p-ISSN : 2335-1357 e-ISSN : 2437-1122

Mediterranean Journal of Modeling and Simulation

Med. J. Model. Simul. 07 (2017) 038-048

An innovative simulation tool for waste to energy generation opportunities

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ARTICLE INFO

Article history :
Received December 2016
Accepted January 2017

Keywords :
Simulation tool ;
Waste management ;
Biogas production ;
Biogas potential ;
Biogas valorization.

ABSTRACT

The new world energy policies encourage the use of renewable energy sources with clean technologies, and abandon progressively the fossil fuel dependence. Another energy generation trend called commonly the "Waste-to-Energy" solution, uses organic waste as a response for two major problems : energy generation and waste management. Thanks to the anaerobic digestion, the organic waste can provide a biogas composed essentially from Carbone dioxide (CO2) and Methane (CH4). This work aims essentially to help students, researchers and even decision makers to consider the importance of biogas generation. The proposed tool is the last version of our previous tool which is enhanced and completed. It presents the potential to produce biogas of any shortlisted kind of waste, including also some energy valorization ways. A technical economical data is introduced for eventual feasibility studies.

Nomenclature

PBT	Payback time on investment
Inv	Total investment cost
Rev	Total revenues from energy sales
Co	Total operation costs
GHG	Greenhouse gas

1. Introduction

The use of renewable energy sources instead fossil sources may be a solution for many environmental and energy considerations, and leads to a sustainable development. In contrast, the irregular and intermittent character of some of these sources like sun and wind need an energy storage system for a permanent power supply, which is in the most cases very expensive. Here comes the biogas as an energy carrier giving a solution for two

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major problems : waste management and energy production.

1.1. State of the art

Several research works regarding the biogas production potential enhancement can be found for different sources of wastes.

Recently, Negri et al. [1] have evaluated the degradation efficiency and the biogas and digestate production during anaerobic digestion of the cereal silages. In the work of Markou [2], a biogas production from poultry litter after lowering its nitrogen content has been improved. Gerber and Schneider [3] studied the Density of biogas digestate under different temperatures and compositions using a pycnometer and a significant feedback has been recorded. Another works regarding the biogas production and use and the life cycle assessment was discussed respectively by Bluemling et al. [4] and recently by Wang et al. [5].

Raha et al. [6] studied the implementation of decentralized biogas plants in some region of India, a good contribution was found on the impact and effectiveness of the National Biogas and Manure Management Program.

Many recent works were also found regarding government policies toward biogas which can really be considered as an energy carrier, (Ferreira et al. [7], Adams et al. [8], Wang C et al. [9]).

Some other impact's study was found in literature as well as the work of Bartoli et al. [10], which deal with the impact of different energy policies regarding biogas production from maize silage in the region of Lombardy. A good 'On – Farm' energy production case was also found in the recent work of Schaffer et al. [11]

Many other recent works exist regarding the same thematic, (Jiangli et al. [12], Sheets et al. [13], Wu et al. [14], Li – Jie Wu et al. [15], Battista et al., [16], Passos et al., [17]) which deals with a "waste to energy" solutions.

This research work is the flagship and the sweet fruit of real data collected from several scientific contributions. The author started from the basic idea that there is a few research works regarding the generation of significant data in the form of decision – making tool, which can be used to convince scientists or local decision makers, to engage public funds on building biogas plants and hence to predict the best way of energy valorization regardful to the payback time factor.

1.2. Importance of waste management

Wastes can be generated from three main categories : from agricultural field, from industrial effluent and communities wastes including households' garbage. It can be produced every day as a result of our daily needs, animal dejections and industrial processes. The idea to go with, is the fact to leave wastes in the nature which may cause very complicated health problems, in addition to the bad odors around the garbage deposit sites, while it can be considered as a renewable energy source for biogas production. With the condition that we must collect our daily wastes for the biogas production, we can then resolve another problem which is the waste management. This operation is a real waste to energy solution.

The advantage of processing waste produced under anaerobic condition, (as well as domestic garbage landfills, manure and raw sewage), compared with aerobic one ; is the larger decrease in waste's volume. For this reason, the industry nowadays prefers anaerobic fermentation to process waste streams. Furthermore, the fermentation operation leads to the production of digestate which can be used as a fertilizer with a good economic gain.

