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Zero-waste energy-efficient agricultural communities in the Greece-North Macedonia cross-border area - ZEFFIROS

DELIVERABLE 3.2

EU policy review on bio-waste management & the circular economy

Sub-Deliverable 3.2.2 – Business value chain modeling for bio-waste management

Authors: Dr. Christos Vlachokostas, Dr. Charisios Achillas

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1. Introduction

During the past decades, the concerns of the depletion of fossil fuels and global warming caused by excess GHG emissions have become the most important driving force for the development and utilization of renewable energy resources. The successful experiences from the EU-28 have proved that bioenergy production from biomass and biodegradable waste is the most reliable and promising solution in today's renewable energy market.

Here, a general model for value chain analysis of bioenergy production from biomass and biodegradable waste is presented, to be used as a candidate foundation for facilitating business decision making of relevant stakeholders active in Serres' municipal area and the wider surrounding area of interest. Based on this model and relevant initially identified existing barriers and motives/ opportunities for business growth via possible collaborations between the stakeholders, a framework is set for selected value chain participants, targeting towards securing their common understanding and the standardization of their inter-communication process via a relevant structured dialogue questionnaire that could potentially confront the barriers and open the way towards collaborations, new business creation and eventually cross-border area growth based on the areal bio-waste resources.

2. Business value chain modelling

2.1. Modelling insights

The appropriateness and benefits of each technological solution should be examined carefully to support treatment decisions, considering the type of biowaste, local characteristics and conditions (Banias et al., 2017; Vea et al, 2019; Delgado et al., 2020). In the material to follow, a generic methodological scheme is developed and demonstrated to support optimal decision making in promoting and implementing UABTs. The basic structure and components combine environmental, economic and social parameters and Multi-Criteria Decision Analysis (MCDA) for the optimal site selection of an UABT. Problems involving the location and promotion of such units include multi-criteria considerations and ought to be modelled likewise. Nevertheless, literature scarcely studied special waste streams, such as biowaste, centralizing mostly on municipal solid waste (MSW) management (Simões Gomes et al., 2008; Vego et al., 2008; Achillas et al., 2013; Rezae et al., 2015; Soltani et al., 2015; Vučijak et al., 2016). MCDA gains wide acceptance in recent years over quantitative modeling, as MCDA embodies both quantitative as well as qualitative variables (Michailidou et al., 2016a) and can be tractably combined with other tools such as life cycle assessment, ecological footprint, environmental indicators (Morrissey et al., 2004). The approach includes the social criterion (e.g. NIMBY - Not In My Back Yard syndrome), usually disregarded (Achillas et al., 2011a; Taelman et al., 2019). It also assists relevant stakeholders, public authorities and producers by providing a roadmap to the feasibility and essential steps for the development of a micro-to-medium-scale localized UABT. Localization is a prerequisite to achieve economies of scale and emphasis is given to optimal location, production of bioenergy and other bioproducts (Soukopová et al., 2017; Taelman et al., 2019).

In this context, the present chapter frames a consistent generic methodology and seeks optimal UABT solutions, based on multiple criteria and parameters. More specifically, apart from defining the optimal site for the installation of a new UABT, the proposed methodology assesses also the recommended technological solution, based on the characteristics and quantities of locally available biowaste, as well as its size and capacity. The methodology is demonstrated for a real-world case in the Region of Serres, Greece.

2.2. Modelling methodology

Figure 3.1 presents the main components and the basic steps of the methodological scheme. More specifically, the first step is to determine the wider area for the development of an UABT (Step 1). Crucial aspects for this decision are the availability, quantity and quality of biowaste regionally. Characteristic typologies can be found in the Waste Framework Directive of 2008 (European Commission, 2008) and related regulations, e.g. park and yard waste, animal waste (feces, urine and manure), kitchen and food waste, vegetal waste (food preparation and products), household and similar wastes, common sludges, mixed waste, undifferentiated materials etc. To assure smooth replenishment and long-term sustainability of an UABT it is important to pre-assess the continuing availability and seasonality of biowaste locally. Regional logistics infrastructure, mainly transportation & storage facilities, are also required to be considered for the available feedstock, due to their criticality in the unit's viability, since transportation cost is a crucial parameter for the viability of the logistics network (Achillas et al., 2011b). All the above data can be the output of a Strengths, Weaknesses, Opportunities, Threats analysis, for the area under consideration. This initial stage of the methodology puts forward a pool of available types of biomass as potential feedstock for an UABT.

In the case that an area is considered "eligible" for the development of an UABT, the second step is the preparation of a detailed biowaste inventory analysis that; (i) identifies meticulously the biowaste sources, (ii) calculates the available biowaste quantities and (iii) describes the characteristics of the available biowaste (Step 2). Such an inventory will detail the availability of exploitable biowaste within the region under study and will assist decision-making.

