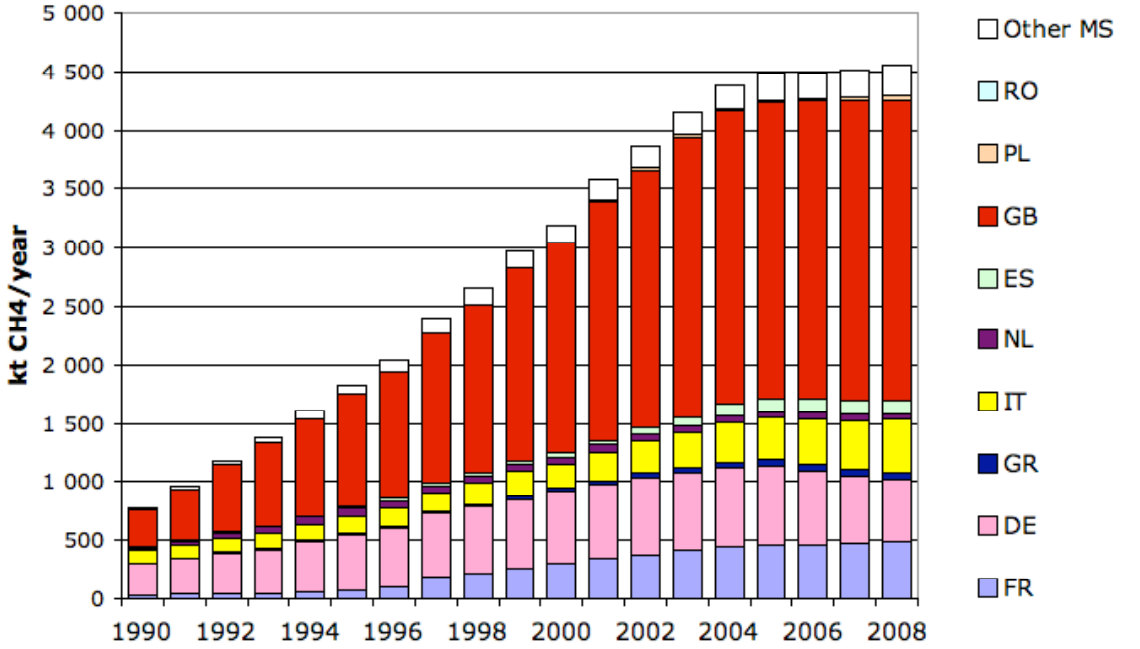


Graph 8. Landfill methane emissions per capita for each MS of EU-27
Source : Solagro based on EEA GHG Inventory 2010

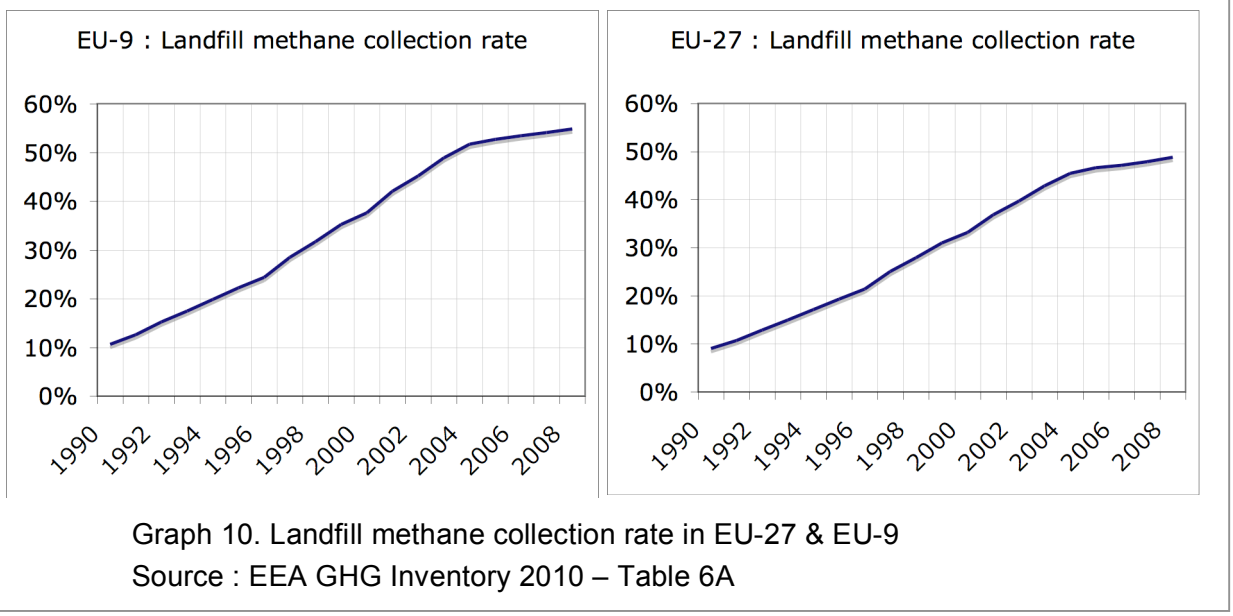
3.2.4 Methane collection in EU-27

Methane collection increased from 0.8 to 4.5 Mt CH_4 from 1990 to 2008 in EU-27 (0.8 to 4.3 for the EU-9). The collection rate rose from 9% in 1990 to 49% in 2008 (respectively 11% to 55% for the EU-9).

Thus, the methane collection rate was multiplied by 5.5 in the EU-27 in 18 years, and by 5.6 in the EU-9.

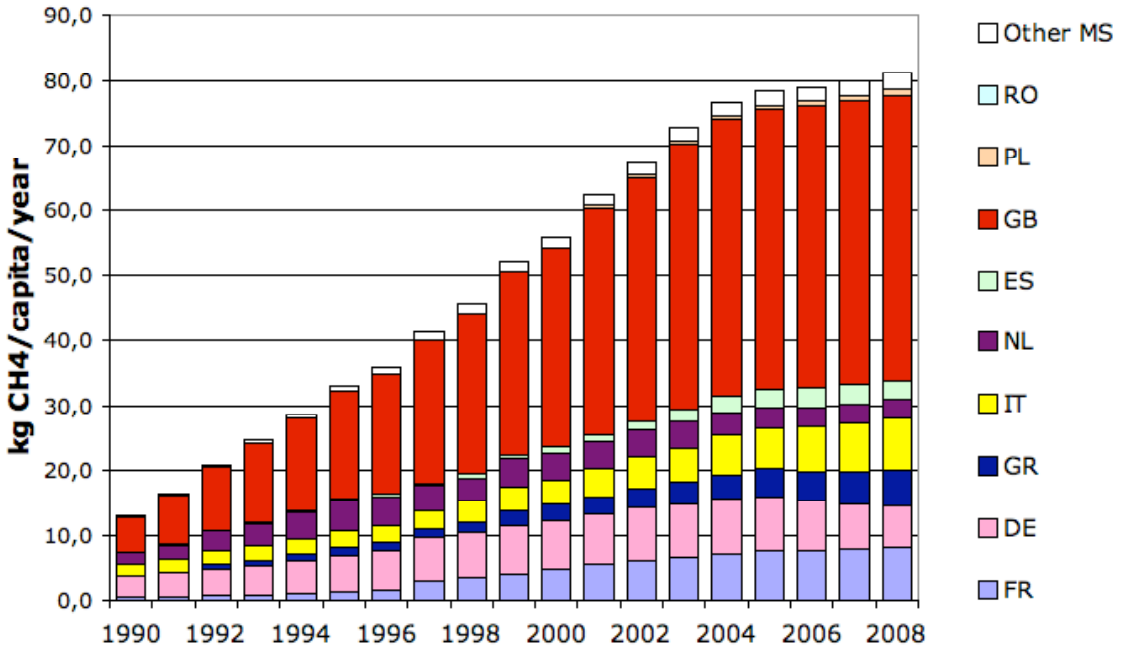


Graph 9. Landfill methane collection in EU-27
Source : EEA GHG Inventory 2010 – Table 6A



Graph 10. Landfill methane collection rate in EU-27 & EU-9
Source : EEA GHG Inventory 2010 – Table 6A

Here is methane collection per capita in EU-27 :



Graph 11. Landfill methane collection per capita in each country of EU-27
Source : Solagro based on EEA GHG Inventory 2010 – Table 6A

3.3 Energy recovery and GHG mitigation

3.3.1 Energy recovery in EU-9

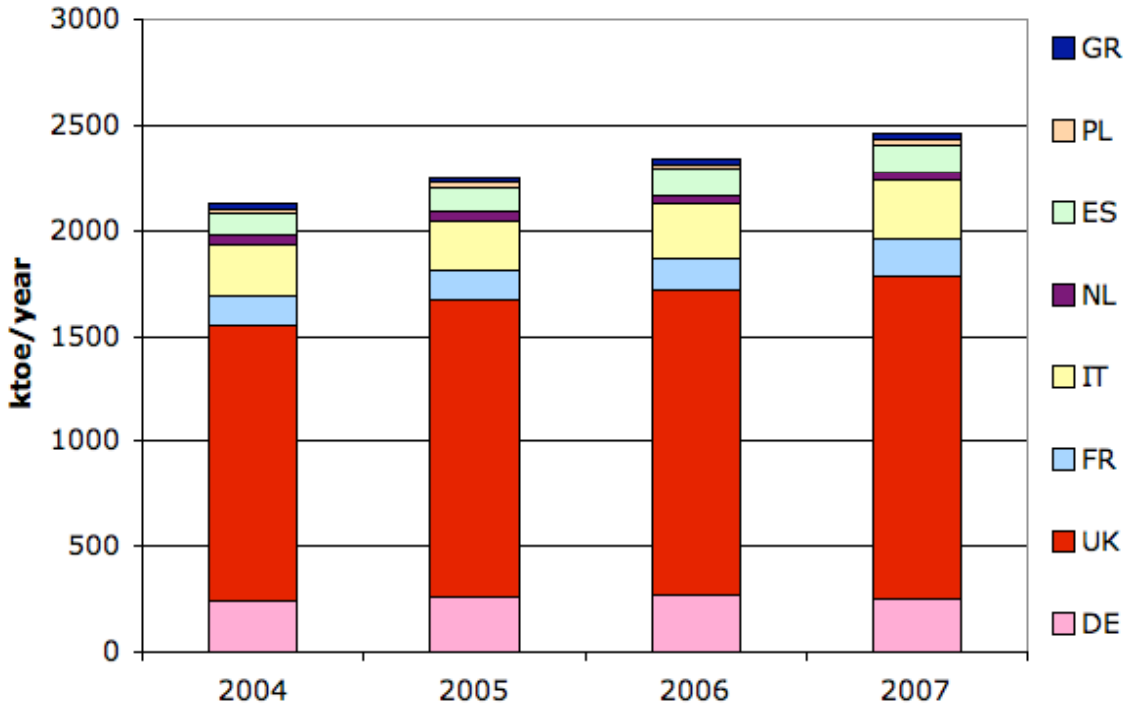
Energy recovery from landfills began in the early 1980' in Europe, but no reliable data for the 9 countries are available before 2004. Usually, member states carry out energy production from landfill gas only where it is "economical feasible", otherwise the gas is flared.

According to RISO (Dansk National Laboratory for Sustainable Energy), landfill gas energy production is 1% of European renewable energy production.

In 2007, 2 Mt of methane were converted into energy in EU-9, most of it with gas engine in order to produce electricity. This corresponded to 2,4 Mtoe (2,8 Mtoe in EU-25). In 2000, the energy recovery did not probably exceed 0.7 Mt CH_4.

In 2007, total energy production from LFG is estimated to 10 TWh. (11,4 TWh in EU-25).

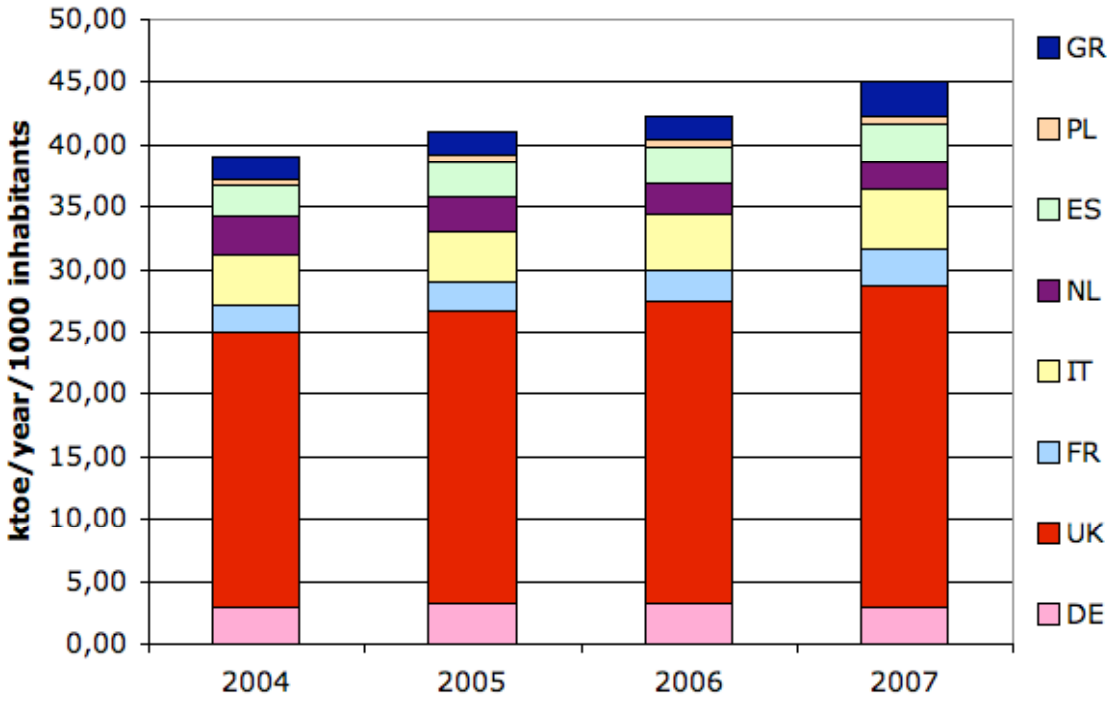
The general trend is an increase of the amount of energy recovered from landfill biogas, except in Germany and Netherlands. No energy is produced from LFG in Romania.



