# Help decision making tool combining AHP method with GIS for implementing food waste valorisation strategies

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## Abstract

This study aims to develop a software tool which helps waste managers to implement a food waste valorisation strategy. Since the feasibility of a food waste valorisation strategy depends on a high number of key factors, all of them must be quantified; weighed and, after establishing the decision rules, assessed in conjunction to insure the success of the process. However, the decision making process involves a great risk of underestimating any of these factors, which could make the full scale implementation of a waste valorisation strategy technically unfeasible, economically unprofitable or environmentally unsustainable. Furthermore, geographical dispersion in waste generation requires both selecting an appropriate site to locate the treatment plant and optimizing the logistics routes for centralizing food wastes in the selected place.
Within this framework, this study, funded by European LIFE programme (LIFE12 ENV/ES/000406), has developed GISWASTE tool which is a help decision making tool, combining Analytic Hierarchy Process (AHP) method with Geographic Information System (SIG), which helps waste managers in the decision making at the time of implementing a food waste valorisation strategy. Thus, this tool reduces the risk associated with the implementation of a food waste valorisation strategy by simulating the feasibility of different scenarios and it also helps to the public waste management authorities or other private organisms to define bio-economy based waste management strategies.

## Keywords

GIS; Analytical Hierarchy Process; software tool; food waste; management

## 1 Introduction

Up to one third of all food is spoiled or squandered before it is consumed by people. Food loss and waste have negative environmental impacts because of the water, land, energy and other natural resources used to produce food that no one consumes [1]. Furthermore, a low percentage of all food wastage is valorised; much of it ends up in landfills, in spite of having a high potential to be reuse in other productive processes. Therefore, according to FAO [1], food wastage's carbon footprint is estimated at 3.3 billion tonnes of $CO_2$ equivalent of GHG released into the atmosphere per year.
Within this framework, EU policies towards bio-economy are promoting the sustainable reuse of biological resources such as food waste to produce new products that can be used in other production processes. Hence, the implementation of food waste valorisation strategies would reduce the environmental impacts associated with food production and improves the natural resource efficiency. Regarding to European Environment Agency (EEA), the emergence of resource efficiency and the low-carbon economy as European policy priorities is grounded in recognition that the prevailing model of economic development, based on steadily growing resource use and harmful emissions, cannot be sustained in the long term. The notion of the 'circular economy where nothing is wasted' within the *Environment Action Programme to 2020* must be central to efforts to boost resource efficiency and food waste valorisation must play a key role in the sustainable economic development in which better valorisation strategies must further reduce environmental pressures.

However, the implementation of a food waste valorisation strategy depends on a high number of key factors and the decision making process involves a great risk of underestimating any of these factors, which could make the full scale implementation of a waste valorisation strategy technically unfeasible, economically unprofitable or environmentally unsustainable. Furthermore, geographical dispersion in waste generation requires selecting an appropriate site to locate the treatment plant and optimizing the logistics routes for centralizing food wastes in the selected place, which reduce the high cost and environmental impact associated with logistics.
Within this framework, the main aim of Life GISWASTE project is to combine GIS and Analytical Hierarchy Process (AHP) methodologies in software tool in order to geo-reference the food wastes generators and then locate the optimal sites for animal feed and biogas valorisation alternatives. Finally, as example of results derived from the software tool, this study shows the assessment of regional food waste sources for biogas production and the sites analysis to choose the best locations for the biogas plant, the energy production capacity as well as calculating the spatially optimized biomass collection area and the transportation distances.

# 2 Methodology

The multi-dimensionality and the complexity of a food waste management strategy implementation involve the necessity of using a Multi-Criteria Decision Analysis (MCDA) methodology [3]. It allows the use of both qualitative and quantitative criteria, which can address different aspects of feasibility indicators [2].
In general, MCDA process includes four stages in which m alternatives are evaluated on n criteria for a complex feasibility assessment: criteria selection, criteria weighing, programming [3]. Hence, the preliminary step in MCDA is to formulate alternatives for a decision-making problem from a set of selected criteria and to normalize the original data of criteria. Secondly, criteria weights are determined to show the relative importance of criteria in MCDA. Then, acceptable alternatives are ranked by MCDA methods with criteria weights. Finally, the ranking of alternatives is ordered with the aim of selecting the most favourable [3]. Furthermore, Geographic Information Systems (GIS) based tools can facilitate spatial-decision making and planning processes.

