An on-line advisor for sizing and economic analysis of anaerobic digestion plants

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Abstract: A web-based service was deployed to appropriately size bio-gas plant capacity and perform its economic viability and return on investment based on biomass availability. The tool is based on accepted biogas plant engineering design practice, incorporating the effects of incentives resulting from energy policies for member nations of the European Union participating in the Bioenergy Farm IEE and EU funded project. The service provides a comprehensive database that allows consultants and farmers to analyze anaerobic digestion systems at different levels of granularity. It also included multilingual support. An adoption program was conducted to increase awareness on the availability of the service and ensure appropriate use and interpretation of its results. Since its deployment, the tool has been frequently used by consultants and farmers. The advisor was used to conduct over 3000 sizing and analysis of biogas production plants and completely fulfill all project targets.

Keywords: Bioenergy, feasibility, viability, subsidy, web application, free

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1 Introduction

Bioenergy production from waste and crops has long been recognized as a significant potential contributor to meeting future energy needs at a global scale (Fischer and Schrattenholzer, 2001; Peck et al., 2011). Studies in this area have shown that it is an economical and environmentally friendly form of sustainable energy production (Börjesson and Tufvesson, 2011). Case studies on successful implementations of biogas plants have been conducted in many regions around the world (Andersons et al., 2013; Lantz, 2012) and have in many cases proven that these plants are profitable. These studies demonstrate that subsidies and fiscal incentives largely influence the profitability of such plants. Today, subsidies and fiscal incentives are implemented in many different countries to encourage production of bio-energy and further promote its production (Kusch and Evoh, 2013).

Additionally, the use of by-products and residues has been widely investigated (Silvestre, Gomez et al., 2013). Various methods can be used for system design which addresses the complexities resulting from technical, financial, regulatory and social requirements. Design for optimum energy conversion is essential for the system to be cost effective, meet economic and regulatory constraints, and use appropriate, reliable and sustainable technologies (Yılmaz and Selim, 2013; Ward et al., 2008). Early attempts to provide a web-based service to evaluate biomass production and logistic costs were conducted by Berruto and Busato (2006). From these early experiences, and the increasing demand for effective decision aids at the EU level, a comprehensive tool was developed and is presented here.

Because of these complexities, to ensure that advisors

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(consultants) and decision makers (farmers) have adequate understanding on design requirements and accurate prediction of economic returns, we must increase the awareness of stakeholders and provide a tool that is both simple to use and able to address these complexities. With this in mind, the Intelligent Energy Europe launched a project named Bioenergy Farm (www.bioenergyfarm.eu), whose goals are listed as follows:

1) Develop an online advisor to size biogas plants considering bio inputs and local regulatory constraints.

2) Produce a feasibility study for any given biogas production scenario.

Establish a program to promote adoption and ensure use and proper application of the online advisor.

2 Methodology

2.1 General overview

This project was composed of three stages: 1) development and implementation, 2) adoption, and 3) assessment and evaluation.

2.1.1 Development and implementation

A web-based tool was developed and implemented tailored to meet the following requirements:

1) Usability. The tool uses a conventional and intuitive interface for different levels of users. Expert users, such as consultants, can use the tool with a high degree of granularity and flexibility in the data and scenario analysis. In addition, novice users can use the tool in such a way that data of typical common scenarios are used.

2) Local Relevance. The tool considers local languages (with addition of English), local requirements such as those imposed by local bio-sources, legal and regulatory requirements, and subsidies in the different member countries (Belgium, Estonia, Germany, Italy, The Netherlands and Poland) participating in the project.

3) Useful decision aid. The tool provides useful information for decision making relevant to biogas production business, planning, and long-term finances.

2.1.2 Program for adoption

To ensure that this tool is used properly and in a beneficial manner, an adoption program was implemented for the following purposes:

1) The tool was integrated into the Bioenergy Farm Portal (http://www.bioenergyfarm.eu) and translated into the languages of seven partner countries.

2) Presentations were made at professional and industry association meetings.

3) Workshops and training sessions were conducted at different locations.

2.1.2 Assessment and evaluation

To evaluate the outcomes of the project, the following targets were considered for the conclusion of the program:

1) Number of unique visitors to the portal bioenergyfarm.eu: 30,000.

2) Number of on-line scans made with the tool: 3,000.

3) Number of expert trained from the partner countries: 52.

4) Number of professional business plans conducted: 80 with a total capacity 80 MW or more analyzed.

5) The service to be used in the implementation of power plants from renewable sources with a total capacity exceeding 40 MW.

These targets were continuously monitored during the project that lasted 30 months, starting in June, 2010.

2.2 Software functions

The software is composed of four principal modules as shown in Figure 1. The first module calculates the amount of biogas that is produced using the available biomass, including a mass balance and nutrient contents. This is a fundamental piece of information to properly size the installations, predict costs and economic returns. The second module focuses on determining the appropriate size of the operation, plant power and storage needs for both substrate and digestate. The third module estimates all exploitation costs, including biomass, energy, maintenance, personnel, depreciation, finance, and insurance. In addition, revenue from energy production is calculated. Finally the fourth module produces a simple and a detailed cash flow for the length of the contribution period. In this last module, users could also produce a complete report on the analysis carried out with all the parameters considered in the analysis and their corresponding values.

Details of the mathematical methods used are too lengthy to be included in this paper and can be found in Van der Werf (2011) at the Bioenergy Farm Portal web page as referenced below.

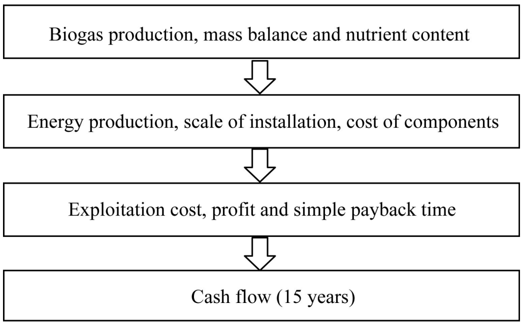


Figure 1 Principal software modules

2.3 Software platform

To manage the complexity of the modeling aspects of the tool, Microsoft Model-View-Controller (ASP.NET MVC) was used. In addition, Microsoft SQL server was used to store and retrieve data and perform computations of results on the server-side.

3 Description of the software

Two stakeholder groups, consultants and farmers, are the primary targeted users of this tool. To address their needs, two versions of online advisor were created and uploaded. Both versions use the same modeling and analysis engines. The primary difference between these two versions is that the version directed to consultants allows a much higher level of granularity in specifying input data. The simplified version, directed to non-experts, reduces data input requirements by using default average data based on location.

The tool addresses four different scenarios:

1) Production of electric energy,

2) Production of electric and thermal energy,

3) Production of biomethane,

4) Production of biomethane and thermal energy.

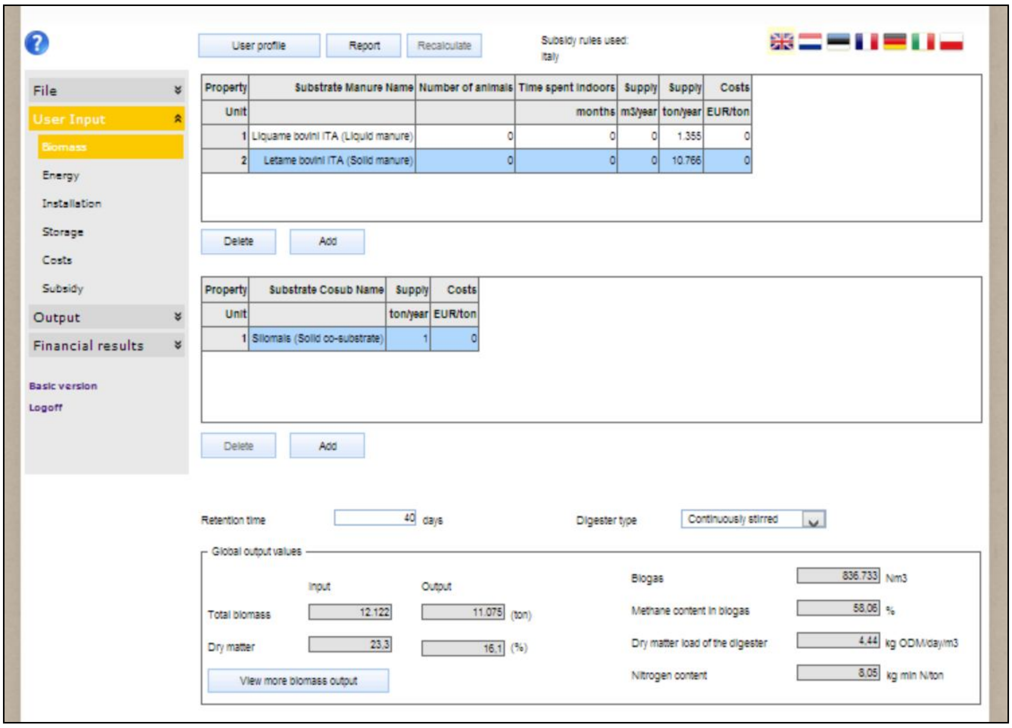
Because design, viability, and payback times vary from country to country due to different local conditions, subsidies, and regulation, it is important to carefully evaluate different alternatives that consider these factors. The tool produces comprehensive reports in the technical-economic context for all four scenarios mentioned above, highlighting the highest return on investment.

3.1 User inputs

User provided input is required through a series of web forms describing properties of: 1) biomass, 2) plant, 3) storage, 4) costs, and 5) energy.