Graph 12. Energy recovery from LFG in EU-9

Source : National Data & Eurobserv'ER consolidated by Solagro

Here is energy recovery from LFG per capita in EU-9 :



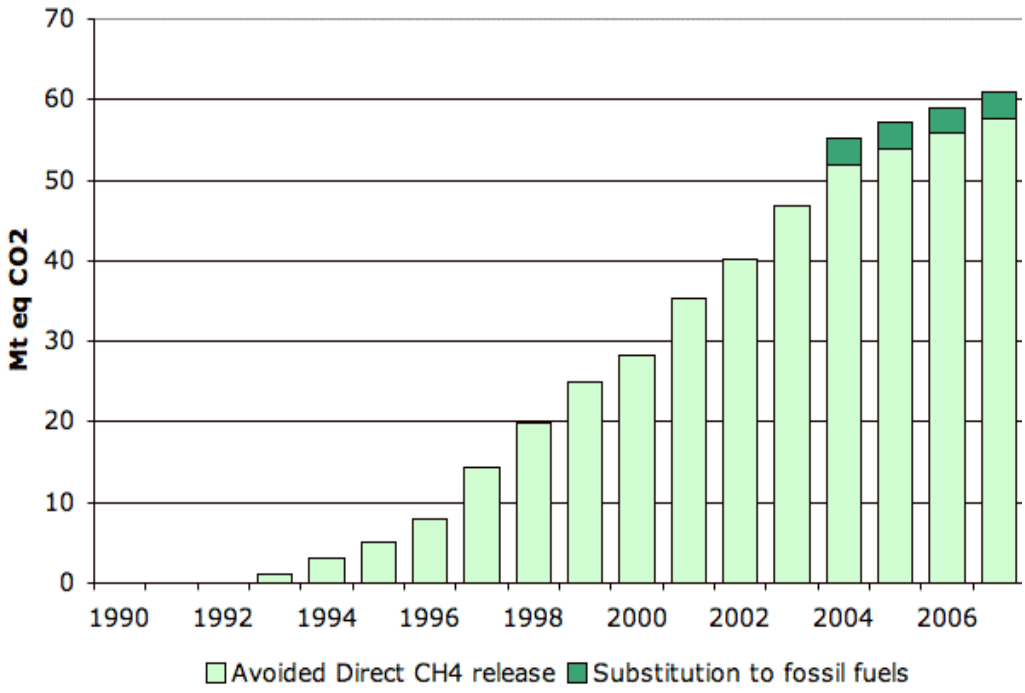
Graph 13. Energy recovery from LFG in EU-9
Source : National Data & Eurobserv'ER consolidated by Solagro

3.3.2 GHG mitigation due to LFG collection and energy recovery

The improvement of methane collection and energy recovery in EU-9, compared to 1990, avoided the emission of 61 Mt CO_2 eq. per year in 2007.

This is due to 2 effects: the avoided direct CH_4 releases and the substitution to fossil fuels.

The reduction of CH_4 emissions with LFG collection avoided 58 Mt CO_2 eq. per year compared to 1990. The substitution to fossil fuels with LFG-to-power plants avoided 3,6 Mt CO_2 eq. per year compared to 1990.



Graph 14. GHG Mitigation in EU-9

Source : Solagro

The contribution of landfills to the total GHG emissions per country was from 0,86 % to 3,51% in 2007. (see table below)

	Inventory EEA 2010 for year 2007									
CO2 eq (Gg)	Unit	FR	DE	GR	IT	NL	ES	GB	PL	RO
Emissions from managed landfill	CO2 eq (Tg)	5	8	1	10	5	10	20	1	3
Emissions from unmanaged landfills	CO2 eq (Tg)	1	0	2	2	0	1	0	5	3
Emissions from landfill per capita	CO2 eq (kg)	94	100	197	187	299	255	332	160	250
Total GHG emissions	CO2 eq (Tg)	531,1	956,1	131,9	552,8	207,5	442,3	636,7	398,9	152,3
%	%	1,13%	0,86%	1,67%	2,00%	2,36%	2,56%	3,16%	1,53%	3,54%

Table 7 Part of GHG emissions due to CH_4 landfills emissions over the total emissions per country. Based on: EEA. Annual European Community greenhouse gas inventory 1990-2008 and inventory

For comparison, total GHG emissions in EU-27 were 10 t CO_2 eq per inhabitant in 2007[1].

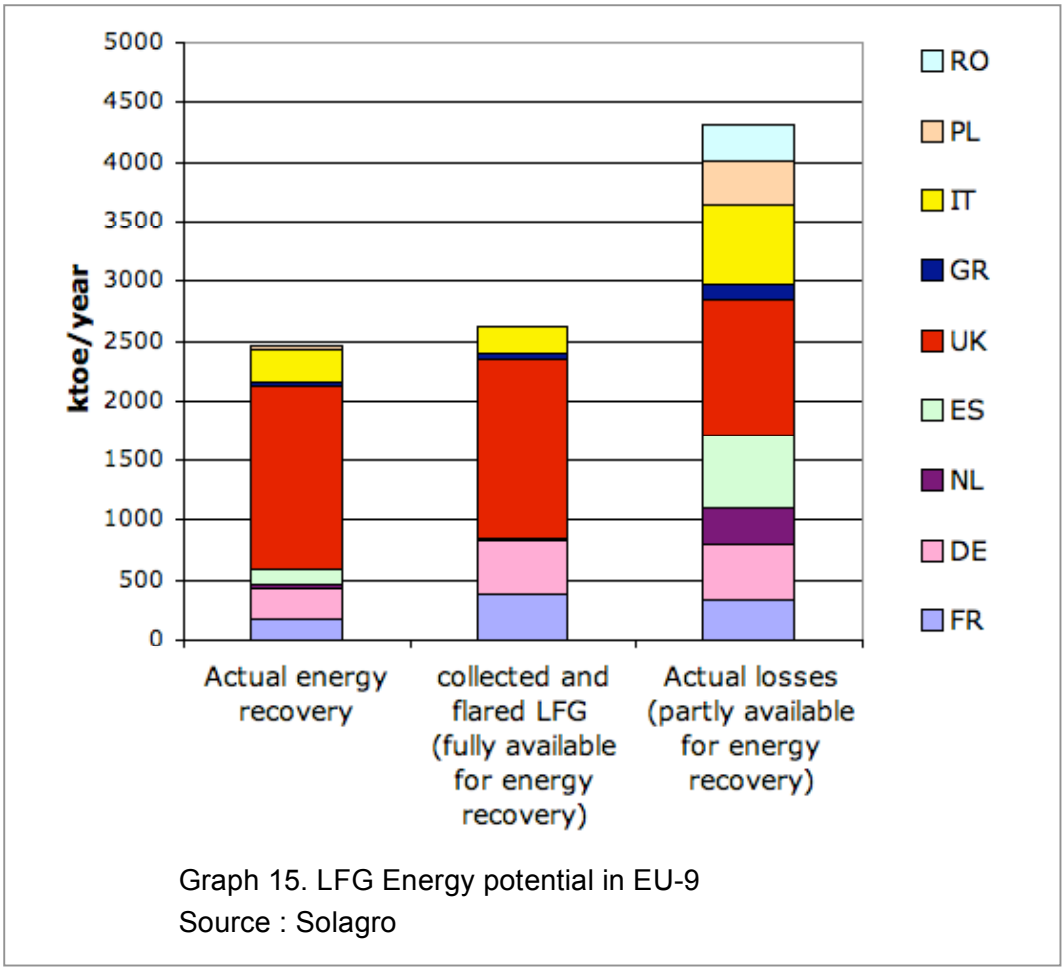
[1]Source : EEA GHG Inventory 2010 with a population of 495 millions of inhabitants

3.3.3 Energy potential from LFG

Energy potential from LFG can be divided into:

- The actual energy recovery, i.e. 2.5 Mtoe/year in 2007
- The quantity of gas collected and flared today, i.e. 2.6 Mtoe in 2007. This gas is fully available for energy recovery.
- The quantity of gas that is not collected today: 4.3 Mtoe. A part of this gas can be recovered depending on the gas collection rate system.

Note: These data reflect only an actual situation but are not suitable as forecast.



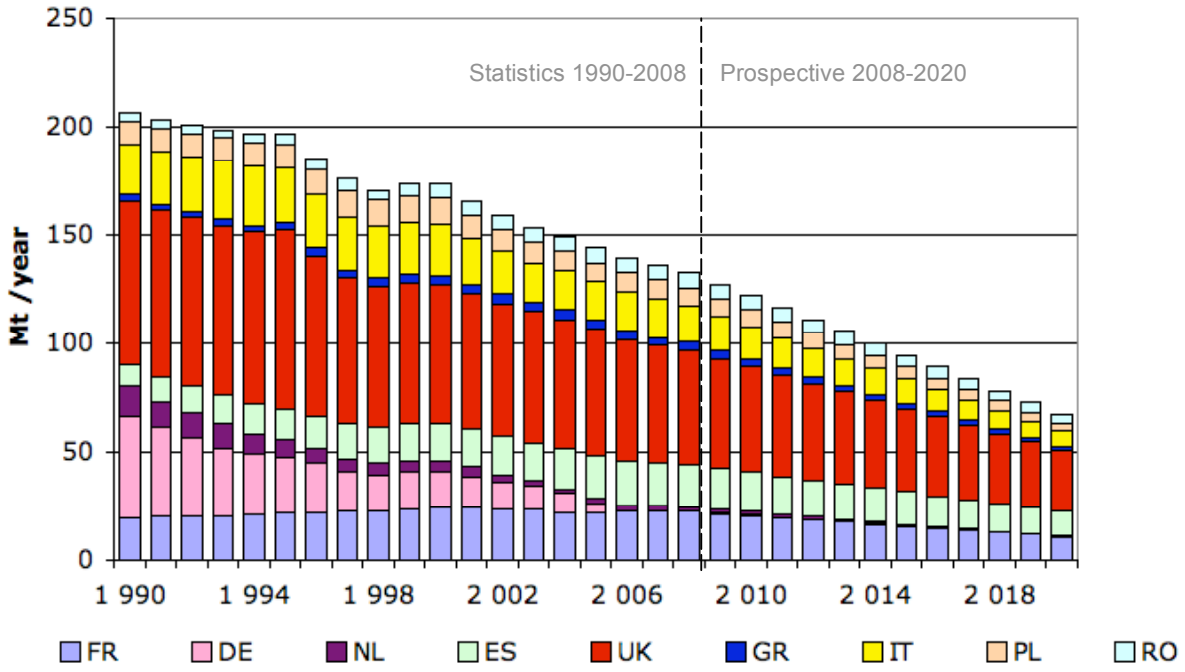
Graph 15. LFG Energy potential in EU-9
Source : Solagro

3.4 Global prospective

3.4.1 Waste landfilling in EU-9

Solid waste landfilling decreased in EU-9, from 207 Mt in 1990 to 133 Mt in 2008.

The assumption of the prospective is that 67Mt will be landfilled in 2020. France, Spain and the UK will landfill more than 10Mt in 2020. [1]



Graph 16. Solid waste landfilling in EU-9

Source : EEA GHG Inventory for 1990-2008 & Solagro for prospective

The special case of Germany should be noticed.

In Germany, according to the Federal Statistic Office, the amount of municipal waste decreased from 4 Mt to 0,307Mt between 2005 and 2006. As far as all waste are concerned – municipal and industrials; hazardous and non-hazardous - the amount of total landfilled waste decreased from 94Mt in 2005 to 73Mt in 2006. This may due to strong waste regulations in Germany. [2]

[1] For methodology please refers to section 2.4.3

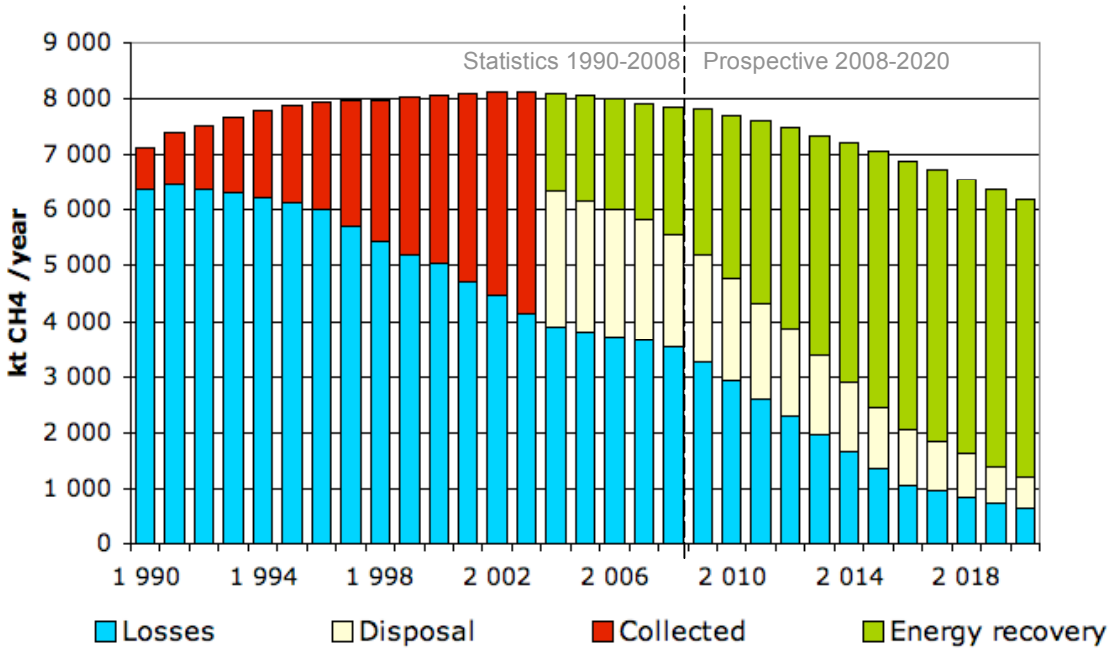
[2] Regarding this point, the Report of the Commission to the Council and the European Parliament on the national strategies for the reduction of biodegradable waste going to landfills in 2004 states : "Germany will fulfil the last reduction target in 2005, not only for municipal waste but for all biodegradable waste. German law provides a general separate collection obligation. Biodegradable municipal waste is separately collected and composted. Waste wood may not be landfilled. Packaging waste is collected and recovered to a high extent, the recovery quota nearing its limit. By 1 June 2005 landfills may only accept municipal waste that has been incinerated (TOC of 3%) or that has undergone mechanical biological treatment (TOC of 18%)."

3.4.2 Gas production, collection and recovery for the EU-9

Up to 3.0 GW el. could be generated in 2020 in the EU-9, i.e. 5.0 Mtoe/year or 24 TWh el./year. This is equivalent to the primary energy consumption of 1 million of inhabitants.

The losses would decrease from 3.7 Mt CH_4 in 2008 down to 633 kt CH_4 that corresponds to 63 Mt CO_2 eq avoided per year.

The largest part comes from the reduction of CH_4 losses thanks to a better collection rate. However the prime mover is the energy recovery that gives an economic value to the landfill gas.



Graph 17. Landfill gas production in EU-9

Source : EEA GHG Inventory for 1990-2008 & Solagro for prospective

3.4.3 GHG effects in the EU-9

Compared to 1990 (6.4 Mt CH_4 lost to the atmosphere i.e. 134 Mt CO_2 eq), 633 kt CH_4 only should be lost in 2020 (i.e. 13 Mt CO_2 eq).

In addition, the energy recovery of LFG (5 Mt CH_4) will avoid the emission of 8.5 Mt CO_2 eq. (2nd effect only).