## *2.1 Criteria selection*

The multiplicity of criteria that is necessary to take into account in waste management shows the importance of the conceptual and methodological work in this area. Hence, taking into account that the main aim of the GISWASTE tool is to help waste managers in the decision making, it is not demonstrated that the consideration of higher number of criteria might be always helpful. Therefore, the different principles applied for the criteria selection are: the *systemic principle*, in which the criteria system should roundly reflect the essential characteristic and the whole performance of the waste management solution; the *measurability principle*, in which the criteria should be measurable in quantitative value as possible or qualitatively expressed and finally, the *comparability principle*, where the decision making result is more rational when the comparability of criteria is more obvious. Additionally, the criteria should be normalized to compare or operate directly when there are both benefit criteria and cost criteria [3]. In addition, the selection of criteria requires parameters related to the simplicity, representativeness and reliability.

## *2.2 Criteria weighing*

Weight is assigned to the criteria with the aim of indicating its relative importance over the feasibility of the waste management solution. Both the rationality and the subjective preference of the decision-makers and the veracity and the variance degree of criteria and the independency of criteria were taken into account in the criteria weighing.
*Equal weigh method* was applied for geographical, economic and environmental criteria weighing. Considering that they are based on the implementation of some geographic requirements, an arithmetic sum of incomes and outcomes and application of a formula with the different environmental aspects with influence over each impact were used respectively. This method requires minimal knowledge of the decision- maker’s priorities and minimal input from decision maker [3].
Otherwise, *rank-order weighing method* was applied for technical criteria with the aim of taking into account the relative importance. For the criteria depending mostly on the requirements of decision-makers, a *subjective rank-order weighing method* was applied. The judgments of decision- makers depend on their available knowledge and information.

For legislative criteria, an *objective rank-order weighing method* was applied. In this case, the judgments of decision-makers at this time depend on the quantitative measured data of waste management solution. Thus, an integrated method for determining the criteria weights was applied [3].

## 2.3 GISWASTE Software tool

### 2.3.1 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) was selected as the most suitable multi-criteria decision analysis method to perform the decision matrixes and rules necessaries to simulate the feasibility of food waste valorisation strategies [4-5]. AHP allowed to assess simultaneously a number of possible choices in the sitting process and to partition the problem focusing on smaller decision sets one at the time [6].

Firstly, the decision-making process was divided into several hierarchical levels: technical, geographical, economic and environmental, and decision matrixes and rules were performed for each level. Secondly, the relative weights of decision-making criteria were integrated to assess the total ranks of the different scenarios. Then, each key factor at the given level is multiplied with its weight and the weighted performances are summed to get the score at a higher level. The procedure is repeated upward for each hierarchy, until the top of the hierarchy is reached and the overall weights with respect to goal for each decision alternative are then obtained. Finally, a decision matrix was made based on the knowledge and experience of many experts. The alternative with the highest score could be considered the best alternative.

### 2.3.2 ArcGIS

The geographical assessment is performed with AHP method combining with ArcGIS version 10.1 software and its associated extensions: spatial analyst and network analyst [7-8]. Furthermore, geographic information about the locations where the scenario under study is sited was collected:

- Land use layer with representation and geographical location of the availability of industrial land. This layer enables to exclude directly all restricted zones such as natural protected areas, areas with high population density, cultural heritage sites, etc.
- Transport network modelling. In this study a network dataset generated from of Tom-Tom was applied but could have used another network dataset.
- Information associated with logistics routes such as type of vehicles, their capacity, features, starting and final points and partial costs was established.

Once geographical information was collected, the first step was to export the scenario data to ArcGIS. It included the geo-referenced food waste generation points (latitude and longitude coordinates). In this study, the centroid of the zip code was used as a location measurement unit.