2. From waste to a useful energy : Toward a sustainable energy carrier

2.1. Biogas production

The biogas production follows a series of biological reactions in an anaerobic tank. In fact, in the absence of oxygen (anaerobic digestion or fermentation) and protected from light, the organic matter of the waste is partially degraded by the combined action of several types of micro-organisms. This biomass fermentation takes several days to form depending on the temperature of the tank. We obtain then a raw biogas containing Carbon Dioxide CO_2, Nitrogen N_2, Hydrogen H_2, Oxygen O_2, Water vapor H_2O, hydroxide sulfur H_2S and the major energy recoverable portion Methane CH_4 which is very harmful to the environment, about 22 times more harmful than CO_2, both of them are considered as a greenhouse gases (GHG). In nature, the fermentation process occurs in places where biological material is fermented in an oxygen deprived environment such as swamps.

2.2. Biogas potential

Biogas potential and composition depends strongly on the source of wastes (raw matter, organic matter and dry matter), fermentation mode (dry or wet) and the tank temperature (mesophilic, psychrophilic or thermophilic). Table 1 shows the composition of biogas from various sources.

Table 1 – Biogas composition from various sources.

Biogas sources	**CH_4 (%)**	**CO_2 (%)**	**H_2S (%)**	**Si (mg/Nm^3)**
Garbage	55 to 60	40 to 45	0 to 0.5	0 to 50
Urban sewage sludge	60 to 65	35 to 40	0 to 1	0 to 20
Industrial effluents	55 to 75	25 to 45	0 to 1	0
Agro – food wastes	60 to 70	30 to 40	0 to 0.5	0
Agricultural waste	50 to 55	45 to 50	0 to 1	0
Landfills gas	40 to 50	25 to 40	0 to 0.5	0 to 50

It can be observed that biogas from a garbage landfill also contains some nitrogen (N_2) and Silicium (Si). The methane part (CH_4) combusts very cleanly with hardly any soot particles or other pollutants, making it a clean fuel, [18]. However, carbon dioxide (CO_2), which is the non-combustible part, lowers the calorific value of the biogas. If it contain 55% of CH_4, it has a calorific value of 21.5 MJ/Nm^3 while pure CH_4 has a calorific value of 35.8 MJ/Nm^3, this is the reason to remove CO_2 from raw biogas, and we can then call it the enriched biogas i.e. biomethane, (with high CH_4 content) ; Table 2 presents a data adaptation of the daily biogas production potential starting from the daily animal dejections [19].

Table 2 – Production of organic matter from animal wastes.

Animal species	**Waste /day /head [kg]**	**Dry matter/raw matter %**	**Organic matter/dry matter %**	**Biogas (CH_4=55%) m^3/ton of waste**	**Biogas (CH_4=55%) m^3/day/head**
Cattle	12	23	55	35	0,42
Sheep	0,5	29	45	26	0,013
Caprine	0,3	40	40	32	0,0096
Horses	2	28	45	26	0,052
Chickens	0,1	58	73	113	0,011

The animal heads number to produce a cubic normal meter (1 Nm^3) of raw biogas with 55% of CH_4 content and 1 Nm^3 of biomethane with 98% of CH_4 content are presented in Table 3.

Table 3 – Heads quantity to produce 1 Nm3 of Biogas.

Animal species	**Biogas (CH_4=55%) Heads**	**Biomethane (CH_4=98%) Heads**
Cattle	3	5
Sheep	77	143
Caprine	105	200
Horses	20	36
Chickens	10	17

2.3. Biogas utilization

Biogas as an energy carrier offer many benefits. Due to its high energy balance which consists on the presence of methane, it can be preferable than many other fossil fuels, e.g. 1 Nm^3 of methane can replace 2,1 kg of wood, 1 l of oil, 1,15 l of petrol or even 1,3 kg of coal.

Besides these energetic profits, we can also have some environmental advantages, like the destruction of many pathogens which unfortunately cannot be treated in landfills. By introducing waste to the anaerobic digesters, we engage ourselves to protect the water occupation surfaces and the groundwater area. Many applications for biogas can be found, i.e. production of heat, electricity, combined heat and power "CHP", automotive fuel and the injection into the urban natural gas network. The summary of the raw biogas produced by an anaerobic digester using animal manure, and the valorization possibilities are presented in Fig. 1.