The net GHG emissions will be so 4.5 Mt CO_2 eq (13 – 8.5), i.e. only 3.4% of the 1990 level or 97% decrease.

Compared to 1990, the contribution of landfill gas to GHG would decrease from 134 Mt CO_2 eq /year to 4.5 Mt CO_2 eq, i.e. a reduction of 129 Mt CO_2 eq /year.

3.4.4 Extrapolation to the EU-27

A simple extrapolation can be made for the EU-27. The extrapolation factor is similar for the population, the GHG emissions from landfills, and the amount of landfilled waste.

		EU-9	EU-27
Population, 2008	Million inhabitants	399	492
Landfilled waste, 2008	Million of tonnes	132	157
CO2 eq emissions from "Managed waste disposal on Land" EEA, Table 6A1, 2008	Mt CO2 eq	74	86
Landfilled waste, 2020	Million of tonnes	67	79
Power, prospective 2020	GW el.	3.0	3.6
Energy, prospective 2020	Mtoe/year	5.9	7
GHG further reduction, prospective 2020	Mt CO2 eq / year	63	76

Table 8 : Extrapolation, source : Solagro

The electrical power may reach 3.6 GW el. in 2020, for a production of 29 TWh el. The further annual reduction of CH_4 emissions would be then equal to 76 Mt CO2 eq. per year.

3.5 LFG Policy overview

In accordance with the Landfill Directive 1999/31/CE (paragraph 4.2 of annexe I), all member states made the collection of landfill gas mandatory for all new landfills (except special cases for islands and underground natural storage). Old landfills should have become compliant (or closed) since July 2009.

In accordance with the directive 2001/77/EC related to renewable energy promotion, all the 9 countries that have been studied in this report put in place either subsidy support (fixed Feed-In Tariff) or market regulation based support (Green Certificate), or both, in order to support the production of renewable energy (including LFG energy).

The only countries that have permitted new landfills since the introduction of the landfill directive are Greece, the Netherlands, Spain and the United Kingdom.

	Feed-in Tariff	Green Certificate market	Solid Waste landfilled in 2008 (EEA-kg/y/capita)	Number of LFG-to-energy plants in 2007	Total Capacity in MW in 2007	Energy from LFG in 2007 (GWh)
UK	YES	YES	853	357 (1)	900	4677
IT	YES	YES	273	No data	297	1127
DE	YES	NO	4	No data (2)	126*	1008
FR	YES	NO	350	46 (3)	106	735
ES	YES	NO	421	34	67*	539
NL	YES	NO	122	39	19*	151
GR	YES	NO	346	2	29	123
PL	NO	YES	228	32 (4)	29	113
RO	NO	YES	321	0	0	0

Table 9 : Summary of EU-9 landfill policy

(1) Number of plants that granted Green Certificate in the UK in 2007 - None in Northern Ireland

(2) German GHG Inventory reports that 95% of the 150 existing landfills collects biogas.

(3) ADEME stated that 71 sites told that they did convert biogas into energy but 49 sites only in 2008 indicated the actual quantity of energy produced. SoES reported 46 sites with energy production in 2007.

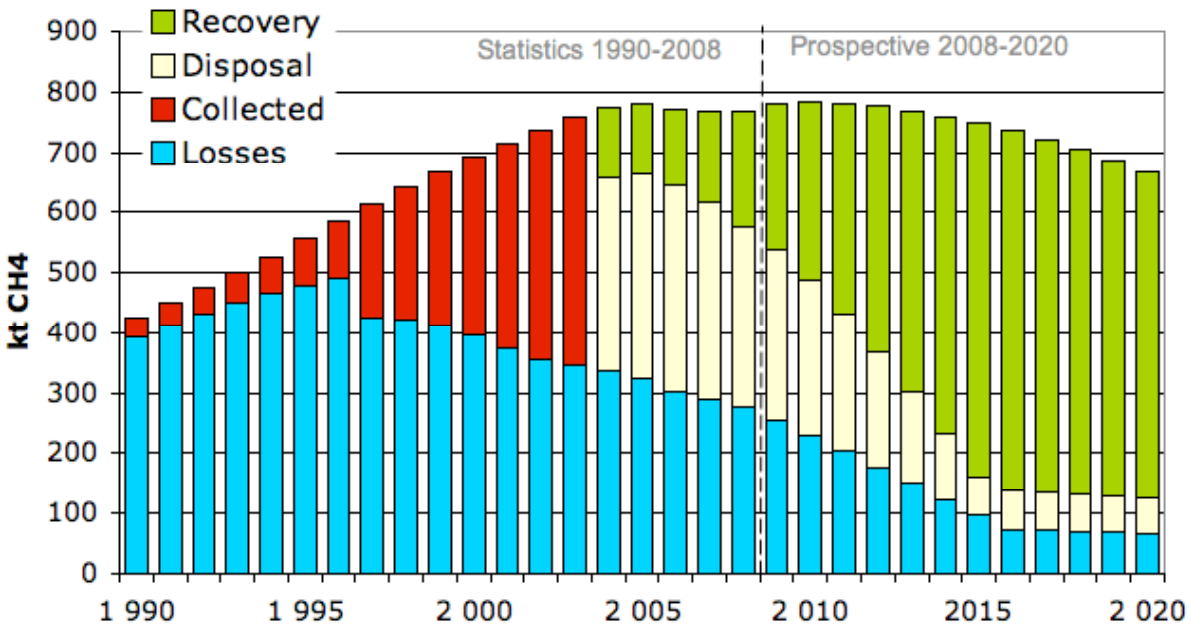
(4) In 2004

* Value calculated from GWh value

4. Detailed review by country

4.1 France

4.1.1 LFG data during the period 1990-2020



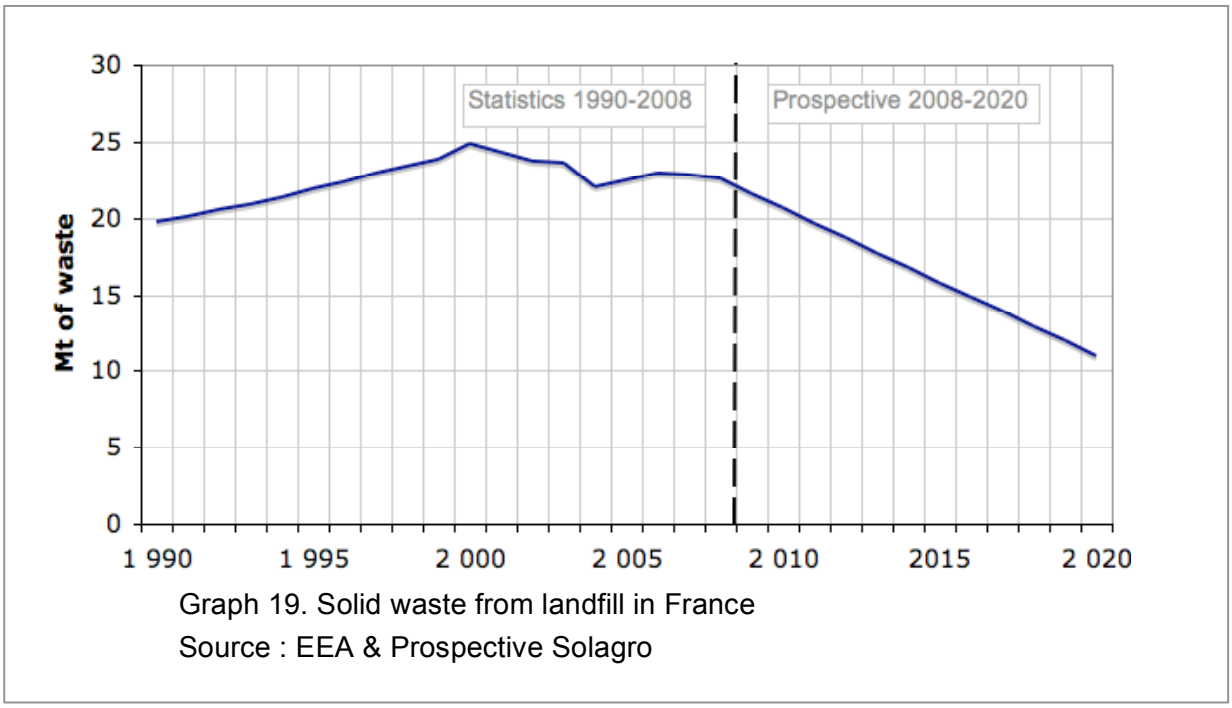
Graph 18. Methane from landfill in France
Source : Solagro & EEA GHG Inventory

		EEA Data				Solagro prospective		
FR	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Landfilled SW	Mt SW	19,7	21,9	24,9	22,5	20,6	15,8	11,0
Production	kt CH4	426	556	692	781	782	748	666
Emissions	kt CH4	392	478	396	323	230	96	67
Collection	kt CH4	34	78	296	459	553	652	599
Collection rate	%	8%	14%	43%	59%	71%	87%	90%
Disposal	kt CH4	-	-	-	340	257	65	60
Energy recovery	kt CH4	-	-	-	118	296	587	540
Recovery rate	%	-	-	-	26%	54%	90%	90%

Table 10. LFG data 1990-2020 - Source: Solagro

4.1.2 Landfilled waste

In France, 22 Mt of waste were landfilled in 2008. In 2007 around 40% of the municipal waste generated was landfilled.



Graph 19. Solid waste from landfill in France

Source : EEA & Prospective Solagro

11 Mt are expected to be landfilled in 2020. Compared to 1995, the expected reduction for the total amount of waste in 2016 is 32%.

4.1.3 Biogas production, collection and flaring

4.1.3.1 Biogas production

The production of LFG in France is estimated to 768 kt CH_4/year (2.2 billion m^3 LFG at 50% methane) in 2008.

4.1.3.2 Methane losses

Methane emissions (lost) keep on decreasing.

4.1.3.3 Biogas use

492 kt CH_4 were collected in 2008 – i.e. 64% of the produced methane. The gas collection increased significantly from 8% in 1990 to 57% in 2004, and seems stable at around 57% since then.

Whereas 27% of methane were converted into energy in 2004, the recovery ratio was 32% in 2008. The electricity production from LFG was around 735 GWh el. in 2007. The heat production from CHP system was 81GWh th. The global capacity of LFG-to-energy plants was 106MW according to official statistics from SoES.

4.1.4 Prospective

According to our assumptions, 14 Mt waste should still be landfilled in 2016. In this estimation both Directive Landfill and Grenelle targets were taken in account. Grenelle target is a reduction of -15% of landfill and incinerated waste in 2012 compared to 2020. ADEME estimates that it should lead to 16Mt of landfilled waste only in 2012 in landfilled operated by private company.

LFG energy recovery increased by 150% from 2004 to 2007 but the potential is still huge. We estimate that it could still increase fivefold to reach 547 kt of CH_4 used for electricity in 2020 (i.e. 2,2 TWh), if the energy recovery ratio increases up to 90% in 2016, which implies a 7% increase ratio per year. This scenario depends, for a part, on how the TGAP discount will impact the current situation.

4.1.5 Current landfill management

Municipalities are responsible for municipal waste. “Departments” are responsible for non-hazardous waste excluding municipal waste. Operators are private or public. According to the BIPRO study there were 303 landfills for non-hazardous waste in 2007. The EEA reports that 75% of landfilled waste are stored in landfills that collect biogas. Actually 195 landfills collect biogas.

In 2009, 71 sites stated that biogas valorisation was available in ADEME survey, however 49 sites only reported the quantity of energy produced. 10 of them are equipped with CHP system.

4.1.6 LFG policy in France

4.1.6.1 Main national legislation references

- « Arrêté du 09/09/97 relatif aux installations de stockage de « déchets non dangereux » » (related to non-hazardous waste landfill) [1]

- « Circulaire du 06/04/10 sur la TGAP » and « Code des douanes – Art . 266 nonies & sexties » (related to the French green tax, landfill included) [2]

- « Arrêté du 10/07/06 fixant les conditions d’achat de l’électricité produite par les installations qui valorisent le biogaz » (related to the feed-in tariff for the electricity recovered from biogas)[1]

4.1.6.2 Synthesis

In France, LFG collection has been mandatory since 1997.
The LFG policy is based on a feed-in tariff for electricity.

- **Feed-in Tariff**

The LFG price of sell has not changed since July 2006. Here is the current regulation:

1) A base price (most cases) depending only on the power: 75 to 90 €/MWh.

A typical 1 MW generator, without energy bonus, can sell the electricity at **83 €/MWh.**

2) An energy efficiency bonus : from 0 € to 30 €

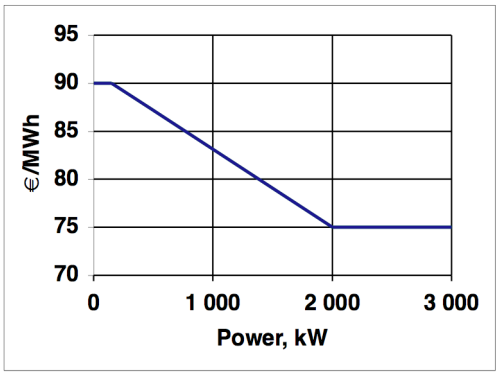


Figure 3 : Base price for LFG electricity

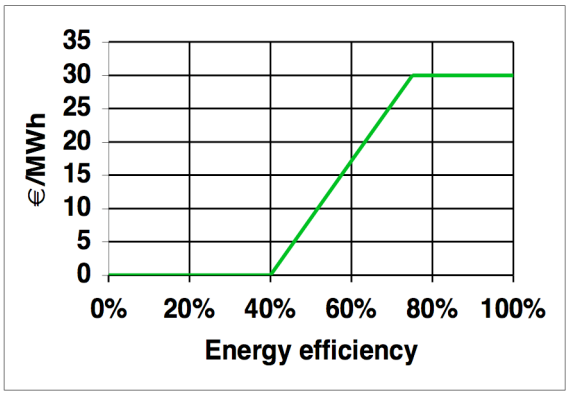


Figure 4 : Energy efficiency bonus

[1] Available in : http://www.legifrance.gouv.fr

[2] Available in : http://www.douane.gouv.fr/page.asp?id=3916

- **Tax on landfill**

The « TGAP » is a French tax paid by the activities which generate pollution. It was created in 1999. Landfills are subject to the TGAP .

Since January 1, 2010, a discount is applied to landfills which use biogas for energy production. Here is the tariff scale :

	Amount of the tax (per ton) without the coefficient k						
Case	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**A partir de 2015**
Non-legislative compliant landfill	50 €	60 €	70 €	100 €	100 €	100 €	150 €
ISO14001 or EMAS certified landfill	13 €	17 €	17 €	17 €	24 €	24 €	32 €
Energy recovery rate * from biogas > 75%	10 €	11 €	11 €	15 €	15 €	20 €	20 €
Others	15 €	20 €	20 €	20 €	30 €	30 €	40 €

Table 11 : Source : Legifrance

* The energy recovery rate from biogas is : the quantity of biogas used for energy over the total quantity of biogas produced (flared gas included). Also a constant is added to take in account the biogas losses so that biogas loss reduction also allows to increase the energy recovery rate.