Secondly, the siting of the food waste treatment plant was performed based on geographical dispersion, the annual food waste generation and the seasonality linked to each type of food waste. Before applying decision rules to ArcGIS software, the cartographic information layer must be superimposed to integrate all key factors in a single layer and quantify the values of each alternative in order to reduce the number of plant sitting points. With the aim of reducing the number of potential sitting points, two following criteria were performed: (1) availability of land for industrial use (<10 Ha), and (2) distance to main roads (<5 km). The introduction of industrial land use layer enables to exclude directly all restricted zones such as natural protected areas, areas with high population density, cultural heritage sites, etc.

Finally, the Network Analyst of ArcGIS was performed to solve complex route calculation. In this study, Street Data Processing Tools of ArcGIS was used for generate the network model based on the highways of Tom Tom. The application computes an area that encompasses all accessible roads. Then, it assigns each food waste generation point to the each potential facility selected in the previous steps.

Finally, GISWASTE tool calculates the total distance and vehicle-specific transportation amounts for centralizing all food waste sources to each potential sites. The alternative with the lowest distance needed could be considered the best alternative.

### 2.3.3 Software programming

The first step was to create a *SharePoint account* (https://giswaste.sharepoint.com) in order to, introduce and maintain all alphanumeric information, as well as to create the different management scenarios which will be further assessed by

GISWASTE tool. SharePoint is a cloud-based service for creating websites and store, organizing and sharing information and it is accessible from any device service online. In addition, SharePoint links the alphanumeric information with GISWASTE software. Therefore, any value changes in SharePoint or in the GISWASTE tool are bi-directionally and automatically modified. Secondly, all decision matrixes and rules that contain all the algorithms and equations for assessing the feasibility of a food waste management solution were programmed. Hence, Microsoft Access® was used for technical, economic and environmental assessment. The technical assessment is based on the fact that each technical key factor is quantified with a different score basis on a scale from 1 (less unsuitable for a waste management solution) to 10 (the most suitable for a waste management solution). This scale was assigned according to experts' experience and international references. Afterwards, the linear summarization was performed to calculate the final score for each food waste generator. The result obtained in this stage was a decision matrix which included all weighted food waste sources (net scenario). Finally, all the generation points outside from the limiting ranges are considered unsuitable for the waste management solution under study. On the other hand, the higher the score of the generation point was, a higher influence of this food waste generator is expected over the overall feasibility. Table 1 shows the different grades of viabilities types and the assigned scores.

Table 1. Types of different viabilities and assigned score ranges.

| Type of Viability | Score Range |
|---|---|
| Very High | 8-10 |
| High | 6-8 |
| Medium | 4-6 |
| Low | 2-4 |
| Very Low | 1-2 |

The economic analysis was carried out to provide insight into the structure of cost and benefits. In order to perform the financial analysis, net present values (NPV), the internal return rate (IRR) and payback time period (PBT) were calculated. Finally, regarding to environmental impact factors, carbon and water footprint and eutrophication potential were also included in the programming stage.
The GISWASTE tool is programmed to provide the following assessment reports:

- A technical assessment report. It includes a list of the food waste generating point that are considering suitable for the waste management solution assessed and which aren´t and an estimation of the technical feasibility of the global scenario assessed.
- A geographical assessment report. It includes the best alternative for siting the treatment plant and a proposal for the optimal logistic routes for centralizing all food waste in the treatment plant.
- An economic assessment report. It includes an economic balance for the waste management solution and the estimation for the investment return period.
- An environmental assessment report. It includes the estimation of carbon foot print, waster foot print and eutrophication potential.

## 3 Results and Discussion

### *3.1 Criteria selection and weighing*

The selected criteria to evaluate the waste management systems are mainly divided into four aspects according to their influence domain: technical, geographical, economic and environmental criteria. Table 2 summarizes the geographic, technical, economic and environmental key factors for biogas and animal feed waste management solutions:

