ENERGY CROPS APPLIED TO LANDFILLS: FUNCTIONAL, ENVIRONMENTAL AND COSTS ANALYSIS

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Abstract

The application of energy crops to landfills represents an important challenge for the near future. In fact, the possibility to use devalued sites for energy production is very attractive. In this study four scenarios have been assessed by comparing with a reference landfill case defined for the North-Italy area. The scenarios were defined taking into consideration current issues of energy crops. In particular, the first scenario was based on their energetic maximization, the second on their phytotreatment ability and the third on their environmental impact. A fourth scenario combined these characteristics emphasized by the previous scenario. A Multi-Criteria Analysis, based on economic, energetic and environmental criteria was performed. From the analysis, the best scenario resulted the fourth, able to pursue several objectives at the same time obtaining the best score both for environmental and energetic criteria. The economic criterion represents instead a criticism. All the scenarios considered, showed some limits from this point of view. Important indications for future designs can be deducted. The decrease in the quantity of leachate production due to the presence of energy crops on top cover, represent a favourable but critical aspect in result definitions.

1 INTRODUCTION

No-renewable resources represent today the main source of energy. However, in last decades, industrial and scientific efforts are evolved toward renewable sources (Lavagnolo et al., 2011). European Union supported this direction: the new EU Framework for climate and energy sets targets to be reached by 2030 including a 40% reduction in Greenhouse Gas emissions (compared to 1990) and at least a 27% share of renewable energy consumption.

The use of energy crops, fast-growing (and possibly low-cost) plants aimed to energy or biofuels production, represents an important alternative to traditional energy source, able also to offer important advantages on the environment and on agricultural and economic development (Garbo et al., 2016, Koçar and Civaş, 2013).

In this work, the application of energy crops to landfills was analysed. Several scenarios were defined and compared with a reference case, representing a representative average landfill of North-Italy. The comparison was realized through a Multi-Criteria Analysis (MCA), based on three criteria: the economic, correlated to the cost of each intervention, the energetic, linked to the potential energy production during the whole landfill life cycle, and environmental, related to effects and impacts of the intervention on the landscape.

2 MATERIAL AND METHODS

The research activity was performed through the following steps:

- Criteria definition: economic, energetic and environmental criteria were defined in order to analyse and compare different scenarios of landfill configurations.
- Scenarios definition: a reference scenario (scenario "zero") and other four scenarios were defined. Current issues of energy crops such as their energetic potential, the possibility of leachate phytotreatment and their impact on the environment were considered.
- Multi-Criteria Analysis: the scenarios were compared by means of a MCA, considering equal weighting of the criteria.

2.1 Criteria definition

The definition of the criteria was fundamental for the analysis of scenarios in the MCA. Three criteria were considered: the economic, which evaluated the total landfill cost (€), the energetic, which considered the energetic net gain for the whole landfill cycle (GJ) and the environmental, which defined the mean biopotentiality index for the landfill site (Mcal/m^2/y).

2.1.1 Economic criteria

The total landfill cost was defined using bills of quantities and redacting financial plans for each scenario. Costs were evaluated through the whole landfill life cycle, considering therefore the design and authorization phase, the construction phase, the operational phase and the aftercare phase.

The last phase consists in monitoring and maintenance activities, which are mainly: top cover maintenance and monitoring, leachate collection system operation and maintenance, landfill gas collection system maintenance and monitoring, landfill gas migration control and monitoring, groundwater and surface water monitoring, security and ground stability maintenance.

The calculation of the final total landfill cost for each scenario allowed to define the values to insert within the evaluation matrix for the MCA ($x_{economic}$). The following expression was used:

$$x_{economic} = C_{reference} - C_i \quad (1)$$

where:

- $x_{economic}$ represented the additional costs or savings compared to the reference scenario, respectively if resulting negative or positive values.
- $C_{reference}$ represented the landfill cost of the reference scenario;
- C_i represented the cost of the i-th scenario.

2.1.2 Energetic criteria

The energetic criterion evaluated the cumulate energy net gain as difference between energetic input and output. The duration of operational phase was defined equal to 10 years as the mean time of a statistical investigation for many landfill in Italy, while the duration of aftercare was defined by EU regulation in 30 years. Therefore, the criterion was evaluated for a time scale of 40 years.

The Joule was adopted as unit of measurement (Angelini et al., 2009; Fiala et al., 2010; Nassi et al., 2010).

Inputs were estimated for each species, considering direct and indirect factors and correlating them to the surface occupied. Direct energy inputs were calculated multiplying the energy equivalent of fuel, fertilizers, herbicides, seeds and manpower with their quantities, defined according to the needs of each species (Table 1). Seeds, manpower and other productive inputs were estimated directly using experimental data depending on the specific crop considered (Angelini et al., 2009; Fiala et al., 2009; Nassi et al., 2010; Venturi P. and Venturi G., 2003). Indirect energy, often not taken under consideration for their difficult quantification, are reported to have a moderate impact on total energy input value, up to 20% of it (Fiala et al., 2009). In this work they were considered equal to the 10% of direct ones.

Table 1: Direct energy inputs values adopted in the calculations (Venturi P. and Venturi G., 2003).

Direct input	Energy value
Fuel (use of machines, etc.)	47.8 MJ/L
Nitrogen fertilization (Urea)	76 MJ/kg
Phosphatic fertilization (P_2O_2),	14 MJ/kg
Potassic fertilization (K_2O),	10 MJ/kg
Herbicides	202 MJ/kg

Instead, energetic outputs values were determined coupling agricultural production data (and so the crop yield, expressed as t/ha) with specific energetic characteristics of final crop products

(Lower Heating Value, LHV) of the final product (grain, oil or biomass) (Venturi P. and Venturi G., 2003).

It must be noted that, in this energetic analysis, output and input were not correlated by a real consistent relationship: it is not always true, in fact, that eventual low (or high) energetic input results into low (or high) energy output(Venturi P. and Venturi G., 2003). For this reason, analysis of specific situations should require precise researches and experimental data.

After the calculation of the energy net gain for each scenario, the values to include within the MCA evaluation matrix ($x_{energetic}$) was assessed using the formula:

$$x_{energetic} = E_i - E_{reference} \quad (2)$$

where:

- E_i was the energy net gain of the i-th scenario;
- $E_{reference}$ was the energy net gain of the reference scenario.

