The state-of-the-art of methodologies related to biodigester location decisions in clustering situations

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Abstract. Bioenergy is a renewable energy obtained from biomass and its main benefits are the reduction of greenhouse gases and the reduction of waste disposal. A common problem in feasibility analysis is the biodigester location due to biomass availability and its spatial dispersion. Therefore, decisions regarding to biodigester location is an important aspect of feasibility design when multiple biomass producers are involved in clusters. Studies in this research field of biodigester location address different methodologies, such as mathematical programming, multicriteria approach, scenario analysis, and Geographic Information System (GIS). This paper presents the state-of-the-art in the biodigester location decisions considering clustering situations. To accomplish that, a systematic literature review using Prisma approach was carried out. As results, a set of feasibility opportunities was arranged after reading 24 papers, allowing to identify that the main methodologies used for biodigester location decisions were mathematical programming (41.16%), followed by multicriteria approaches (29.16%) and GIS (12.50%).

Keywords: Biodigester, location decisions, biomass, GIS

1. Introduction

Renewable energy is a solution to problems such as pollution, climate change and energy crisis [1] fulfilling its important role in the global strategy for reducing greenhouse gases [2]. In the context of renewable energy appears as an alternative bioenergy [3]. It is obtained through biomass decomposition [4] that is, waste of vegetation, waste of animal, waste of agriculture in addition to waste urban and certain types of industrial waste [2].

The treatment of biomass can be done through aerobic decomposition (with the presence of air) or anaerobic decomposition (without the presence of air). Anaerobic decomposition is associated with the reduction of pollution and also the production of biogas (methane, carbon dioxide, water vapor, nitrogen and traces of hydrogen, ammonia and carbon monoxide concentration) and biofertilizers [5–7].

Where to locate the anaerobic digester is important because the biomass is geographically and spatially dispersed [8] and its poorly chosen location may interfere with the operational viability of the anaerobic digester project. In this context, studies that address the location of the anaerobic digester are being carried out in different countries.
K. Ioannou et al. [9] developed a study in Greece that aims to locate anaerobic digesters. Therefore, the authors combine spatial decision methodology, fuzzy logic and the Analytical Hierarchy Process (AHP). The main result of the research is the use of tools and statistics to identify the location where the anaerobic digester can be installed, maximize use and reduce environmental impact and costs. In Portugal, a survey by S. Silva, L. Alçada-Almeida and L.C. Dias [10] addresses the problem of anaerobic digester location in milk producers, thus, randomly defining the size of the plant and the amount of manure that will be processed for energy production. In the study it is proposed about a linear mixed multiple integer program (MMILP) model to optimize the location of the anaerobic digester. In Spain, J.S. Jeong and Á. Ramírez-Gómez [8], proposed a model that seeks to optimize the location of anaerobic digester through the combination of techniques such as Geographic Information System (GIS), Multi-Criteria Decision Analysis (MCDA) and Fuzzy-Decision-Making Trial and Evaluation Laboratory (FDEMATEL). The main criteria studied by the authors were divided between the environmental, geophysical and socio-economic groups. Finally, the most appropriate place for the construction of the anaerobic digester was determined by overlaying maps. In the United States, the authors D. Mukherjee et al. [11] carry out a research that aims to map sources of useful bio-waste for co-digestion in a region dominated by small dairy farms and seeks to find suitable places to install anaerobic biodigester plants. As it also selects the appropriate size and number of digesters in the study, the Mixed Integer Programming (MIP) technique is used in the optimization model. The bioenergy generated through the biodigester becomes interesting to farms that have agricultural or livestock production because animal and crop residues are generated and if not treated can pollute the environment. Thus, the biomass’s application as a raw material is an environmental solution because the waste is does not dispersed in the environment and also an economical solution when biomass is used to generate renewable energy [1].

In the presented context, it is necessary to verify in greater depth the techniques used to locate biodigester because in literature there are not enough studies about this topic due to a gap in the literature. Thus, this study seeks to answer the following question: Which optimization technique is most present in the literature to find the optimal location of biodigesters? To achieve the objective, a literature review was carried out.

