Revista Nacional de
Gerenciamento de Cidades
ISSN eletrônico 2318-8472, volume 09, número 69, 2021

Biodigester models used worldwide in the context of intelligent cities

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ABSTRACT

Urban development is marked by challenges associated with energy demands at a variety of levels, as well as the need of an efficient solid waste management. In the next 30 years an increase of the world's population and of this population in urban areas is predicted, turning such dilemma a reality. In this context, organic waste can be recycled as a clean, renewable energy resource by means of biogas, which is a sub-product of anaerobic digestion and which can be converted into electric and thermal energy by burning, and therefore be used in heating and as fuel. Biogas is produced in biodigesters, which consist of an airtight chamber with compartments for the substrate inlet and the final product outlet. From a bibliographic research, the present study investigates the main models of biodigesters used in Europe, Asia, Africa and South America, in order to present an up-to-date scenario of the application of such equipment in the context of intelligent cities. The results indicate contrasting biodigester installations among the continents. Whereas Europe relies on high-technology models, in Africa, for example, biodigesters are usually built with basic materials, which make biogas production inefficient. Similarly to other energy sources and waste management models, the countries with better infrastructure and resources can better benefit from the use of biodigesters, thus improving the quality of life, whereas poorer countries cannot totally exploit the same productivity potential.

KEYWORDS: Biogas. Biodigesters. Intelligent cities.

1. INTRODUCTION

In the following decades the world will face an accelerated population growth, which will require multiple actions for the supply of basic elements to the human civilizations (ONU, 2019a). Likewise, a drastic growth of urban areas on Earth is also predicted, and one of the biggest challenges to minimize crises that are bound to happen in the future is the efficient and sustainable energy supply (ONU, 2019b).

It is important to stress that the effects of population growth and urbanization are implicated in the expressive accumulation of solid waste generated in the cities (DAS et al., 2019). Therefore, it is necessary that populations and their representatives pay attention to the rising daily waste production trends, which must reach peaks in 2025 and 2050, according to Kumar and Samadder (2017).

Kumar et al. (2020) point out that the cities face the challenge of creating strategies that should not only minimize the structural impacts that already affect them, but also be the starting point for new opportunities to improve the quality of life at all levels. The authors also highlight that intelligent solutions should not be restricted to the supply of technology, because it is essential to promote actions that encourage the sharing of the urban dynamics, with greater participation of the population and short- and long-term planning.

In this sense, within the scope of improving local energy grids in association with waste management, the use of biodigesters and biogas production is considered a means for waste valorization and, at the same time, an opportunity to increase energy supply (MATHERI et al., 2018; OCTAVIANTHY; PURWANTO, 2018).

Biodigesters are equipment that enable the handling of biogas productivity. They are airtight structures composed of an inlet box – a chamber into which the substrate is deposited and which also stores the gas thus produced – , and of an outlet box for the gas and the biofertilizer, the latter also known as digestate (FRIGO et al., 2015). Weiland (2010) explains that biogas is a sub-product of the anaerobic digestion, a natural process of organic matter degradation, promoted by the action of bacteria whose metabolic activities do not depend on the presence of oxygen. Biogas is composed of methane and carbon dioxide; it is inflammable and, when burnt, it produces thermal energy, from which electric energy is obtained. Biogas is also the base of environmentally-friendly fuels.

Biogas production via biodigesters is still predominant in rural areas, because of the greater biomass supply in short periods of time (VIEIRA; POLLI, 2020). