Optimization Models of Organic Solid Waste: Review Article

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***Abstract*-This paper presents a review of the use of organic solid waste models in the years 2010-2014 with the support matrix for the identification of technical and economic models' variables. Similarly, an optimization methodology is identified through the use of a mathematical linear programming approach as a tool for decision-making scenarios of waste management and energy systems.**

Keywords- Optimization Model; Linear Programming; Aerobic Composting; Anaerobic Digestion; Vermiculture; Biofertilizers

I. INTRODUCTION

It must be considered, first and foremost, that about 1.3 million tons of Municipal Solid Waste (MSW) are produced per year. It is estimated that by 2025 the amount of waste will multiply [1]. Currently, organic solid waste (OSW) grows in proportion to the population. The elimination of such waste poses environmental, social and economic problems [2]. As a consequence of the growth of cities and municipalities, the rate of waste disposal has increased, leading to the establishment of new landfills and incinerators [3].

Latin America and the Caribbean have not integrated sufficient actions in the process of reducing, reusing, and recycling. Particularly in Central America, 20 to 40% of waste is recyclable and of organic origin [4]. Indeed, inequality and lack of proper disposal services are the norm in Haiti, Guatemala, and Colombia. The use of OSW is linked to informal schemes that operate without adequate facilities and often with economic and social vulnerability. In Colombia, especially in the Department of Cundinamarca, the use of organic solid waste is seen as an isolated process within the public toilet system [5]. For having a sustainable development in town waste management, it is necessary to implement phases of impact on the planning, design, operation, and closure [6]. Naturally, in the spectrum of new and existing technologies for waste management, strategies for maintaining environmental quality and the sustainability of future goals have been explored. This type of evolution allows industries and government agencies to address common needs in recycling biodegradable materials in order to expand the supply of renewable energy, and in turn to offer more socially acceptable options for preserving biodiversity and natural ecosystems. Harvesting techniques that employ organic solid waste include aerobic composting, anaerobic digestion, vermiculture, and bio-fertilizer production [7]. In the case of aerobic composting, organic material is transformed into reduced weight and volume through the aerobic conversion of organic compounds to CO_2 and water, in turn stabilizing the material. Therefore, the process is divided into two phases: (1) decomposition and, (2) maturation of the material, which is related to the temperature change [7]. In the first phase, degradation from microbial activity and temperature increases. Then, a reduction of the available material must occur, reducing the activity and leading to a slow drop in temperature [7]. This article's main objective is to offer a synthesized review of the literature on the use of organic solid waste models for identifying technical-environmental and economic variables in the years 2010-2014 around the world.

II. METHODOLOGY

Applied research on this topic has been of the exploratory type, since researchers were asked about the issue of solid organic waste use and had to define, identify, and delineate the aspects of understanding, synergies, and delimitation of the subject discussed. Furthermore, according to the time of occurrence of events and registration information related to the topic of study, the type of applied research was also considered a retrospective, in the sense that it facilitated a fundamental knowledge of the subject. The information we collected (i.e., the literature study) was categorized and classified according to the structure of and the correlation between the use of solid organic waste and the models applied.

III. DEVELOPMENT

Anaerobic digestion is a biological process that converts complex substrates into biogas and digestate. It occurs due to microbial activity in the absence of oxygen through four main stages: (1) hydrolysis, (2) acidogenic, (3) acetogenesis, and (4) methanogenesis [8]. This process is highly desirable, because it offers limited environmental impact and high energy recovery potential. On the other hand, vermiculture (where earthworms are used as the biological agent) is an appropriate technology for

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the management of many biodegradable materials [9]. The worm humus is an organic fertilizer [10]. Another biological treatment is a biofertilizer that not only has the ability to fertilize but also contains microorganisms that colonize plants when applied inside [11]. Similarly, it promotes growth by increasing the supply or availability of primary nutrients to the host plant.

Based on the processing techniques of solid organic wastes, models studying the influence of variables arise simultaneously, because they have been created to understand many complex chemical, physical, biochemical mechanisms and biological areas that interact in order to perform an optimization process and obtain a stable product [12]. Among these are the assessment tools of systems engineering models, which are formally classified systems in this field to illuminate the challenges, trends, prospects [13], benefits prediction models, and optimization models. Some trends in the currently developed models are: engineering system models (including cost-analysis and integrated modeling sysetms), information system evaluation tools, system decision support, expert system, scenario development, analysis of material flow, life-cycle inventory assessment, risk assessment, environmental impact assessment, strategic environmental assessment, socio-economic assessment, and sustainable assessment. In a sense, the models support new system design. However, the models focus primarily on the evaluation of existing forms [14]. As indicated in figure 1.