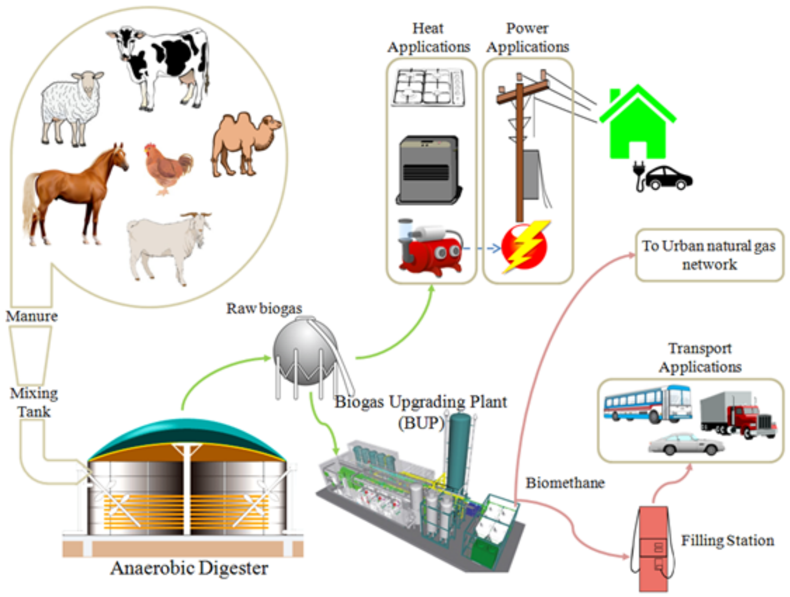

Fig. 1 – Summary of biogas production and Applications.

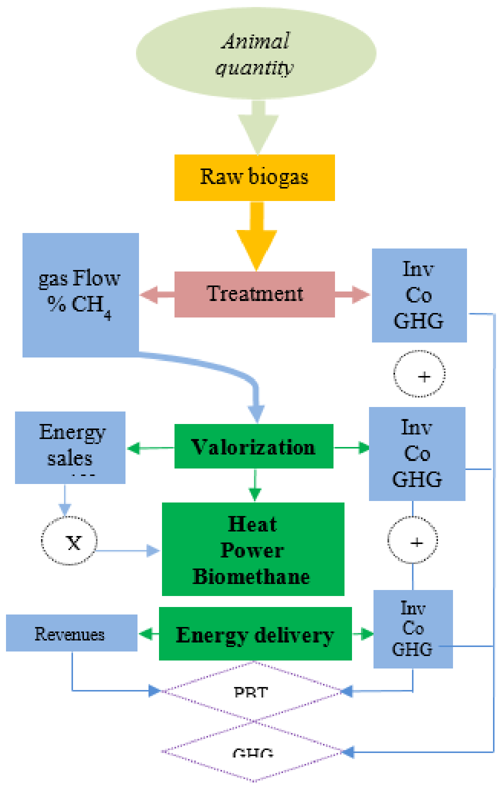

Fig. 2 – The tool calculation levels and key steps.

3. Data generalization and analysis

3.1. The innovative decision support tool description

It's a very rich tool and so easy to use, the integrated scenarios (valorization ways) are compared based on economic, energetic and environmental criteria. It is an Excel-based spreadsheet and database program that calculates the pay back times on investment and CO_2 avoided emissions starting from any waste and dejections quantities. The tool provides extensive technical and economic information about integrated processes, from the incoming raw biogas to the final use of the energy. The investment, operation, and maintenance costs are estimated for each unit necessary for the process. The tool calculation levels and key steps are illustrated in Fig.2.

The first interface called "Filling Form" of the second version of this tool is presented in Fig. 3.