2.1.3 Environmental criteria

The environmental criterion took into consideration the effects on the environment caused by energy crops application. In this work the indicator adopted was the biopotentiality index or Biological Territorial Capacity of vegetation (BTC), an index typical of the Landscape Ecology discipline. The BTC is measured as Mcal/m^2/year and represents the latent energy of a given site, therefore the energy that a vegetative system has to dissipate in order to maintain the degree of organization. The time-evolution analysis of BTC for a specific site allows the assessment of the landscape transformation. In particular, a decrease of the BTC value generally corresponds to a degradation of the site, since a net loss of its self-rebalancing capabilities. On the contrary, an increase of the BTC value results in an improvement of the quality of the site.

The procedure followed for the definition of the mean BTC values can be summarized in these fundamental points (Pivato et al., 2013):

- Establishment of the proper scale for the analysis (spatial-temporal);
- Definition of BTC_i for each landscape element;
- Evaluation of the mean BTC runnig Monte Carlo method.

A proper choice of the spatial-temporal scale is fundamental since it determines the limits for applicability of the analysis itself (Figure 1) (Pivato et al., 2013). The time scale adopted must be able to allow the comparison of the state of the landfill site before the operational phase with those at the end of the aftercare phase, avoiding longer periods that can make results unrealistic. The spatial scale must not be too small, in order to avoid errors for the specificity of the assessment: the consideration of the surface within 300 m of distance from the landfill perimeter allows to obtain an average response of the landfill site and its surrounding areas. In this case, the surroundings are assumed to be mainly agricultural areas.

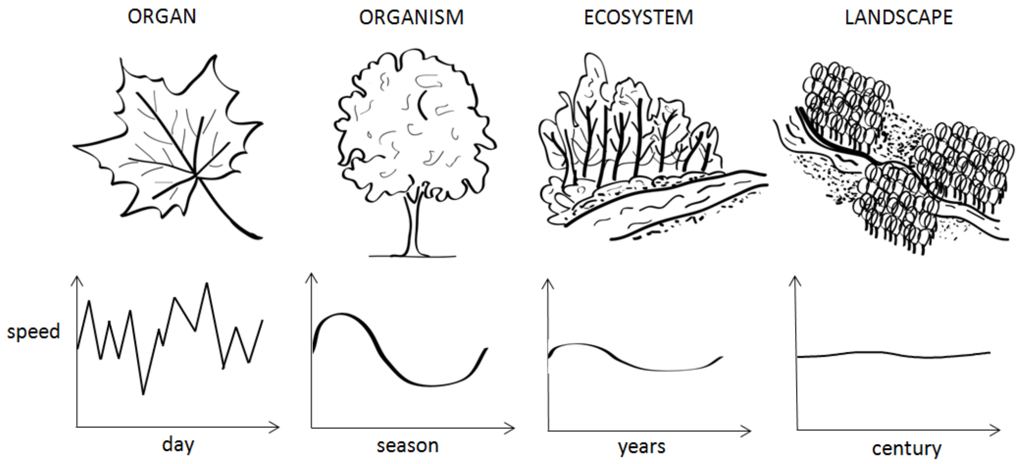

Figure 1: Higher level of the ecological system are characterized by lower speeds of the process: examples for the photosyntesys production (adapted from Ingegnoli, 2015)

The BTC was defined for each landscape element, considering data from Ingegnoli (2011), Ingegnoli and Giglio (1999) and Pivato et al. (2013) (Table 2).

The mean BTC (BTC_{mean}) was calculated using (Pivato et al., 2013):

$$BTC_{mean} = \frac{(\sum_i S_i \cdot BTC_i)}{S_{domain}} \quad (3)$$

where BTC_{mean} ($Mcal/m^2/year$), was the mean Biopotentiality related to the spatial domain considered S_{domain} (m^2) and BTC_i ($Mcal/m^2/year$) was the biopotentiality of the *i*th landscape element characterized by a surface S_i (m^2).

A probabilistic approach able to minimize uncertainty and eventual errors in BTC_i value definition was considered. In particular, the Monte Carlo method was adopted: the method is based on the random sampling from each distribution probability of the variables considered and their successive combinations on the basis on an analytical formulation fixed by the user (in this case represented by equation (3)). The variables corresponded to the BTC_i, and were defined by a log-normal Probability Density Function (PDF). The variance of each variable was assumed to be equal to the 10% of its average value, an assumption that appears realistic since, in this way, an increase of landscape ecological complexity means a higher uncertainty about the variable itself. The variables were assumed to be independent. Of course, this assumption is not realistic but, since the high quantity of data needed, cannot be avoided in practice (Pivato et al. 2013).

As for the previous criteria, the values to include within the MCA evaluation matrix ($x_{environmental}$) was calculated using the formula:

$$x_{environmental} = BTC_i - BTC_{reference} \quad (4)$$

where:

- BTC_i was the biopotentiality of the i-th scenario;
- $BTC_{reference}$ wass the biopotentiality of the reference scenario.

Table 2: BTC_i values assumed for the landscape elements used in the analysis

Landscape elements	BTC_i (Mcal/m^2/year)
Landfill in operation	0.40
Service area	0.30
Artificial water channel	0.20
Leachate and LFG treatment, temporary storage, wastewater treatment	0.30
Roads	0.40
Annual crop field	0.80
Simple crop field	1.30
Grass	0.70
Shrubs and grass associations	2.40
Woods plantation	3.10

2.2 Scenario definition

Each scenario should represent a possible solution for energy crops application to landfills. In particular, the scenarios were chosen according to the energetic characteristics, the phytodepuration efficiency and environmental impact of energy crops. Factors as climatic conditions and relationship between crop and site characteristics were considered (Venturi P. and Venturi G., 2003; Zegada-Lizarazu and Monti, 2011).

2.2.1 The reference scenario (scenario "zero")

The reference scenario was based on the design of a landfill model representing the main geometry (volume and surface) and the constructive characteristics of landfills in the North-Italy area. The landfill was defined as non-hazardous waste landfill (Municipal Solid Waste and Special Waste). The design was performed according to current legislation (D.Lgs. 36/2003), on the suggestions of national landfills guidelines (CTD, 1997; DGR n. X/2461/2014) and on best practices.