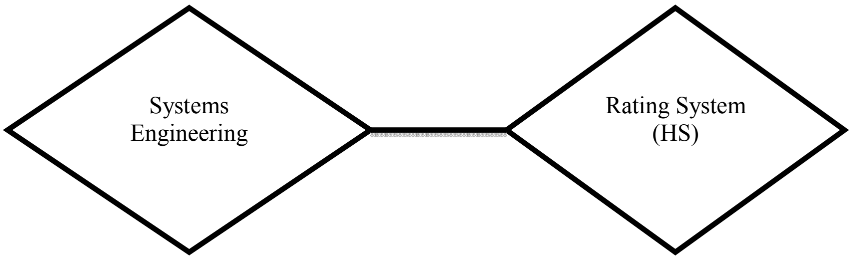

Fig. 1 Tools of analysis in the waste management system

Source: Juul, N., Münster, M., Ravn, H., & Ljunggren, M., 2013

In conducting the review of existing models of exploitation, it was found that several authors address the exploitation model with their respective variables. These items are presented in Table 1 (content techniques-environmental variables) and Table 2 (economic variables).

TABLE 1 DETERMINATION OF TECHNIQUES THAT USE MODELS OF ORGANIC SOLID WASTE VARIABLES

ITEM	VARIABLES ITEMS	VALUE	FREQUENCY	IMPORTANCE	% WEIGHT
RATES	The recovery rate of the separate components at source [15].	NP	1	B	2%
	Waste generation rate in the district j in period k [16].	(toneladas / year)	3	M	5%
	Entrance fee for external resources in period t [17].	(t / year)	1	B	2%
	The rate of production of product during the period [17].	(units / year)	1	B[1]	2%
	SO2 emission rate [18].	(kg / ton of waste)	2	M[2]	3%
	Gas emission rate [19-21].	(waste g / ton per day)	5	A[3]	8%
	Landfill gas emission rate (residue WTE) [20, 21].	(waste g / ton per day)	2	M	3%
	Annual emission CO_2 per kWh in a plant supplies heat and power [21].	kg / kWh	1	B	2%

[1] L: Low
[2] HH: Half
[3] H: High

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	Carbon process p in period t [17].	(t / year)	1	B	2%
	Generation rate of landfill leachate [3].	(m3 / ton of waste per day)	1	B	2%
ENVIRONMENTAL	Temperature [22].	(° C)	1	B	2%
	Humidity [19].	(% D.M.)	1	B	2%
	Water [23].	(t / t)	1	B	2%
	CO2 emissions [19].	(mg/Nm3)	1	B	2%
	Nitrogen (N) [16].	(kg / ha)	1	B	2%
	potassium (K) (kg / ha) [16].	(kg / ha)	1	B	2%
PROCESS	Phosphate (P) (kg / ha) [16].	(kg / ha)	1	B	2%
	Percentage of methane in the biogas [15].	(v/v)	1	B	2%
	Lower heating value of the methane [15].	(kWh/Nm_3)	1	B	2%
	The use of biogas for heat [24].	(m3)	1	B	2%
	Biogas for power generation [24], [25].	(m3)	2	M	3%
	The use of biogas [24].	(× 103 CNY)	1	B	2%
	Compost fertilizer [24].	(× 103 CNY)	1	B	2%
	Biogas production (average) [26].	(Nm3 / h)	1	B	2%
	Organic material input [26].	(ton / year)	1	B	2%
	Methane yield [27].	$m^3 kg^{-1}$	1	B	2%
	Output organic material [26].	(ton / year)	1	B	2%
	District waste stream for installation j and k in the period [21].	(ton / day)	1	B	2%
	Flow of waste recycling plants and composting at landfill [28, 21].	(% incoming mass)	2	M	3%
TREATMENT PLANT	Landfill capacity [28, 21].	(t)	2	M	3%
	Capacity of recycling and composting facilities [19, 29, 21].	(ton / day);	3	M	5%
	Waste stream from the study area for composting plant during c the period k [28].	(t / day)	1	B	2%
	Amount collected waste [26].	(tons)	1	B	2%

