Open Access Journal
Journal of Power Technologies 94 (1) (2014) 1–19
journal homepage:papers.itc.pw.edu.pl

Location selection analysis for biological treatment plants for municipal waste

Grażyna Wójcik[*,a], Małgorzata Jacyno[b], Jolanta Korkosz-Gębska[c], Ewa Krasuska[d], Anna Oniszk-Popławska[e], Dominika Trębacz[f]

[a] *Warsaw University of Life Sciences (SGGW)*
Faculty of Production Engineering, Poland
[b] *Institute of Sociology, Faculty of Philosophy and Sociology*
University of Warsaw, Poland
[c] *Institute for Organisation of Production Systems, Faculty of Production Engineering*
Warsaw University of Technology, Poland
[d] *Automotive Industry Institute*
Renewable Energy Department, Poland
[e] *Institute for Renewable Energy, Poland*
[f] *Automotive Industry Institute, Poland*

Abstract

This article aims to analyze the choice of location for an organic recycling plant for biodegradable municipal solid waste prepared for small and medium-sized enterprise investments. The multi-criteria analysis (using compromise programming) is based on a mathematical selection of the best solution, taking into account all the circumstances and making a full description of the selected options. A point analysis of the selected locations is made: expert evaluation using appropriate evaluation criteria—technical, geographical, legal, economic and social. Based on this SWOT analysis was performed, designed to aid evaluation of the locations from the perspective of 23 criteria categorized into groups (strengths, weakness, opportunities, threats). A four-level scale of expert evaluation was used in the assessment.

Keywords: Organic recycling and energy recovery plants, Management of biodegradable municipal solid waste, Multi-criteria analysis, Expert analysis of investment sitting

1. Introduction

This paper aims to select the best location for organic recycling and energy recovery plant based on Anaerobic Digestion (AD plant) running on the separated at source organic fraction of municipal solid waste (OFMSW). The AD plant sitting is based on the example of selected municipalities in the Mazowsze region in Poland. This planned venture is likely in the near future to be one of the key elements in the field of waste management, while at the same time generating green energy. The solution might eventually be used as a tool by small and medium-sized enterprises (SMEs) seeking locations for investments in the field of ecological waste management and green energy production. This article continues the topic

*Corresponding author

Email addresses: grazyna_wojcik@sggw.pl (Grażyna Wójcik*,), jacynoma@is.uw.edu.pl (Małgorzata Jacyno), j.korkosz@wip.pw.edu.pl (Jolanta Korkosz-Gębska), e.krasuska@pimot.org.pl (Ewa Krasuska), aoniszk@ieo.pl (Anna Oniszk-Popławska), d.trebacz@pimot.org.pl (Dominika Trębacz)

dealt with in the article titled The concept of biogas plants using municipal waste [1].

The OFMSW fraction is suitable for anaerobic digestion to produce biogas includes biodegradable garden and park waste, food and kitchen waste from households, restaurants, catering units and retail units, as well as comparable waste from food manufacturing and retail. The AD plant based on OFMSW is similar in principle to the agricultural biogas plant, but with additional technological modules (pre-treatment of waste). A key element of the AD plant for OFMSW is its location in or near urbanized areas, where there it is easier to separately collect OFMSW due to a better technical infrastructure.

In line with the EU policy, Member States should ensure the management of waste in accordance with the principles of sustainable development. This refers in particular to the waste hierarchy defined in the Waste Framework Directive 2008/98/EC [2], which gives priority to measures preventing waste generation, followed by the recovery and recycling. Poland implemented the Directive and it became effective as of July 2013. The estimated amount of organic fraction of municipal solid waste (OFMSW) to be recycled and treated to avoid landfill in Poland is 2.19 Mt/a (50%) in 2013, 1.53 Mt/a (35%) in 2020 [3].

Poland has not yet developed an organizational base for the mass deployment of organic recycling plants for OFMSW, although they are successfully used in 17 countries in Europe (e.g. Germany, France, Spain, Denmark, Sweden).

There are 200 commercial facilities treating OMSW in Europe for biogas production (90% of anaerobic plants worldwide), with a total capacity of 6 Mt/a [4]. About 100 facilities of this type have been installed in Germany, with an average capacity of 23 kt/a [5], followed by Spain and France [6]. The average capacity has grown from 12 kt of waste a in the 1990's to 30 kt/y in 2010. However, systems that use mixed municipal waste have greater capacity: 100...200 kt/a. The size of the planned facilities varies depending on the waste collection system prevailing in the country. In countries where separate collection is not widely used (France, Spain, United Kingdom), planned mixed waste facilities are larger than 100 kt/a. In other countries, where separate collection takes place, such as Switzerland, Austria, Sweden and Norway, smaller units of 8 kt/a capacity have been installed. In Germany, Belgium and Italy medium-sized facilities 30...50 kt/a are more common [4, 6, 7].

The first biogas plants based on municipal waste erected in the 1990's were based on co-fermentation with other substrates [8]. Currently, the co-fermentation with substrates of agricultural origin is not often used, but it has been noted that operators of agricultural biogas plants are seeking new sources of feedstock due to the rising cost of obtaining energy crops as feedstock [7].

The preliminary stage in the construction of OFMSW treatment plants is choosing the right location. This choice depends in particular on the technological requirements of the facility, as well as technical and legal, geographical and socio-political issues.

2. Summary of the delimitated research area

Table 1: General characteristics of the areas studied [9]

Location	Type	Population '000	Area '000 ha	Population density inhabitants/km^2
A	rural-urban	42.7	10.7	398
B	rural	4.8	5.0	66
C	urban	3.9	1.0	388
D	rural	10.9	5.5	198
E	urban	16.3	1.3	1216
F	rural	7.5	10.5	71

The Table 1 presents a brief characterization of the six analyzed areas in the region (voivodship).

Location A is a local employment center and one of the most industrialized suburbia cities of the Warsaw agglomeration. Its main function is industry and services. The municipality operates a sewage treatment plant and a plant composting biodegradable municipal solid waste serving adjacent areas. The unpleasant smell is a major source of conflict with residents. It is assumed that, after upgrading, the composting facility will become a part of the regional municipal solid waste management system. The city has a power reduction station 110/15 kV (PCO). Apartment blocks, commercial and industrial buildings are heated with district heating systems and local boiler houses, the rest are equipped with individual boilers. The city area is powered by a high pressure gas pipeline.