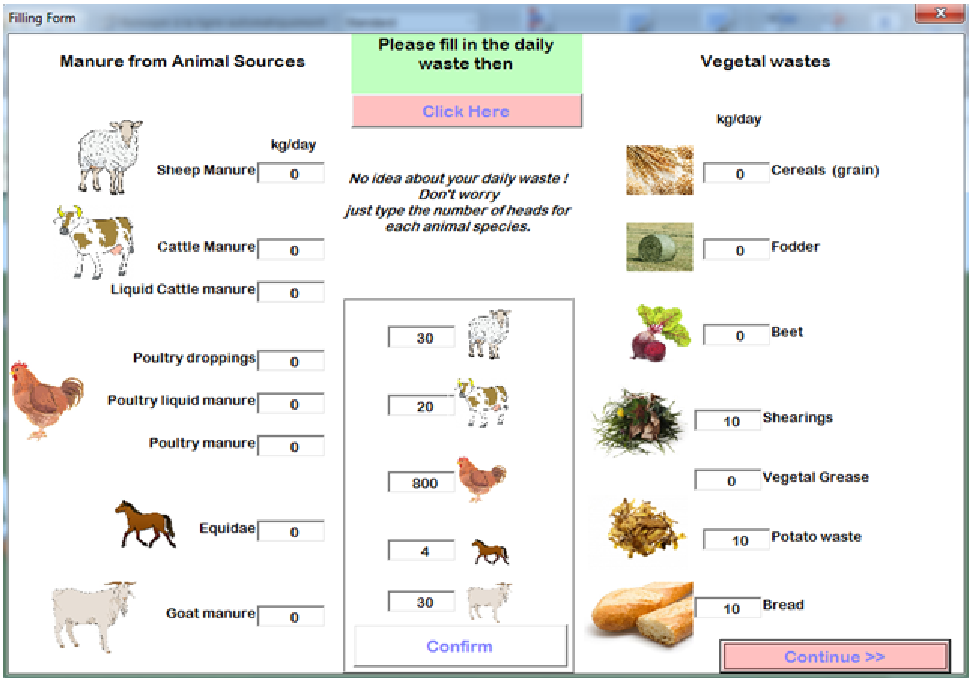

Fig. 3 – The innovative tool filling form.

The innovative tool data generalization

The best way for biogas valorization depends on many factors such as the origin of waste, the investment and running costs of the future utilization, the animal investment of the farmer and the energy delivery distance. A good review on this issue was discussed in the previous work of the author, [18]. Fig. 4 Summarizes the payback time of the proposed valorization ways of any given raw biogas volume.

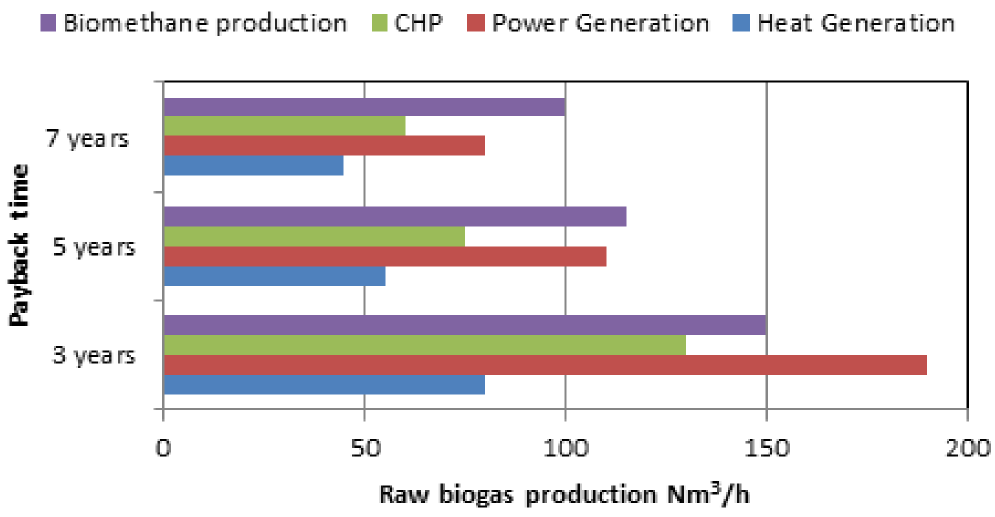

Fig. 4 – The payback time for the proposed valorization ways.

The innovative tool data analysis

As an example, the heat valorization way needs up to 140000 Caprine heads to get a reasonable payback time (PBT) of 5 years, compared to 12000 chicken heads and about 3200 cattle heads, see Table 4.

Table 4 – Animal heads estimation for biogas production following the Heat valorization Way.

		Heat Valorization Payback time		
		3 years	5 years	7 years
Raw Biogas	m^3/h	80	55	45
	m^3/day	1920	1320	1080
Cattle		4571	3143	2571
Sheep		147692	101538	83077
Caprine		200000	137500	112500
Horse		36923	25385	20769
Chicken		17455	12000	9818

The animal investment cost is depending on the animal species, Table 5 presents the local prices of the given animals at early age in Algerian Dinar [DZD].

Table 5 – The local prices of the given animals at early age in Algerian Dinar [DZD].

	Animal Price [DZD]
Cattle	120 000
Sheep	25000
Caprine	20000
Horse	150 000
Chicken	200

From the information of this table, the innovative biogas tool generates the data represented in Fig. 5, It concerns animal investment costs.