Table 2. Geographic, technical, economic and environmental key factors for biogas and animal feed waste management solutions

| Aspect | Criteria | Waste management option |
|---|---|---|
| Technical | Quantity per month | Biogas; Animal feed |
| | Potential methanization | Biogas |
| | Volatile solids | Biogas |

| | | |
|---|---|---|
| | MOD / MO | Biogas |
| | C/N | Biogas |
| | Total solids | Biogas |
| | Nutritional parameters: | Animal feed |
| | Initial moisture; Energy; Crude protein; Crude fiber; Crude fat; Carbohydrates; Acid detergent fiber; Neutral detergent fiber; Digestibility; VFA | Animal feed |
| | Undesirable substances: | |
| | Nitrite; Aldrin and Dieldrin; Chlordane; DDT; Endosulphan; Endrin; Heptachlor; Hexachlorobenzene; Hexachlorocyclohexane (alpha, beta and gamma isomer); Aflatoxin B1; Arsenic; Cadmium; Fluor; Mercury; Lead; Dioxins | |
| Geographical | Industrial land available | Biogas; Animal feed |
| | Available free surface | Biogas; Animal feed |
| | Proximity to main roads | Biogas; Animal feed |
| Economic | Cost for 1st plant and machinery implementation | Biogas; Animal feed |
| | Cost for processing food waste | Biogas; Animal feed |
| | Cost for 1st land implementation | Biogas; Animal feed |
| | Cost for administrative issues | Biogas; Animal feed |
| | Cost for the hypothetic plant decommissioning | Biogas; Animal feed |
| | Cost for collecting food waste | Animal feed |
| | Income for the management of food waste | Biogas; Animal feed |
| | Income for selling biogas or for heat saving | Biogas |
| | Income for selling digestate | Biogas |
| | Income for selling electricity | Biogas |
| | Income for selling the produced flour | Animal feed |
| Environmental | Carbon footprint | Biogas; Animal feed |
| | Water footprint | Biogas; Animal feed |
| | Eutrophication potential | Biogas; Animal feed |

Tables 3 and 4 summarize the weights of geographic, technical, economic and environmental key factors for biogas and animal feed waste management solution.

Table 3. Weights of geographic, technical, economic and environmental key factors for biogas waste management solution

| 1st hierarchy level | Weighing of 1st hierarchy level | 2nd hierarchy level | Weighing of 2nd hierarchy level |
|---|---|---|---|
| Technical | 20% | Potential methanization | 40% |
| | | Volatile solids | 10% |
| | | MOD / MO | 30% |
| | | C / N | 10% |
| | | Total solids | 10% |
| Economic | 40% | Cost for 1st plant and machinery implementation | 10% |
| | | Cost for processing food waste | 10% |
| | | Cost for 1st land implementation | 10% |
| | | Cost for administrative issues | 10% |
| | | Cost for the hypothetic plant decommissioning | 10% |
| | | Income for the management of food waste | 10% |
| | | Income for selling biogas or for heat saving | 10% |
| | | Income for selling digestate | 10% |
| | | Income for selling electricity | 10% |
| | | Income for selling the produced flour | 10% |
| Geographic | 20% | Industrial land available | 40% |
| | | Available free surface | 20% |
| | | Proximity to main roads | 40% |
| Environmental | 20% | Carbon footprint | 40% |

| | | | |
|---|---|---|---|
| | | Water footprint | 40% |
| | | Eutrophication potential | 20% |

Table 4. Weights of geographic, technical, economic and environmental key factors for animal feed waste management solution.

| 1st hierarchy level | Weighing of 1st hierarchy level | 2nd hierarchy level | Weighing of 2nd hierarchy level |
|---|---|---|---|
| Technical | 20% | Quantity per month | 30% |
| | | Nutritional parameters | 40% |
| | | Undesirable substances | 30% |
| Economic | 40% | Cost for 1st plant and machinery implementation | 12,5% |
| | | Cost for processing food waste | 12,5% |
| | | Cost for 1st land implementation | 12,5% |
| | | Cost for administrative issues | 12,5% |
| | | Cost for the hypothetic plant decommissioning | 12,5% |
| | | Cost for collecting food waste | 12,5% |
| | | Income for the management of food waste | 12,5% |
| | | Income for selling the produced flour | 12,5% |
| Geographic | 20% | Industrial land available | 40% |
| | | Available free surface | 20% |
| | | Proximity to main roads | 40% |
| Environmental | 20% | Carbon footprint | 40% |
| | | Water footprint | 40% |
| | | Eutrophication potential | 20% |

### *3.2 Case study:*

The scenario selected to apply the GISWASTE tool assessment was the Basque Country region (north of Spain) for the biogas waste management solution. Basque Country has one of the highest population densities in Spain (299 inhabitants / km$^2$) and includes both rural agricultural and built-up urban areas, so it could be considered such as one of the most representative region of Europe.