Compared to the other locations under consideration, this area is characterized by less social capital investment and comparatively less experience in the field of collective action. A relatively lower sense of local identity can be anticipated, because many residents work outside their local neighborhood. We should bear in mind, however, that a sense of empowerment and collective identity can exist in a “hibernation”, where there is no clear and inclusive context for action, but can be activated very quickly if the occasion arises. This shows the dangers, but also the possible opportunities for a OFMSW investment in this location. It is necessary to recognize right from the start that protests and ’waves’ of sentiment can spread. The advantages of this location include the fact that the sense of local identity is seen as a scarce good and that all activities and cultural and educational initiatives aimed at creating or recreating the “local us” would be efficient in a symbolic sense.

Location B is a rural district with a predominance of high quality soils (I-III quality class), heavily dominated by agriculture, particularly market gardening. The decrease in profitability of agricultural production will increase interest in other forms of investment in rural areas. Due to the presence of dense areas of good soils, the B municipality is mainly used for agricultural purposes, but is also open to investment from industrial and service sectors. The largest designated area lies at the intersection of regional roads in the central part of the municipality. Outside investors have shown no interest in doing business in the municipality. Upgrading and expansion of the road network infrastructure is essential to ensure easy access to all locations. 400 kV and 220 kV power cables are running across the municipality. The area is dominated by single-family houses and homesteads heated by individual heating systems, the vast majority using coal-fired boilers.

The inhabitants are mostly middle class, which in some circumstances reduces, and in others increases, the social risk. It is generally said that the people belonging to the middle classes favor investments related to clean technologies”. It should, however, be remembered that the environmental awareness of the middle classes is conducive not only to solidarity, but also to rivalry as to who will be the giver” and who will be the recipient” of risk, as defined by [10]. The relative lack of a tradition or history of collective action in this area may be compensated for by a strong sense of integration arising from a similar orientation in life, be it real or perceived. In other words, the belief that what unites us is that we made similar choices in terms of place of residence, is significant and symptomatic for groups within the middle classes who share a specific life orientation. We can also expect that the protests in this place will immediately form a well-organized resistance to prevent inhabitants becoming a recipient” of risk.

Location C is an urban area, mostly made up of parklands. In administrative terms the municipality consists of built-up areas and forests. The municipality also includes a number of listed historic monuments. Low levels of local production and services means that the majority of the population works or has a source of income outside of the town (a poor district with rich residents).

The character of the terrain as a recreational and health resort in principle rules out the possibility of infrastructural investment planning. Authorities and numerous cultural and social organizations working in the area interact well with each other and are involved not only in efforts to maintain and improve the recreational and health resort features of the area. These features are also an essential element of the identity and image of the municipality. Experience from the not too distant past indicates that violent protests can arise in the locality.

Location D is a rural municipality, but is characterized by unfavorable soil conditions for agricultural production (land valuation classes V and VI). Only a small number of farms produce commercially. In recent years, its function has been to provide housing and recreation for the people of the surrounding towns. Individual properties are heated using natural gas, coal and coke. A high-pressure gas pipe-line runs through the western part of the municipality. The municipality does not have a sewage treatment plant. It has a high potential for recreation and relaxation. Pull factors include the proximity to nature reserves, woodland and hiking routes.

The presence of attractive recreational areas tends to discourage the investment planning. It should be noted that even if the recreational attractiveness of the given area is less compared to the three other municipalities—as is the case here—the direct vicinity of municipalities with areas that are recognized as valuable in terms of nature and culture is likely to encourage competition in this regard and intensify action taken by authorities and residents aimed at achieving a similar level of attractiveness.

Location E is mainly an urban area, consisting mostly of parkland. These areas contain particularly valuable plant life. Location E has an ecological policy, based on sustainable development. The city authorities have made significant strides that are leading to an improved quality of life. The municipality borders a high-impact waste composting plant in Location A, which has triggered much social conflict. Two large boilers operate in residential areas.

The presence of valuable and attractive recreational sites prevents investment planning. This fact is confirmed by recent conflicts associated with investment proposals. The actions of authorities and cultural organizations are focused on maintaining and enhancing the image of the municipality as a place of great natural value and with recognized symbolic capital.

Location F is a rural municipality. The soil conditions for agricultural production are average (60% of the land is class V and VI). The tradition of out-of-town residences in municipality F dates back to the nineteenth century. It boasts a particularly large number of monuments, in the form of 11 historic residences or ruins. Holiday-makers form a major proportion of the population, using seasonal recreational plots. The district has its own landfill site. It is expected that it will take municipal waste until 2013. The district has good conditions for light industry along main roads. The municipality is supplied with electricity from neighboring municipalities. Due to the great interest in construction sites, there is a need to construct a municipal power supply point in the area and expand the grid. The district owns property earmarked for this purpose.

Location F is an attractive area in terms of its natural and cultural heritage. In recent years, the population has grown. The new residents are mainly middle class inhabitants seeking prestige and a healthy environment. The infrastructural investment planning would raise protests from the outset. The presence of middle class inhabitants and the large social capital accumulated from previous experience in a joint action, suggest that conflict would immediately assume the form of a well-organized protest, the purpose of which would not only be to protect selected, specific places or structures.

3. Basic assumptions for small and medium-sized enterprises

Described below there are the basic assumptions regarding technical, geographical, legal, economic and social requirements for OFMSW treatment plant defining the criteria important for the location of such an investment.

3.1. Basic technical assumptions

The most important element of the investment for the biological recycling plant for organic municipal waste fractions is to determine the amount of waste for the studied area. Waste sources are households and other entities (trade, services, crafts, education, "social" industry and others) [11].

The average annual production of municipal waste in Poland is 316 kg/capita and this figure is significantly lower than in the EU as a whole (512 kg/capita). However, Poland produces as much as 29% of the municipal solid waste generated in the new EU Member States(12.1 million tons) [3].

In this article we focus only on OFMSW separately collected at source. Germany already has many years of experience in the separate collection of the biodegradable waste fraction of municipal waste OFMSW (which grew from 2.1 million tons in 1990 to 8.6 million tons in 2006). In 2009, 79.2% of the population of Germany was able to separate OFMSW at source, and the system was used by 69% of the country) [12]. The selective collection of waste involves 56% of the population—more than 8 million tons of OFMSW per year, of which 2 million tons are allocated as input for AD plants [5]. In green areas in Germany such as parks and cemeteries, the amount of waste is estimated at 5 t/ha., and in areas where mowing is required: 3.5 t/ha (of which 25...50% is usable). The amount of waste from gardens is estimated at 0.5...1 kg/m^2 garden/year [13, 14]. The selective waste collection will be required in all municipalities from 2015. In Sweden, 153 of 290 municipalities had selective collection in 2009 [15]. In the EU-11, including Poland, the efficacy of selective collection at source, has so far been unsatisfactory [3].

The plant size is determined by the estimated amount of OFMSW produced in the region analyzed AD plants only uses waste from selective collection at source. The quantities of feedstock are estimated on the basis of the indicators.

To perform a quantitative analysis it is necessary to:

- identify sources of waste,
- determine the mass or volume of waste accumulation, i.e. the amount of waste produced annually by a statistical inhabitant of a given type of community, expressed in kg or m^3 respectively.

Table 2: The estimated theoretically obtainable amounts of BIO waste generated according to type of municipality, in Poland in the Mazovian region [16]

Substrates	Kitchen and garden waste
Urban	113 kg/ inhabitant /r
Rural-urban	128 kg/ inhabitant /r
Rural	78 kg/ inhabitant /r

The following technical criteria have been identified for the multi-criteria analysis:

- the municipality has a large potential for OFMSW substrates,
- in the municipality there is no alternative for processing of OFMSW,
- OFMSW can be processed together with waste from the agricultural/ food processing industry(co-fermentation).

3.2. Basic geographical assumptions

Infrastructure constraints can include difficulties in accessing the grid or too great a distance from the existing heating network. A prerequisite for the realization of AD plants for OFMSW is the expansion of local roads (for efficient collection of waste).

When analyzing the logistics of supplying OFMSW substrates at a given location , attention must be paid to the possibility of increased road traffic, which can trigger protests. It is essential that roads are designed for transporting substrates in heavy duty vehicles. It may be that a suitable access road to the site does not exist and must be built from a scratch.

In principle, the plant will be located in areas that cause the least inconvenience to residents, preferably in areas designated for that purpose in the spatial policy documents of municipalities (the Study of Conditions and Directions of Spatial Development (SCDSD). Ideally, the organic recycling AD plant should rely on the existing municipal infrastructure, in predestined areas. The location will enable the collection and use of products generated by the AD

plant: gas, energy (heat, electricity) and organic fertilizer.
The following geographical criteria have been identified for the multi-criteria analysis:

- the ability to use existing or planned municipal facilities,
- the possibility of increased traffic,
- there is an PDP (Power Distribution Point) or MPP (Main Point of Power) (regional or primary power station connected to the high voltage grid) and a 110kV line in the district,
- a pipeline or the first degree pressure reduction station runs through the district,
- a proximity to a boiler-house, district heating network or major heat consumers,
- there is no risk of flooding.

3.3. Basic legal assumptions

Investors are encouraged to use innovative technology by the existing regulatory mechanisms. This includes on the one hand a set of directives /laws/ regulations in the area of waste management; on the other hand the impact of legal mechanisms in the production of green energy will also play an important role. In terms of waste management, Poland must comply with the Waste Framework Directive 2008/98/EC [2].
The directive promotes selective collection and treatment of OFMSW, obliges Member States to develop and implement strategies to reduce landfill disposal of biodegradable waste and calls for action to achieve targets to reduce landfill disposal of biodegradable municipal waste. An important requirement is the duty to reduce the quantities of bio-waste sent to landfills. In 2013, Poland will have to find another way of disposing of approximately 2.1 million tones of additional waste, and in 2020, as much as 2.8 million tons of OFMSW waste [3].
Local laws impact any investment assessment. For the investor—a developer interested in building an AD plant—the first step is to legally secure property (purchase, public ground lease or private lease of land) and to protect legal rights on neighboring properties (e.g. by establishing a transmission easement). The investor will explore the possibility of acquiring a property by checking its legal status at the District Court (entry in the land register), as well as the possibility of signing contracts for the use of power line infrastructure, when it passes through neighboring territory not belonging to the land. In cases where the land is owned by the municipality or local government, the Treasury will be involved in the procurement procedure or sale of the lease.
Although the spatial policy document (SCDSD) is not an act of local law, study findings are binding on the municipal authorities preparing local spatial development plans (LDP). If SCDSD does not provide for the location of industrial investments, a consent must be obtained for a change in the land use. If the municipality is expected to identify areas for devices generating power from renewable energy sources in excess of 100 kW_{el} (a AD plant usually has an output greater than 500 kW_{el}) the distribution will be determined in the SCDSD document.
The following legal criteria have been identified for the multi-criteria analysis:

- the district owns land, which could potentially be allocated to such an investment.
- in the SCDSD or LDP, areas are identified for waste treatment facilities.

3.4. Basic economic assumptions

Whether selective collection of BFMW will be profitable in a given area depends on the generation of BFMW per capita in an area of a given population density. The higher the population density, the lower the threshold required for waste generation per capita, which is associated with the unit expenditure on waste transport [12, 14]:

- for areas with a population density below 1,000 inhabitants/km^2 the threshold for separate collection is 120 kg/inhabitant/year (food and green waste). In rural areas with extensive development, the limit of profitability for separate collection is a population density of over 150 persons per km^2,

- for areas with a population density between 150...1,000 inhabitants/km^2 the threshold for a separate collection is 80 kg/inhabitants/year,

- for areas with a population density above 2,000 inhabitants/km^2, the threshold for separate collection is 50 kg/inhabitant/year.

Other criterion includes: the participation of at least 70...75% of population (practically achievable only in subarbial areas).

For an investment to make sense from an economic point of view a primary source of certain substrates must be provided. The location chosen by the investor should ensure the availability of substrates which enable the established levels of power generation. The ideal situation is one in which the AD plant for OFMSW is based on the input produced in a given municipality. However, in practice this is difficult to implement and biomass is transported to within a radius of a dozen or even dozens of kilometers. The aim should always be, however, to minimize the need for transport.

One of the benefits of implementing AD plants for OFMSW in a given area may be local tax revenues: from a corporate income and property tax.