The model landfill is underground (60% of the investigated landfills are underground), since realized in a gravel pit, with a total waste volume of 800,000 m^3 and the surface, at the ground level, of 50,000 m^2. The height of the waste mass (and so excluding daily, temporary and top cover system) is about 23 m. The landfill has rectangular shape with a top cover characterized by two slopes: the upper central part with slope of 4%, has a surface of 21,417 m^2, and the remaining part with slope of 24%, has a surface of 29,412 m^2. The landfill is subdivided into 4 sectors.

The leachate collection system is designed based on leachate production calculations (Canziani et al., 1989).

Calculations on leachate productions (Canziani et al., 1989, Blakey, 1992) show a maximum yearly leachate production of 5,549.16 m^3/year in operational phase and a constant production of 2,027.54 m^3/year in aftercare. The total leachate produced in 40 years is calculated to be 103,366.46 m^3 (42,540.31 m^3 in operational phase and 60,826.15 m^3 in aftercare). Leachate is collected and stored in four fibreglass tanks of 100 m^3 located within a concrete-made containment basin of 420 m^3 representing a safety measure in case of eventual failure.

Landfill gas is designed according to production quantities estimated using model suggested by Cossu et al. (1992). The total calculated production is 15,981,180.24 Nm^3 in 40 years (3,955,642.71 Nm^3 in operational phase and 12,025,537.53 Nm^3 in aftercare) with a methane content assumed to be 50% and collection efficiency 70% (DGRV n. 995/2000). Energetic recover is not considered worthwhile (DGRV n. 995/2000). A torch is included, designed in accordance with D.Lgs. 36/03 and CTD (1997).

The service area has a surface of 3,950 m^2, including temporary storage, tire washing system, truck scale, office building and vehicles parks.

The landfill inflow waste is assumed to be 30% Municipal Solid Waste (MSW) and 70% Special Waste. The waste characterization assumed, on wet weight base and referred to residual and pre-treated fractions, is: paper 1.5%, cardboard 1.5%, glass and inert 52%, plastic 12%, metals 3%, stabilized inert 15%, and sludge 15%. All the values assumed are in accordance with the case studios considered. A waste density is 1.1 t/m^3, which result in a yearly waste inflow of 88,000 t/year.

The application of a simple grass cover over the landfill, allow to easy compare the interventions planned in the other scenarios. The reference scenario is represented in Figure 2.

2.2.2 The first scenario (energetic maximization scenario)

This scenario was defined considering the energetic potential for most important energy crops species. In particular, the choice was directed to an option able to guarantee a positive energetic balance between input and output, characterized therefore by a good energetic net gain. Miscanthus (*Miscanthus x giganteus*) proved very promising from this point of view (Venturi G. and Monti, 2005; Venturi P. and Venturi G., 2003). Miscanthus is an herbaceous plant characterized by low nutrients requirements, low weeds and pests risk, and really high crop yield. Since perennial, it is cut yearly, between the autumn and the late winter period. The product can be managed similarly to lands of hay grass, with reduction of the biomass produced in mown bales.

In this scenario, Miscanthus plantation was planned during the aftercare phase. Miscanthus lifetime of 15 years was assumed. At the end of the 15 years, the whole Miscanthus plantation was assumed to be removed and then reinstalled, thus allowing another Miscanthus cycle until the end of aftercare (30 years).

The whole top cover surface with small slope (4%) was considered cultivated, for a total of 21,417 m^2. In order to prevent eventual problems of liners damaging due to the roots infiltration, an additional 0.5 m thickness of natural soil was considered to be added to the final top cover. In fact, Miscanthus plants can be characterized by a deep root mat: the achievement of depths in the order of 2 m are not unusual. However, the high density of the roots system can prevent water leaching through the top cover system, decreasing therefore the leachate production (Lewandowski et al., 2000). The leachate production was estimated by means of the commercial software “Visual HELP”, that is able to include the different thickness and composition of the top cover. Also, an increased evapotranspiration was considered. Results, after proper calibration of the software, showed a decrease of leachate production in aftercare, respect the reference scenario, for a value of about 91.53 m^3/year (total reduction of 2,745.92 m^3 in 30 years).

It was assumed zero biomass production for the first year of installation, 10 tonnes for the second, 20 for the third and 25 from the 4^{th} to the 15^{th} (Lewandowski et al., 2000; Veneto Agricoltura, 2010).

A small artificial water pound of 550 m^3 was considered in order to guarantee the hydric sustainability and irrigation independence of the landfill site.