Those tariffs are then multiplied by a coefficient k depending on the ICPE classification. Last update of those coefficients has been done by the “Décret n° 2010-576” on May 31, 2010. For the 2760 ICPE section, applied to non-hazardous landfill, the coefficient is unchanged. It is equal to 3 or 6 depending on the plant capacity.

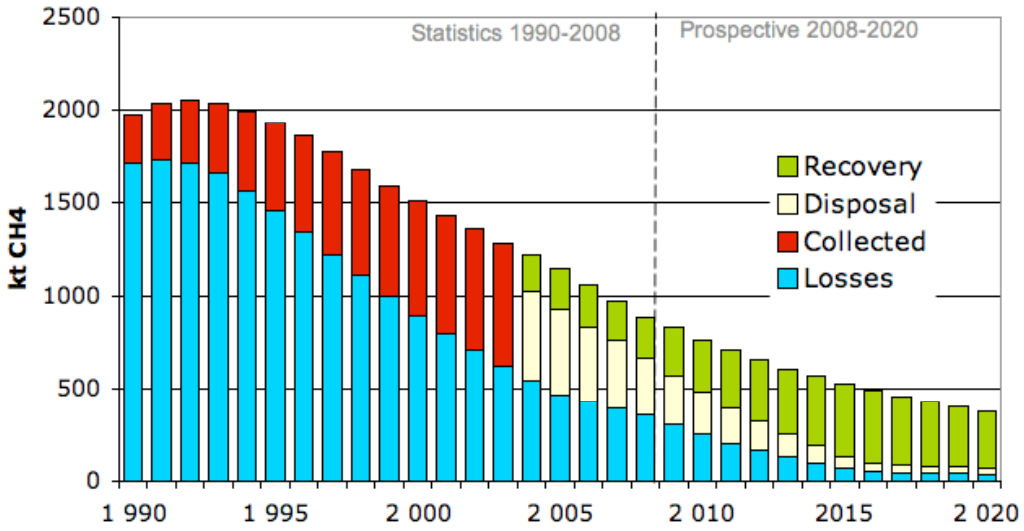
Also the Decret n°2009-1441 (November 2009) allows a total exemption of TGAP for bioreactor plants that:

- are used as waste disposal and
- are classified as ICPE and
- are equipped with a system allowing to convert 100% of produced biogas into energy as soon as they are opened and starts energy production no longer than 1 year after the opening date.

The exemption is cancelled if energy production is stop longer than 48 hours during the year.

4.2 Germany

4.2.1 LFG data during the period 1990-2020



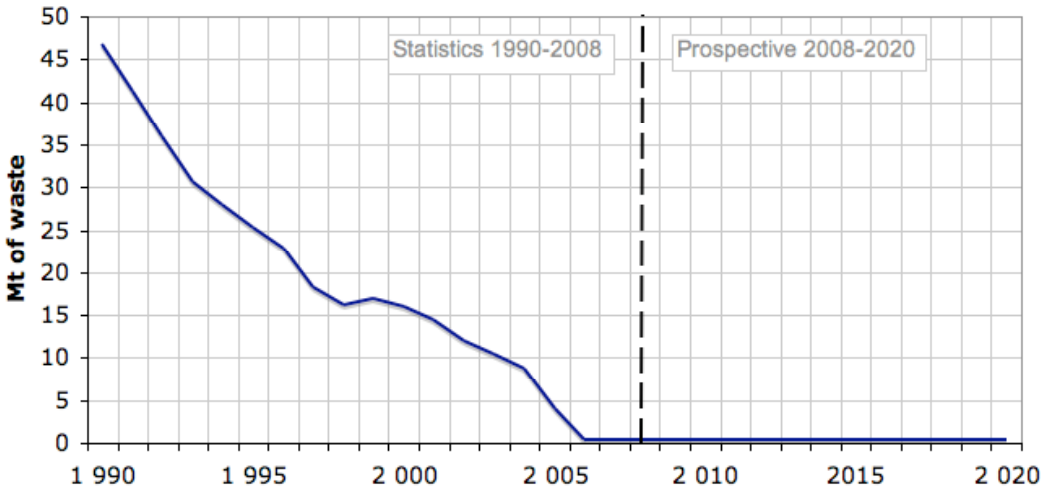
Graph 20. Methane from landfill in Germany
Source: EEA & Prospective Solagro

		EEA Data				Solagro prospective		
DE	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Landfilled SW	Mt SW	46,7	25,4	16,0	4,1	0,3	0,3	0,3
Production	kt CH4	1978	1932	1512	1147	763	525	372
Emissions	kt CH4	1710	1461	892	464	251	73	37
Collection	kt CH4	268	471	620	683	512	452	335
Collection rate	%	14%	24%	41%	60%	67%	86%	90%
Disposal	kt CH4	-	-	-	463	229	58	33
Energy recovery	kt CH4	-	-	-	220	283	394	301
Recovery rate	%	-	-	-	32%	55%	87%	90%

Table 12 : Source: EEA & Prospective Solagro

4.2.2 Landfilled waste

In 2008, Eurostat reported that 296 t of municipal waste were landfilled. In 2005, around 4Mt were reported as being landfilled.



Graph 21. Solid waste from landfill in Germany

Source: EEA & Prospective Solagro

Since July 1, 2005, biodegradable waste landfilling is forbidden. To be landfilled waste must have been burnt or processed by Mechanical-Biological Treatment before.

There is a high recovery rate of waste in Germany. Most biodegradable waste are collected and recovered separately and then processed into compost.

4.2.3 LFG production, collection and flaring

4.2.3.1 Biogas production

The production of LFG in Germany is estimated to 884 kt CH_4/year (2.4 billion m^3 LFG at 50% methane) in 2008.

4.2.3.2 Methane losses

Methane emissions keep on decreasing, as the gas production is also decreasing.

4.2.3.3 Biogas use

526 ktCH_4 were collected in 2008 – i.e. 60% of the produced methane. The gas collection ratio increased from 14% in 1990 to 60% in 2005 but seems stable since then.

According to the German Ministry of the Environment, electricity production from LFG was around 1020 GWh el. in 2008. The heat production, if any, is not reported by statistics.

4.2.4 Current landfill management

According to the EEA, in 2004, there were 150 landfills in Germany. 95% of the landfills collected the biogas with an average efficiency of 60%.

In Germany there are no known illegal landfills. Landfills without permit in the new Federal States after the reunion in 1990 were closed or permitted within a short time.

4.2.5 Prospective

As European targets are met already by Germany, minor evolution is expected. The amount of biogas produced should decrease slowly, where as the collection rate and energy efficiency may increase to 90%. The amount of energy produced is expected to be stable (i.e. around 1000 GWh el.).

4.2.6 LFG policy in Germany

4.2.6.1 Main national legislation references

- « Erneuerbare-Energien-Gesetz 2009 » (law about renewable energies 2009) [1]

4.2.6.2 Synthesis

The new feed-in tariff entered in force on January 1, 2009. The tariff increased for small plants. Section 24 of the EEG 2009 describes the tariff that should be applied to LFG:

Condition	Tariff
LFG-to-energy plants < 500kW	**90 €/MWh**
LFG-to-energy plants from 500kW to 5MW	**61,6 €/MWh**

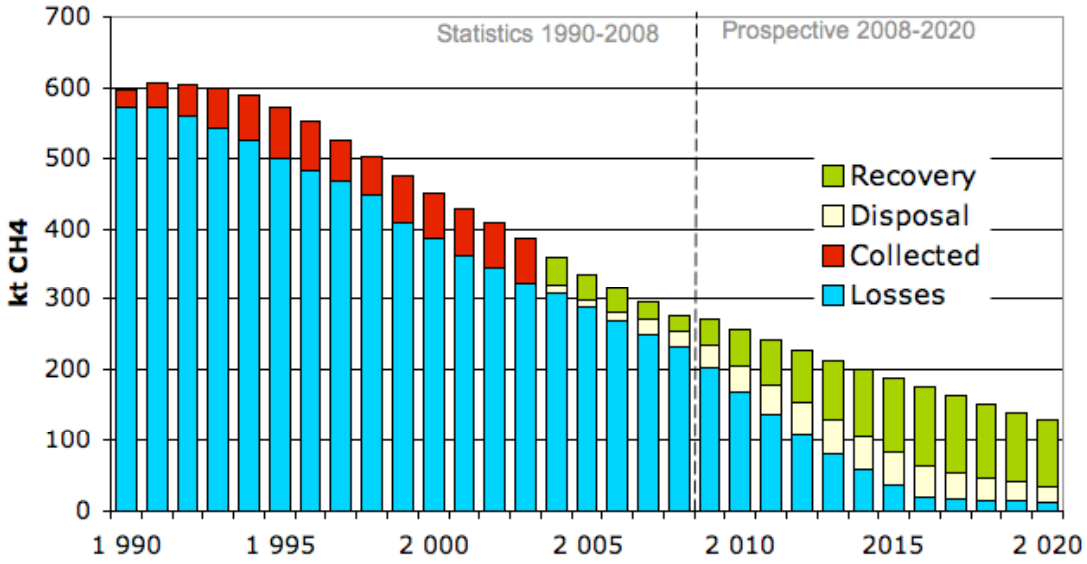
Table 13 : Source : *: Erneuzebare-Energien Gesetz 2009*

According to the efficiency of the plant, an « innovative technology bonus » from 10 €/MWh to 20 €/MWh can be added.

[1] Available in : http://www.erneuerbare-energien.de/inhalt/43019/40508/

4.3 The Netherlands

4.3.1 LFG data during the period 1990-2020



Graph 22. Methane from landfill in the Netherlands

Source: EEA & Prospective Solagro

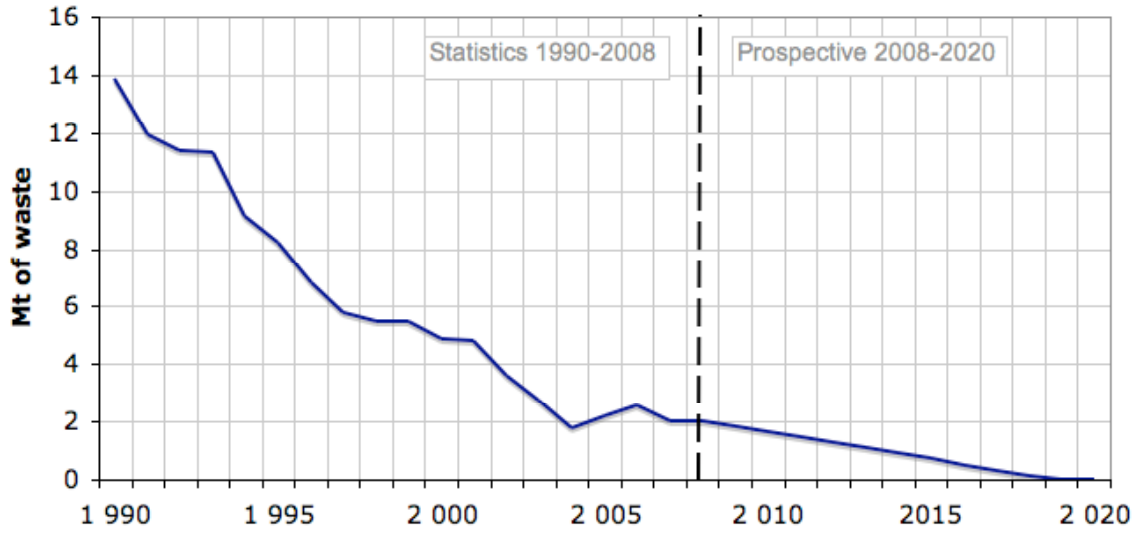
		EEA Data				Solagro prospective		
NL	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Landfilled SW	Mt SW	13,9	8,2	4,8	2,2	1,6	0,7	0,0
Production	kt CH4	598	574	451	336	256	188	131
Emissions	kt CH4	572	500	386	289	168	37	13
Collection	kt CH4	26	74	66	47	88	151	118
Collection rate	%	4%	13%	15%	14%	34%	80%	90%
Disposal	kt CH4	-	-	-	9	38	47	22
Energy recovery	kt CH4	-	-	-	38	50	104	95
Recovery rate	%	-	-	-	80%	57%	69%	81%

Table 14 : Source: EEA & Prospective Solagro

The collection rate is lower than collection rate stated by other countries. According to NL experts, these data are based on actual measured gas collection rates. Consequently they are more reliable than estimated collection rate provided by other countries.

4.3.2 Landfilled waste

In the Netherlands, 2 Mt of waste were landfilled in 2008. In 2007, around 3% of the municipal waste generated was landfilled.



Graph 23. Solid waste from landfill in the Netherlands
Source: EEA & Prospective Solagro

4.3.3 LFG production, collection and flaring

4.3.3.1 Biogas production

Production of LFG is estimated to 277 kt CH_4/year (0.275 billion m^3 LFG at 50% methane) in 2008.

4.3.3.2 Methane losses

Methane losses keep on decreasing as gas production also decreases.

4.3.3.3 Biogas use

44 ktCH_4 were collected in 2008 – i.e. 16% of produced methane. The biogas collection rate is stable at around 15% since 2000.

Electricity production from LFG was around 110 GWh el. in 2007. The heat production was 10,45GWh th for own use of the sites and 5,3GWh th were injected to the Grid.[1]

[1] Source : SenterNovem. Afvalverwerking in Nederland. Nederland : November 2007 – p70-71 – Table 5-C

4.3.4 Current landfill management

In 1997, there was a decision to centralise responsibility for waste management from provincial authorities through central government authorities.

No illegal landfills are known however, as in other countries, 3 900 old landfills are still reactive. 39 landfills recover energy from landfill biogas.

In the Netherlands waste policy strongly aims at reducing landfilling. Today, recycling rate is 77% of the waste production.

The objective of the National Waste Management Plan (2002-2012)[1] is to achieve 2 Mt of landfilled waste in 2012. The waste plan is as follows : high recycling and re-use rate and incineration with high-energy efficiency of residual combustible waste.

To achieve the goal of « preventing landfilling » several mechanisms were put in place.

- Landfill bans were created by the Waste Decree in 1995 and covered 35 types of waste, including household in 1998. Therefore, biodegradable municipal waste are banned from landfills. The objective is that all combustible waste are banned from landfills and incinerated with high-energy efficiency instead.
- A tax on landfill was established in 1995 and was raised since then. The tax was at 13.27 € per ton in 1995 and increased to 85 € per ton in 2009 for combustible waste. Thus combustible waste landfilling is more expensive than incineration.

4.3.5 Prospective

The context is similar to situation in Germany. However the collection rate is very low (16%) (as methodology report for methane emissions is different than other countries) that is the reason why the estimation foresees an increase of the produced energy up to 683 GWh el. in 2016 and then a decrease down to 432 GWh el. in 2020.

4.3.6 LFG policy in the Netherlands

4.3.6.1 Main national legislation references

- Environment Taxes Act (1995)
- Environment Act (1993) which made LFG collection mandatory from 1993.

4.3.6.2 Synthesis

Regarding landfill biogas, green certificates and feed-in tariff exist.

- **Feed-in tariff**

The new support system is called « Subsidies Duurzame Energie » (SDE). The tariff is decided for one year. Thus each year the Ministry of Economic Affairs publishes the new tariffs. The tariffs are evaluated and changed each year depending on the electricity market price.

In 2010, feed-in tariff for electricity from landfill biogas is of **59 €/MWh** (all inclusive, electricity market price included).

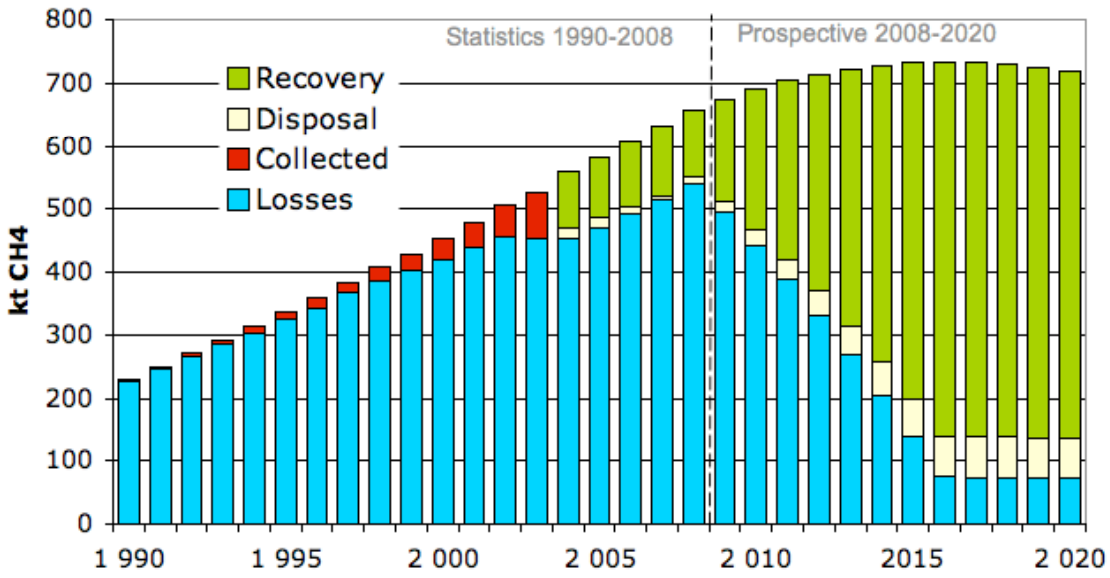
- **Green Certificate**

A green certificate market also exists for renewable electricity and renewable gas but no GC are issued for LFG for many years.

[1] The National Waste Management Plan 2002-2012 can be downloaded from: http://www.senternovem.nl/Waste_Management_Department/policy/national_wmp/policy_framework.asp

4.4 Spain

4.4.1 LFG data during the period 1990-2020



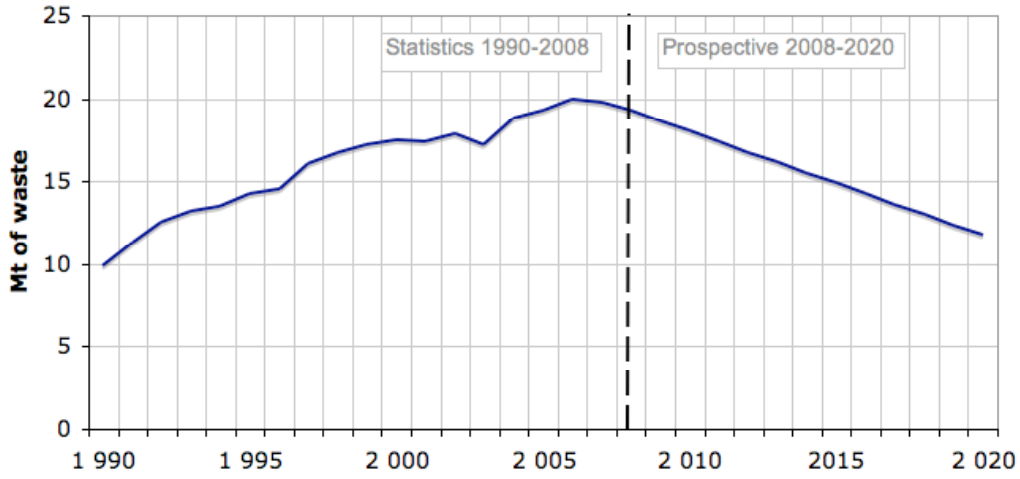
Graph 24. Methane from landfill in Spain
Source: EEA & Prospective Solagro

		EEA Data				Solagro prospective		
SP	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Landfilled SW	Mt SW	9,9	14,3	17,5	19,3	18,0	14,9	11,8
Production	kt CH4	229	336	454	583	691	732	720
Emissions	kt CH4	226	323	419	470	443	140	72
Collection	kt CH4	3	13	35	113	248	591	648
Collection rate	%	1%	4%	8%	19%	36%	81%	90%
Disposal	kt CH4	-	-	-	16	25	59	65
Energy recovery	kt CH4	-	-	-	97	223	532	583
Recovery rate	%	-	-	-	86%	90%	90%	90%

Table 15 : Source: EEA & Prospective Solagro

4.4.2 Landfilled waste

In the Spain, 19 Mt of waste were landfilled in 2008. In 2007, 68% of the municipal waste generated were landfilled. The amount of waste landfilled started decreasing in 2006.



Graph 25. Solid waste from landfill in Spain
Source: EEA & Prospective Solagro

4.4.3 LFG production, collection and flaring

4.4.3.1 Biogas production

Production of LFG is estimated to 656 kt CH_4/year (1.8 billions m^3 LFG at 50% methane) in 2008.

4.4.3.2 Methane losses

Methane losses remain high and are still increasing as the amount of waste increased until 2006 .

4.4.3.3 Biogas use

117 ktCH_4 were collected in 2008 – i.e. 18% of the produced methane. The gas collection rate increased from 1% in 1990 to 19% in 2004. It is stable since then.

Over the period 2004-2007, the energy recovery ratio is very high (around 90%). This may indicate that these landfills that are equipped with a gas collection system, are automatically equipped with a LFG-to-Energy plant. The electricity production from LFG was 490 GWh el. in 2006 according to the national plan for renewable energy called “PANER” (i.e. need of 130 000 households).

4.4.4 Current landfill management

In Spain, landfill of municipal waste is the competency of Autonomous Regions and local entities. The National Plan for waste management (PNIR) published in 2008 indicates 183 municipal landfills in Spain in 2006. In 2007, the ATEGRUS association reported 207 non-hazardous landfills. The repartition based on the size is as follow:

< 5kt/y	5kt/y - 10kt/y	10kt/y - 50kt/y	50kt/y-100kt/y	100kt/y-300kt/y	>300kt/y
12%	13%	32%	17%	17%	9%

Table 16 . source : ATEGRUS

Since 2005, 13 landfills were opened and 21 were closed (considering all types of landfills). [1]

Regarding biogas management, here are the main figures provided by the Spanish Ministry of the environment for 2006 :

- 19% of the total number of landfills implemented energy recovery from biogas. (i.e. 34 municipal landfills and 63% of the total amount of landfilled municipal waste)

- 13% of landfills burned the biogas. (i.e. 24 municipal landfills and 6% of the total amount of landfilled waste).

That means that 68% of the total number of landfills did not perform any biogas treatment.

For the BiPRO project, ATEGRUS association analysed landfill management. It states that 35% of the landfills in 2007 in Spain were not equipped with a gas collection system.

ATEGRUS also gives figures about the link between the size of the landfills and the gas treatment. 85% of the big landfills (over 100kt) perform gas treatment whereas 50% of the 5 to 10 kt landfills perform gas treatment and 35% of the small landfill (under 5kt).

Energy recovery increases with the size of the landfill: none of the landfills under 10kt do energy recovery whereas 70% of the gases of the landfills over 300kt are converted into energy. On the contrary, the part of burned gas does not depend on the size of the landfill.

Major issues identified by the BiPRO project regarding landfill biogas use:

- lack of accredited laboratories
- problems to achieve obligation of gas treatment at small sites
- insufficient energy recovery and controlled biogas flaring

However ATEGRUS noticed an improvement compared to the situation in 2005.

[1] ATEGRUS Observatorio IV Edicion 2005-2007 - BiPRO Project

4.4.5 Prospective

The target of the National Waste Management Plan (2011-2020) is to landfill 4,2Mt of biodegradable in 2016.

Following a median scenario, landfilled waste are expected to decrease to 11Mt in 2020.

Gas production is expected to increase until 2016.

Production target for biogas energy (considering all sources of biogas) was 235 MW in 2008 (i.e.1417 GWh el.) according to the Spanish Renewable Energy Plan (2005-2010). In 2007 the capacity of the biogas plants (all sources considered) was 165 MW and landfill biogas production was 35% of total biogas production. Keeping the same proportion of landfill biogas the objective was of 495 GWh el. in 2008 for landfill biogas.

The Renewable Energy Plan for 2011-2020 (PANER), published in June 2010, set an objective of diverting combustible waste from landfill for 2016-2020 and producing more energy from landfill biogas. The plan set the following targets: 140 ktep (i.e 569GWh) from landfill biogas in 2015 and 110 ktep (i.e 447GWh) from landfill biogas in 2020.

Our estimation expects an energy production of 2.3 TWh in 2020 with the assumption that collection rate is strongly improved up to 90% and the energy recovery ratio remains the same (90%).

4.4.6 LFG policy in Spain

4.4.6.1 Main national legislation references

- Royal Decree 661/2007 (related to feed-in tariff)

4.4.6.2 Synthesis

Renewable energy producer have to choose between 2 options:

- register to a fixed feed-in tariff during the programming period

or

- sell the electricity with the current electricity market price and add a fixed premium.

Formulas for those 2 tariffs are:

Electricity sold to the grid (Regulated Tariff) = Ptr + CR (+ DH) (+ Cef) - Des

Electricity sold on the market (Market Tariff) = MP + P + CR (+ Cef) - Des

Where :

For both tariffs :

CR : Bonus for installation that uses reactive energy (better energy efficiency)

Cef : Bonus for energy efficiency (applicable to CHP only).

Des : Penalty for difference between forecast and real production

Regulated tariff only :

Ptr : Regulated tariff, ~80 €/MWh

DH : Bonus for peak power (applicable to CHP only).

Market tariff only :

MP : Market price

P : Prime (only for plants that are less than 15-year-old)

a) Market Tariff

Market Tariff depends on market price for electricity as following. For plants that are more than 15 year old, no prime is given. The renewable electricity is sold at market price.

	A	B	C	D
Market price (MP)	≤ 36,6	36,6≤MP≤51,8	51,8≤ MP ≤89,6	>89,6
P (Prime)	Δ	37,8	Δ	0
MP + P	74,4	74,4 ≤ MP+P≤ 89,6	89,6	= MP

Table 17 : Electricity pricing in Spain for landfill biogas (section b.7.1) – RD 661/2007

Case A :

If Market Price is under 36,6 €/MWh, then a prime is given to the producer in order to guarantee a price of 74,40 €/MWh. The price paid to the producer may include several other components.

Case N :

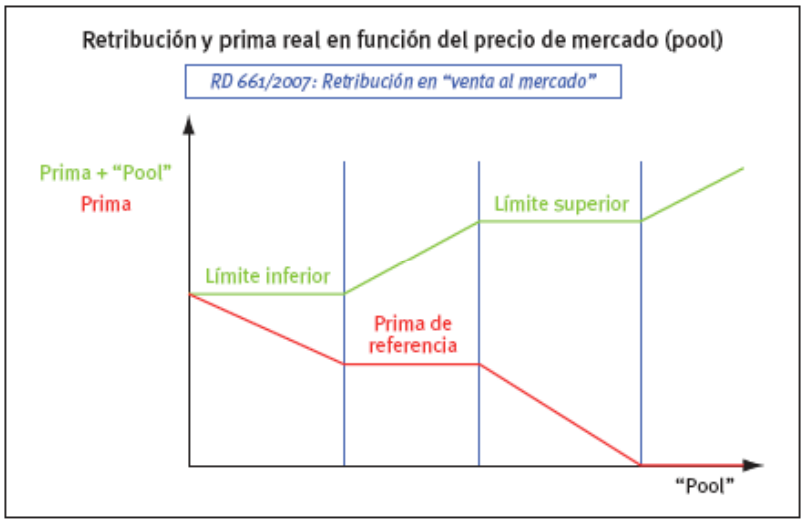
If Market Price is between 36,6 and 51,8 €, the prime is fixed at 37,784€. The payment to the producer varies with the market price.

Case C :

If Market Price is between 51,8 and 89,6 €, the prime decreases in order to maintain the payment at 89,6 €

Case D :

Over 89,6 €, there is no more prime and the payment is directly linked to the market price.



Graph 26. Electricity pricing in Spain

Source: IDEA. "Biomasa : Produccion electrica y cogeneration". 2007

b) Energy Efficiency bonus

The calculation of the Energy efficiency bonus for CHP is base on the REE or "electricity equivalent efficiency".

REE = E / (Q - V / thEff) with :

E = electricity produced

Q = fuel consumption (LCV of the landfill gas)

V = cogenerated heat, effectively used

Th EFF = efficiency of the boiler for the substituted fuel

For landfill gas, in minimum REE (REE min) is set at 50%.

The REE of a LFG energy recovery scheme must be higher than this REE min.

The efficiency bonus is calculated according to this formula :

Cef = 1,1 x (1/ REE min - 1 / REE) x Cmp, with:

Cmp = price for fuel, ~20 €/MWh

According to Spanish experts, the maximum efficiency bonus is about +3 €/MWh el.

c) Regulated Tariff

The regulated tariff is from 65€/MWh el. to 82€/MWh el. depending on the kind of energy system and the age of the facility.