This article was structured as follows: section 2 presents the materials and methods. In section 3 the result and discussion are presented and finally in section 4 contains the conclusion and suggestions for future studies.

2. Materials and methods
The intention of this research is to identify in the literature the most present optimization techniques for the location of the biodigester. To obtain the final portfolio of papers was conducted PRISMA approach proposed by A. Liberati et al. [12]. Thus, four steps were taken in PRISMA approach: Research Phase, Filtering Phase, Reading Phase and Inclusion Phase, as shown in figure 1. A systematic literature review was applied through the Methodi Ordinatio (MO) proposed by R. Pagani, J. Kovaleski and L. Resende [13] to ranking the existing knowledge regarding the location of a biodigester. This method considers the three most important factors in a publication: impact factor, year of publication and number of citations.
In the Research phase, the search through keywords was performed, as shown in table 1, in the Scopus, Web of Science and Science Direct databases.

**Table 1. Keywords and databases.**

| Query (keywords)                                      | Scopus | Web of science | Science direct |
|------------------------------------------------------|--------|----------------|----------------|
| "anaerobic digestion" AND "location"                 | 176    | 66             | 64             |
| "anaerobic digestion" AND "spatial decision"         | 1      | 1              | 1              |
| "bioreactor" AND "location"                          | 459    | 138            | 88             |
| "biomass" AND "spatial decision"                      | 15     | 14             | 9              |
| ("anaerobic digestion" AND "location") AND "multicriteria") | 2   | 3              | 0              |
| ("anaerobic digestion" AND "spatial decision") AND "multicriteria") | 1 | 1              | 0              |
| ("bioreactor" AND "location") AND "multicriteria")  | 1      | 1              | 0              |
| ("anaerobic digestion" AND "location") AND "multiobjective") | 1 | 1              | 0              |

| Total per database                                   | 656    | 225            | 162            |
| Total                                                | 1043   |                |                |

In the research phase, 1043 articles were found. The next step was the filtering phase, 569 duplicate articles were excluded with the use of the Mendeley Desktop® software, leaving the portfolio with 474 articles. After it the reading of the titles and abstracts of the articles were made, eliminating 447 articles that did not fit the research proposal, leaving the final research portfolio with 27 articles.

In the reading phase were excluded 3 papers. It became the article portfolio with 24 papers that will be analysed. Thus, the JabRef® software was used to export the data to an Excel® software spreadsheet, in order to apply the MO to classify the most relevant articles for the study. Table 2 was prepared, and it contains InOrdinatio index and title of articles. The InOrdinatio rank the papers to the most relevant until the least relevant.
Table 2. InOrdinatio index and title of articles.

| Title of articles                                                                 | InOrdinatio |
|----------------------------------------------------------------------------------|-------------|
| A network design model for biomass to energy supply chains with anaerobic digestion systems | 105         |
| Optimizing the location of a biomass plant with a fuzzy-DEcision-MAking Trial and Evaluation Laboratory (F-DEMATEL) and multi-criteria spatial decision assessment for renewable energy management and long-term sustainability | 102         |
| Evaluation of biogas potential from livestock manures and rural wastes using GIS in Iran | 101         |
| Multicriteria assessment in GIS environments for siting biomass plants            | 101         |
| A spatial analysis of biogas potential from manure in Europe                      | 97          |
| Optimal location of biorefineries considering sustainable integration with the environment | 97          |
| A cyberGIS approach to uncertainty and sensitivity analysis in biomass supply chain optimization | 96          |
| A spatial decision support system framework for the evaluation of biomass energy production locations: Case study in the regional unit of drama, Greece | 96          |
| What can the location of biogas plants tell us about agricultural change? A case study from the Czech Republic | 94          |
| Multiscale scheme for the optimal use of residues for the production of biogas across Castile and Leon | 93          |
| Planning the optimal site, size, and feed of biogas plants in agricultural districts | 93          |
| Multiobjective programming for sizing and locating biogas plants: A model and an application in a region of Portugal | 91          |
| Fuzzy spatial decision tool to rank suitable sites for allocation of bioenergy plants based on crop residue | 89          |
| Assessment of the impact of incentives and of scale on the build order and location of biomethane facilities and the feedstock they utilise | 84          |
| A multicriteria GIS-based assessment to optimize biomass facility sites with parallel environment - A case study in Spain | 84          |
| Designing optimal supply chains for anaerobic bio-digestion/energy generation complexes with distributed small farm feedstock sourcing | 83          |
| Spatial decision support system to evaluate crop residue energy potential by anaerobic digestion | 82          |
| Robust facility location problem for bio-waste transportation                      | 81          |
| Site selection for landfill gas extraction plant by fuzzy analytic hierarchy process and fuzzy analytic network process in the city of Najafabad, Iran | 81          |
| CyberGIS-BioScope: A cyberinfrastructure-based spatial decision-making environment for biomass-to-biofuel supply chain optimization | 71          |
| A systemic approach for dimensioning and designing anaerobic bio-digestion/energy generation biomass supply networks | 63          |
| Optimal location of centralized biodigesters for small dairy farms: A case study from the United States | 63          |
| Optimal renewable energy systems for industries in rural regions                  | 58          |
| Parametric Optimization of Linear and Non-Linear Models via Parallel Computing to Enhance Web-Spatial DSS Interactivity | 31          |

3. Results and discussion
Deterministic techniques are optimization models based on mathematical programming while multicriteria techniques evaluate conflicting criteria in decision making. In this study, emphasis will be given to the multicriteria techniques AHP, fuzzy and FDEMATEL as they were found in the analysed articles.

After reading the articles, the techniques used to locate biodigester were summarized in mathematical programming, multicriteria, GIS and others (scenario analysis, barycenter, NPV and P-Graph). Graph
1 was elaborated, which contains the optimization methods and their respective frequencies found in the literature.

**Graph 1. Optimization methods.**

It was obtained as a result that the multicriteria and mathematical programming methods were the most used contained in 10 and 7 articles respectively. The use of only GIS techniques were found in 3 articles. The other methods (scenario analysis, barycenter, NPV and P-Graph) were observed once in the remaining articles.

After applying the MO it was observed that the countries with more publications are Spain and the United States with 4 articles, followed by Colombia, Czech Republic, Greece, Iran and Italy with 2 articles and with only one article are Brazil, Ireland, Mexico, Portugal and Turkey, as shown in **Graph 2.**

**Graph 2. Countries with more publications.**

Regarding the years of publications, it was observed that the theme of biodigester localization increased until 2017, with a small drop in 2018, a period that had 2 publications less than the previous year. It is interesting to note that the subject of the study has few papers in the literature, presenting in 2017 the largest number of publications on the subject, as shown in **Graph 3.**

**Graph 3. Publication year.**

The journal that published more articles addressing the location of the biodigester was Renewable Energy with 4 publications, followed by Applied Energy with 3 publications, Journal of Cleaner Production with 2 publications and other journals with only 1 publication, according to **Graph 4.**
4. Conclusion and suggestions
Renewable energy is an alternative to combat environmental degradation, and it is a solution for environmental issues because it reduces CO2 emissions. Thus, bioenergy appears as a choice of renewable energy and has gained relevance. The location of the anaerobic digester is important to guarantee its construction and operational viability. Therefore, studies are being developed to assist in this stage of the planning project, in this sense, aiming at consolidating the optimization techniques used by the authors and covering the literature gap with the consolidation of these, this article was developed, obtaining as the main result that the mathematical programming (41.16%) and multicriteria (29.16%) techniques are the most used by the literature to develop models for optimizing the location of the biodigester. For future studies, it is recommended to consolidate the environmental, social and economic parameters used in the models proposed by the authors to locate anaerobic digester.

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