The feedstock considered for bio-methane production were dairy and meat waste from processing industries and vegetable wastes from retail trade sector. Hence, the scenario under study was established by taking into account the spatial distribution of these food waste sources. Each food waste source was stored in a geo-referenced database in which each attribute of the different kinds of food waste, corresponding to each key factor that influence the biogas waste management solution, was quantified.

#### 3.2.1 Technical assessment

After loading the scenario under study, the first step was the screening of suitability of the food waste generators by its assessment beneath two exclusion criteria: (i) minimum required volumes for collection and/or, (ii) a minimum specific methane production rate. Hence, the food waste sources that generate less than 500 kg per month and/or have a specific methane production rate of less than 90 Nm3/kg VS d were considered unsuitable for the anaerobic digestion and they were directly ruled out from the gross scenario.

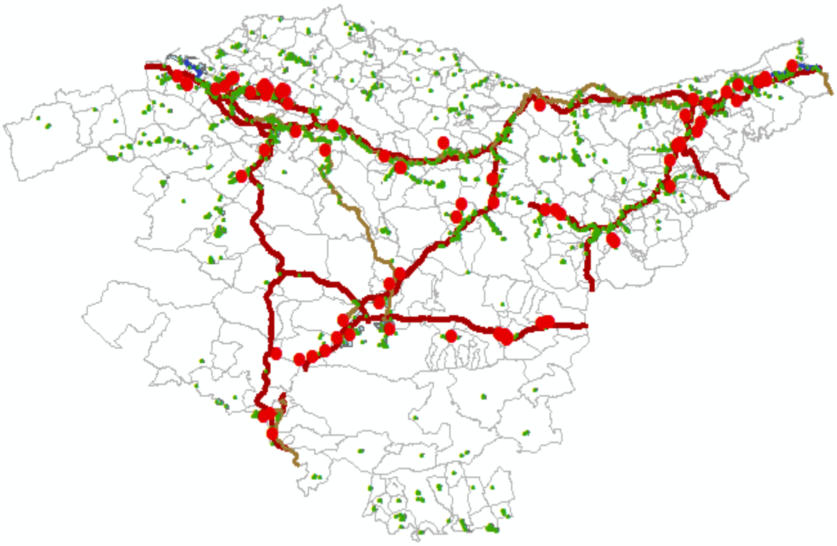
Once the net scenario was performed, ruling out unsuitable generation points, each technical key factor was scored on the scale from 1 (less unsuitable for biogas plant sitting) to 10 (the most suitable for biogas plant sitting). The final score of each food waste generator was calculated by applying the linear summarization of the 1-10 scale.

Finally, the technical feasibility of producing biogas from vegetable, dairy and meat waste in Basque Country was scored with 7.1 points. According with the scale established in the methodology, this biogas solution is high feasible for the scenario under study.

#### 3.2.2 Geographical assessment

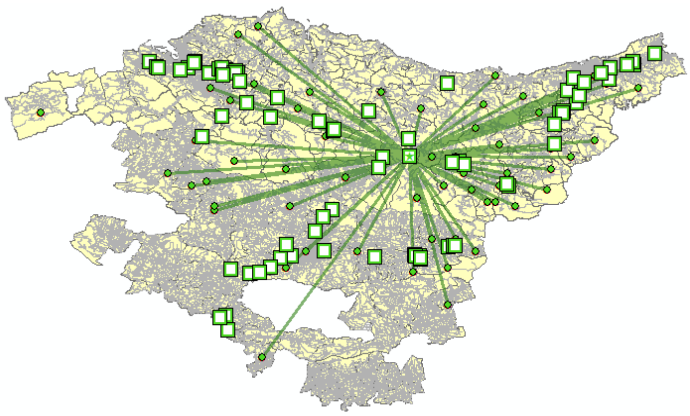
After the technical assessment, the siting of the biogas plant was performed based on geographical dispersion, the annual food waste generation and the seasonality linked to each type of food waste. The first screening was applied taking into account two criteria: (1) availability of land for industrial use (<10 Ha), and (2) distance to main roads (<5 km) and the result was around 250 potential sitting points, as it is shown in the Figure 1:

Figure 1. Sitting points selected after applying the availability of land for industrial use and the distance to main roads criteria.