The following economic criteria are identified for the multi-criteria analysis:

- local investment income as an incentive for residents (local income from the investment will be an important item in the budget of the municipality),

- favorable ratio of waste transport distances with waste quantities.

3.5. Basic social assumptions

With nearly every initiative relating to environmental protection, critical moments arise for investments such as criticism and negative evaluation, which is the result of emotional conflicts of interests, the occurrence of crisis situations leading to losses and delays. These negative phenomena should be prevented by properly prepared information/promotion campaigns. It should be remembered that social resistance stems from three basic issues:

- use of industrial waste,

- wrong choice of location,

- inadequate supervision and inadequate levels of cleaning during operation.

It is important to create a positive social climate for investment in renewable energy, such as a biological treatment plant for organic fraction of municipal solid waste. Winning the favor of the local community is also an important element in meeting the regulatory requirements established by law. Biological treatment of municipal waste will be accepted if harm to the environment is minimized through:

- protection of residential areas,

- reduction of undesirable odors and noise,

- optimization of feedstock supply logistics and export of digestate,

- use of best available technology.

To reduce the possible negative impacts of AD plants on the environment (noise, odor and possible consequences of failure) the plants should be at the necessary distance to minimize the negative impacts of the installation on the health and safety of people.

Other cultural factors limiting the development of AD plants for OFMSW include the lack of social acceptance and the presence of structures and areas listed as historical monuments or protection zones.

The following social criteria are identified for the multi-criteria analysis:

1. residents are positively disposed towards environmental investments, as is shown in the history of activities in the district,
2. there have been no protests in the municipality related to infrastructure projects,
3. the district is not a holiday or health resort,
4. there are industrial activities in the municipality,
5. there are no areas of natural or cultural value in the municipality,
6. a number of people work in environmental protection in public administration.

4. Analysis of social risk associated with the investment

4.1. SMEs—assessing social risk associated with the investment

It should be noted that in places, where there is a tradition of collective action for environmental protection and high social capital, as is the case for places C and E, people have a strong sense that they are right, and possess the appropriate skills for self-assessing the various short and long-term side effects of the project.

In foreseeing potential conflicts, not only the actual effects of prior, misguided investments should be considered, but also how the size of these effects is seen and interpreted by the people. It is very likely that some of the previous failures are seen not only in their immediate and noticeable effect, but also as a failure of the local environment and the partial loss of an important local identity attribute, namely the autonomy. Risky ventures are often preceded by a research survey to identify the level of social acceptance. Note, however, that traditional surveys do not "reveal" what already exists (attitudes, capabilities). Surveys are (more or less successfully) a form of environmental intervention, if only because the problems or intentions are named in a certain way. Survey results depend largely on whether the manner of presenting the problem relates directly to the current experience of residents (smell, lack of recreation for children, view spoiled by the local scrap yard), or refers to a high level of generality, relating poorly to everyday experience (statistics, concepts associated with bureaucratic jargon). Social risk can also be estimated using data that does not require costly tests. The presence in the local market of organic products, the activities of cultural organizations or the fact that inhabitants discipline one another in matters of the aesthetics of local space—these are indicators, which are easy to identify and, which can give an indication of the level of acceptance of environmental investments. Especially in areas, where there are existing cultural and social organizations, there is an opportunity for SMEs, because they are entities, which can be reached during the implementation and operation of the project. Such organizations are also intermediaries, who normally perform the work of interpreting local, global and political problems in order to understand what is going on and what residents are experiencing and why.

4.2. SMEs—the ability to manage social risks

It should be borne in mind that social risk is not a constant value, but a quality that can be at least partially managed. The advantage of SMEs is that smaller projects, which are easier to fit in with the scale of local experience, can count today on a friendlier welcome. Large projects, associated with "globalization" are seen as a manifestation of anonymous forces of action and actors. The benefits and opportunities of large infrastructural investments (e.g. new jobs) are seen as temporary and uncertain, because residents feel that they are likely to disappear just as suddenly as they came along [17]. For this reason, placing emphasis on "symmetry" at each stage between the planned investment by SMEs and the level of 'localness' can be an important advantage. "Localness" in the popular consciousness of individuals and the government is seen as a resource and quality that resists globalization, understood as an anonymous, impersonal, or top-down influence. A sense of local identity is manifested among others by the fact that different places which are not covered by legal protection should, in the opinion of inhabitants, be protected because of their social importance (e.g. places of recreation or sites of local historical importance known only to residents).

The second local effective context for appeals is technological citizenship [10]. The technological citizenship is a term referring to issues of citizenship in relation to the world of technology and things. A sense of a lack of the empowerment is in fact often associated with "invasive" technology. Local aspirations relating to a sense of empowerment may be at odds with a new technological venture right from the outset. The risk posed by each technological project is seen as the risk of handing over decisions to "people at the top" and allowing in their own back yard what is called, writes [10], "no man's rule," or the rule of technology and things (which do what they want, act how they want, and may be in the near or distant future unpredictable). The "logic" of technology is seen as a threat to the autonomy of cultural and social processes and, in the present case, to the social meanings that local communities have given specific places. The opportunity to support or join SMEs in relatively low cost activities, which aim to civilize public spaces (increasing access to public space, helping to eliminate local problems, improving the appearance of public spaces) can significantly increase acceptance of the planned investment.

4.3. Possible social conflicts

The social risk associated with the new investment is manifested here by the fact that in the first phase of the investment it is difficult to discern who is "for" and who is "against". This is not due to the weakness of research techniques, but because of the fact that many of the inhabitants cannot be certain of their attitudes. It may, therefore, be necessary to conduct multiple surveys of social acceptance for the project. These studies would take into account the effectiveness of the information and educational activities.

It is possible to give some pointers to ensure public acceptance and thus reduce social risk. Firstly, the survey of public acceptance should be linked to environmental interventions, the aim of which would be education in the field of "green consumption" and the expansion of environmental imagination in such a way as to create a sense of solidarity. Secondly, these activities should avoid bureaucratic and expert jargon because this would give rise to the sense that the investment is linked to the activities of people "from above" and is the result of decisions that were made "behind our backs". Thirdly, information and education campaigns should place particular emphasis on formulating statements that relate to individual and local experience. People, as the researchers note, in spite of everything are more inclined to believe their own instincts than numerical, abstract information about the destruction of the environment. It is not the generally known "ills" and "screaming numbers", but information from everyday life and individual experience that is more readily heard [18]. Instead of talking about the ozone hole and endangered species in the world and the potential effects of these phenomena, it is better to talk more about what people already face now on a daily basis (even if it is not directly connected with the planned investment) dirty beaches, lack of recreation space, allergies, etc. [18].