Following table gives regulated tariff :

			Feed-in tariff
Landfill biogas	Capacity (MW)	Life (year)	Feed-inTariff (€/MWh)
Biomasse	-	0-15	79.92
Biomasse	-	>15	65.1

Table 18 : Source RD 661/2007 - section b.7.1

4.4.6.3 Modifications planned in PANER 2011-2020

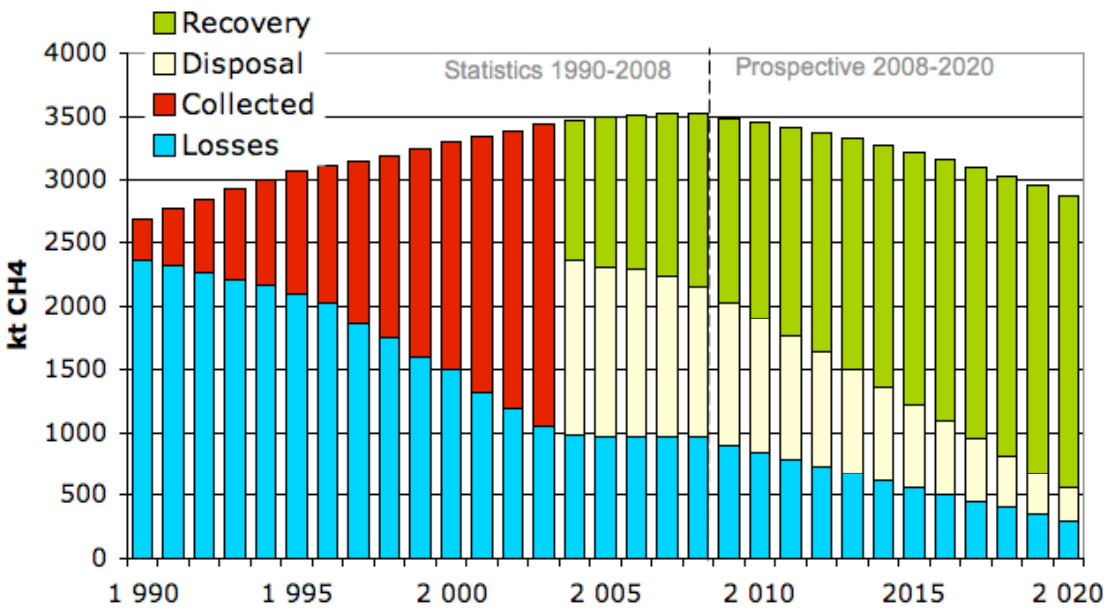
Both fixed tariff and primes is expected to increase by 5€/MWh in average and the period is expected to be extended from 15 years to 25 years.

Dos opciones de venta de electricidad			**Opción a)**	**Opción b) Venta en el mercado organizado de la electricidad**		
Subgrupo	**Potencia**	**Plazo**	**Tarifa regulada c€/kWh**	**Prima de referencia c€/kWh**	**Límite superior c€/kWh**	**Límite inferior c€/kWh**
b.7.1 (biogás de vertederos)		primeros 25 años	8,4551	4,4721	9,4792	7,8711
		a partir de entonces	6,8872			

Table 19 : Source PANER 2011-2020 - Pricing for electricity from Landfill biogas

4.5 United Kingdom

4.5.1 LFG data during the period 1990-2020



Graph 27. Methane from landfill

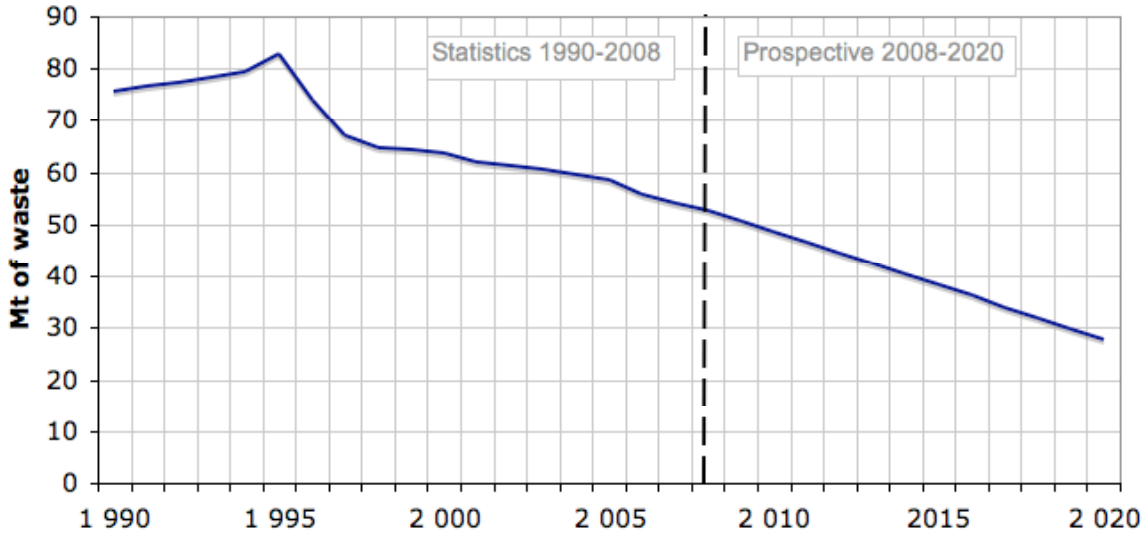
Graph 19. Source: EEA & Prospective Solagro

		EEA Data				Solagro prospective		
UK	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Landfilled SW	Mt SW	75,6	82,7	63,8	58,4	48,5	38,2	27,9
Production	kt CH4	2685	3060	3294	3492	3454	3219	2869
Emissions	kt CH4	2363	2099	1501	964	845	562	300
Collection	kt CH4	322	962	1793	2528	2609	2657	2569
Collection rate	%	12%	31%	54%	72%	76%	83%	90%
Disposal	kt CH4	-	-	-	1346	1054	661	257
Energy recovery	kt CH4	-	-	-	1182	1556	1996	2312
Recovery rate	%	-	-	-	47%	60%	75%	90%

Table 20 : Source: EEA & Prospective Solagro

4.5.2 Landfilled waste

In the United-Kingdom, 52 Mt of waste were landfilled in 2008. In 2007, around 60% of municipal waste generated were landfilled. The UK is the European country that has the largest amount of landfilled waste.



Graph 28. Solid waste from landfill in United Kingdom

Source: EEA & Prospective Solagro

4.5.3 LFG production, collection and flaring

4.5.3.1 Biogas production

Production of LFG is estimated to 3521 kt CH_4/year (9.9 billion m^3 LFG at 50% methane) in 2008.

4.5.3.2 Methane losses

Methane losses decreased until 2003. Since then they are stable and are equal to 960 kt CH_4/year.

4.5.3.3 Biogas use

2561 ktCH_4 were collected in 2008 – i.e. 73% of produced methane. This is the most important methane recovery ratio in the EU-25. This ratio is stable since 2004. The energy recovery rate increased from 44% in 2004 to 50% in 2007.

Electricity production from LFG was around 4.7 TWh in 2008[1]. The global capacity of LFG-to-Energy plants was 908 MW el. in 2008[1]. The primary energy of LFG used for heat production was 13ktoe (compared to 1560 ktoe for electricity production) [1].

4.5.4 Current landfill management

The tradable green certificate system led to a large expansion of landfill gas use.

The UK uses the possibility given by the Landfill Directive 1999/31/EC to delay the completion of biodegradable landfilling objectives to 4 years after since more than 80% of the waste were landfilled in 1995.

Regarding non-hazardous waste, there were 284 landfills in 2008 in the UK.

[1] source : DUKES All energy statistics are available in :
http://www.decc.gov.uk/en/content/cms/statistics/publications/dukes/dukes.aspx

4.5.5 Prospective

The target of the United Kingdom government is to reach 10Mt of biodegradable landfilled waste in 2020. This target is still in discussion with the European commission.

Following a median scenario, the amount of landfilled is expected to decrease to 27Mt in 2020.

Our estimation foresees an energy production of 11.5 TWh in 2020 with the assumption that collection rate and energy recovery ratio are strongly improved up to 90%.

In 2007, 357 LFG-to-energy plants claimed ROC. In Northern Ireland, there is no energy recovery from LFG.

4.5.6 LFG policy in United Kingdom

4.5.6.1 Main national legislation references

- Utilities Act 2000 (related to ROC)

4.5.6.2 Synthesis

Three financial supports take place in UK for renewable energies : Feed-In Tariff, Renewable Obligation Certificate (ROC) and Climate Change Levy (CCLL).

- **Renewable Obligation Certificate (ROC)**

Since April 2002, electricity providers are obliged by the Secretary of State to include a specified percentage of renewable energy in their total electricity sales in the UK. The percentage is increasing. In 2005 it was 5.5% (2.5 % in Northern Ireland). In 2008, 7.9%, and it is planned to reach 14.5% in 2015. To control this obligation, they must get a certain amount of Renewable Obligation Certificates each year.

To get a ROC they can either produce the accurate amount of renewable energy by themselves or buy a ROC to a renewable energy supplier. In case they fail to show the correct amount of ROC, they have to pay a buy-out price to the Ofgem (regulation organism). The « buy-out » funds are then shared between the suppliers that have a correct amount of ROC.

Here are the new prices and figures related to ROC mechanism :

Average price for a ROC (25/03/2010) : 57,8 €/ROC

Buy-out price (2010) : 44,7 €/ROC

To the ROC value, the electricity market price is added.

Electricity market price (2008) : 104 €/MWh

Technology	Level of Support (ROCs/MWh)	Number of MWh to be generated for 1 ROC to be awarded
Landfill gas in the UK (Except Northern Ireland)	0,25	4
Landfill gas in Northern Ireland	1	1

Table 21 : ROC Reward in 1st of April 2010. Source : Ofgm [1]

Reward has been decreased for landfill biogas as it is a well-established technology except in the North of Ireland.

[1] See: **Ofgm**. *Renewables Obligation : Guidance for generators*. London : April 2010. Available in : www.ofgm.gov.uk

In 2006-2007, the landfill biogas is the main renewable energy chain that took advantage of this financial system. Thus, 28% of the total amounts of ROCs provided to the Ofgem were from landfill gas. This seems to be due to the profitability of landfill biogas chain compared to other renewable energy resource. Indeed the UK system promotes the most profitable chain.[2]

Those figures lead to a total price of sale of **118 €/MWh** for landfill biogas electricity in England , Scottish and Wales; and 162 €/MWh in the Northern Ireland.

- **Climate Change Levy (CCL)**

The Climate Change Levy (CCL) is a charge on energy usage for business and the public sector introduced to encourage energy efficiency. It entered in force in 2001.

To be compliant, consumers that buy energy must :

- Pay the charge : 5,65 €/MWh (2010) or
- Get a 80% discount due to Climate Change Agreements (negotiated in some activity sectors) or
- Give a Levy Exemption Certificate (LEC)

LEC are provided by the supplier of the renewable energy or very efficient plant (CHP).

- **Feed-In Tariff (FIT)**

In April 2010 a Feed-In Tariff scheme was introduced for micro and small generators located in England, Wales and Scotland. This new scheme replaced the Renewables Obligation as the main support for most small-scale generation in Great Britain.

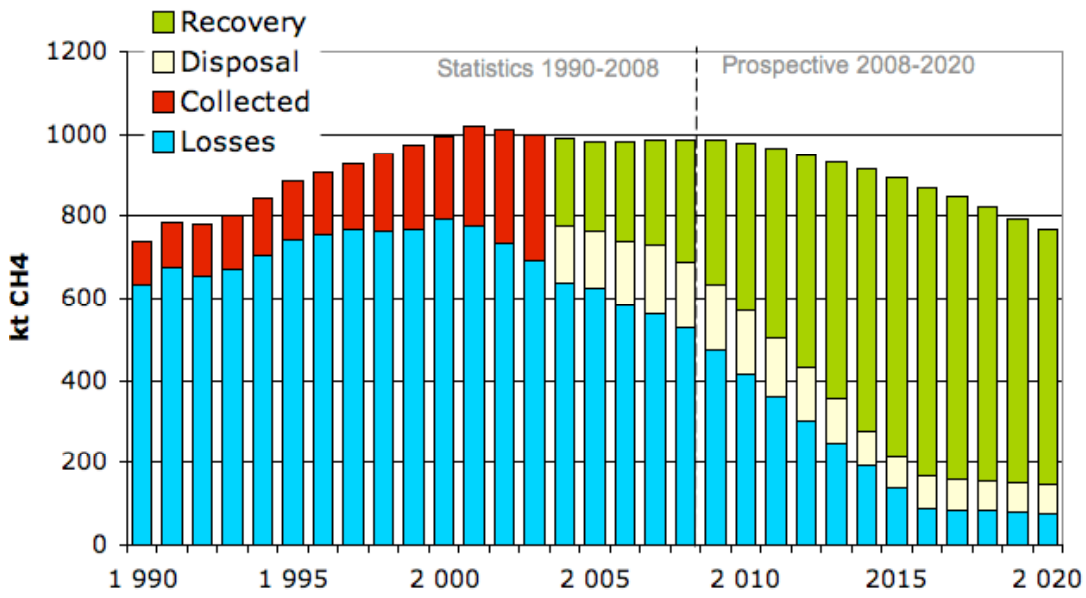
Sewage gas and landfill gas will not be eligible for the FIT, and they will continue to receive ROCs.

The new UK's Feed-in Tariff Programme review is scheduled for 2013.

[2] See: Eurobserver Barometer 186 (June 2008)

4.6 Italy

4.6.1 LFG data during the period 1990-2020



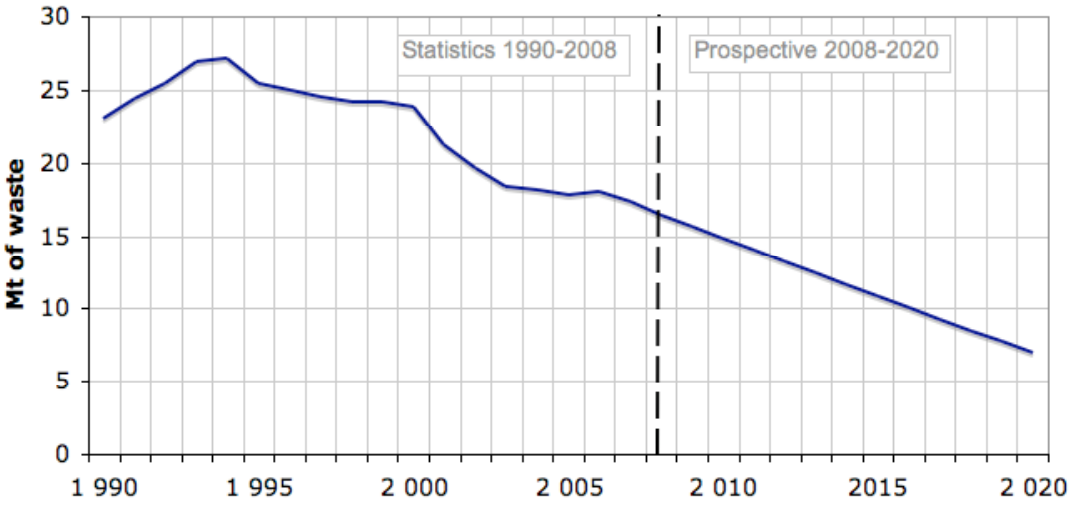
Graph 29. Methane from landfill in Italy
Source: EEA & Prospective Solagro

		EEA Data				Solagro prospective		
IT	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Landfilled SW	Mt SW	23,0	25,5	23,8	17,8	14,8	10,9	6,9
Production	kt CH4	740	883	995	981	976	892	767
Emissions	kt CH4	633	741	794	625	417	140	77
Collection	kt CH4	107	142	201	356	559	752	690
Collection rate	%	15%	16%	20%	36%	57%	84%	90%
Disposal	kt CH4	-	-	-	139	154	75	69
Energy recovery	kt CH4	-	-	-	216	405	677	621
Recovery rate	%	-	-	-	61%	73%	90%	90%

Table 22 : Source: EEA & Prospective Solagro

4.6.2 Landfilled waste

In Italy, 16 Mt of waste were landfilled in 2008. In 2007, this represented around 50% of the municipal waste generated.