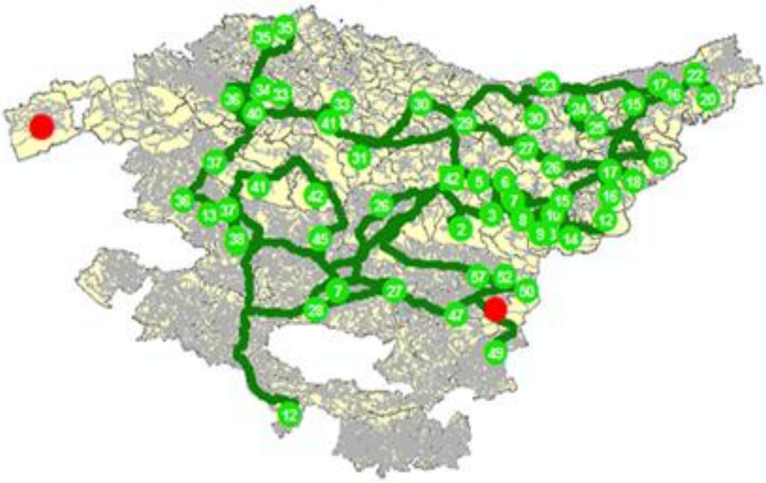
The second screening selects the most suitable sitting point for the biogas plant based on the location-allocation model in GIS, as it is shown in the Figure 2. This tool solves the p-median problem by choosing facilities such that the total sum of weighted distances allocated to a facility is minimized.

Figure 2. Origin-destination connectivity between waste generators and chosen biogas plant in the Basque Country (Spain)



Once the optimum site of the biogas plant was geo-referenced, the next step was to calculate the routes between the food waste sources and biogas plant location. The total calculated distance per route was 916 km. Figure 3 shows the optimized routes for food food waste collection.

Figure 3. Optimized logistic route for food food waste collection in the Basque Country (Spain)



3.2.3 Economic assessment

The cost derived from the operation and maintenance was deemed to be the 3 % of the total capital costs. The half of this percentage (1.5 %) is linked to the biogas upgrading through pressure swing adsorption technology. The manpower costs were estimated to be 45,000 €/year based on gross Spanish average salary for two full-time plant operators (6.25 €/operation hour). Finally, cost arising from transport of food waste was accounted considering 0.9397 €/km for a full loaded 25-26 tonnes three-axle truck. The updated annual cost and revenue rates were assumed to be 1.5 % and 1.0 %, respectively.

The expected revenues were estimated considering electricity (0.13 €/$kWh_e$) and thermal energy sales (0.036 €/$kWh_t$). Thermal energy might be sold as an alternative heat source to natural gas in the surroundings houses, companies, etc.

Waste management savings (5-10 €/t depending on the type of food waste) and the revenues from the sales of digestate as fertilizer (0.09 €/t) were also considered in the revenues calculation. They were also considered non-refundable funds (20 % of the total investment) established by the Basque Energy Agency (EVE) and 10 % of funds from a private investor. On the other hand, it was also assumed that the plant's capital has no value and no further capital cost will be required after plant's lifetime. Finally, the annual repayment mortgage and discount rate were both set as 5 %. Table 5 and 6 summarize the economic and financial results given by GISWASTE software tool for the anaerobic digestion valorisation alternative.