5. Multi-criteria analysis

The Multi-Criteria analysis, often called Multi-Criteria Decision Making (MCDM) or Multi-Criteria Decision Aid methods (MCDA), is a branch of Operations Research models which deals with the process of making decisions in the presence of multiple objectives. These methods, which can handle both quantitative and qualitative criteria, deal with the design/selection of alternatives. The multi-criteria analysis is a mathematical selection of the most effective solution, taking into account all circumstances and making a full description of selected options. The Analytical Hierarchy Process (AHP) is the most popular technique followed by outranking techniques PROMETHEE and ELECTRE to validate results, develop interactive decision support systems and to tackle uncertainties in the data [19].

Multi-criteria decision-making methods can provide useful insights for decision makers and stakeholders on local waste management and energy planning issues [20–25]. The main problematical points of site selection applications are risks connected with the ecological damage and the social acceptance. To give due consideration to these factors a decision structure needs to be found that eliminates problems simultaneously [26]. Successful implementation of the strategy will not just be based on economic criteria, or diversion rates from landfill, but also on social issues such as stakeholder inclusion [27].

The following describes the basic methods of the multi-criteria evaluation (decision variants), both in the case of a single and multiple criteria [28]:

- mathematical methods (standardization, normalization method, John von Neumann and Oskar Morgenstern, PATTERN, synthetic formula ratings),
- geometric methods (spider web, resultant vector),
- taxonomic methods (Taxonomic measure of development, the Czekanowski method, Wroclaw taxonomy),
- quantitative methods (quality evaluation index, global measure of quality, economic effect,

comprehensive indicator of quality, average quality traits, experts).

Advanced mathematical methods for the multi-criteria evaluation are: ELECTRE, AHP, the ideal point method, the entropy method and the method using elements of logic.
In this paper it is an attempt to choose the best location for anaerobic digestion plants for OFMSW using the multi-criteria optimization method, which is called 'compromise programming'.
Compromise programming, first used in a MOLP context [29], is a distance-based technique designed to identify a compromise solution that is determined to be the closest, by some distance of measure, to an ideal solution.

5.1. Score points

Potential locations for investment in Locations A...F are identified by the use of criteria, to which participants in the pre-investment process assign appropriate values. All indicators for site evaluations should be described in full to enable comparison of different locations. Therefore, selecting the measurement indicators and measuring them is the hardest task in the comprehensive assessment of the location.
For a full task description, the number of criteria is usually very high, and in addition they often represent conflicting goals. The criteria adopted for evaluating the location, are thus, according to the SWOT analysis, presented in five groups: technical, spatial, legal, economic, social.
This division into groups makes it easy to calculate and adopt a hierarchy of importance of the criteria in groups rather than assessing each of them separately. For the purposes of the point analysis the same criteria are adopted for each potential location. The criteria are chosen in such a way as to present a comprehensive evaluation of issues analyzed and to limit subjectivity as far as possible.
Table 3 presents a summary of the selected individual indicators with a suitable criterion to be used to give an evaluation score.
To assess social risk it may be important to obtain two types of data. One type of data is information that can be obtained from institutional documents. The second type of data can be extracted from community members (community organizations, citizens).

5.2. SWOT analysis for the considered OFMSW biological treatment plants locations

The SWOT analysis can be used as a tool to assist the comparative assessment of planning solutions, in this case the location of plants in the Mazovian region. The SWOT analysis is based on the set of information obtained for each of the locations analyzed, evaluation and determination, in four groups of strategic factors. For each location an evaluation is given, the following are specified:

- S Strengths: internal factors—facts and circumstances, which are an asset, advantage or benefit for placing the plant in that location.
- W Weaknesses: internal factors—facts and circumstances which are a weakness, defect or barrier for placing the plant in that location.
- O Opportunities: external factors—positive: characteristics and trends which, if used appropriately for the realization of the investment, will spur the development in the locality.
- T Threats: external factors—negative social, environmental or technical factors, which may hinder, delay or even prevent realization of the investment in that location.

Descriptive SWOT analysis for the Locations A...F are presented in Tables 4...9.

5.3. Evaluation with analysis results

Six potential plants sites have been described and characterized on a point scale. The SWOT analysis described them in such a way that it was possible to evaluate and compare them with one another. A comparison of point-valued criteria alone does not give a clear answer to the question of which location is the most advantageous. An attempt to solve this problem was made using a multi-criteria compromise programming technique.
This paper presents the analysis, assuming at this stage the duly designated evaluation criteria. The characteristics of each location with an attempt to evaluate the adopted and reported indicators (scale

Table 4: Descriptive SWOT analysis for Location A

Strengths	Weaknesses
Increased income of the district.	Existing social protests over a malfunctioning infrastructure.
Easy and economical to obtain an input OFMSW for the AD plants. Quality infrastructure. Technical infrastructure (sewage treatment, composting).	No political will to deal with the topic of waste treatment.
Opportunities	**Threats**
Composting in the municipality was designated as part of the regional waste management plan.	No legal support at the national level supporting the investment.
The pressure from inhabitants to upgrade composting and sewage treatment.	Protests expected in neighboring municipalities against expansion of composting.
The ability to tap the EU 2014–2020structural funds.	

Table 5: Descriptive SWOT analysis for Location B

Strengths	Weaknesses
Increased income of the district.	Small municipality—insufficient amounts of OFMSW input for AD plants.
Municipality seeks new non-agricultural activities, income, and local jobs. Farmers could specialize in providing substrates for AD plants. Designated sites for an investment. The investment will attract new investors. Activation of farmers—the creation of cooperatives. Quality infrastructure.	No provision of heat (no heating network).
Opportunities	**Threats**
The ability to tap the EU 2014–2020 structural funds.	No legal support at the national level, supporting the investment. No charge available for AD plants from neighboring municipalities.