The inventory analysis is followed by the Multiple Criteria Decision Analysis (MCDA) for the optimal location of the UABT (Step 3a). This process is strongly interrelated and usually realized in parallel to the selection of the most appropriate technology (Step 3b). Multi-criteria mathematical modeling examines criteria that are usually in conflict in the decision-making process (Hokkanen et al., 1997; Rousis et al., 2008; Iakouvou et al., 2009; Banias et al., 2010; Silva et al., 2014; Le Hesran et al., 2019). On this basis, and after screening all legislative constraints (e.g. Environmental Permits), the appropriate multi-criteria analysis technique needs to be determined. The literature reports a considerable number of techniques available, with different characteristics and uses (Ishizaka et al., 2013; Chatterjee et al., 2019). Multi-criteria analysis techniques are more or less suitable depending on the special characteristics of the case under consideration (Al-Shemmeri et al., 1997). In scientific literature, modelling of waste management solutions mostly takes into account economic and environmental dimensions of the problem, whilst the social concerns are usually neglected. It should be noted that the social pillar constitutes a crucial matter for the future viability of the investment in cases like the one examined in the material to follow. On this basis, social concerns should be simultaneously considered for deciding on the optimal UABT site.

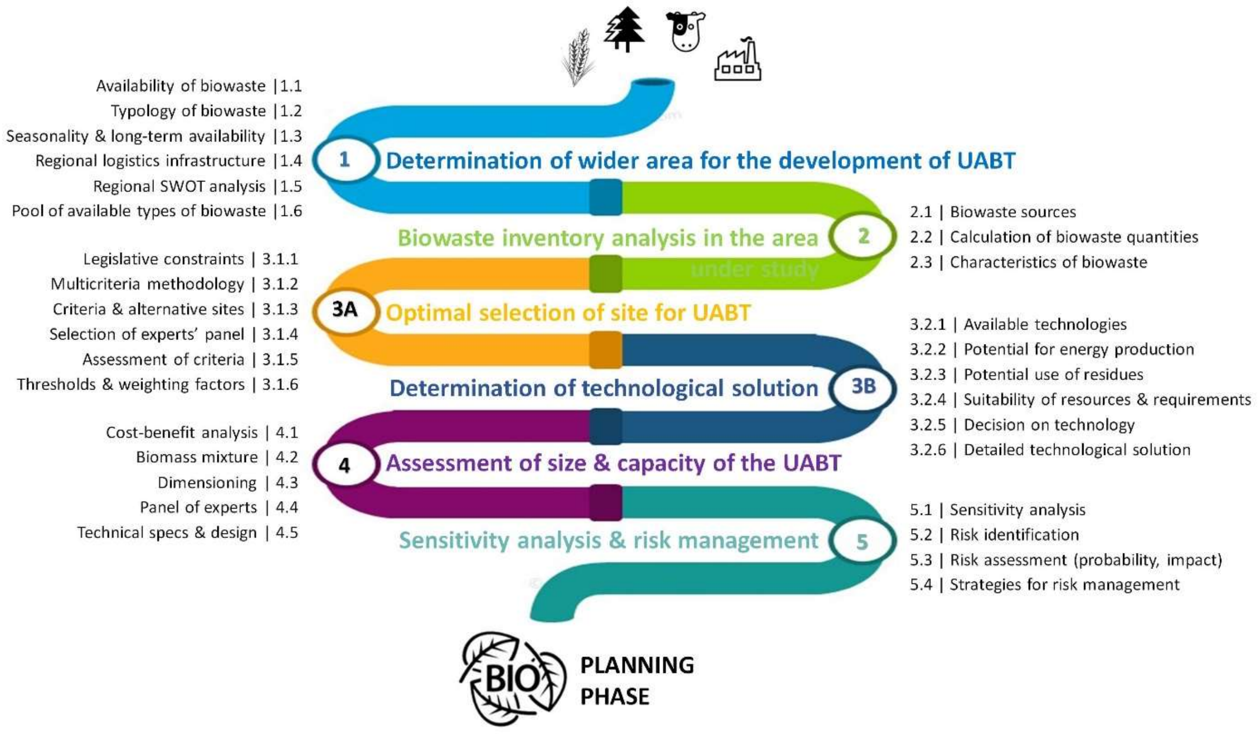


Figure 3.1. Basic structure and components of the methodological framework

The methodology developed herein adopts the ELECTRE III technique (Roy, 1978). A main characteristic of this technique is the use of the pseudo-criteria concept in order to depict the different angles of the studied case/problem. ELECTRE III utilizes three pseudo-criteria and initiates a robust comparison of each option with another in relation to all criteria included in the analysis. An ascending and descending distillation process forms the basis for the construction of two complete pre-orders. The intersection of the two complete pre-orders produces a final classification of the alternatives. An advantage of this technique is the sensitive analysis capability. In the framework of the sensitivity analysis, scenarios for the values of the main parameters are performed in order to further test the solution by observing the effect of the adopted values' variation to the result. Comparative assessment of the pre-orders for each scenario leads to final robust outcome or to a model re-analysis. This technique is widely used in the examination of environmental problems and waste management issues, which provides an advantage to the others (Rogers et al., 1998; Vlachokostas et al., 2014; Spyridi et al., 2015).