3.1.1 Biomass module

The Biomass module (Figure 2) is used to define the available substrates that can be used for the production of biogas, including sewage, manure and/or any crop biomass. Any of these substrates may be purchased or



Subsidy rules used:
Italy

Property	Substrate Manure Name	Number of animals	Time spent indoors	Supply	Supply	Costs
Unit			months	m3/year	ton/year	EUR/ton
1	Liquame bovini ITA (Liquid manure)	0	0	0	1.355	0
2	Letame bovini ITA (Solid manure)	0	0	0	10.766	0

Property	Substrate Cosub Name	Supply	Costs
Unit		ton/year	EUR/ton
1	Silomais (Solid co-substrate)	1	0

Retention time 40 days

Digester type Continuously stirred

Global output values

	Input	Output	
Total biomass	12.122	11.075	(ton)
Dry matter	23,3	16,1	(%)

Biogas 836.733 Nm3

Methane content in biogas 58,06 %

Dry matter load of the digester 4,44 kg ODM/day/m3

Nitrogen content 8,05 kg min N/ton

Figure 2 Biomass data entry web form

is already available in the farm. For each substrate it is necessary to specify its provision (t/y), and the cost of acquisition or production. In addition, for the purpose of sizing of a plant, the necessary residence time of the substrates in the digester (retention time) and the type of digester must be specified.

Information stored in the database includes data related to byproducts associated to sewage and manure resulting from animal production, herbaceous biomass and crop residues, and other substances such as glycerin, sugar beet wastes, and corn silage. In total, twelve materials originating from animal biomasses and twenty-six resulting from vegetable or animal residues and by-products are included. Other biomaterials can be added by the user if they are not present in the database.

The supply of biomass available and its type determines the levels of electrical and thermal power obtainable, and the rate of production of biogas. Logistics operations for the transport of biomass and animal waste, if they are paid by the biogas plant, should all be included in the cost of biomass. Therefore, they have to be incorporated in the form shown in Figure 2. Detailed calculations of logistics costs, including the effects of transfer distance can be carried out at the Bioenergy Farm portal or at http://www.bioresource4energy.eu (Berruto, et al., 2012).

3.1.2 Energy module

Once the substrates and type of digester to be used are specified, the user must decide: 1) whether a heat recovery system will be used, and 2) whether heat will be used locally or distributed to a third party. Alternatively, the conversion of the biogas into methane may be chosen.

If thermal energy distribution to a third party is to take place, it is necessary to indicate the distance of the plant from the heat usage, the heat demand, the complexity of the distribution network, and the temperature difference between the supply and the return of the heated water. These data affect the outcomes for each of the four scenarios cited above.

3.1.3 System treatment module

The user must specify the treatments to be applied to the biomass or digestate. These treatments include: 1) whether a pre-treatment with heat (pasteurization of substrates or digestate) will be used, 2) whether separation into liquid and solid fractions will take place, and 3) whether further processing of the liquid fraction or drying of the solid fraction is required.

To determine total cost of ownership of the plant, the value of the land where the plant is going to be located and other costs associated to the investments are considered (e.g. special insurance).

3.1.4 Cost module

The development of a successful business plan requires careful estimation of all costs related to ownership of production plant (Figure 3). Accurate costing of components can be difficult, especially where there are no available data or experience. To address this issue the system provides typical costs of components, management, and finances.

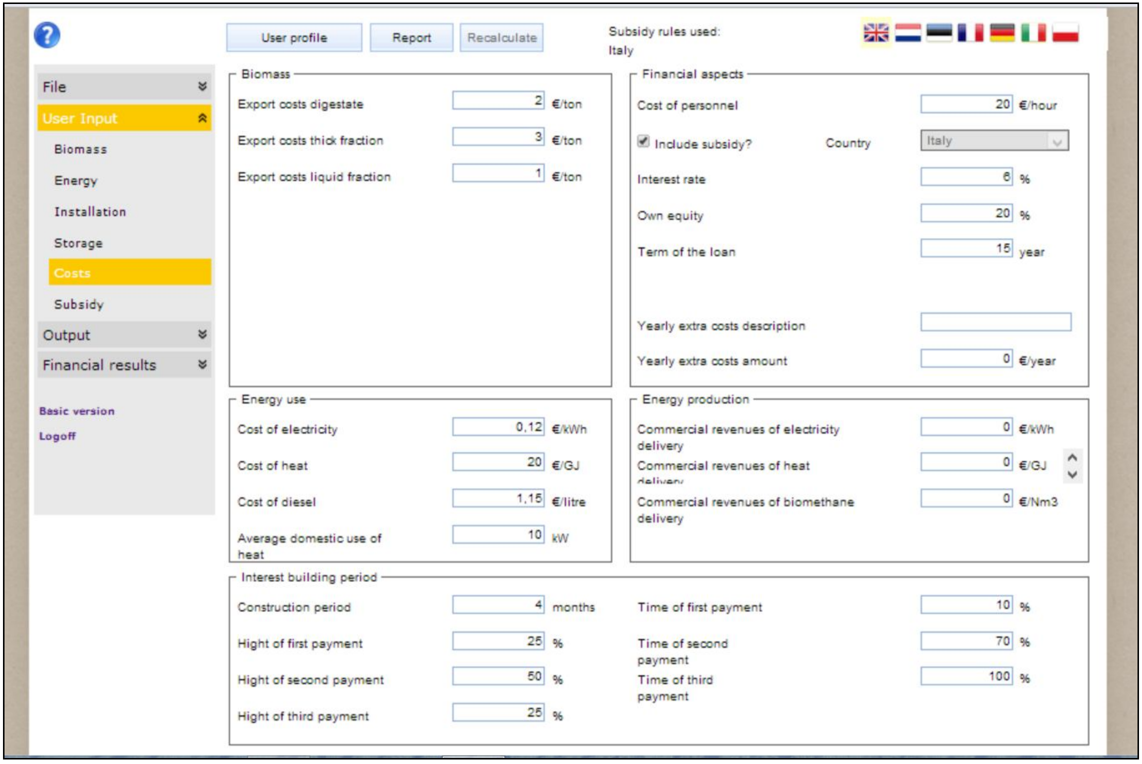
One type of cost that is often overlooked is related to the facilities required for storage of raw materials and digestate. The dimensions of related facilities are an important cost component and depend on the volume and retention times of the various products and byproducts of the production process. The program calculates the volume needed and the cost for the construction of any trenches or tanks. Existing storage facilities can be specified as this will reduce the marginal cost of implementation, therefore improving the outlook of the business plan for the production system.