0...3) are presented in the Table 10 and taken into account when defining the criteria and weights for these criteria in the multi-criteria analysis. The values adopted for the analysis in Table 10 form the basis for decision-making.
The scale used:

- 0—inadequate
- 1—satisfactory
- 2—good
- 3—very good

The point evaluation in the table 11 reinforces the results of the preliminary assessment presented earlier. Ranking from the highest place:

1. Location A (48 points) including 14 very good and 2 good assessment ratings,
2. Location B (31 points) including 7 very good and 2 good assessment ratings,
3. Location C (17 points) including 3 very good and 3 good assessment ratings,

Table 6: Descriptive SWOT analysis for Location C

Strengths	Weaknesses
Increased income of the district.	Small municipality—insufficient amounts of substrates for AD plants.
A large amount of waste from maintenance of green areas.	Social protests—district used for recreation and leisure. Insufficient appropriate land for the investment.
Opportunities	**Threats**
The ability to strengthen the environmental image of the municipality. The ability to tap EU 2014–2020 structural funds.	No legal support at the national level supporting the investment. No charge available for AD plants from neighboring municipalities.

Table 7: Descriptive SWOT analysis for Location D

Strengths	Weaknesses
Increased income of the district.	Small municipality—insufficient amounts of substrates for AD plants.
Designated sites for the investment. Municipality seeks new non-agricultural activities.	Social protests—district used for recreation and leisure. Insufficient appropriate land for the investment.
Opportunities	**Threats**
The ability to tap the EU 2014–2020structural funds.	No legal support at the national level supporting the investment. No charge available for AD plants from neighboring municipalities.

4. Location D (22 points) including 2 very good and 5 good assessment ratings,
5. Location E (24 points) including 6 very good and 2 good assessment ratings,
6. Location F (27 points) including 4 very good and 5 good assessment ratings.

5.4. *Criteria weightings*

While the location is ultimately described by measuring and determining the value of each criterion, the question may arise as to whether all criteria are equally important. The hierarchy would be determined differently by ecologists, business analysts and local residents owing to their differing preferences. A properly conducted decision-making process takes into account the interests of all groups interested in the shape of the project. It must, therefore, strive to develop, as far as possible, uniform preferences, so that all interested parties are satisfied.

The importance of criteria is reflected by weighting factors. In this study, the weighting factors for each criterion were adopted by the authors of the study. Adopted values are shown in the table of final results.

5.5. *Results of the multi-criteria analysis*

For calculations, the compromise programming method of multi-criteria analysis was used. Its strategy is to order alternatives depending on their distance from the "utopian (ideal) point". This is a hypothetically established strategy in which all the criteria achieve the best value. The method makes it possible to additionally weight criteria by using the formula exponent α. The exponent allows for additional weighting of each deviation from the ideal point, in proportion to their size. The greater the value of α, the greater the importance of deviations from the ideal point.

The distance from the ideal point is calculated for each variant. The following formula is used to determine the distance of a variant from the ideal point:

Table 8: Descriptive SWOT analysis for Location E

Strengths	Weaknesses
Increased income of the district.	Social protests – district used for recreation and leisure.
A large amount of waste from maintenance of green areas. Easy and economical to obtain a charge for AD plants.	
Opportunities	**Threats**
The ability to tap EU 2014–2020 structural funds. The ability to resolve problems arising from defective composting, together with Location A.	No legal support at the national level supporting the investment.

Table 9: Descriptive SWOT analysis for Location F

Strengths	Weaknesses
Increased income of the district.	Small municipality—insufficient amounts of substrates for biogas plants.
Municipality seeks new non-agricultural activities. Quality infrastructure.	
Opportunities	**Threats**
The ability to tap EU 2014–2020 structural funds.	No legal support at the national level supporting the investment. No charge available for AD plants from neighboring municipalities.

$$d(a) = \left(\sum_{i=1}^{n} w_i \left(g_i^* - g_i(a) \right)^{\alpha} \right)^{\frac{1}{\alpha}}$$

where w_i—weight of i-th criterion, g_i—i-th criterion ($i = 1, 2, ..., 23$), a –variant location, n—number of criteria, α—coefficient, g_i^*—value of i-th criterion for the ideal point.

After the distances for all variants were determined, they were ordered from the smallest to the largest distance and thus rank variants were determined.

Coefficient α can have any positive value, but the compromise programming method usually uses three values of this coefficient: $\alpha = 1$, $\alpha = 2$ and $\alpha = \infty$.

In individual cases, the distance formula takes the form:

For $\alpha = 1$

$$d(a) = \sum_{i=1}^{n} w_i \left(g_i^* - g_i(a) \right)$$

For $\alpha = 2$

$$d(a) = \sqrt{\sum_{i=1}^{n} w_i \left(g_i^* - g_i(a) \right)^2}$$

For $\alpha = \infty$

$$d(a) = \max_i \left(w_i \left(g_i^* - g_i(a) \right) \right)$$

Individual calculations taking into account the different values of the coefficient α are presented in three columns in the Table 13.

The first column also shows the previously described criteria weighting adopted here by the authors of the paper. It defines the importance of each criterion group (technical - geographical - legal - economic - social). For example, in the first row, all of the groups of criteria are weighted as 1, in the second row the group of technical criteria is given a weight of 2, while the rest are given a weight of 1, etc.

Depending on the weighting of criteria, results of the analysis are shown in the subsequent columns. Individual locations AD plants for OFMSW are ranked, taking into account the previously assessed criteria.

Table 10: Summary of scores for each criterion in the analyzed locations

Location Criterion	Ideal	A	B	C	D	E	F
K1	3	3	0	1	0	3	0
K2	3	0	3	3	3	3	3
K3	3	3	3	0	1	1	1
K4	3	3	0	0	0	2	2
K5	3	3	0	0	1	0	1
K6	3	3	3	0	0	0	3
K7	3	3	0	0	0	1	0
K8	3	3	0	0	2	0	0
K9	2	2	1	1	2	0	1
K10	3	3	1	0	0	0	2
K11	3	3	2	0	0	0	2
K12	3	0	3	0	0	0	0
K13	3	0	3	3	3	0	3
K14	3	2	1	2	1	3	0
K15	3	1	1	2	0	3	2
K16	2	0	0	2	1	2	1
K17	3	0	3	0	2	0	2
K18	3	3	2	0	0	0	0
K19	3	3	1	0	1	0	1
K20	1	1	1	0	1	0	0
K21	3	3	3	0	0	0	0
K22	3	3	0	3	2	3	3
K23	3	3	0	0	2	3	0

Source: own study

Table 11: Summary of point marks

Location	Sum of scores	Details on the number of scores			
		(3)	(2)	(1)	(0)
A	48	14	2	2	5
B	31	7	2	6	8
C	17	3	3	2	15
D	22	2	5	6	9
E	24	6	2	2	2
F	27	4	5	5	9

45 calculations were performed assuming different hierarchies of importance of various groups of criteria. In the results Location A was chosen as the best location 23 times, and B was chosen as the best location 22 times.