The designation of three thresholds is prerequisite, i.e. (i) preference threshold (p), (ii) indifference threshold (q) and (iii) veto threshold (v). ELECTRE III uses these thresholds in its mathematical rationale in order to better include real-life uncertainties (Roy et al., 1993). Another advantage of this multi-criteria technique is the simultaneous consideration of quantitative (e.g. price of sites, distances, etc.) and qualitative criteria (e.g. landscape degradation, aesthetics, social acceptance etc.), as this approach depicts a good fit of data in such applications.

It goes without saying, that a meticulous investigation in the wider area under study is needed in order to landmark all the available locations appropriate for the installation of an UABT. As a next step, assessment of different, usually conflicting, criteria is performed in parallel with defining the weighting factor of each criterion. The weighting factor expresses its relative significance in comparison to the others. Clear definition of the parameters included in the analysis is necessary in order to reliably value all available alternatives and perform the pairwise comparison process. After defining criteria and weighting factors, relating information and data should be assembled. Multi-criteria evaluation of sites for UABT location is mathematically formulated with the use of a set of criteria (Cr1, Cr2, Cr3…) applicable to a set of alternatives (A1, A2, A3…). Vj(A) mathematically expresses the evaluation of alternative A i, for the Criterion j. ELECTRE III is a ranking method, thus it puts forward a ranking prioritization, that is grounded on binary outranking relations for two interrelated concepts i.e. (i) "Concordance" (cj) and (ii) "Non-Discordance" (dj). More specifically the concept of "Concordance" relation is applicable when alternative A1 outranks alternative A2 in case a sufficient majority of criteria are in favor of alternative A1. "Non-Discordance" relation is applicable when the concordance condition holds, none of the criteria in the minority should be opposed strongly to the outranking of A2 by A1. Credibility index characterizes the assertion that A1 outranks A2 and illustrates the true degree of this assertion (Roussat et al., 2009). A pair of alternatives is compared for each criterion with the use of pseudo-criteria, namely indifference (qj) and preference (pj) for which they apply:

When $V_j(A1) - V_j(A2) \leq q_j$, then no difference between A1 and A2 is identified for the specific criterion j, thus $c_j(A1, A2) = 0$.

When $V_j(A1) - V_j(A2) > p_j$, then A1 is strictly preferred to A2 for criterion j, thus $c_j(A1, A2) = 1$.

The concordance index cj (A1, A2) of each criterion j is mathematically formulated as follows:

$$V_j(A_1) - V_j(A_2) \leq q_j \Leftrightarrow c_j(A_1, A_2) = 0$$
$$q_j < V_j(A_1) - V_j(A_2) < p_j \Leftrightarrow c_j(A_1, A_2) = \frac{V_j(A_1) - V_j(A_2) - q_j}{p_j - q_j}$$
$$V(A_1) - V(A_2) \geq p_j \Leftrightarrow c_j(A_1, A_2) = 1$$

A global concordance index $C_{A_1A_2}$ for each pair (A_1, A_2), is calculated with the use of c_j (A_1, A_2) as mathematically illustrated below:

$$C_{A_1A_2} = \frac{\sum_{j=1}^{n} w_j \cdot c_j(A_1, A_2)}{\sum_{j=1}^{n} w_j}$$

w_j expresses the weighting factor of criterion j.

Discordance index (dj) is computed with the adoption of indifference (qj), preference (pj) and the veto threshold (vj), which expresses the maximum acceptable difference for not rejecting the assertion “A1 outranks A2”. More specifically:

When Vj(A1) - Vj(A2) ≤ pj, no discordance exists and therefore dj(A1, A2) = 0.

When Vj(A1) - Vj(A2) > vj, then dj(A1, A2) = 1.

Thus, dj (A1,A2) is mathematically formulated as:

$$\begin{cases} V_j(A_2) - V_j(A_1) \leq p_j \Leftrightarrow d_j(A_1, A_2) = 0 \\ p_j < V_j(A_2) - V_j(A_1) < v_j \Leftrightarrow d_j(A_1, A_2) = \dfrac{V_j(A_2) - V_j(A_1) - p_j}{v_j - p_j} \\ V_j(A_2) - V_j(A_1) \geq v_j \Leftrightarrow d_j(A_1, A_2) = 1 \end{cases}$$

The index of credibility $\delta_{A_1A_2}$ of the claim “A_1 outranks A_2” is then formulated as:

$$\delta_{A_1A_2} = C_{A_1A_2} \prod_{j \in \bar{F}} \frac{1 - d_j(A_1, A_2)}{1 - C_{A_1A_2}}$$

with

$$\bar{F} = \{j \in F, d_j(A_1, A_2) > C_{A_1A_2}\}$$

The claim “A1 outranks A2” is rejected if vj is exceeded for at least one of the criteria under consideration. After constructing the ranking scheme, as a last step sensitivity analysis is activated, considering that values and assessments are often subjective in real-world cases and originate from less or more reliable estimations (criteria qualitative expression, threshold parameters, weighting factors, etc). As already highlighted, this is considered a major advantage of the adopted MCDA technique due to the high data uncertainty in the thematic area under study (Vlachokostas et al., 2011).