Cost related data required for the analysis include: 1) management cost related to the digestate, 2) the use and production of energy, 3) financial, such as interest rates, long-term loan, capital property, and others, and 4) the plant's construction period (time and rate of payments).

To facilitate data entry, the service provides typical values. The costs of distribution of the digestate can be calculated with accuracy through calculation of biomass production costs.

3.1.5 Financial aid module

To complete the total cost of ownership, it is necessary to specify any grants or subsidies for various types of bioenergy produced by the plant. These are the result of policy implementation and vary from country to country. Financial aid is generally provided to subsidize: 1) the production of electric (€ kWh_e^{-1}) and thermal energy (€ kWh_t^{-1}), and 2) construction of the production system.



Subsidy rules used:
Italy

Biomass

Export costs digestate 2 €/ton
Export costs thick fraction 3 €/ton
Export costs liquid fraction 1 €/ton

Financial aspects

Cost of personnel 20 €/hour
☑ Include subsidy? Country Italy
Interest rate 6 %
Own equity 20 %
Term of the loan 15 year
Yearly extra costs description
Yearly extra costs amount 0 €/year

Energy use

Cost of electricity 0,12 €/kWh
Cost of heat 20 €/GJ
Cost of diesel 1,15 €/litre
Average domestic use of heat 10 kW

Energy production

Commercial revenues of electricity delivery 0 €/kWh
Commercial revenues of heat delivery 0 €/GJ
Commercial revenues of biomethane delivery 0 €/Nm3

Interest building period

Construction period 4 months
Hight of first payment 25 %
Hight of second payment 50 %
Hight of third payment 25 %
Time of first payment 10 %
Time of second payment 70 %
Time of third payment 100 %

Figure 3 Data requirements for cost estimations

Currently feed-in tariffs subsidize electricity produced for varying classes of generated power. Subsidies vary by country, resulting in different rules for different locations. Rules implementing these differences are used in the analysis conducted by the system. For example in the case of Italy, the rules that apply are shown in Table 1.

Table 1 Subsidies in Italy for electric generation from biogas in place as of January 1st, 2013*.

Electric power generated	$1<P\le300$ /kW$_e$		$300<P\le600$ /kW$_e$		$600<P\le1000$ /kW$_e$	
	all	biomass	all	biomass	all	biomass
Feed mix	≤30% crop biomass >70% by-products	>30% crop biomass <70% by-products	≤30% crop biomass >70% by-products	>30% crop <70% by-products	≤30% crop biomass >70% by-products	>30% crop <70% by-products
Incentives (€ MWh^{-1})						
Base incentive	236	180	206	160	178	140
Efficient Cogeneration	10	40	10	40	10	40
Heating network	30	N/A	30	N/A	30	N/A
Nitrogen separation	30	30	30	30	30	30
Maximum Contribution	306	250	276	230	248	210