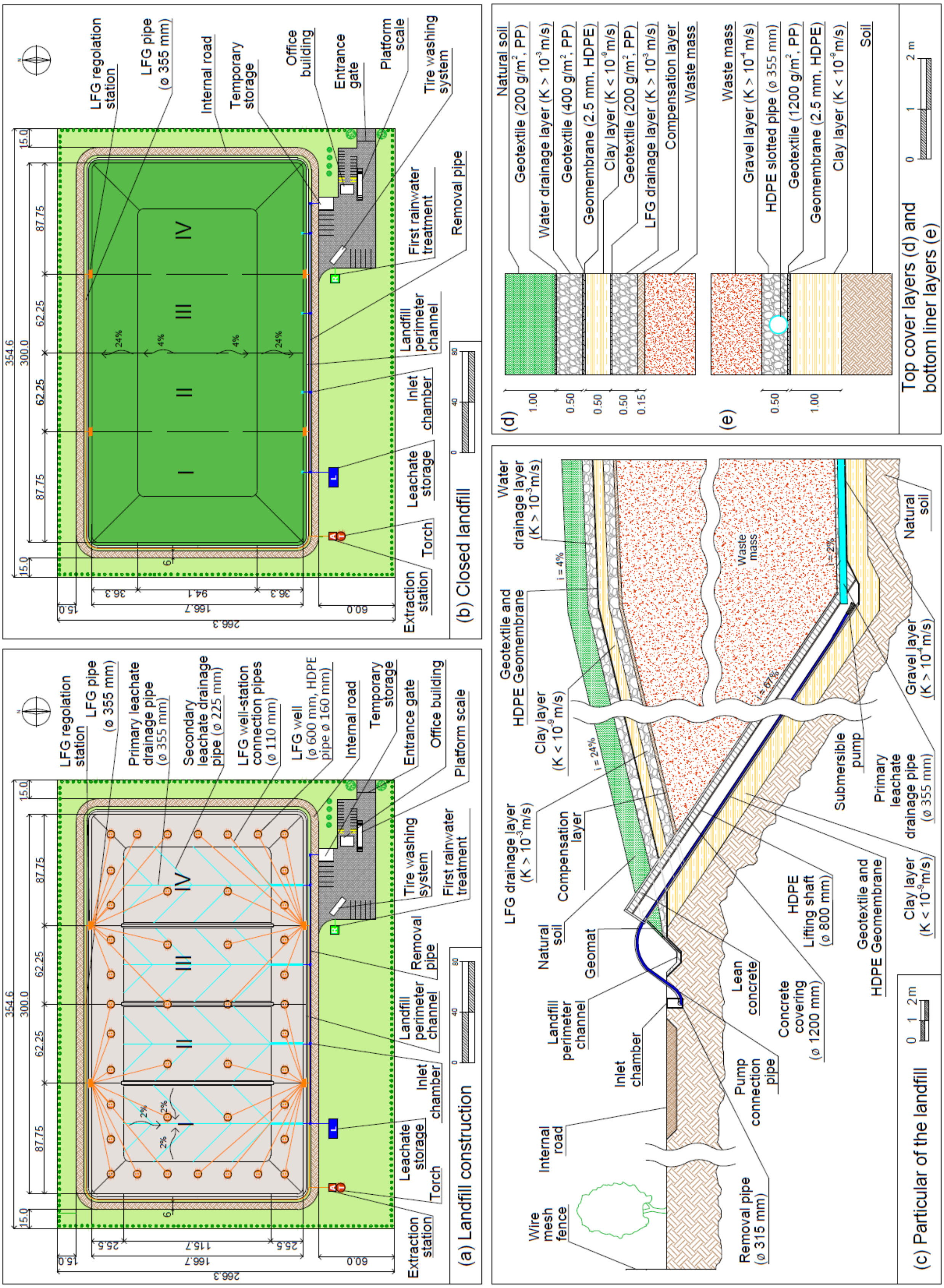

Figure 2: Reference scenario

2.2.3 The second scenario (phytodepuration scenario)

The scenario was defined taking into consideration the phytodepuration ability of some energy crops. Several authors showed in fact the effectiveness on wastewater and leachate contaminant abatements (Garbo et al., 2016; Jones et al., 2006). In this scenario, the application of Sunflower (*Helianthus annuus L.*), Rapeseed (*Brassica napus)* and Soybean **(***Glycine max***)** was considered. Garbo et al. (2016) and Lavagnolo et al. (2011, 2016, 2017) showed experimentally their good performances achieving efficiencies higher than 80% for COD removal, higher than 70% for total N and higher than 95% for total P removal, thanks to the good soil and plant synergic effects.

The rotation assumed for calculations was biennial: first year with Sunflower in the spring-summer period and with Rapeseed seeding in autumn, second year with Rapeseed harvesting at the end of the spring and Soybean application in summer period. The yearly crop yields were assumed to be 2 t/ha years for Sunflower, 2.2 t/ha for Rapeseed and 2.3 t/ha for Soybean.

The fields were assumed to be placed within basins created by proper surrounding clay levees, in order to avoid the dispersion of the phytotreatment outflow. These basins were installed on the top cover of the landfill, in the area characterized by lower slope. According to Garbo et al. (2016) and Lavagnolo et al. (2016b), the basins should require at least two layers: a drainage layer and a crops growing layer. A value of 0.3 m of thickness of crops growing layer was considered sufficient for allowing the contact of the plant's roots system with the mix to depurate (introduced within the drainage layer) and the correct performance of soil tillage works. The phytotreatment basins was realized on a temporary cover, characterized by the same composition of the final top cover but differenced by a natural layer of 0.3 m instead of 1 m. This temporary top cover could be then easily transformed into a final top cover at the end of agricultural activities, by simply adding 0.7 m thickness of natural soil on it. The layers composition for the temporary and the final top cover is shown in Figure 3. Note that, by comparison with the scheme adopted for the reference scenario (Figure 1 (d)), also an additional 0.5 m thickness of clay is considered, in order to minimize eventual infiltrations to the landfill body.

The assumption of the use of a temporary cover affects also the duration of the period for energy crops cultivation, since directly correlated to the landfill operation phase. The starting of the aftercare phase can occur in fact only once the final top cover is installed: an eventual lengthening of agricultural works reflects therefore in an extension of duration of the operation phase, with high additional costs on total landfill cost. A proper preliminary analysis was performed in order to define and assess, from an economic point of view, an alternative able to minimize the sum of costs of construction and operation phases.

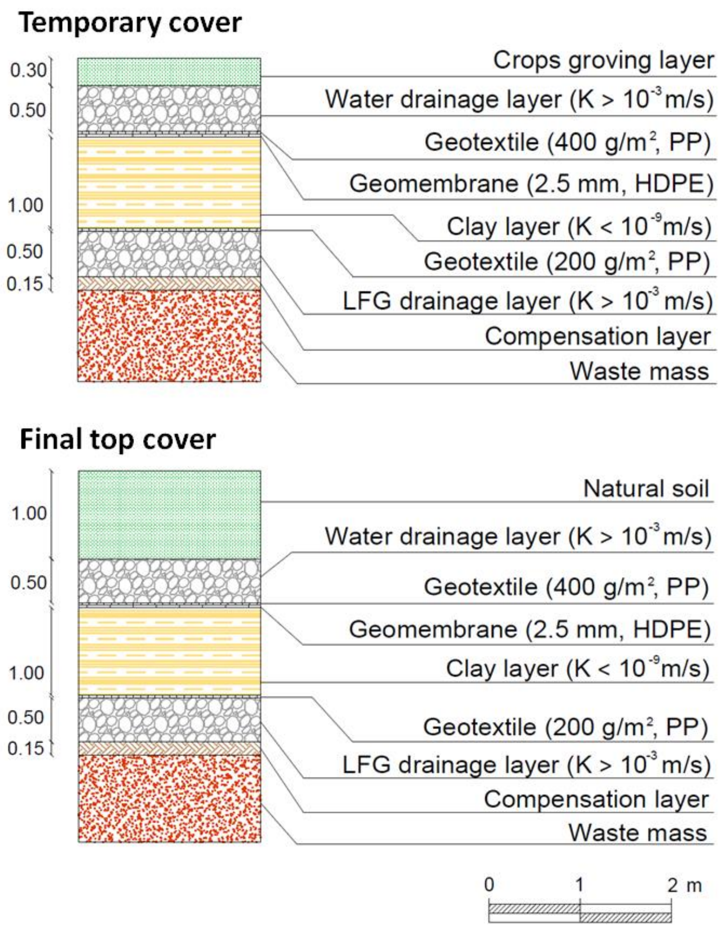

Figure 3: Temporary and final top cover adopted for the phytotreatment basins in the second scenario.