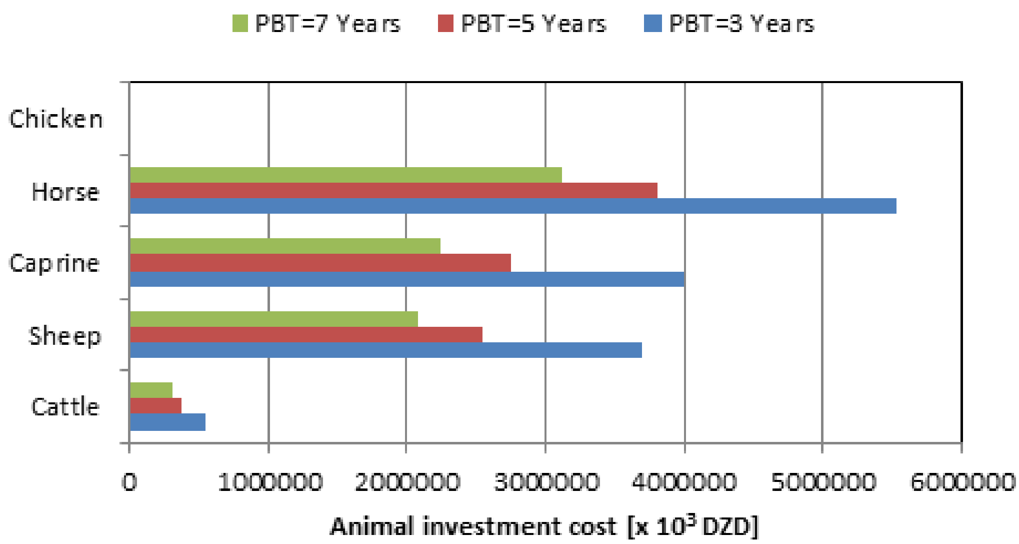

Fig. 5 – The Animal Investment Costs.

It is clear that the lowest investment cost is dedicated to chicken even if we can have much biogas from cattle manure, but we prefer already the biogas production from chicken manure. Nowadays, chicken farms are well equipped, and there are fewer hazards than before. The reproduction period is more quick and effective than the other animal species, and the manure collect action is simple. A detailed data for chicken investment for each payback time is given in Fig.6.

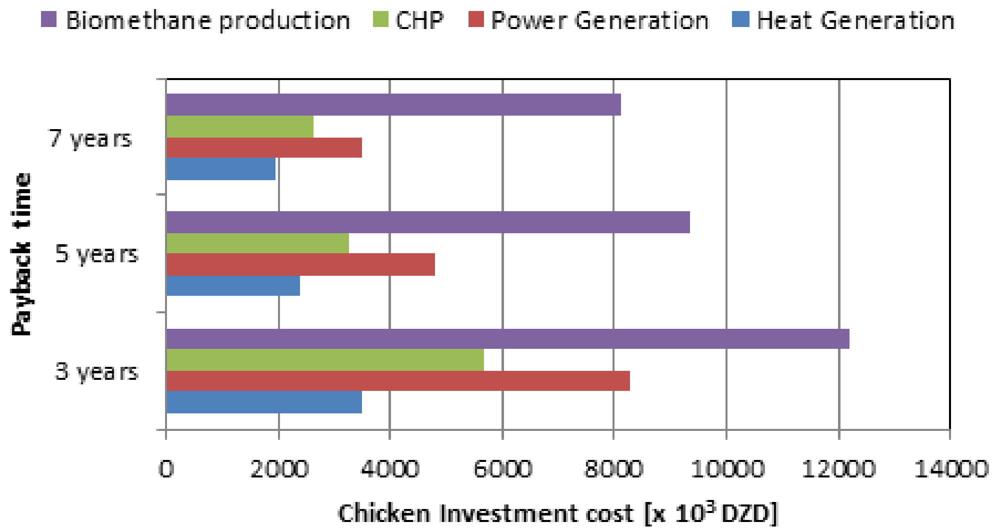

Fig. 6 – The Biogas valorization Payback times from chicken manure.

4. Conclusions

Biogas production is a great solution for two problems, energy generation and waste management. A significant data on biogas valorization ways is illustrated in this work.

The completion and improvement of the innovative decision support tool, called previously BUDS tool, by real and actualized data ; leads to this second enhanced version.