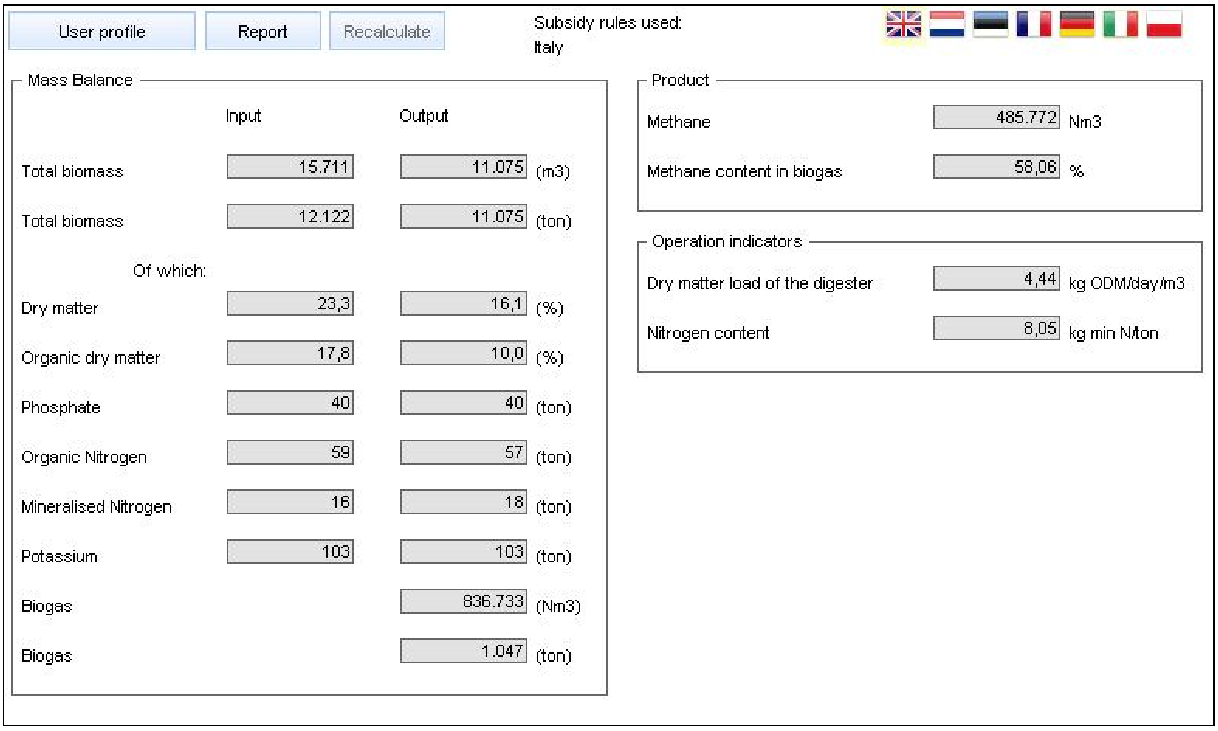
Note: * The base incentive for anaerobic digestion, depending on feed mix and generated power, can be increased by efficient cogeneration, heating network, and nitrogen separation.

3.2 Output Module

Once all data are ready for a given scenario, the algorithms described by Van de Werf (2011) are applied and results are returned to the user.

The system returns the balance of biomass inflows and outflows, in volume (m^3) and weight (mg), with details of their composition (dry matter, organic matter, phosphorus, nitrogen, etc.), and most importantly the amount of biogas or methane produced (Figure 4).

In addition, a summary of the storage capacity (digester volume and detail of the individual fractions), the CHP (cogeneration) power installed, the surface area required for installing the system and other parameters related to the electrical and thermal efficiency are reported (Figure 5).



Subsidy rules used:
Italy

Mass Balance

	Input	Output	
Total biomass	15.711	11.075	(m3)
Total biomass	12.122	11.075	(ton)
Of which:			
Dry matter	23,3	16,1	(%)
Organic dry matter	17,8	10,0	(%)
Phosphate	40	40	(ton)
Organic Nitrogen	59	57	(ton)
Mineralised Nitrogen	16	18	(ton)
Potassium	103	103	(ton)
Biogas		836.733	(Nm3)
Biogas		1.047	(ton)