The decision for the optimal site in the wider area presents strong interrelationship with the determination of the technology to be adopted (Step 3b). A range of available technologies are available (e.g. anaerobic digestion, aerobic digestion, gasification, pyrolysis) and possibly combination of those. The key factors that need to be considered for selecting the optimal technology are the potential for bioenergy production (electricity, heat or gas), possible utilization of the residues of each technological solution (e.g. biofertilizer), suitability of available bioresources and pre-treatment requirements. All this information supports the optimal decision on technology for the UABT, based on constraints related to the type of biowaste and specific technological solutions used.

As a next step the assessment of size and capacity of the UABT is realized (Step 4), which is based on a Cost-Benefit Analysis (CBA) and the determination of biomass mixture for the UABT (range of sources depending on biowaste quality). The latter ultimately leads to the dimensioning and the detail of the technical specifications for the UABT. Highlighting strategies for risk management is the last step of the methodological roadmap presented (Step 5). The above-mentioned methodological framework is expected to support policy-makers to facilitate the conceptual phase towards the development of an UABT, before advancing to the next phase of the planning phase where more resources are required. In this light, decision-makers may screen available options and give a "green light" for further analysis only to those cases where the endeavour is proven viable.

2.3. Modelling results

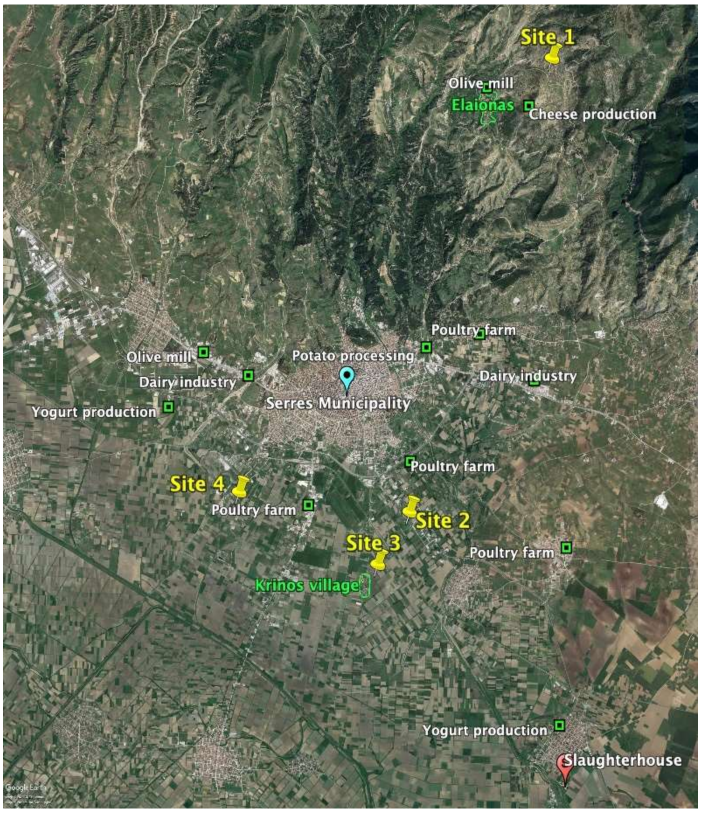
The applicability of the methodological framework is validated in a real-life case study in the Region of Serres, Greece. The Region of Serres under study is pre-selected based on the considerable regional agricultural activity and biomass availability. The population of the wider Serres area is approximately 200,000, out of which 25% is urban, 20% semi-urban and 55% rural/agricultural. Its economic activity mainly deals with the primary sector and especially with agriculture (approximately 60%). In the Region, there are 162,800 ha of cultivated land and 113,300 ha of pasture land. More than 90% of the cultivated land is private. In the area, there is a well-developed agricultural production which contributes 3.4% of the total national agricultural product, with main drivers the dairies and meat production. Apart from the farmers, within a range of 20 km from the Municipality of Serres, there is a number of agri-food manufacturers. Specifically, the relevant production activity consists of 2 leading dairy industries, 6 small cheese/yogurt production units, 2 olive mills, 1 potato packing and processing unit, 4 poultry farms, more than 30 cattle and pig rearing units for dairy and meat production and 1 slaughterhouse.

These facilities are capable of supplying adequate quantities of biowaste to generate a mixture that ensures the continuous operation of an UABT. Considering the available data and given the population and basic economic activity characteristics of the wider area under study, a primary course of action regarding biowaste energy content could be supported by recent legislative framework set in Greece regarding “Energy communities” (Republic of Greece, 2018). The legislation sets the rules for the incorporation of quasi-private entities with the option for participation of the municipalities as shareholders, also providing the alternative of subsidized (or with tax-incentives) renewable energy plants. Such strategic schemes could also opt from the formation of public-private partnerships.