Graph 30. Solid waste from landfill in Italy

Source: EEA & Prospective Solagro

4.6.3 LFG production, collection and flaring

4.6.3.1 Biogas production

Production of LFG is estimated to 986 kt CH_4/year (2.8 billion m^3 LFG at 50% methane) in 2008.

4.6.3.2 Methane losses

Methane emissions kept on increasing until 2000. Since then they decrease significantly thanks to an increasing methane recovery rate in landfills [1]

4.6.3.3 Biogas use

458 ktCH_4 were collected in 2008. The gas collection rate increased continuously from 15% in 1990 to 46% in 2007. Over the period 2004-2007, the energy recovery ratio is stable around 55%.

Electricity production from LFG was around 1355 GWh el. in 2008 with a global capacity of 307MW in 2008. In 2006, 1062 GWh el. were produced from electrical only plants and 115GWh el. were produced from CHP plants.[2]

4.6.4 Current landfill management

There are around 269 landfills in Italy, most of them are located in the South of Italy. More than 50% should be closed at the end of 2009 because they are not compliant. From 2003 to 2006, 200 landfills were closed.

[1] Analysis from EEA GHG Inventory 2010

[2] Official national statistics from ISTAT.

4.6.5 Prospective

Landfills are the main source of biogas (aside of sewage sludge and agricultural plants). In 2006, separate collection rate of recoverable waste was 25.8%, the target is now 45%. This will lead to a decrease of landfilled waste.

The Italian waste management plan set a target for landfilled waste of 81kg/year of biodegradable waste per capita in 2018 (5Mt).

Our estimation foresees 7Mt of municipal waste landfilled in 2020.

Our estimation foresees an energy production of 2.5 TWh in 2020 with the assumption that collection rate and energy recovery ratio are strongly improved up to 90%.

4.6.6 LFG policy in Italy

4.6.6.1 Main national legislation references

- Budget Law 2008 (Law 24/12/2007 n°244) (TGC & FIT)

4.6.6.2 Synthesis

In Italy, both green certificates and feed-in tariffs exist for LFG-to-energy plant operators.

- **Tradable Green Certificate (TGC)**

This system is similar to the UK system.

Electricity generator must use a certain percentage of Renewable Energy in electricity production. In 2007, the percentage was 3.05%. This percentage should increase annually by 0.75% to 2012. After 2012, a new annual increase percentage will be established by the Italian government.

Tradable Green Certificates are the evidence of the renewable energy sourcing. Thus a TGC market exists between electricity generators and renewable energy suppliers. The TGC price reached a peak of 139,1 €/MWh in January 2007 then falling down to 80 €/MWh in 2008.

The average value for TGP is currently: 100 €/MWh.

Depending on the renewable source, the Green Certificate corresponds to different amounts of energy. For landfill gas, 0.8 TGP is granted for 1MWh produced.

This is the lowest coefficient. The highest equivalence is for small agricultural biogas plants, big “short chain” farmer biogas plants and high heat efficiency farmer biogas plants.

To the TGC value, the electricity market price is added.

Electricity market price (2008) : 146 €/MWh

Those prices lead to a total price of sale of around 246 €/MWh for landfill biogas electricity.

- **Feed-in Tariff**

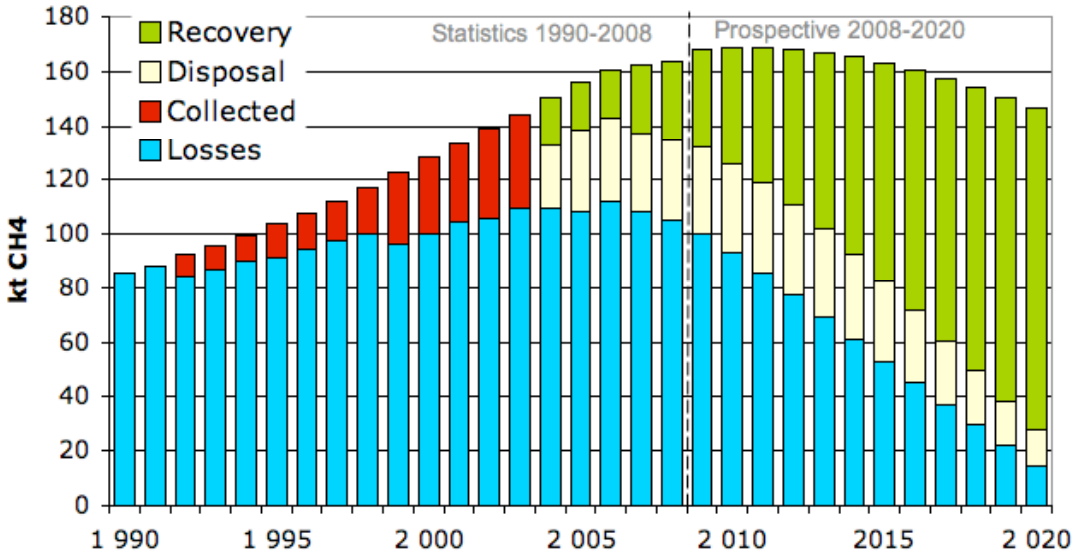
This option is available for small Renewable Energy suppliers (instead of TGP) that started production after January 1, 2008 and whose power is under 1MWh. The electricity is paid after 15 years.

Feed-in Tariff (2009) : 180 €/MWh - This tariff is all-inclusive (i.e. electricity sale price included).

The landfill gas feed-in tariff is the lowest among all renewable sources.

4.7 Greece

4.7.1 LFG data during the period 1990-2020



Graph 31. Methane from landfill in Greece

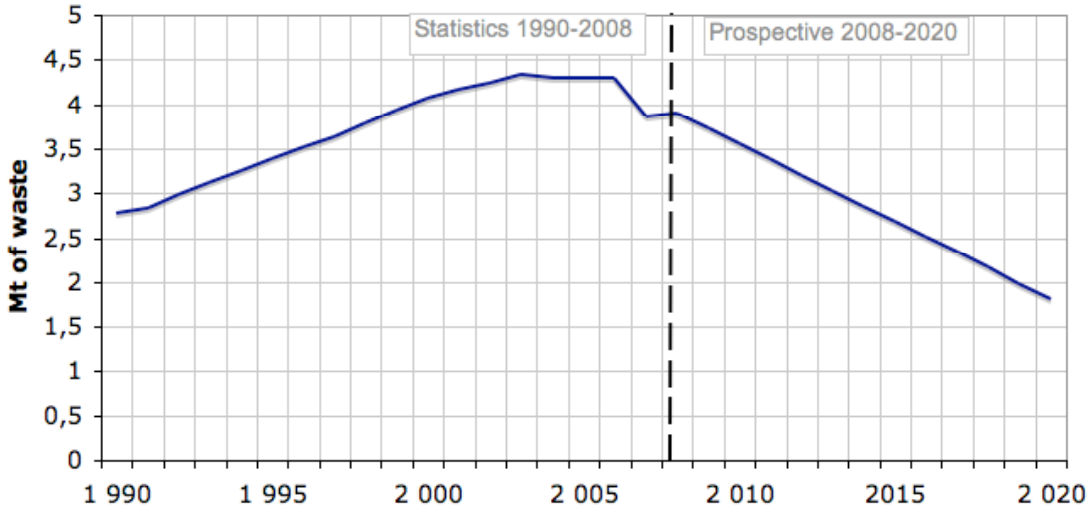
Source: EEA & Prospective Solagro

		EEA Data				Solagro prospective		
GR	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Landfilled SW	Mt SW	2,8	3,4	4,1	4,3	3,5	2,7	1,8
Production	kt CH4	85	104	128	156	169	163	146
Emissions	kt CH4	85	91	100	108	93	53	15
Collection	kt CH4	0	13	28	48	76	110	132
Collection rate	%	0%	12%	22%	31%	45%	67%	90%
Disposal	kt CH4	-	-	-	31	33	29	13
Energy recovery	kt CH4	-	-	-	17	43	81	119
Recovery rate	%	-	-	-	36%	57%	74%	90%

Table 23 : Source : EEA & Prospective Solagro

4.7.2 Landfilled waste

In Greece, 4 Mt of waste were landfilled in 2008. In 2007, around 80% of municipal waste generated were landfilled.



Graph 32. Solid waste from landfill in Greece

Source: EEA & Prospective Solagro

4.7.3 LFG production, collection and flaring

4.7.3.1 Biogas production

Production of LFG is estimated by the EEA to 164 kt CH_4/year (0.5 billion m^3 LFG at 50% methane) in 2008.

4.7.3.2 Biogas use

59 ktCH_4 were collected in 2008 – i.e. 36% of the produced methane.

The gas collection started in 1992 (as far as EEA data are concerned). The collection ratio was 9% in 1990, it increased progressively until 36% in 2008.

The electricity production from LFG was around 120 GWh el. in 2007.

Most of the LFG-to-Energy plants produce electricity.

In 2008, according to a survey of the Centre of Renewable Energy Sources, the power capacity is 28.8MWe thanks to 2 LFG-to-energy systems (23.5 MW el. at Ano Liossia, 5.3 MW el. in Tagaraded).

Another 12.22 MW additional capacity is planned through 2 landfills that have already received their permit.

4.7.4 Current landfill management

The Waste Management Authority of each Administrative Area carries out waste management activities. There is also Regional Waste Management Planning.

In 1998, the intermediate National Planning promoted the construction of 75 landfills in order to accept waste from 75% of the total population. In 2000, 124 landfills were to be constructed. Majority of landfills had a capacity of less than 50 ton per day.

Regarding municipal waste, in 2008, there were 46 landfills in operation. 47 new landfills and 18 extensions were under construction. 30 new landfills and 8 extensions were planned. 37 landfills were considered as "managed" by the EEA. Over the 37 managed landfills, 4 were collecting biogas.

The Ano Liossas (Athena) landfill is the largest landfill in Europe, with 800 kt of waste landfilled per year. This landfill is equipped with gas collection and LFG-to-energy plant.

In 2008, there were 3000 illegal landfills in Greece. 88% were already out of service or closed. According to the Hellenic Solid Waste Management Association, most of the existing landfills will be illegal in 2012 with respect of the landfill directive.

4.7.5 Prospective

National waste management plan target that 2,7Mt of biodegradable waste should be diverted in 2016.

Landfilled waste are expected to decrease to 1.8Mt in 2020.

Our estimation foresees an energy production of 613 GWh el. in 2020 with the assumption that collection rate and energy recovery ratio are strongly improved up to 90%.

4.7.6 LFG policy in Greece

4.7.6.1 Main national legislation references

- Law 3468/2006 (FIT) [1]
- JMD 29407/3509/2002 Annex 1 (related to the landfill gas control)

4.7.6.2 Synthesis

A feed-in tariff exists since June 2006 for LFG in Greece.

Generation of electricity from :	**Interconnected System**	**Non-interconnected islands**
Sanitary landfill	73 €/MWh	84.6 €/MWh

Table 24 : Source : Hellenic Republic Ministry of Development [1]

Particularity of Greece is the numerous islands. They have a specific feed-in tariff.

Those tariffs should be unchanged until 2010.

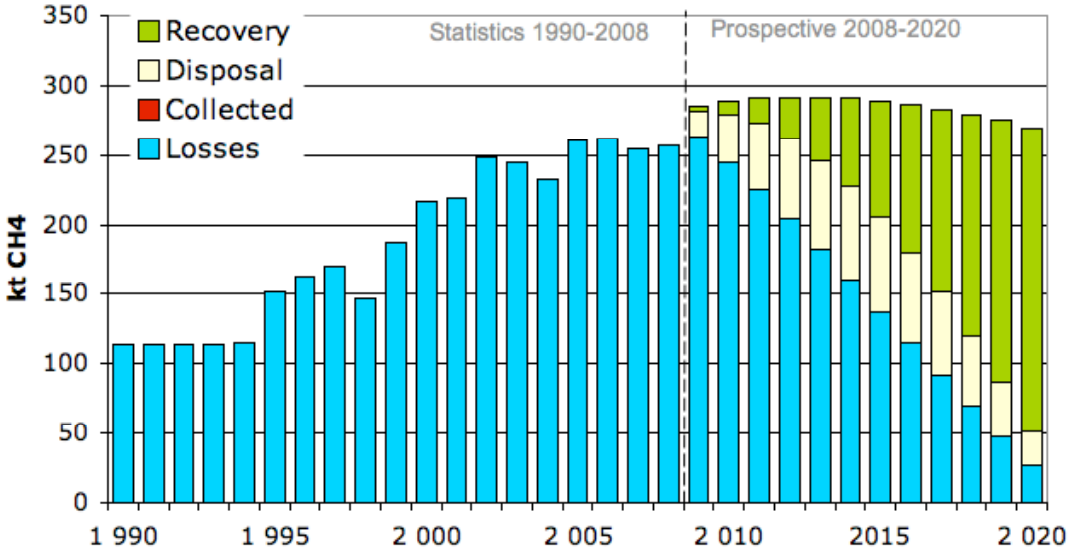
The Greece, as the UK, asked for a 4 year extra delay to implement the 1999/31/EC Landfill Directive.

[1] Legal text available in : www.ypan.gr/docs/LAW_3468-2006__RES.doc

4.8 Romania

Romania is a European member state since the 1st of January 2007.