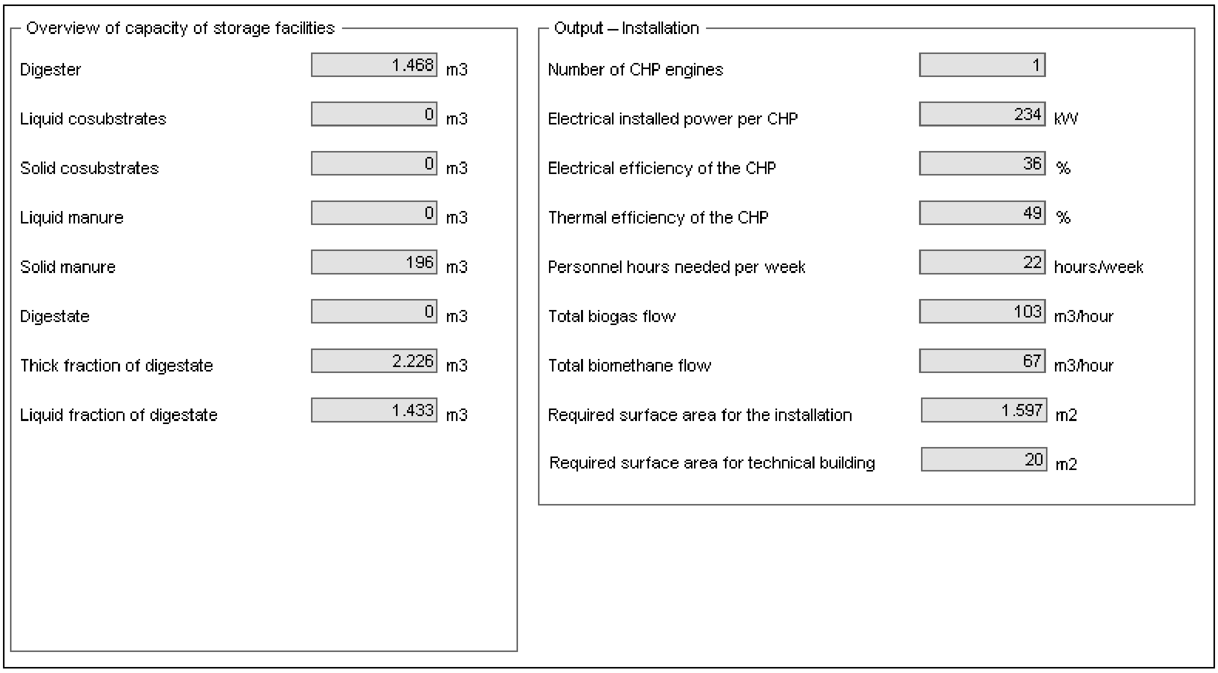
Product

Methane	485.772	Nm3
Methane content in biogas	58,06	%

Operation indicators

Dry matter load of the digester	4,44	kg ODM/day/m3
Nitrogen content	8,05	kg min N/ton

Figure 4 Mass balance of the biogas plant



Overview of capacity of storage facilities

Digester	1.468	m3
Liquid cosubstrates	0	m3
Solid cosubstrates	0	m3
Liquid manure	0	m3
Solid manure	196	m3
Digestate	0	m3
Thick fraction of digestate	2.226	m3
Liquid fraction of digestate	1.433	m3

Output – Installation

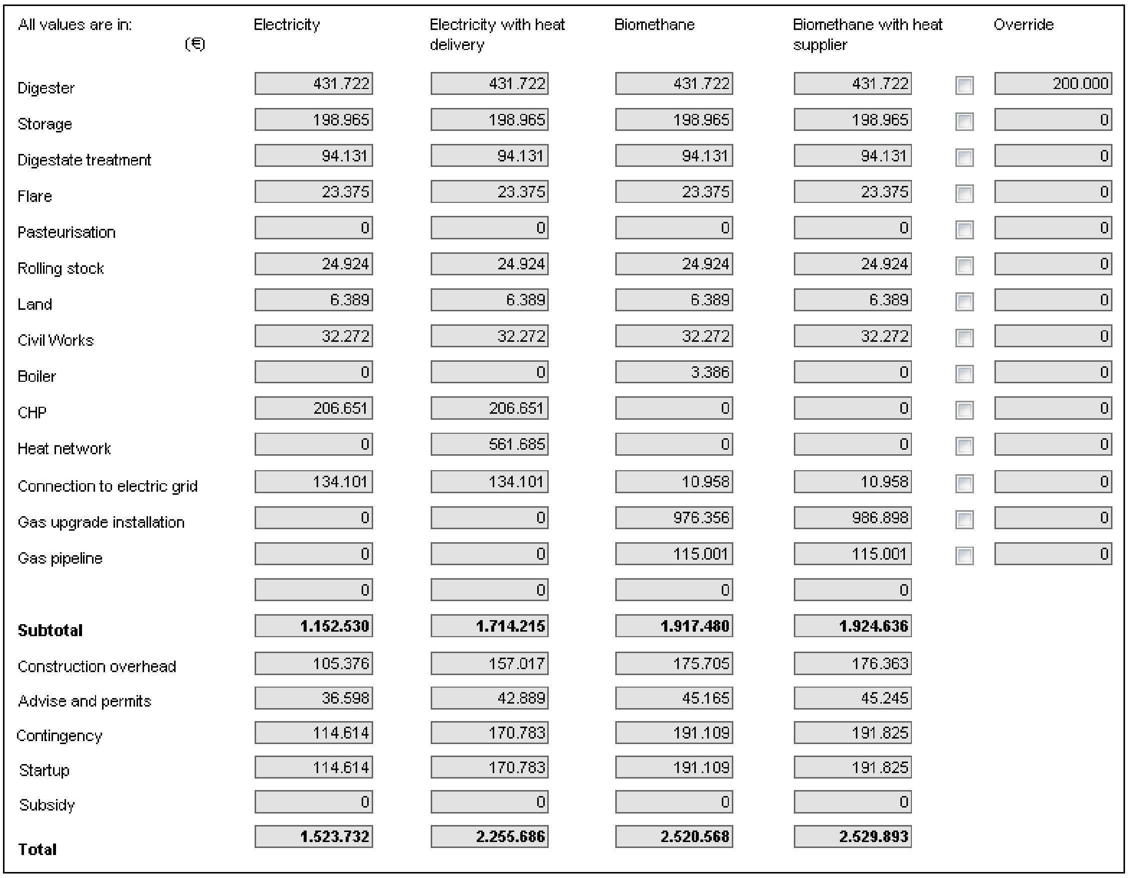
Number of CHP engines	1	
Electrical installed power per CHP	234	kW
Electrical efficiency of the CHP	36	%
Thermal efficiency of the CHP	49	%
Personnel hours needed per week	22	hours/week
Total biogas flow	103	m3/hour
Total biomethane flow	67	m3/hour
Required surface area for the installation	1.597	m2
Required surface area for technical building	20	m2