The region under study has a great potential for applying a productive UABT model due to many reasons, such as; (i) availability of resources and biowaste, (ii) scientific potential and know-how, (iii) existence of primary sector with growth potential and needs for modernization and reduction of production costs. Last but not least, local farmers are strongly interested to adjust their traditional economic “attitudes”. This high level of engagement was the result of intense awareness raising activities (including flyers/brochures dissemination, press and media publicity, public presentations, visits to demonstration projects) as well as public opinion surveys that leaded to accurate expectations mapping of all involved local stakeholders.

According to the methodology described, different locations for the development of the UABT within the area under study are promoted. Following a detailed survey on land availability, four alternative available fields are selected, as those sites are summarized in Table 3.1.

Table 3.1. Alternative locations for UABT development in the area under study



Site 1	Located in a public area in Eleonas in the Forage Park. Access is through a forest road network with great difficulty. Road and water supply projects are required. Distance from the city is about 10 km and 23 km from the Slaughterhouse.
Site 2	Located in a public area in the Farm of Serres, 2 km from Serres and 7 km from the Slaughterhouse. Access is easy via the “Serres-Neos Skopos” provincial road. A few meters from the site, there is a municipal vegetable garden and a greenhouse.
Site 3	Located in a municipal area in the Farm of Serres, 0.5 km from Krinos village and 8 km from the Slaughterhouse (via dust road, or 12 km via municipal roads).
Site 4	Located in a public area in the Farm of Serres, near the Omonia Sports Park. The site is 13.5 km from the Slaughterhouse via municipal roads and 0.5 km from the city.

Next, the criteria for the analysis are defined in order to interlace financial viability, environmental performance and acceptance by local community, taking additionally into account all legislative constraints. A critical mass of local experts, aware also of the local special characteristics, were invited. In total, 13 experts representing local and regional authorities and the business sector in the study area were interviewed to decide on the criteria to be used in the case under study. This resulted to the following criteria; (Cr_1) Distance from biowaste source, (Cr_2) Accessibility of site with the existing infrastructure, (Cr_3) Distance from units for consumption of energy (electricity and heat) produced, (Cr_4) Distance from farms for compost use, (Cr_5) Value of land, (Cr_6) Impacts on local populations (e.g. air pollution, odors, noise pollution), (Cr_7) Impacts on local ecosystems, (Cr_8) Aesthetic degradation, (Cr_9) Increase in road traffic due to UATB's operation, (Cr_{10}) Social Acceptance.

The four site locations are assessed over their performances on the ten designated criteria (Table 3.2). Criteria Cr_2, Cr_6, Cr_7, Cr_8, Cr_9, Cr_{10}, were qualitatively assessed by the experts involved in the survey. Those criteria that are related to the distances (Cr_1, Cr_3, Cr_4) were assessed with the use of Google maps and the location of available biowaste sources and facilities where the outputs of the UABT could be exploited (farms and manufacturers). Cr_5, which is related to the value of the land, was assessed with mean objective values, as those were provided by the Hellenic Statistical Authority. For all selected criteria, the higher the performance, the preferable the alternative is assessed.

Weighting factors are also depicted in Table 3.2. Those are estimated as averages of the experts' views. In order to overcome subjectivity issues, sensitivity analysis follows. In our case, low computational time is required to re-calculate optimal solutions with modified parameters. The calculation of p_i (preference thresholds) for the selected criteria is based on the use of Equation (1), while the calculation of q_i (indifference thresholds) is based on the use of Equation (2) (Haralambopoulos et al., 2003; Kourmpanis et al., 2008; Michailidou et al., 2016b).

$$p_i = \frac{1}{n}(V_i\,max - V_i\,min) \quad (1)$$

$$q_i = 0.3 \cdot p_i \quad (2)$$

Based on the above analysis, a combination of anaerobic and aerobic digestion is promoted as the selected technological solution. Anaerobic Digestion (AD) fits well local agricultural and farming since manure, cheese whey, side products (i.e. rotten potato pulp, oil mill waste) and slaughterhouse waste are efficient substrates available in the area. AD is considered as the process where value is produced mainly for generation of bioenergy (CHP) and biofertilizer. AD is a fermentation process, which is realized in an air-sealed biodigester (under conditions of oxygen absence). The feedstock (biowaste substrates) is converted into fuel gas and digestate (as a bio-product). The biogas which is produced comprises mainly of CH_4 (50-70%) and CO_2 (30-50%). Moreover, in smaller quantities, the biogas consists of H_2O vapor, H_2S, and other elements. The digestate is produced from the digestion of substrates, after biogas extraction. Wet digestate comprises of nutrients (e.g. nitrogen, lignin, phosphorous), inorganic salts (e.g. ammonium, phosphate, potassium), as well as other minerals. Therefore, it is suitable for use as a naturally derived fertilizer. In literature, there are many studies related to the exploitation of AD (Pramanik et al., 2019; Kumar et al., 2020; Srisowmeya et al., 2020; Wainaina et al., 2020). The substrates used determine the appropriate technical infrastructure that is required (e.g. pipes' sizing, pumps' specifications, gas storage requirements, gas treatment technology and CHP design).