Thanks to this tool, more accurate data is obtained and should be used to convince Algerian decision makers on funding biogas plants. This action can also lead to the development and creation of several jobs, regardful to the potential need of qualified persons in the biogas plants and non qualified persons for the daily waste collect.

The chicken manure choice for biogas production seems to be the best one regarding the investment cost.

REFERENCES

[1] M. Negri, J. Bacenetti, M. Fiala, S. Bocchi, Evaluation of anaerobic degradation,biogas and digestate production of cereal silages using nylon-bags, Bioresour. Technol. 209 (2016) pp 40–49.

[2] G.Markou, Improved anaerobic digestion performance and biogas production from poultry litter after lowering its nitrogen content, Bioresour. Technol. 196 (2015) pp 726–730.

[3] M. Gerber, N. Schneider, Density of biogas digestate depending on temperature and composition, Bioresour. Technol. 192 (2015) pp 172–176.

[4] B. Bluemling, A.P.J. Mol, Q. Tu, The social organization of agricultural biogas production and use, Energy Policy. 63 (2013) pp 10–17.

[5] Q.L. Wang, W. Li, W. Gao, S. J. Li, Life cycle assessment on biogas production from straw and its sensitivity analysis, Bioresour. Technol. 201 (2016) pp 208– 214.

[6] D. Raha, P. Mahanta, M.L. Clarke, The implementation of decentralised biogas plants in Assam, NE India : The impact and effectiveness of the National Biogas and Manure Management Programme, Energy Policy. 68 (2014) pp 80 – 91.
[7] M. Ferreira, I.P. Marques, I. Malico, Biogas in Portugal : Status and public policies in a European context, Energy Policy. 43 (2012) pp 267 – 274.
[8] P.W.R. Adams, W.G. Mezzullo, M.C. McManus, Biomass sustainability criteria : Greenhouse gas accounting issues for biogas and biomethane facilities, Energy Policy. 87 (2015) pp 95 – 109.
[9] C. Wang,Y. Zhang, L. Zhang, M. Pang, Alternative policies to subsidize rural household biogas digesters, Energy Policy. 93 (2016) pp 187 – 195.
[10] A. Bartoli, D.Cavicchioli, D. Kremmydas, S. Rozakis, A. Olper, The impact of different energy policy options on feedstock price and land demand for maize silage : The case of biogas in Lombardy, Energy Policy. 96 (2016) pp 351 – 363.
[11] A. Schaffer, C. Düvelmeyer, Regional drivers of on-farm energy production in Bavaria, Energy Policy. 95 (2016) pp 361 – 369.
[12] J. Li, C. Kong, O. Duan, T. Luo, Z. Mei, Y. Lei,. Mass flow and energy balance plus economic analysis of a full – scale biogas plant in the rice – wine – pig system, Bioresour. Technol. 193 (2015) pp 62–67.
[13] J.P. Sheets, X. Ge, Y.F. Li, Z. Yu, Y. Li, Biological conversion of biogas to methanol using methanotrophs isolated from solid – state anaerobic digestate, Bioresour. Technol. 201 (2016) pp 50–57.
[14] S. Wu, P. Ni, J. Li, H. Sun, Y. Wang, H. Luo, J. Dach, R. Dong, Integrated approach to sustain biogas production in anaerobic digestion of chicken manure under recycled utilization of liquid digestate : Dynamics of ammonium accumulation and mitigation control, Bioresour. Technol. 205 (2016) pp 75–81.
[15] L.J. Wu, T. Kobayashi, H. Kuramochi, Y.Y. Li, K.Q. Xu, Improved biogas production from food waste by co – digestion with de – oiled grease trap waste, Bioresour. Technol. 201 (2016) pp 237–244.
[16] F. Battista, D. Fino, G. Mancini, Optimization of biogas production from coffee production waste, Bioresour. Technol. 200 (2016) pp 884–890.
[17] F. Passos, A. Hom – Diaz, P. Blanquez, T. Vicent, I. Ferrer, Improving biogas production from microalgae by enzymatic pretreatment, Bioresour. Technol. 199 (2016) pp 347–351.
[18] B. Abderezzak, B. Khelidj, A. Kellaci, M. Tahar Abbes, The smart use of biogas : decision support tool, AASRI Procedia, 2 (2012) pp 156 – 162.
[19] Minagri, Algerian Ministry of Agriculture, « Récapitulatif des superficies, des productions, des rendements et les taux d'accroissement 2006/2005 ». Ministry web site : www.minagri.dz.