Figure 5 Biogas and electric power production

Storage requirements presented in the results are those needed in addition to those already present in the farm. Finally, a summary of the investments and details of the individual expenses related to the construction of the plant are presented (Figure 6). Individual items (investment costs) can also be overridden with other available data, such as cost estimate of the system.

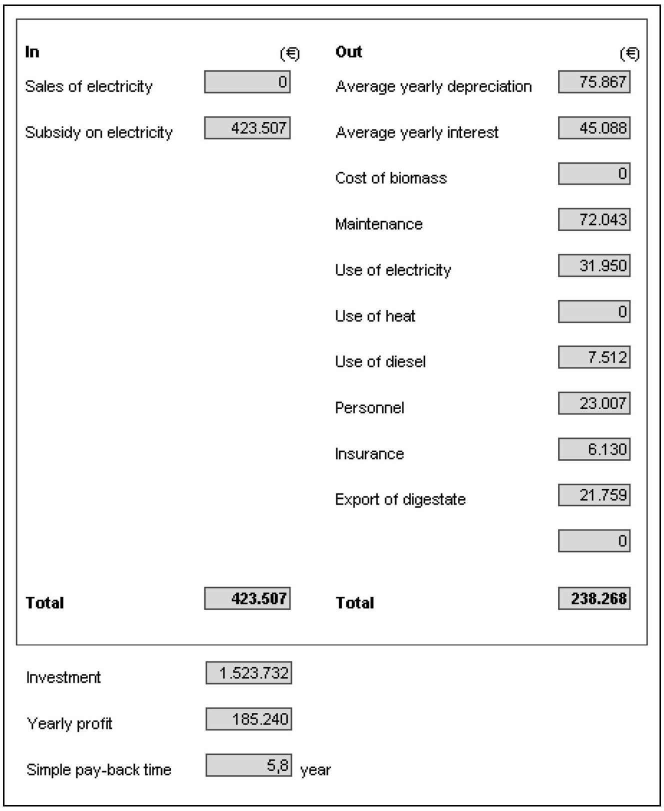
The financial results are returned for each scenario, in the form of financial statement figures with total revenue and expenditures (Figure 7). It optionally includes an in-depth detail of the budget year to year (not shown).

In addition to tabulated values, graphics are available to aid in the interpretation of the results. For example, the cash flow (Figure 8) for each scenario developed by the program. The example shown is the cash flow for an electricity production scenario.



All values are in: (€)	Electricity	Electricity with heat delivery	Biomethane	Biomethane with heat supplier		Override
Digester	431.722	431.722	431.722	431.722	☐	200.000
Storage	198.965	198.965	198.965	198.965	☐	0
Digestate treatment	94.131	94.131	94.131	94.131	☐	0
Flare	23.375	23.375	23.375	23.375	☐	0
Pasteurisation	0	0	0	0	☐	0
Rolling stock	24.924	24.924	24.924	24.924	☐	0
Land	6.389	6.389	6.389	6.389	☐	0
Civil Works	32.272	32.272	32.272	32.272	☐	0
Boiler	0	0	3.386	0	☐	0
CHP	206.651	206.651	0	0	☐	0
Heat network	0	561.685	0	0	☐	0
Connection to electric grid	134.101	134.101	10.958	10.958	☐	0
Gas upgrade installation	0	0	976.356	986.898	☐	0
Gas pipeline	0	0	115.001	115.001	☐	0
	0	0	0	0		
Subtotal	**1.152.530**	**1.714.215**	**1.917.480**	**1.924.636**		
Construction overhead	105.376	157.017	175.705	176.363		
Advise and permits	36.598	42.889	45.165	45.245		
Contingency	114.614	170.783	191.109	191.825		
Startup	114.614	170.783	191.109	191.825		
Subsidy	0	0	0	0		
Total	**1.523.732**	**2.255.686**	**2.520.568**	**2.529.893**		