The best solution was estimated as the one that considered the use of the first two closed sectors for the phytotreatment basin. A surface of 6,425 m^2 was estimated allowing the treatment of about 4,440.96 m^3 of leachate in four years of activities. The leachate quantity introduced directly into the phytotreatment system has to be diluted with rain water; it was calculated as percentage of the total inflow flux of the phytodepuration basin and this quantity is not fixed a priori, since depend mainly from the response of the plants. In the current analysis, a percentage of 30% of the total inflow was considered. (Garbo et al., 2016). The inflow flux was calculated assuming a mean porosity of the 30% within the phytotreatment basin (range 20-50%) and a Hydraulic Retention Time of 15 days (HRT, range 7 days-1 month). The quantity of outflow from the phytotreatment process was assumed to be 50% of the inflow. Therefore, the total outflow was calculated to be 7,401.60 m^3 in four years of activities. This rough estimation is affected by many uncertainties; in this view, an accurate hydrological balance should be developed, able to take into consideration the seasonal variations in precipitations, irrigation and plants hydric requirement, but also other important terms such as evapotranspiration, evaporation or soil humidity regulation processes.

A small lake pound of 500 m^3 was considered, in order to ensure the complete water self-independence of the site even during drought periods.

Due to the presence of the phytotreatment basins on top cover, the software Visual HELP showed a decrease of leachate production respect the reference, for a total of about 1,336 m^3 in the 4 years of phytodepuration during the operation phase (total cumulate of 42,540.31 m^3 in the reference versus the 41,204.11 m^3 of this case) and of about 30 m^3 in the 30 years of aftercare.

Additional monitoring investigations were considered during the period of phytotreatment. The most important regarded the periodic soil sampling (concentrations of contaminants in the soil should not exceed the limits defined in Table 1 of Annex 5 to Part IV of D.Lgs.152/2006) and the chemical analysis of the inflow and outflow liquid of the phytodepuration.

2.2.4 The third scenario (environmental compensation scenario)

The scenario was defined taking into consideration the environmental impacts of energy crops. However, in the analysis, it must be considered that energy crops were considered applied in a territory already transformed and damaged (by the landfill construction, but also previously by the gravel pit). In this sense, the introduction of energy crops, may be able to reduce the negative effects of the intervention. For instance, the use of wood plantations for biomass production is already a well-established reality, with well-known advantages on ecological (biodiversity increase, CO_2 adsorption, wildlife habitat, etc), protective (soil protection from erosion, etc), sanitary (defence from noise and contaminants, etc) and aesthetic (recreational and touristic activities) aspects (Santacroce et al., 2007).

In this scenario, the following interventions were provided:

- Creation of a green belt made mainly with Poplar. A medium cutting frequency of 5 years was planned (Medium Rotation Forestry, MRF). This type of installations is characterized by having a life time of 15 years: for this reason, two installations were planned during the 30 years of the landfill aftercare phase. At the end of the aftercare phase, plants were not removed but left there as frame for the recreational area. A planting system with plants spaced 3 m each to the others (both on the row and intrarows) allowed the installation of 870 plants in a surface of 7,020 m^2. The value is in accordance with ranges defined in literature for MRF (1,100 and 1,500 plants/ha, Bergante and Facciotto (2006)) The crop yield was assumed 65 t_{dm}/ha constant for every cycle of cuttings (range around 60 -120 t_{dm}/ha, Santacroce et al.(2007) and Fiala et al. (2010))

- Creation of a wood plantation located along the south side of the landfill. The plantation has the same characteristics of the green belt explained at the previous point. In this case, 756 Poplar plants were assumed to be installed in a surface of 6,175 m^2.
- Shrubbery placed on top cover. Shrubs were considered installed over the landfill top cover, by creating shrubs spots of about 20 plants each (about 40 spots/ha). The installation of shrubs allows a better landfill inclusion on the landscape, promoting the development of a cenosis and improving the ecological value of the area. The shrubs could be of several species, belonging to the autochthonous vegetation heritage of the site. The introduction of shrubs is accompanied by the creation of walk paths, which allow the exploitation of the surface as recreation area.

The choice of shrubs on top cover considered the compensation effect rather than the energy crops application: in fact, the application of lignocellulosic energy crops, which can be considered the closest type of plants for a compensatory measure, can lead damages to the landfill top cover liners.

2.2.5 The fourth scenario (combination scenario)

This scenario combined the solutions adopted for the other three scenarios. In particular, it assumed: the Miscanthus cultivation on top cover during aftercare (as the energetic maximization scenario), the oil crops phytotreatment field during operation (as the leachate phytodepuration scenario) and the Poplar and shrubs plantation (as the case of the compensation scenario). The characteristics of these intervention are similar to those previously explained in detail for each scenario. However, in this case, the shrubs installation was planned only at the end of the aftercare phase. This scenario, so defined, allowed to combine the specific characteristics of energy crops emphasized by each of the other scenario (Figure 4).

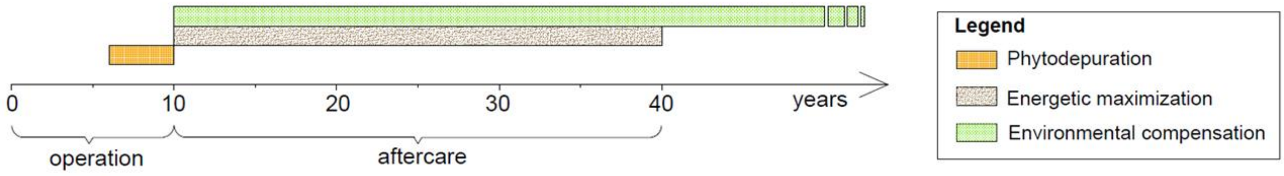

Figure 4: Characteristics emphasized by energy crops scenarios, according to time. The fourth scenario, since combination of the other scenarios, is able to cover several goals.