Table 3.2. Assessment of alternative site locations *(in 1-10 scale, where 10 is the most preferable)*

Criterion	Site 1 (1-10)	Site 2 (1-10)	Site 3 (1-10)	Site 4 (1-10)	Weights (%)	p_i	q_i
Cr_1 - Distance from biowaste source	1.46	8.92	6.92	5.69	15	1.87	0.56
Cr_2 - Accessibility of site	1.69	9.62	6.31	6.77	14	1.98	0.59
Cr_3 - Distance from units for energy consumption	2.00	9.46	7.54	7.15	12	1.87	0.56
Cr_4 - Distance from farms for compost use	3.85	9.23	8.31	7.69	8	1.35	0.40
Cr_5 - Value of land	2.85	9.15	7.62	7.23	12	1.58	0.47
Cr_6 - Impacts on local populations	9.23	7.31	2.62	2.00	10	1.81	0.54
Cr_7 - Impacts on local ecosystems	3.85	8.00	5.92	5.77	10	1.04	0.31
Cr_8 - Aesthetic degradation	4.85	8.46	4.69	3.23	6	1.31	0.39
Cr_9 - Increase in road traffic due to UATB	3.08	7.08	2.85	3.46	5	1.06	0.32
Cr_{10} - Social Acceptance	8.69	8.46	2.69	2.23	8	1.62	0.48

The technology adopted does not add to the CO_2 load in the atmosphere, since CO_2 produced is offset by prevented emissions of CH_4 in the case that slurry is storage in open spaces. In this light, biogas can significantly contribute towards decarbonization of economy. Furthermore, a decentralized bioenergy generation from biofuel in UABTs with CHP is becoming more attractive for the cases where generated heat is exploited in facilities within the proximity of the UABT. Moreover, the use of UABTs' end-products (energy and bioproducts) need to be meticulously examined within the pre-planning phase. In this context, the use of the produced bio-fertilizer in farms close to the developed UABTs highly supports their financial performance and effectiveness. Sufficiency of arable land for spreading available biofertilizer and available adjacent market for the digestate needs to be investigated. In addition, biofertilizers' nutrients are predominately contained in a mineral form, which allows ease of absorption by plants and increased uptake efficiency, in comparison to nutrients in raw manure or in slurry (Al Seadi et al., 2018).

Based on the above, it is proven in practice by the operation of such multi-functional facilities that this technology offers reduced local community energy costs, low-cost and environmentally safe recycling of manure and biowaste, cheap and efficient crop biofertilization means and reduction of odors due to intensive farming activity. Thus, considering also that in many areas organic substances are still disposed in landfills (contributing to local CH_4 emissions), the proposed UABT apparently dually contributes towards global warming mitigation; through (a) the decreased CH_4 emissions in animal farms (due to digestate management and avoidance of open slurry storage), and (b) the production of a "green", decarbonized (bio-)fuel. Along with the latter, improved digestate nutrient management, in combination with sustainable agri-practices (Holm-Nielsen et al., 1997), has a positive effect on the reduction of NH_3 and NO_x emissions, as well as eutrophication of surface and ground water since leakages can be decreased or even avoided. Furthermore, local eutrophication is also achieved through biogas treatment of manure (Fagerström et al., 2018).

The use of ELECTRE III in the case herein examined is realized with LAMSADE software. The two distillations (ascending and descending) that result from the analysis of the sites' performances are graphically displayed in Figure 3.2a. Both ascending and descending distillations promote Site 2 as the optimal alternative for UABT's location. This is also displayed in Figure 3.2b, where the four alternatives ae hierarchically ranked. Site 2 (optimal location) is approximately 1.5 km south-southwest of the city of Serres, within a Municipality-owned land of approximately 16 acres.

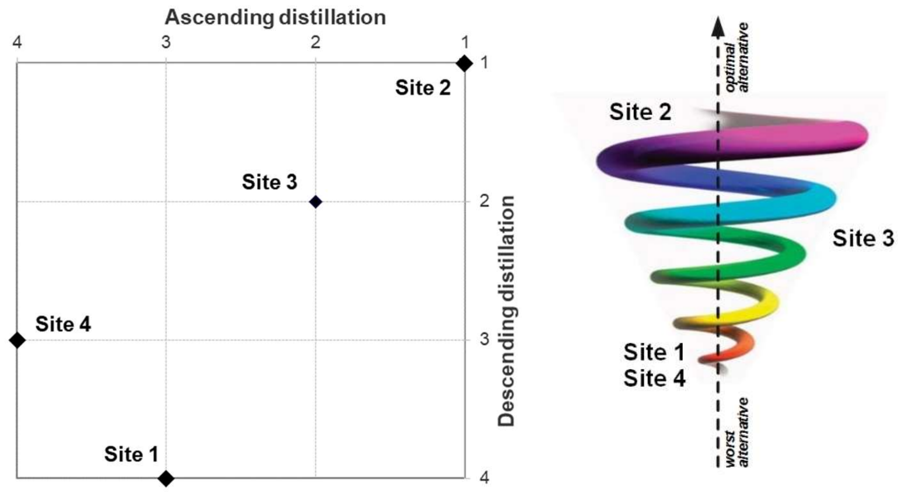


Figure 3.2. Optimal UABT location: (a) Ascending and descending distillations - (b) Ranking of alternative locations

References

Achillas Ch., Moussiopoulos N., Karagiannidis A., Banias G., Perkoulidis G. (2013) Use of multi-criteria decision analysis to tackle waste management problems: A literature review. Waste Management & Research, Volume 31(2), pp 115-129.