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	Rotation speed [25].	(rpm)	1	B	2%
	Length of term t [21].	H	1	B	2%
	Cleaning Method C [30].	NP	1	B	2%
	Processing time variable i [30].	NP	1	B	2%
	Efficiency [31].	(%)	1	B	2%
	Temporary Storage Recyclable [31].	NP	1	B	2%
	Produced [26].	(t)	1	B	2%
	Total production (t) [26].	(t)	1	B	2%
	Total production per capita [26].	(kg/enh.dia)	1	B	2%
	Number of installed technologies [19].	NP	1	B	2%
	The energy density [22].	(MJ/m3)	1	B	2%
	The consumption of non-renewable energy [23].	(GJ / t)	1	B	2%
	Volume [22].	(m3)	1	B	2%
	Density reduction [20].	d = q / QCR	1	B	2%
SOCIAL	Total number of houses [32].	Thousands	1	B	2%
	Number of persons (resident or not) [32].	Thousands	1	B	2%
	Number of housing sector [32].	Thousands	1	B	2%
	Total population [21].	Millions	1	B	2%

Source: Article's authors.

Table 1 features an analysis of the technical variables present in all articles on models' use of organic solid wastes. The variable with the highest percentage of representation in the reviewed articles is the Gas Emission Rate (8%), followed by the variable rate of Waste Generation with 5% of significance within the technical approach.

TABLE 2 DETERMINATION OF ECONOMIC VARIABLES MODELS USE OF SOLID ORGANIC WASTE

ITEM	**VARIABLES OF ARTICLES**	**VALUE**	**FREQUENCY**	**IMPORTANCE**	**% WEIGHT**
PRICES	Market price MSW compost and anaerobic digestate [18, 17, 15].	(€ / t)	3	M[4]	6%
	Unit sales price for the product [33, 26].	($ / gal)	2	B[5]	4%

[4] HH: Half.

[5] L: Low.

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EXPENSE	Operating costs and maintenance of installations i in period k [35, 2].	($ / tonelada)	9	A[6]	17%
	Cost of Capital [16, 17].	USD	2	B	4%
	Total processing cost resource [36].	(USD)	3	M	6%
	The net cost of the system [37].	($)	2	B	4%
	Unit cost biomass [34].	($ / dt)	1	B	2%
	The capital cost of composting plant expansion option c by mail in the period k [28].	($ / t)	1	B	2%
	The cost of construction [36].	($)	1	B	2%
	Maintenance costs [36].	($)	1	B	2%
	Unit cost of entry [27].	(€ ton^{-1})	1	B	2%
	The specific investment cost [18].	[MEUR / (GWhbiogas / año)]	2	B	4%
	Total cost of allowances for the year and conventional technology i [19].	(€ / MWel)	1	B	2%
	The cost of raw materials [32].	[€/ year]	1	B	2%
	The annual cost of equipment [35].	[€/ year]	1	B	2%
INCOME	Income of the facilities of recycling and compostaje in period k [38].	($ / tons)	5	M	10%
	Economic income total [26].	103 €	1	B	2%
	Total benefit [35].	(USD)	4	M	8%
	The capture of landfill gas and leachate collection landfill gas [2].	($ / g)	17	B	2%

[6] H: High.

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BUDGET	Budget allocated by the city government for the opening and operation of sorting centers in period t [35].	($).	1	B	2%
EXPENSES	Collection costs during the period [28].	($ / t)	1	B	2%
	Operating costs of the transfer station t during the period k [28].	($ / t)	1	B	2%
DEMAND	The maximum demand for product [16].	NP	2	B	4%
	Product minimum demand [15].	NP	2	B	4%
TAX	CO_2 taxes ÑL [21].	€/kg CO2	1	B	2%
DEPRECIATION	Depreciation [16].	(M € / año)	2	B	4%

Source: Article's authors.

Therefore, Table 2 shows evidence that most variables delve into the study of models of use. We can conclude that the most important variable is Operating Costs and Facility Maintenance (accounting for 17%), followed by Revenue Recycling Facilities and Composting Period, with 10% of relevance in the inclusion of economic variables.

IV. RESULTS

The optimization models focus primarily on waste management, including the energy system. Few models have integrated both solutions, but most of this integrated the energy system. While it is true that waste is a limited resource that can be treated in different ways, the most relevant treatment is the recycling of a fraction of waste and subsequent utilization for energy production. Optimization models allow for improvement in processes and parameters that make decisions via mathematical methodologies.