The location A has favorable technical conditions, therefore, in this position, significant weighting was given to these criteria, and therefore this location is selected as the most advantageous.

The location B has slightly inferior technical conditions. However, its considerable distance from residential clusters meant that social criteria were given more weighting. Therefore, in terms of social criteria Location B was chosen as the most advantageous, and Location A moved into second position.

The least favorable location according to the calculations was Location C—the character of the area as a recreation and health resort generally rules out the possibility of planning the investment there.

6. Summary

The aim of this study was to propose a methodology for the selection of the best location for the construction of a anaerobic digestion plant for organic fraction of municipal solid wastes in the Mazovian region. The planned project may in the future be a key component of the waste management system. On the basis of certain basic criteria, six potential sites were identified for the facility.

The locations of six potential sites for AD plants were described and characterized on a point scale. The SWOT analysis described them in such a way that it was possible to evaluate and compare them with one another. A point-valued criteria comparison does not give a clear answer to the question of which location is the most advantageous. An attempt to resolve this problem was made using multi-criteria analysis—the method of compromise programming. This paper presents this analysis, assuming at this stage duly designated evaluation criteria.

Each of the potential sites was briefly described—in terms of location, currently existing technical infrastructure, population, geographical conditions, as well as the potential for social conflict.

A point analysis of the locations in question—expert evaluation—was conducted, taking into account the relevant criteria for the assessment of technical, legal, geographical, economic and social factors. Within these criteria, sub-criteria appropriate were

determined, each of which was evaluated according to an adopted four-point scale: 0—inadequate, 1—satisfactory, 2—good, 3—very good.
In addition, a SWOT analysis (strengths, weaknesses, opportunities and threats) was performed for each location.
The multi-criteria analysis was performed based on a mathematical selection of the most effective solution, taking into account all the circumstances and assessment options chosen.
On the basis of point scores, the preferred location is A (48 pnts.), followed by B (31 pnts.) and (F): 27 pnts. The calculations carried out in the multi-criteria analysis showed that the most favorable location was A with B coming directly after, and this location should be taken into account in the later stages of the planned project proceedings.

Acknowledgements

This publication is part of the project: “Scientists for the Mazowsze economy” co-financed by the European Union under the European Social Fund:
http://www.bioenergiadlaregionu.eu/pl/naukowcy-dla-gospodarki-mazowsza/

References

[1] M. Jacyno, J. Korkosz-Gębska, E. Krasuska, J. Milewski, A. Oniszk-Popławska, D. Trębacz, G. Wójcik, The concept of biogas plants using municipal waste, Energy Market 105 (2) (2013) 69–77.

[2] European Parliament and the Council, O.J. of the E. Union: Directive 2008/98/EC on waste and repealing certain Directives (2008).

[3] Ernst and Young, Key challenges in municipal waste management in EU-11 countries, in Polish (2011).

[4] O. P. Karthikeyan, C. Visvanathan, Bio-energy recovery from high-solid organic substrates by dry anaerobic bioconversion processes: a review, Reviews in Environmental Science and Bio/Technology 12 (2013) 257–284.

[5] S. Siebert, M. T. Jungling, Composting and Quality Assurance in Germany, Power Point presentation. Kompost e.V. (2012).

[6] L. de Baere, L. Mattheeuws, Anaerobic digestion of solid waste: state-of-the-art, Water Science and Technology 41 (2010) 283–290.

[7] S. E. Nayono, Anaerobic digestion of organic solid waste for energy production, Karlsruher Berichte Zur Ingenieurbiologie, 2010.

[8] A. Karagiannidis, G. Perkoulidis, A multi-criteria ranking of different technologies for the anaerobic digestion for energy recovery of the organic fraction of municipal solid wastes, Bioresource Technology 100 (2009) 2355–2360.

[9] (GUS) Central Statistical Office, Statistical Vademecum Local Government Members, Portraits Counties (2012).

[10] U. Beck, In search of the lost security, Vol. 237, Scientific Publishing House SCHOLAR, Warsaw, 2012, Ch. Global risk society, pp. 146–147, translation: Bogdan Baran.

[11] A. Jędrczak, Analysis concerning the quantities produced and developed biodegradable waste going, in Polish (2010).

[12] VHE - Verband der Humus- und Erdenwirtschaft e.V, VHE Studie Einführung und Optimierung der getrennten Sammlung zur Nutzbarmachung von Bioabfällen, in German (2008).

[13] A. Hanc, P. Novak, M. Dvorak, J. Habart, P. Svehla, Composition and parameters of household bio-waste in four seasons, Waste Management 31 (2011) 1450–1460.

[14] Ministerium für Umwelt Klima und Energiewirtschaft (MUKE) des Landes Baden-Württemberg, Optimierung des Systems der Bio- und Grünabfallverwertung Ein Leitfaden, in German (2012).

[15] A. Bernstad, J. la C. Jansen, A life cycle approach to the management of household food waste – a swedish full-scale case study, Waste Management 31 (2011) 1879–1896.

[16] Z.W. Mazowieckiego, Voivodship Waste Management Plan for Mazovia years 2012 - 2017 including the years 2018 - 2023 (2012).

[17] F. Jameson, Postmodernism, or the cultural logic of late capitalism, Jagiellonian University Press, Krakow, 2011, translation Maciej Płaza.

[18] P. Macnaghten, J. Urry, Natural alternative. The new way of thinking about nature and society, Scientific Publishing House SCHOLAR, Warsaw, 2005, translation Bogdan Baran.

[19] M. Pohekar, S. D. Ramachandran, Application of multi-criteria decision making tosustainable energy planning - a review, Renewable and Sustainable Energy Reviews 84 (2004) 365–381.