2.3 Multi-Criteria Analysis

Multi-Criteria Analysis (MCA) was performed in order to compare the scenarios. In this kind of analysis, the weighting of the criteria covers a fundamental role, since allows the definition of criteria priorities. However, different actors can express contrasting views (even if legitimate) about a define subject and the solution can sometimes be addressed according to their preferences. The weighting process subject is therefore highly discussed and often represents a reason of misunderstandings. In the present case, it was assumed equal weight for all the three criteria considered.

The evaluation matrix was composed by the x_i values (with i = economic, energetic or environmental according to the criteria) as previously defined (equations (1), (2) and (4)). The built matrix was then linearized using a simple interval standardization:

$$\frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (5)$$

where x_{min} and x_{max} were respectively the minimum and the maximum values resulting between the scenarios for the i-th criterion. This linearization allowed to refer the values of each criteria assigning “0” to the minimum value and “1” to the maximum. The criteria were assumed to have the same weight (w_i). Then, the best scenario was represented by the scenario that satisfied the following equation:

$$\text{Best scenario} = \text{Max} \sum_i x_i * w_i = \text{Max} \sum_i x_i * 1/3 \quad (6)$$

3 RESULTS AND DISCUSSIONS

The results for economic, energetic and environmental criteria are reported respectively in Tables 2, 3 and 4.

The total cost for the reference scenario was calculated to be 68,833,045.81€. The energetic net gain was zero, since no energy crops were applied. The BTC_{mean} was calcutated to be 0.89 Mcal/m^2/year before the landfill operation and 0.90 Mcal/m^2/year at the end of the 40 years.

Regarding the first scenario, the landfill cost was calculated to be 69,279,106.78€, resulting in 446,060.98 € more than the reference. The main differences arise from the construction phase costs, where an increase of 455,287.88€ respect the reference is shown: the cost is explained by the addition of 0.5 m thickness of natural soil in the cultivated field (231,946.11€) and from the investment for irrigation system and water pound construction (78,327.82€).

The operation costs of this scenario do not substantially differ from the reference, since no difference in operation works occur. Saving are mainly possible from the agricultural activity and the leachate management during the aftercare, calculated to be respectively 13,333.56 € and 110,766.37€ in 30 years of aftercare. The agricultural works considered in the calculations were different according to the year considered. Great efforts are required in particular in the first year for the Miscanthus installation (soil tillage operations and transplantation of Miscanthus roots). The prices considered for agricultural works refer mainly to the agro-mechanical works price list of the province of Verona (A.P.I.M.A. Verona, 2011). It must be point out that, the economic value of agricultural activities and of their revenue, are subjected to significant annual fluctuations, function of the market request, which are not considered in the present work.

Regarding the second scenario, the landfill cost was calculated to be 68,952,498.16 €, resulting in 119,452.35€ higher than the reference. The total construction phase cost resulted 154,788.59€ more respect the reference. Differences in landfill management costs occur in the operational phase, with savings of 66,590.36 € respect the reference. The reduction in the quantities of leachate production, due to the placement of the basins on the top cover, allow a saving of 53,447.90€ on leachate management costs. Also, savings of 29,606.40€ were obtained from the leachate phytotreatment process. In this case, a unit cost of 20 €/m^3 for the treatment of the outflow was considered (half respect the common unit costs assumed for leachate treatment).

The agricultural works considered were similar at the three crops, including soil tillage operations, seeds sowings, chemical and mechanical weeding, harvesting and transport of products. No fertilization was considered since the high nutrients content of the water-leachate mix.

Regarding the third scenario, a total landfill cost of 69,139,071.58€ was calculated, resulting in 306,025.78 € more than the reference. In this case, the total construction phase cost includes the cost for installation of Poplar trees and shrubs species, calculated to be 132,390.00 €. During the landfill aftercare phase, the cost calculation took under consideration agricultural works needed for the use of Poplar as energy crop (fertilization, phytosanitary control, cuttings, transport, etc.) and those needed for the maintenance of shrubs and walk paths created. A cost of 56,417.12 € and of 13,021.80€ was calculated respectively. Revenue, from the sale of the biomass collected, was calculated to be 49,877.10€ in 30 years of aftercare.

Regarding the fourth scenario, a total landfill cost of 69,189,190.40€ was calculated, resulting in 356,144.59 € more than the reference. The costs calculation was based on considerations made for the other scenarios and opportunely combined. The most important costs were in the construction phase, with 556,301.91 €. The operation and the aftercare phases allow a saving of 65,190.19 € and 237,346.98 €.

Note that in all the scenario the calculations of revenue from agricultural activity were related only to the sale of the final products: public subsidies, land benefits and other type of funds are not considered.

The energetic net gain was defined calculating inputs values variables during the production of Miscanthus (43.79 GJ/ha in the first year, 15.84 GJ/ha from the second to the 14th year and 30.46 GJ/ha the 15th year) and Poplar (45.66 GJ/ha for the installation, 23.36 GJ/ha for the 5th and 10th years, 29.55 GJ/ha for the 15th year and 7.99 GJ/ha for all the other years). Constant input of

29.02 GJ/t, 21.33 GJ/t and 27.18 GJ/ha was calculated instead respectively for Sunflower, Rapeseed and Soybean. According to Venturi P. and Venturi G. (2003), these last values include an addition in order to consider also the energy effort required by the post-harvesting process, related to the oil production.
For the output calculation, the LHVs assumed were 17.60 GJ/t for Miscanthus, 38.40 GJ/t for Sunflower, 37.40 GJ/t for Rapeseed, 36.40 GJ/t for Soybean and 17.80 GJ/t for Poplar. By-product were not considered in this analysis. All the values used for energetic analysis are consistent with literature data (Venturi G. and Monti, 2005; Venturi P. and Venturi G., 2003).