4.8.1 LFG data during the period 1990-2020



Graph 33. Methane from landfill

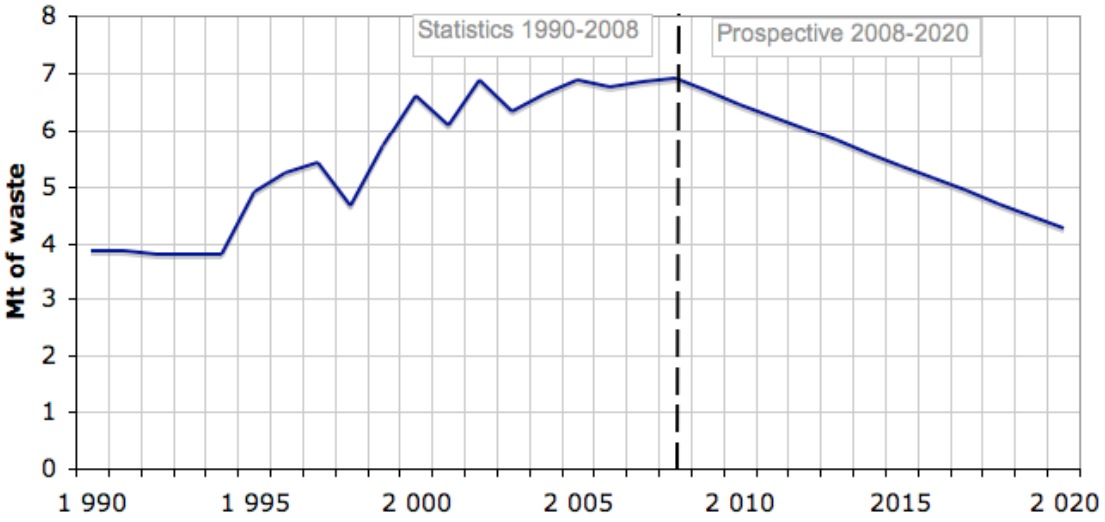
Source: EEA & Prospective Solagro

		EEA Data				Solagro prospective		
RO	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Landfilled SW	Mt SW	3,9	4,9	6,6	6,9	6,5	5,4	4,3
Production	kt CH4	114	152	216	261	288	289	270
Emissions	kt CH4	114	152	216	261	245	137	27
Collection	kt CH4	0	0	0	0	43	152	243
Collection rate	%	0%	0%	0%	0%	15%	53%	90%
Disposal	kt CH4	-	-	-	0	34	68	25
Energy recovery	kt CH4	-	-	-	0	9	84	218
Recovery rate	%	-	-	-	0%	21%	55%	90%

Table 25 : Source: EEA & Prospective Solagro

4.8.2 Landfilled waste

In Romania, 7 Mt of waste were landfilled in 2008. In 2007, around 90% of municipal waste generated were landfilled.



Graph 34. Solid waste from landfill in Romania
Source: EEA & Prospective Solagro

4.8.3 LFG production, collection and flaring

4.8.3.1 Biogas production

Production of LFG is estimated to 256 kt CH_4/year (0.7 billions of m^3 LFG at 50% methane) in 2008.

4.8.3.2 Methane emissions

Methane emissions are stabilized around 250kt CH_4/year since 2000.

4.8.3.3 Biogas use

Romania has a net excess of electricity production due to high hydropower system (large investment before 1990). Thus no further investment was made after 1989 for other renewable resources. Before 1989, 400 biogas facilities existed owned by the State. After the fall of the regime, the companies were reorganized and no more plants exist from the previous 400 plants now days. From 2006, NGO's and State Agency restart the biogas effort.

In 2008, 2 facilities existed using animal manure and sludge from wastewater treatment plant. Currently, no landfill gas energy is produced in Romania.

According to LFG ENERGY company, some projects, with private investments are on going to install LFG-to-energy plants. [1]

In spite of the fact that the 1999/31/CE is implemented in Romania, no biogas is currently collected from landfill in Romania. According to the Local Energy Agency, as far as they know, the gas collection is not mandatory and they do not know any plant where biogas is collected.

[1] See : http://www.lfgenergie.ro/

4.8.4 Current landfill management

The waste management is based on Romanian National Strategy for Waste Management and National Plan for Waste Management approved in 2004. The whole waste system management is being implemented. The municipalities are responsible for the waste disposal. 10% of the rural population do not benefit of the waste services.

Actually no selective municipal waste collection exists of any type. Some selective collect pilots are being tested.

More than 20 large landfills are owned and operated by private sector.

Over 239 existing landfills, 26 are compliant with the EU standards; 100 have received an exemption until 2017 ; others will be closed.

One of the action of the waste program 2008-2016 is the construction of 45 new compliant landfills (as well as some recycling plants, composting plants and incinerators).

4.8.5 Prospective

Our estimation foresees an energy production of 890 GWh el. in 2020 with the assumption that collection rate and energy recovery ratio are strongly improved up to 90% in 2020. This is more a potential than an estimation since no element shows that the energy recovery rate and the collection rate can reach the objective of 90% in 2020. Indeed, this would imply an energy recovery rate increase of 7% per year starting from 0%.

In Bucharest, the waste management program plans for 2013 :

- implementation of selective collection of household and assimilative waste
- construction of : 2 sorting plants, 1 MBT plant, 2 composting plants, new cells at the existing landfills
- modernization of the existing landfills (landfill gas collection and recovery)

4.8.6 LFG policy in Romania

4.8.6.1 Main national legislation reference

- Government Decision 1535/2003 (related to the " Strategy for the Promotion of Renewable Sources of Energy"

- Government Decision 958/2005 & Law n° 220/2008 (related to the promotion of the production of electrical energy from renewable energy sources)

- Governmental Decision 349/2005 on the landfill of waste (2005)

4.8.6.2 Synthesis

There is no specific legislation on biogas generation, use and transport. All the legislation applying to the RES is applying also to biogas.

- **Green Certificates**

There is no Feed-in Tariff but a Green Certificates market.

An increasing mandatory green quota system has been established in 2005. Thus in 0.7% of the energy produced by electricity generators should have been sourced from renewable source. This part will reach 8.3% in 2010-2012. For now 1 GC is granted for each MWh delivered in the grid.

Average GC price : 55 €/MWh (June 2009)

Average electricity market price : 88 €/MWh (2008)

So the landfill biogas could be sold at 138 €/MWh in average.

The law n° 220/2008 was adopted in 2008 but has not taken effect because no application norms were published. This law allows the energy producers that use biogas as resource to receive 3 GC for every 1 MWh they produce. [1]

- **Clean Development Mechanism of the Kyoto Protocol**

Also the Clean Development Mechanism created by the Kyoto Protocol may improve the economic viability of new landfill gas collection project.

- **Subsidy from Ministry of Environment**

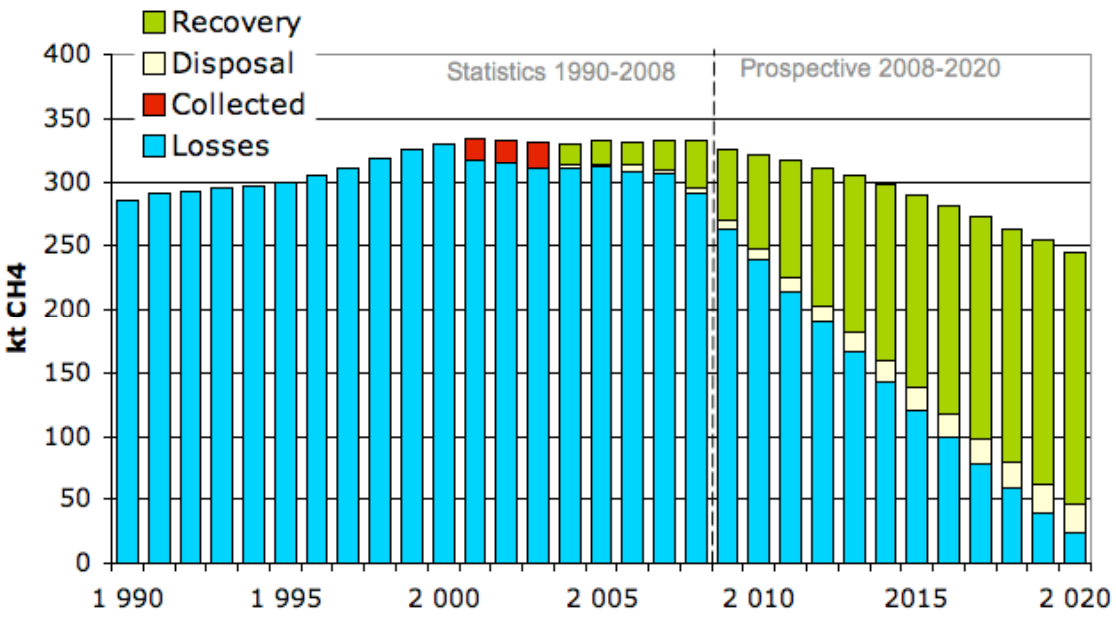
In August 2008, a program started with the support of the Ministry of Environment, permitting to subsidy until 90% of the private investment for renewable energy project.

However, according to BiG>East project synthesis, Romania does not rely on biogas and no major contribution of biogas is expected in the near future to reach the national objectives regarding renewable energy resources. Also BiG>East foresees a biogas development (if any) mainly based on agriculture waste.

[1] Wall-Street Business in real time (Romanian Newspaper) : http://www.wall-street.ro

4.9 Poland

4.9.1 LFG data during the period 1990-2020



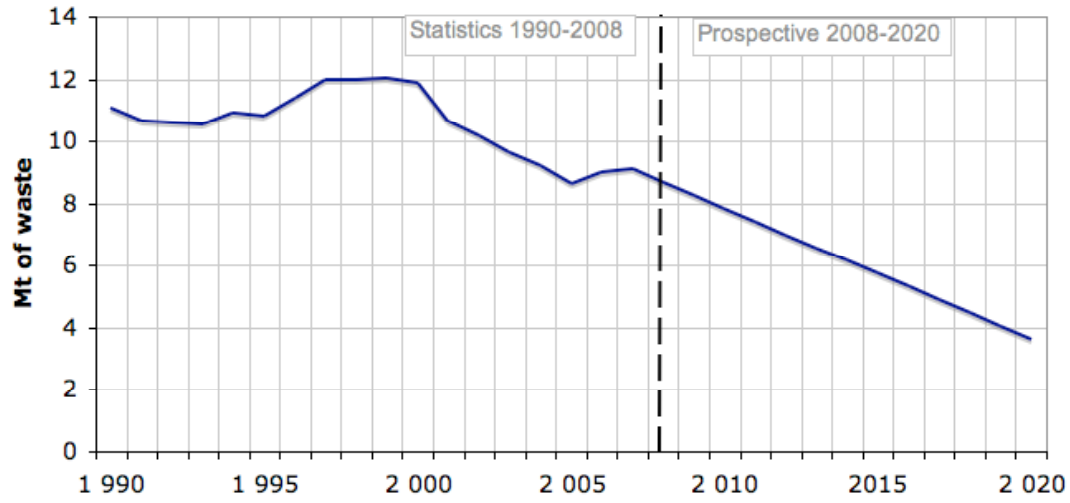
Graph 35. Methane from landfill in Poland
Source: EEA & Prospective Solagro

		EEA Data				Solagro prospective		
PL	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Landfilled SW	Mt SW	11,1	10,8	11,9	8,6	7,8	5,7	3,6
Production	kt CH4	286	299	330	332	322	290	244
Emissions	kt CH4	286	299	330	312	239	121	24
Collection	kt CH4	0	0	0	20	83	169	220
Collection rate	%	0%	0%	0%	6%	26%	58%	90%
Disposal	kt CH4	-	-	-	1	10	18	22
Energy recovery	kt CH4	-	-	-	19	74	151	198
Recovery rate	%	-	-	-	95%	89%	89%	90%

Table 26 : Source : EEA & Prospective Solagro

4.9.2 Landfilled waste

In Poland, 8,7 Mt of waste were landfilled in 2008. In 2007, around 90% of municipal waste generated were landfilled.



Graph 36. Solid waste from landfill in Poland

Graph 27. Source: EEA & Prospective Solagro

4.9.3 LFG production, collection and flaring

4.9.3.1 Biogas production

Production of LFG is estimated to 256 kt CH_4/year (716 thousand m^3 LFG at 50% methane) in 2008. It is stabilized since 2000.

4.9.3.2 Methane losses

Methane emissions are decreasing slowly since 2000. Indeed, the gas production is stabilized and the gas collection is being improved.

4.9.3.3 Biogas use

43 ktCH_4 were collected in 2008 – i.e. 13% of the produced methane. The collection started in 2001 according to EEA data. The collection rate remained low (around 6%) until 2006 and then increased up to 8% in 2007 and 13% in 2008. The energy recovery rate is high (around 88%). As for Spain, we can guess that all collection system were also equipped with LFG-to-energy system as soon as they were put in place.

According to Poland official statistics, electricity production from LFG was around 148 GWh el. in 2008 with a global capacity of 31MW. Heat production was 148 TJ.

4.9.4 Current landfill management

Almost all the municipal waste are landfilled. In 2006, 765 municipal landfill sites were registered in the National Waste Management Plan.

According to LFG Energy Company, the 100 largest of these produce around between 10 kt/year to 400 kt/year. Most of them do not meet the EC standards. The main concern of the waste management policy of Poland is the illegal landfills.

LFG Energy Company estimates that at least 25-30% of the methane produced could be exploited in an economically sound way, mainly at around 80-100 larger landfill sites. Most of this potential still remains unused.

Official Poland statistics (GUS) reports that in 2004, 207 landfills were with degaseification system, 41 of those landfills collected LFG. 27 landfills produced electricity and 5 produced heat

Most of the Poland's landfills are owned by local authorities. Waste management is the responsibility of the municipalities. The operating is done by private companies influenced by municipalities (ownership or management board).

Major difficulties faced with landfill biogas use:

- The ministry cannot close a landfill without operator agreement. The law shall change in 2010.
- Local authorities do not have sufficient power and administrative fees are not high enough to make landfill compliant (gas collection, illegal landfills)

4.9.5 Prospective

By the end of 2014, the goal of the government is to reduce the mass of municipal waste landfilled to maximum 85% of waste generated.

Our estimation foresees an energy production of 808 TWh in 2020 with the assumption that collection rate and energy recovery ratio are strongly improved up to 90%.

4.9.6 LFG policy in Poland

4.9.6.1 Main national legislation reference

- Act on Waste of 27 April 2001 (Section 52 and 60) (related to gas collection)
- Power Law Act (related to TGC)

4.9.6.2 Synthesis

- **Clean Mechanism Development of the Kyoto Protocol**

According to the LFG Energy company, there are several Joint Implementation projects between Poland and The Netherlands on a landfill gas-to-energy plants for which the financing was provided by the Dutch Government in exchange of a part of the emission reduction units (ERU) for the reduction of the GHG emission for the years 2008-2012 which will be transferred from Poland to the Netherlands.

- **Gas collection obligation**

The authorities that deliver a construction and an operating permit shall specify requirements regarding management of the landfill – including "a manner of gathering, cleaning and using or disposing storage gas". The authorities may also modify the landfill authorisations if the landfill does not work properly (i.e.-e does not meet authorities requirements).

- **Tradable Green Certificate (TGC)**

All generator of electricity or retailers of such energy to the end-users are obliged to obtain and submit to the President of Power Sector Regulatory Office the certificates of origin confirming that energy has been generated at renewable sources of energy for the purposes of their cancellation. High penalties are planned if the companies fail.

TGC price: in between 35 €/MWh and 49 €/MWh [1] (year 2010)

Average electricity market price : 93 €/MWh (2008)

[1]Source: Market price given by Towarowa Gielda Energii S.A Polish Power in http://www.polpx.pl