Specifically, use models are based on methodologies to optimize the endogenous energy of investment decisions, and to fulfill a specific purpose [39] Table 3. Usually, they are implemented by companies or municipalities to obtain optimal investment strategies and for national energy planning to analyze the prospects of the energy system [39]. The mathematical approach used is, in most cases, Linear Programming (LP). LP is a practical technique to find the arrangement of activities that maximize or minimize the activities' defined criteria, and it is subject to operational limitations [39]. Focused mathematical relationships' LP are expressed in linear functions where all coefficients remain constant [38]. Optimization models using this approach are also relevant for national energy planning and they are used in studies on to the selection of energy technologies [38].

TABLE 3 CRITERIA EVALUATION AND OPTIMIZATION APPROACH

No ART	JOURNAL PUBLICATION	YEAR	COUNTRY	FOCUS		OPTIMIZATION IN		DECISIONS							AUTHORS
								strategic					tactical		
				SDE	GR	E$	MA	D	T	TP	U	P	TIC	DA	

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1	Resources, Conservation and Recycling	2013	Greece	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	1. Minas Minoglou. 2. Dimitrios Komilis.
2	Waste Management	2011	Canada		✓	✓			✓	✓		✓	✓	✓	1. H. Zhu. 2. G.H. Huang.
3	Journal of Cleaner Production	2014	Malaysia	✓	✓	✓	✓	✓							1. Sie Ting Tan. 2. Chew Tin Lee. 3. Haslenda Hashim. 4. Wai Shin Ho. 5. Jeng Shiun Lim.
4	Journal of Environmental Management	2011	China	✓	✓	✓	✓	✓	✓			✓	✓	✓	1. C. Dai. 2. Y.P. Li. 3. G.H. Huang.
5	Waste Management	2013	Greece	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	1. George Mavrotas. 2. Sotiria Skoulaxinou. 3. Nikos Gakis. 4. Vassilis Katsouros. 5. eorgopoulou.
6	Science of the Total Environment	2010	China	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1. Y.P. LiG. 2. H. Huang.
7	Journal of Integrative Agriculture	2014	China	✓	✓		✓	✓	✓			✓	✓	✓	1. LU Wen-cong. 2. MA Yong-xi. 3. Holger Bergmann.
8	Expert Systems with Applications	2012	India		✓	✓	✓			✓					1. Amitabh Kumar Srivastava. 2. Arvind K. Nemab.
9	Applied Thermal Engineering	2013	France	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	1. Samira Fazlollah. 2. François Maréchal.
10.	Chemical Engineering Science	2013	USA	✓		✓	✓	✓	✓	✓		✓	✓	✓	1. W. Alex Marvina. 2. Lanny D. Schmidt. 3. Saif Benjaafa. 4. Prodromos Daoutidis.
11	Computers and Chemical Engineering	2013	USA	✓		✓	✓			✓		✓	✓		1.Dajun Yue 2. Fengqi You
12	Computers & Industrial Engineering	2013	USA	✓		✓						✓	✓		1. Eric D. Antmann 2. Xiaoran Shi. 3. Nurcin Celik. 4.Yading Dai
13	Wageningen Journal of Life Sciences	2010	Netherlands	✓	✓	✓	✓	✓	✓			✓	✓	✓	1, Solomie A. Gebrezgabhera 2. Miranda P.M. Meuwissena 3. Bram A.M. Prinsb 4. Alfons G.J.M. Oude Lansinka
14	European Journal of Operational Research	2014	Brazil		✓	✓		✓					✓	✓	1. Eli Angela V. Toso. 2. Douglas Alem.
15	Energy Policy	2013	Iran	✓		✓		✓	✓			✓	✓	✓	1. Sahar Safarian. 2. Yadollah Saboohi. 3. Movaffaq Kateb.
16.	Energy	2012	Sweden	✓		✓			✓					✓	1.Martin Börjesson 2.Erik O. Ahlgren