Figure 6 Summary of predicted investment costs with option to enter actual costs



In	(€)	**Out**	(€)
Sales of electricity	0	Average yearly depreciation	75.867
Subsidy on electricity	423.507	Average yearly interest	45.088
		Cost of biomass	0
		Maintenance	72.043
		Use of electricity	31.950
		Use of heat	0
		Use of diesel	7.512
		Personnel	23.007
		Insurance	6.130
		Export of digestate	21.759
			0
Total	**423.507**	**Total**	**238.268**

Investment	1.523.732	
Yearly profit	185.240	
Simple pay-back time	5,8	year

Figure 7 Example result using synthetic incentives offered by the new subsidy law for Italy (See Table 1) for a plant of 234 kW_e, powered with a predominance of byproducts (e.g. slurry, manure), and with efficient cogeneration (subsidy of 246 € MWh_e^{-1})

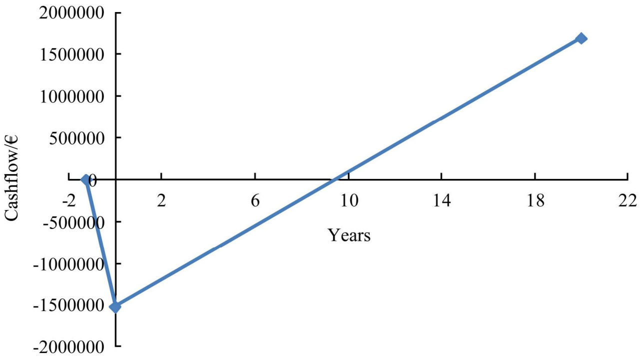


Figure 8 Cumulative cash-flow for the scenario with selling of electric energy

4 Impact of subsidies on payback periods

One of the particular interests is the effects of different policies as they affect subsidies for investments in biogas production. For example, the impact of recent changes of incentives provided to biogas production in Italy can easily be assessed by using this tool.

Four scenarios were calculated under the incentives in place as of December 31, 2012 (flat rate of 280 € MWh_e^{-1}) and the new incentives that became effective of January 1, 2013. All parameters, with the exception of the incentives, remained unchanged for the purpose of comparison.

Reduction of incentives led to longer payback period. In particular, systems most affected were those that do not have ready access to byproducts (e.g. manure, slurry) and are subject to low feed-in tariffs. Systems between 600 kW_e and 1 MW_e showed an increase in the time required reaching positive returns from 4 to 14 yr, whiling for plants between 300 kW_e and 600 kW_e the increase was from 6 to 15 yr. For plants of less than 300 kW_e, with prevalence of manure and/or slurry, the payback period increased from 7 to 10 yr without nitrogen separation, and from 7 to 8 yr with devices for separating nitrogen (Table 2).

Table 2 Payback period for production of electricity as affected by new incentives

Electric power /kWe	Prevalence of by product /waste	Nitrogen separation	New subsidy /€ MWh_e^{-1}	Payback with old subsidy/yr	Payback with new subsidy/yr
428	No	No	200	6	15
844	No	No	180	4	14
274	Yes	No	246	7	10
274	Yes	Yes	276	7	8

5 Adoption efforts and outcomes

The performance metrics used to monitor the project are listed in Table 3.

Table 3 Performance metrics at the end of the project

Performance metric	Planned target	Actual achievement
Bioenergy farm portal	30.000 visits to the portal	35.365 visits
Bio-energy profit calculator	3.000 online scans	3.044 online scans
Trained experts	52 trained experts	53 trained experts
Implementation support	80 business plans for a total of 80 MW	83 business plans for a total of 127 MW in business plans (energy from biogas)
Implementation of biogas plants	Positive decision to invest in 40 MW power for all participating countries	50.7 MW of positive investment decisions

The target performance levels of the project were exceeded in all cases. In addition, user satisfaction levels of experts during national and international training session were high. Other positive feedbacks were obtained from surveys placed on the portal web site at bioenergyfarm.eu.

6 Conclusion

The on-line service has proven its value in assisting consultants and farmers in conducting preliminary feasibility studies for sizing biogas plants and to evaluate technical and economic performance.

The analysis and the feedback of the online service have demonstrated the following uses:

1) Algorithms used in the calculation of technical and economic parameters of biogas plants are indeed based on current best scientific knowledge and engineering.

2) The tool is readily available, and at no cost, without the need for any installation on the end users' devices.

3) The tool operates well on any device through a web interface and is supported by major browsers.

4) Normalized results through the same method of calculation and use of the same coefficients for all users allow for a common and consistent comparison platform.

5) The functionality and reliability of the tool for decision making is enforced by:

- The ability to compare alternative scenarios to assess the most economically sustainable.
- The implementation of a large amount of vetted information within the system that facilitates the use and reduces the time required for the data entry by the user.
- The use of standard parameters on the characteristics of the biomass (methane production, moisture content, density, etc.).
- The production of explanatory reports that provide detailed feedbacks on the feasibility of installing a biogas plant.
- The storage of the user's profile and relative data for further processing.

Finally, adoption of the advisory tool exceeded project target levels and user satisfaction was consistently high.

Acknowledgements

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