Achillas Ch., Vlachokostas Ch., Moussiopoulos N., Banias G., Kafetzopoulos G., Karagiannidis A. (2011a) Social acceptance for the development of a Waste-to-Energy plant in an urban area: Application for Thessaloniki, Greece. Resources, Conservation and Recycling, Volume 55, pp 857-863.

Achillas, Ch., Vlachokostas, Ch., Moussiopoulos, N., Perkoulidis, G., Banias, G., Mastropavlos, M. (2011b) Electronic waste management cost: A scenario-based analysis for Greece (2011) Waste Management and Research, 29 (9), pp. 963-972.

Al Seadi T., Stupak I., Smith C. T. (2018) Governance of environmental sustainability of manure-based centralised biogas production in Denmark. Murphy, J.D. (Ed.) IEA Bioenergy Task 37:2018:7.

Al-Shemmeri T., Al-Kloub B., Pearman A. (1997) Model choice in multicriteria decision aid. European Journal of Operational Research, Volume 97(3), pp 550-560.

Banias G., Achillas Ch., Vlachokostas Ch., Moussiopoulos N., Stefanou, M. (2017) Environmental impacts in the life cycle of olive oil: a literature review. Journal of the Science of Food and Agriculture, Volume 97(6), pp 1686-1697.

Banias G., Achillas Ch., Vlachokostas Ch., Moussiopoulos N., Tarsenis S. (2010) Assessing multiple criteria for the optimal location of a construction and demolition waste management facility. Building and Environment, Volume 45(10), pp 2317-2326.

Chatterjee P., Yazdani M., Chakraborty S., Panchal D., Bhattacharyya S. (editors) (2019) Advanced Multi-Criteria Decision Making for Addressing Complex Sustainability Issues. Advances in Environmental Engineering and Green Technologies, 1st Edition, IGI Global.

Delgado M., López A., Cuartas M., Rico C., Lobo A. (2020) A decision support tool for planning biowaste management systems. Journal of Cleaner Production, Volume 242, Article 118460.

European Commission (2008) Directive 2008/98/EC on waste (Waste Framework Directive).

European Investment Bank (2019) Circular Economy Guide – Supporting the circular transition. January 2019. Available online at: https://www.eib.org/en/publications/the-eib-in-the-circular-economy-guide (last access: 10.3.2020).

Fagerström A., Al Seadi T., Rasi S., Briseid T, (2018) The role of anaerobic digestion and biogas in the circular economy. Murphy J. D. (Ed.) IEA Bioenergy Task 37:2018:8.

Haralambopoulos D., Polatidis H. (2003) Renewable energy projects: Structuring a multi-criteria group decision-making framework. Renewable Energy, Volume 28(6), pp 961-973.

Hokkanen J., Salminen P. (1997) Choosing a solid waste management system using multicriteria decision analysis. European Journal of Operational Research, Volume 98(1), pp 19-36.

Holm-Nielsen J.B., Halberg N., Hutingford S., Al Seadi T. (1997) Joint biogas plant. Agricultural advantages - Circulation of N, P and K. Report made for the Danish Energy Agency, 2nd edition, August.

Iakovou E., Moussiopoulos N., Xanthopoulos A., Achillas Ch., Michailidis N., Chatzipanagioti M., Koroneos C., Bouzakis K.-D., Kikis V. (2009) Multicriteria Matrix: A methodology for end-of-life management. Resources, Conservation and Recycling, Volume 53, pp 329-339.

Ishizaka A., Nemery Ph. (2013) Multi-criteria Decision Analysis: Methods and Software. Wiley, June.

Kourmpanis B., Papadopoulos A., Moustakas K., Kourmoussis F., Stylianou M., Loizidou M. (2008) An integrated approach for the management of demolition waste in Cyprus. Waste Management and Research, Volume 26(6), pp 573-581.

Kumar A., Samadder S. (2020) Performance evaluation of anaerobic digestion technology for energy recovery from organic fraction of municipal solid waste: A review. Energy, Volume 197, Article 117253.

Le Hesran C., Ladier A. L., Botta-Genoulaz V., Laforest V. (2019) Operations scheduling for waste minimization: A review. Journal of Cleaner Production, Volume 206, pp 211-226.

Michailidou, A.V., Vlachokostas, C., Moussiopoulos, N., Maleka, D.(2016a) Life Cycle Thinking used for assessing the environmental impacts of tourism activity for a Greek tourism destination. Journal of Cleaner Production, 111, pp. 499-510.