The mean biopotentiality was calculated for all the scenarios, implementing the Monte Carlo method using the commercial software Crystal Ball. The results could be strongly affected by eventual wrong assignments of the BTC_i values, especially with regard to the agricultural land, which represented the predominant area (between 88.5% and 91.1% of the total area, according to the scenario). Besides, an important aspect was represented by the spatial scale assumed. Considering a larger or a smaller scale, the changes in BTC_{mean} can be respectively less or more visible. For instance, in the third scenario, the assumed surface of 827,050 m^2 allows to see an improvement of the BTC_{mean} of about 0.16 Mcal/m^2/year, considering the temporal interval between the start of landfill operation and the end of aftercare. The consideration of a larger surface of about 4 km^2 instead reduces this improvement of about one order of magnitude less (an increase of 0.0088 Mcal/m^2/year), while, on the contrary, the consideration of the barely landfill site, increase the BTC_{mean} of one order of magnitude (an increase of 1.66 Mcal/m^2/year). From practical point of view, this means that even if the proposed interventions are important from ecological point of view, they are usually really site specific and represent a local improvement. For this reason, the compensation applied to the landfill should be seen as a part of a larger compensation measure, realized for instance also through the introduction of ecological corridors or green buffer zones (USDA, 1999; Lineah et al., 1995).
The linearized evaluation matrix based on x_i values defined previously is shown in Table 5.
From the MCA, the fourth scenario resulted first in the final score between the cases considered, since able to maximize the energetic and the environmental criteria. This fact alone allows it to easy exceed the final score obtained for the other scenarios. However, it represents the second most expansive scenario.

The cheapest solution is represented by the reference scenario, where no interventions of energy crops are realized. All the others show additional cost. In particular, none of the solutions proposed, where energy crop fields are placed on top cover, seems able to cover the additional investment costs required, in particular if an increase of the top cover layer thickness was considered. The energetic maximization scenario for instance, without considering this cost, may be able also to give a positive economic balance.

The use of energy crops able to fit the energetic and the environmental criteria without affecting the top cover composition should be better considered. However, from economic point of view, good perspectives are offered in the leachate phytodepuration scenario. In this case, an effective solution may result from the consideration of longer periods of time for leachate treatment, for instance by extending the application of the phytodepuration process in the aftercare phase. In this view, the current normative restrictions related to the composition of the final top cover are limiting. A better integration of legislation with applications related to new technologies should be studied. In fact, without these law limitations, the final score obtained with the leachate phytodepuration scenario could be different, since some important economic savings could be potentially possible.

The energetic and environmental criteria result maximized when lignocellulosic crops were considered. Regard the energetic, the first scenario is able to obtain better results thanks to the higher crop yield offered by Miscanthus. The environmental criterion instead resulted better in the third and fourth scenario, since evaluated after the end of the aftercare phase.

It must be underlined that these considerations are based on data which could be subjected to many variations.

The introduction of the social impact as criteria of the MCA could be also interesting, since here not considered. The thought is that interventions, aimed to apply energy crops in sites such as those of landfills, should improve the social acceptance of the site, by creating new works places (agricultural activities), by improving the aesthetic vision of the site and by the creation of eventual recreational areas.

Tale 2: Results obtained from the analysis of the scenarios according to the economic criterion. The evidenced row represent the categories directly affected by the energy crops application. In the last row the $x_{economic}$ for the MCA is calculated.