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17	Waste Management	2010	Greece	✓	✓	✓			✓		✓	✓		1. G. Perkoulidis 2. A. Papageorgiou 3. A. Karagiannidis S. 4. Kalogirou
18	Applied Energy	2013	Slovenia	✓	✓	✓		✓		✓	✓	✓		1. Zdravko Kravanja. 2. Lidija Cucek.
19	Applied Energy	2014	Belgica	✓	✓	✓		✓			✓	✓	✓	1. Davide Ziviani 2. Asfaw Beyene 3. Mauro Venturini
20	Biomass and Bionergy	2012	United Kingdom	✓	✓	✓	✓	✓				✓	✓	1. James Keirstead. 2. Nouri Samsatli. 3. A. Marco Pantaleo 4. Nilay Shah
21	Energy	2012	Slovenia	✓		✓		✓						1. Lidija Cucek. 2. Petar Sabev Varbanov. 3. Ji rí Jaromír Kleme. 4. Zdravko Kravanja.
22	Energy Policy	2014	United Kingdom	✓	✓	✓	✓	✓	✓			✓	✓	1. Athanasios Rentizelas 2. Dimitrios Georgakellos
23	Computers and Chemical Engineering	2012	Slovenia	✓	✓	✓	✓	✓				✓	✓	1. Lidija ˇCuceka 2.Rozalija Drobeˇz 3. Bojan Pahorc 4. Zdravko Kravanjaa
24.	Energy Policy	2013	United Kingdom	✓	✓	✓	✓	✓			✓	✓	✓	1.Philip Jones 2.AndrewSalter
25.	Bioresource Technology	2012	Italy	✓	✓	✓	✓	✓	✓		✓	✓	✓	1. Sara Giarol 2.Nilay Shah 3. Fabrizio Bezzo
26.	Applied Energy	2012	Spain	✓		✓	✓	✓					✓	1. E. Martine 2. A. Marco 3. A. Al-Kassir 4. M.A. Jaramillo 5.A.A. Mohamad
27.	Computers and Chemical Engineering	2013	USA	✓		✓	✓	✓					✓	1. P. Sharmaa 2. R. Vloskyb 3.J.A. Romagnolia
28.	Energy	2010	Norway	✓		✓	✓	✓				✓	✓	1. Silke van Dyken 2. Bjorn H. Bakken 3. Hans I. Skjelbred
29.	Computers and Chemical Engineering	2013	Korea	✓	✓	✓	✓					✓	✓	1. Muhammad Rizwana 2.Jay H. Leea 3.Rafiqul Ganib
30.	Waste Management	2010	Portugal	✓	✓		✓						✓	1. Lino Tralhão 2. João Coutinho-Rodrigues 3. Luís Alçada-Almeida
31.	Renewable Energy	2013	France	✓								✓		1.Nicklas Forsell 2. Gilles Guerassimoff 3. Dimitris Athanassiadis 4. Alain Thivolle-Casat 5. Daphné Lorne 6. Guy Millet 7. Edi Assoumou
32.	Energy	2011	Spain	✓	✓	✓	✓	✓				✓	✓	1. Monica Carvalho 2.Luis Maria Serra 3.Miguel Angel Lozano
33.	Renewable Energy	2013	Sweden	✓			✓	✓				✓	✓	1. Shahnaz Amiri 2. Dag Henning 3. Björn G. Karlsson a
34.	Resources, Conservation and Recycling	2012	Portugal	✓	✓				✓			✓	✓	1. Rui Cunha Marques. 2. Nuno Ferreira da Cruz. 3. Pedro Carvalho

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One of the current problems with optimization models is the need to develop an objective function (linear or nonlinear equation). This function would be expressed as a mathematical equation of decision variables and other parameters that minimize or maximize the need for a problem, in addition to a set of constraints (linear or nonlinear) [39].

Consequently, when the objective and constraints are expressed in a linear optimization formula, the model becomes a linear programming model (LP) [40]. If the model takes integer values, it becomes an integer programming model (IP) [47]. If the model takes continuous and integer variables simultaneously, it will become a mixed integer programming model (IPM) [40]. The current literature is based on optimization models used as technical and economical tools for decision-making that address the strategic and tactical supply chain in waste management. These tactical models are useful for short periods of time (i.e. less than a year) but they offer long-term strategies [40]. In pursuing strategies to solve a number of problems in the planning, production, transportation, and finance of waste disposal, these scenarios are studied in the presence of uncertainty [41]. The scenarios address the 21st-century energy systems to meet important objectives in environmental, social, and economic dimensions based on sustainable development [42]. The models reviewed aim to accomplish multiple objectives and they provide numerous technologies available for a systemic approach to solving the energy system [43].

V. CONCLUSIONS

There are gaps in current optimization models of solid organic waste disposal. Some of these gaps include appropriate system analysis methodologies that would allow us to learn about, evaluate, optimize, and adapt treatment strategies for energy systems and waste management. Ultimately, this review article aims to show the number of items with the evaluation criteria of plant size, plant location, and final products indicating that there are goals to accomplish in the research of these variables.

Use models have pointed to energy system optimization and improved waste management. Indeed, the process of harvesting techniques necessarily includes environmental and economic variables. Any decision-maker must have access to a tool that aims to demonstrate the feasibility of a proposed treatment plant, according to the minimization criteria for carbon footprint and investment costs.

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