[20] G. Vego, S. Kucar-Dragicevic, N. Koprivanac, Application of multi-criteria decision-making on strategic municipal solid waste management in dalmatia, croatia, Waste Management 28 (2008) 2192–2201.

[21] G. Zotos, A. Karagiannidis, S. Zampetoglou, A. Malamakis, I.-S. Antonopoulos, S. Kontogianni, G. Tchobanoglous, Developing a holistic strategy for integrated waste management within municipal planning: Challenges, policies, solutions and perspectives for hellenic municipalities in the zero-waste, low-cost direction, Waste Management 29 (2009) 1686–1692.

[22] A. Generowicz, H. Skowron, Integrated Waste Management, PZITS O/Wielkopolski, Poznań, 2009, Ch. Feasibility studies of localization of municipal waste incineration plant in Szczecin – comparison of SWOT and multi – criteria analysis, pp. 199–217.

[23] A. Generowicz, Z. Kowalski, M. Banach, A. Makara, The

application of multi-criteria analysis in the management of waste in cracow, poland, Waste Management 32 (2) (2012) 349–351.

[24] A. Generowicz, A. Kraszewski, Multi-criterial analysis of cracov municipal waste incineration plant location, Archives of Waste Management and Environmental Protection 7 (2008) 73–88.

[25] A. Generowicz, Z. Kowalski, J. Kulczycka, Planning of waste management systems in urban area using multi-criteria analysis, Journal of Environmental Protection 2 (6) (2011) 736–743.

[26] M. K. Korucu, B. Erdagi, A criticism of applications with multi-criteria decision analysis that are used for the site selection for the disposal of municipal solid wastes, Waste Management 32 (2012) 2315–2323.

[27] A. J. Morrissey, J. Browne, Waste management models and their application to sustainable waste management, Waste Management 24 (2004) 297–308.

[28] M. Książek, Comparative analysis of selected methods of multi-criteria evaluation of investment projects, Civil and Environmental Engineering 2 (2011) 555–561.

[29] M. Zeleny, Compromise programming. Multiple criteria decision making, University of South Carolina Press, Columbia, S.C., 1973.

Table 3: Summary of the criteria in thematic groups

Group of criteria	Description of criterion	Criterion
Technical	The district has a lot of potential OFMSW substrate	K1
	In the municipality there is no alternative for processing OFMSW waste	K2
	OFMSW can be processed together with waste from the agricultural / food industry	K3
Geographical	Ability to use existing or planned municipal facilities	K4
	Road infrastructure	K5
	There is a PDP or MPP station and a 110 kV line in the municipality	K6
	Proximity to a boiler-house, district heating or major heat consumers	K7
	A high pressure gas pipeline passes through the municipality and 1st degree pressure reducing station	K8
	No risk of flooding	K9
Legal	The municipality owns land that can potentially be allocated for such an investment	K10
	In spatial policy document SCDSD or LDP areas are identified that could be designated for waste treatment facilities	K11
Economic	The local investment income as an incentive for residents	K12
	Local impacts arising from an investment location will be an important item in the budget of the municipality	K13
	Favorable ratio of waste transport distance to waste quantities	K14
Social	Inhabitants are positively disposed towards environmental investments, as shown by the history of community activities (information obtained from administrative staff)	K15
	Previous environmental investments have led to other changes (on the local market organic products are available)	K16
	In the municipality there have been no protests related to infrastructure projects	K17
	The municipality is not a holiday or health resort	K18
	There is other industrial activity in the municipality	K19
	There are no areas of natural or cultural value in the municipality	K20
	Areas that are undeveloped, have no recreational value for local people (information obtained from residents of where they spend their free time)	K21
	There are cultural and community organizations, which can act as mediators during investment realization	K22
	A number of people work in environmental protection in public administration	K23

Table 12: Adopted criteria weightings (example)

Group criterion	Criterion	Weight assigned	to each criterion
	K1	0.333	
Technical	K2	0.333	1
	K3	0.333	
	K4	0.167	
	K5	0.167	
Geographical	K6	0.167	1
	K7	0.167	
	K8	0.167	
	K9	0.167	
Legal	K10	0.500	1
	K11	0.500	
	K12	0.333	
Economic	K13	0.333	1
	K14	0.333	
	K15	0.111	
	K16	0.111	
	K17	0.111	
	K18	0.111	
Social	K19	0.111	1
	K20	0.111	
	K21	0.111	
	K23	0.111	

Table 13: Results of a multi-criteria analysis for the OFMSW treatment plant sitting

Weights of individual groups of criteria	Rankings of locations		
	alpha = 1	alpha = 2	alpha = infinity
1:1:1:1:1	A→B→F→E→D→C	A→B→F→E→D→C	A→B→F→E→D→C
2:1:1:1:1	A→B→F→E→D→C	A→B→F→E→D→C	E→A→B→F→D→C
5:1:1:1:1	A→B→E→F→D→C	A→B→E→F→D→C	E→A→B→F→D→C
1:2:1:1:1	A→B→F→E→D→C	A→B→F→D→E→C	A→B→F→D→E→C
1:5:1:1:1	A→F→B→D→E→C	A→F→B→D→E→C	A→F→B→D→E→C
1:1:2:1:1	A→B→F→E→D→C	A→B→F→E→D→C	A→F→B→E→D→C
1:1:5:1:1	A→F→B→E→D→C	A→F→B→E→D→C	A→F→B→E→D→C
1:1:1:2:1	A→B→F→E→D→C	A→B→F→D→E→C	B→A→F→D→E→C
1:1:1:5:1	B→A→C→F→D→E	B→A→C→F→D→E	B→A→C→F→D→E
1:1:1:1:2	A→B→F→E→D→C	A→B→F→E→D→C	A→B→F→E→D→C
1:1:1:1:5	A→B→F→E→D→C	A→A→F→D→E→C	B→A→F→D→E→C
5:1:1:1:5	A→B→F→D→E→C	A→B→F→D→E→C	A→B→F→D→E→C
5:1:5:1:5	A→B→F→E→D→C	A→B→F→E→D→C	A→B→F→E→D→C
5:5:1:5:1	A→B→F→E→D→C	A→B→F→E→D→C	A→B→F→E→D→C
5:1:1:5:1	B→A→E→C→F→D	B→A→E→C→F→D	B→A→E→C→F→D