Items		Cost (€)				
		Reference scenario	First scenario	Second scenario	Third scenario	Fourth scenario
1	Design and Authorization Phase	870,303.61	897,111.28	879,417.67	881,785.30	903,059.05
1.1	Design and Authorization Cost	870,303.61	897,111.28	879,417.67	881,785.30	903,059.05
2	Construction Phase	18,031,437.69	18,486,725.57	18,186,226.28	18,226,437.01	18,587,739.60
2.1	Area Acquisition	1,417,500.00	1,417,500.00	1,417,500.00	1,417,500.00	1,417,500.00
2.2	Construction Cost	10,503,795.11	10,838,890.95	10,617,720.86	10,647,316.31	10,913,238.16
2.2.1	Preliminary Works	164,987.20	164,987.20	164,987.20	164,987.20	164,987.20
2.2.2	Morphological Shaping	271,455.00	271,455.00	271,455.00	271,455.00	271,455.00
2.2.3	Bottom Liner System	2,849,076.45	2,849,076.45	2,849,076.45	2,849,076.45	2,849,076.45
2.2.4	Top Covers System	4,671,169.43	4,903,115.54	4,697,521.94	4,671,169.43	4,872,542.55
2.2.5	Leachate System	409,841.30	409,841.30	409,841.30	409,841.30	409,841.30
2.2.6	Landfill Gas System	458,982.86	458,982.86	458,982.86	458,982.86	458,982.86
2.2.7	Monitoring	32,135.10	32,135.10	32,135.10	32,135.10	32,135.10
2.2.8	Landfill Hydraulic Settlement	25,386.66	25,386.66	25,386.66	25,386.66	25,386.66
2.2.9	Underground Utilities	170,621.27	170,621.27	170,621.27	170,621.27	170,621.27
2.2.10	Internal Road and Service Area	274,463.58	274,463.58	274,463.58	274,463.58	274,463.58
2.2.11	Facilities	179,000.00	179,000.00	179,000.00	179,000.00	179,000.00
2.2.12	Environmental Restoration Works	137,746.59	137,746.59	137,746.59	137,746.59	137,746.59
2.2.13	Final Works	80,870.77	159,198.59	160,005.07	213,760.77	258,611.59
2.2.14	Safety	778,058.90	802,880.81	786,497.84	788,690.10	808,388.01
2.3	Machinery Purchase	1,350,000.00	1,350,000.00	1,350,000.00	1,350,000.00	1,350,000.00
2.4	Financial Expenses	4,760,142.58	4,880,334.62	4,801,005.42	4,811,620.71	4,907,001.45
3	Operation Phase	29,325,233.72	29,327,089.28	29,258,643.36	29,325,233.72	29,260,043.52
3.1	Operation Cost	10,039,565.86	10,039,565.86	9,973,294.85	10,039,565.86	9,973,294.85
3.1.1	Staff	4,598,350.00	4,598,350.00	4,598,350.00	4,598,350.00	4,598,350.00
3.1.2	Consumptions and Materials	400,000.00	400,000.00	401,200.00	400,000.00	401,200.00
3.1.3	Leachate Management	1,917,973.00	1,917,973.00	1,834,596.98	1,917,973.00	1,834,596.98
3.1.4	Landfill Gas Management	458,982.86	458,982.86	458,982.86	458,982.86	458,982.86
3.1.5	Daily Top Cover	464,760.00	464,760.00	464,760.00	464,760.00	464,760.00
3.1.6	Monitoring	344,500.00	344,500.00	355,000.00	344,500.00	355,000.00
3.1.7	Maintenance	750,000.00	750,000.00	750,405.01	750,000.00	750,405.01
3.1.8	Other Services (technical costs, etc.)	1,105,000.00	1,105,000.00	1,110,000.00	1,105,000.00	1,110,000.00
3.2	Pollution Liability Protection in Operation	180,000.00	180,000.00	180,000.00	180,000.00	180,000.00
3.3	Financial Guarantees in Operation	118,787.86	120,643.42	118,468.51	118,787.86	119,868.67
3.4	Contribution for Environmental Annoyance and Landfill Tax	18,986,880.00	18,986,880.00	18,986,880.00	18,986,880.00	18,986,880.00
3.4.1	Contribution for Environmental Annoyance	5,807,120.00	5,807,120.00	5,807,120.00	5,807,120.00	5,807,120.00
3.4.2	Landfill Tax	13,179,760.00	13,179,760.00	13,179,760.00	13,179,760.00	13,179,760.00
4	Aftercare Phase	7,149,570.29	7,024,477.56	7,148,358.03	7,189,288.60	6,912,223.31
4.1	Aftercare Cost	6,557,113.38	6,433,013.45	6,555,910.75	6,596,675.20	6,321,650.11
4.1.1	Staff	2,035,570.00	2,035,570.00	2,035,570.00	2,035,570.00	2,035,570.00
4.1.2	Consumptions and Materials	244,000.00	244,000.00	244,000.00	244,000.00	244,000.00
4.1.3	Leachate Management	3,068,401.95	2,957,635.58	3,067,199.32	3,068,401.95	2,839,732.21
4.1.4	Landfill Gas Management	229,491.43	229,491.43	229,491.43	229,491.43	229,491.43
4.1.5	Monitoring	422,250.00	422,250.00	422,250.00	422,250.00	422,250.00
4.1.6	Maintenance	512,400.00	499,066.44	512,400.00	531,961.82	505,606.46
4.1.7	Other Services (technical costs)	45,000.00	45,000.00	45,000.00	65,000.00	45,000.00
4.2	Pollution Liability Protection in Aftercare	540,000.00	540,000.00	540,000.00	540,000.00	540,000.00
4.3	Financial Guarantees in Aftercare	52,456.91	51,464.11	52,447.29	52,613.40	50,573.20
5	General Expenses and Net Income	13,456,500.51	13,543,703.10	13,479,852.82	13,516,326.95	13,526,124.91
5.1	General Expenses	7,198,950.89	7,245,602.48	7,211,443.89	7,230,956.80	7,236,198.51
5.2	Net Income	6,257,549.62	6,298,100.62	6,268,408.92	6,285,370.14	6,289,926.40
TOT	TOTAL COST - NO VAT (22%)	68,833,045.81	69,279,106.78	68,952,498.16	69,139,071.58	69,189,190.40
	$x_{economic}$	0	-446,060.98	-119,452.3490	-306,025.78	-356,144.59

Table 3: Results obtained from the analysis of the scenarios according to the energetic criterion.

	Reference scenario	First scenario	Second scenario	Third scenario	Fourth scenario
Energy input in 40 years (GJ)	0	1199.94	107.35	737.68	2,044.97
Energy output in 40 years (GJ)	0	24,877.99	101.86	11,414.73	36,394.57
Net gain (output – input) in 40 years (GJ)	0	23,678.05	-5.49	10,782.06	34,454.62
$x_{energetic}$ (GJ)	0	23,678.05	-5.49	10,782.06	34,454.62

Table 4: Results obtained from the analysis of the scenarios according to the environmental criterion.

	Reference scenario	First scenario	Second scenario	Third scenario	Fourth scenario
t = 0, before the landfill construction (Mcal/m^2/year)	0.89	0.89	0.89	0.89	0.89
t > 40 years, after the closure of landfill (Mcal/m^2/year)	0.90	0.90	0.90	1.06	1.06
$x_{environmental}$ (Mcal/m^2/year)	0	0	0	0.16	0.16

Table 5: Evaluation matrix linearized.

Criteria	Reference scenario	First scenario (Energetic maximization scenario)	Second scenario (Leachate phytotreatment scenario)	Third scenario (Environmental compensation scenario)	Fourth scenario (Combination scenario)
Economic criterion	1.0000	0.0000	0.7322	0.3139	0.2016
Energetic criterion	0.0002	0.6873	0.0000	0.3130	1.0000
Environmental criterion	0.0000	0.0000	0.0000	1.0000	1.0000
Final score	0.3334	0.2291	0.2441	0.5423	0.7339

4 CONCLUSIONS

The work tried to suggest some design possibilities for the application of energy crops to landfills. In the first and second scenario, the results showed that the benefits related to the presence of energy crops on top cover are not cost-effective. In general, the study shows that landfill costs resulted greater than the reference scenario for all the scenarios considered, and therefore not economically favourable. However, difficulties on the evaluation of the quantities reduction in the leachate production, due to presence of energy crops on top cover, can affect the results in an important way.

From an economic point of view, the consideration of longer periods of leachate phytodepuration in the second scenario is an option to consider. Extending the period in the aftercare phase could allow important economic savings. The obstacles of the normative, which limits the implementation of new technologies to landfill sites, should be better take into consideration by legislator.

The energetic and environmental criteria resulted maximized by lignocellulosic crops in the third and fourth scenario. The higher crop yield of Miscanthus and higher biopotentiality of Poplar and shrubs species had a fundamental weight in the analysis.

The MCA determined the fourth scenario as the best solution between those considered, since able to obtain best results in energetic and environmental criteria, keeping a cost not far from that obtained in the other scenarios.
The study of the configurations able to avoid (or minimize) the increase in thickness of the top cover layers should be considered. In this optic, more discussion and studies are required.

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