Table 5. Total investment, revenues and costs

| | |
|---|---|
| Total investment (€) | 4,663,324 |
| Total revenues (€/year) | 1,726,642 |
| Revenues from electricity, thermal energy and digestate sales (€/year) | 1,670,432 |
| Revenues from waste management (€/year) | 56,211 |
| Total costs (€/year) | 460,295 |
| Operational expenditures (€/year) | 231,778 |
| Manpower (€/year) | 48,367 |
| Logistics costs (€/year) | 134,279 |
| Other costs (€/year) | 45,871 |

Table 6. Financial structure and indicators

| | |
|---|---|
| Financial structure | |
| Public subsidies (€) | 932,665 |
| Investor's capital (€) | 500,000 |
| Loan (€) | 3,230,659 |
| Percentage of subsidies (%) | 20 |
| Percentage of investors' capital (%) | 11 |

| | |
|---|---|
| Percentage of loan (%) | 69 |
| Loan interest rate (%) | 5.0% |

| Financial indicators | |
|---|---|
| Earnings before interests, taxes, depreciations and amortizations (EBITDA) (€) | 1,086,197 |
| Net present value (NPV) (€) | 11,840,450 |
| NPV/total investment | 2.5 |
| Internal return rate (IRR) (%) | 37.40 |
| Payback time period (PBT) (years) | 3.43 |
| Discount rate (t) (%) | 4.64 |
| Capital recovery factor (CRF) (%) | 9.40 |

While the advantage of the NPV is its predictability and the respect of the time value money, it does not express the accurate rate of profitability. Therefore, IRR was chosen since it allows comparing very easily different projects sizes. IRR criterion is very simple: if the project IRR is higher that the discount rate, the project is accepted, otherwise, it should be rejected. Under considered assumptions, since calculated IRR value is higher than discount rate the construction of the biogas plant is profitable. It must be noted that the findings presented here depend on unpredictable fluctuating variables set out as constant to enable the economic assessment. Thus, it is necessary to predict how the different variables may change over time and their effects over NPV through a sensitivity analysis.

### 3.2.4 Environmental assessment

In order to determine the environmental benefits of the anaerobic digestion in terms of carbon dioxide emissions avoided, it was compared the use of biogas as fuel in combustion process, with the natural decomposition of these wastes [9]. The results showed that energetic valorisation of food waste in the Basque Country would generates 1,189,352 t $CO_2$ equivalents. The equivalent carbon dioxide emissions were determined considering that methane is 23 times more effective than carbon dioxide to absorb long wave radiation reradiated from the Earth. The differences between the emissions of carbon dioxide that would be generated if all wastes were dumped in a landfill and emissions from combustion of biogas produced via their anaerobic were also considered [10]. Additionally, water footprint impact was also calculated. The food waste valorisation through anaerobic digestion would prevent 17,209 $m^3$ $H_2O$ equivalents.

## 4 Conclusions

AHP method combined with GIS allows developing a powerful tool for helping making decision in the waste management. It allows solving logistics problems, such as the location of biogas plant and the routes to centralizing food waste in this plant, and simulating the technical, economic and environmental feasibility of a defined scenario.

Specifically, GISWASTE tool allows assessing the biogas and animal feed waste management solutions.

A total of 26 factors, for biogas solution, and 42 factors, for animal feed, were identified and clustered into geographic, technical, economic and environmental feasibilities. The selection of factors (weighted criteria) had a considerable effect on the entire evaluation process.

The food waste generators that do not achieve the minimum values of the key factors which make the collection technically or economically unfeasible are excluded in a preliminary screening.

The GIS methodology used the existing road network and the ArcGIS network analyst extension in the site suitability analysis. The use of this tool allowed improving the most suitable location for food waste treatment plant as well as calculating the real road transportation routes and collection frequencies.

The construction of a centralized biogas plant for treating the food waste generated in the Basque Country (Spain) demonstrated to be feasible from geographic, technical, economic and environmental points of view. The expected theoretical potential was found to be 9,831 $MWh_e$ (845 toe) in the Basque Country (Spain) while the NPV, PBT and IRR are within those values typically found for biogas plants.

Additionally to natural, environment and economic factors, complex political and social issues might also influence the selection process.

Nonetheless, the GISWASTE software tool will reduce the risk associated with the implementation of a centralized biogas valorisation plants. The implementation of the tool might also help to public waste management authorities or other private organisms to define bio-economy based waste management strategies.

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