Michailidou A.V., Vlachokostas C., Moussiopoulos N. (2016b) Interactions between climate change and the tourism sector: Multiple-criteria decision analysis to assess mitigation and adaptation options in tourism areas. Tourism Management, 55, pp. 1-12.

Morrissey A. J., Browne J. (2004) Waste management models and their application to sustainable waste management. Waste Management, Volume 24(3), pp 297-308.

Pramanik S. K., Suja F. B., Zain Sh., Pramanik B. K. (2019) The anaerobic digestion process of biogas production from food waste: Prospects and constraints. Bioresource Technology Reports, Volume 8, Article 100310.

Republic of Greece (2018) Law 4513/2018 on energy communities. Official Government Gazette 9/A’/23.01.2018.

Rezaei J. (2015) A systematic review of multi-criteria decision-making applications in reverse logistics. Transportation Research Procedia, Volume 10, pp 766-776.

Rogers M., Bruen M. (1998) Choosing realistic values of indifference, preference and veto thresholds for use with environmental criteria within ELECTRE. European Journal of Operational Research, Volume 107, pp 542-551.

Rousis K., Moustakas K., Malamis S., Papadopoulos A., Loizidou M. (2008) Multi-criteria analysis for the determination of the best WEEE management scenario in Cyprus. Waste Management, Volume 28(10), pp 1941-1954.

Roussat N., Dujet C., Mehu J. (2009) Choosing a sustainable demolition waste management strategy using multicriteria decision analysis. Waste management, Volume 29(10), pp 2-20.

Roy B. (1978) Electre III; Algorithme de classement base sur une representation floue des preferences en presence de criteres multiples. Cahiers de CERO, Volume 20(1), pp 3-24.

Roy B., Bouyssou D. (1993) Aide multicritere a la decision: Methods et cas. Economica, Paris.

Silva S., Alçada-Almeida L., Dias L. (2014) Biogas plants site selection integrating Multicriteria Decision Aid methods and GIS techniques: A case study in a Portuguese region. Biomass and Bioenergy, Volume 71, pp 58-68.

Simões Gomes C., Nunes K., Xavier L.H., Cardoso R., Valle R. (2008) Multicriteria decision making applied to waste recycling in Brazil. Omega, Volume 36, pp 395-404.

Soltani A., Hewage K., Reza B., Sadiq R. (2015) Multiple stakeholders in multi-criteria decision-making in the context of Municipal Solid Waste Management: A review. Waste Management, Volume 35, pp 318-328.

Soukopová J., Vaceková G., Klimovský D. (2017) Local waste management in the Czech Republic: Limits and merits of public-private partnership and contracting out. Utilities Policy, Volume 48, pp 201-209.

Srisowmeya G., Chakravarthy M., Nandhini Devi G. (2020) Critical considerations in two-stage anaerobic digestion of food waste - A review. Renewable and Sustainable Energy Reviews, Volume 119, Article 109587.

Spyridi D., Vlachokostas C., Michailidou A.V., Sioutas C., Moussiopoulos N. (2015) Strategic planning for climate change mitigation and adaptation: The case of Greece. International Journal of Climate Change Strategies and Management, 7 (3), pp. 272-289.

Taelman S., Sanjuan-Delmás D., Tonini D., Dewulf J. (2019) An operational framework for sustainability assessment including local to global impacts: Focus on waste management systems. Resources, Conservation & Recycling, Volume 2, Article 100005.

Vea E. B., Romeo D., Thomsen M. (2018) Biowaste valorisation in a future circular bioeconomy. Procedia CIRP, Volume 69, pp 591-596.

Vego G., Kučar-Dragičević S., Koprivanac N. (2008) Application of multi-criteria decision-making on strategic municipal solid waste management in Dalmatia, Croatia. Waste Management, Volume 28, pp 2192-2201.

Vlachokostas, C., Michailidou, A.V., Matziris, E., Achillas, C., Moussiopoulos, N. (2014) A multiple criteria decision-making approach to put forward tree species in urban environment. Urban Climate, 10 (P1), pp. 105-118.

Vlachokostas Ch., Achillas Ch., Moussiopoulos N., Banias G. (2011) Multicriteria methodological approach to manage urban air pollution. Atmospheric Environment, Volume 45, pp 4160-4169.

Vučijak B., Kurtagić S. M., Silajdžić I. (2016) Multicriteria decision making in selecting best solid waste management scenario: A municipal case study from Bosnia and Herzegovina. Journal of Cleaner Production, Volume 130, pp 166-174.

Wainaina S., Awasthi M. K., Sarsaiya S., Chen H., Singh E., Kumar A., Ravindran B., Awasthi S. K., Liu T., Duan Y., Kumar S., Zhang Z., Taherzadeh M. (2020) Resource recovery and circular economy from organic solid waste using aerobic and anaerobic digestion technologies. Bioresource Technology, Volume 30, Article 122778.

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Organization: Aristotle University of Thessaloniki

Deliverable responsible: Dr. Christos Vlachokostas

Contact details: vlahoco@auth.gr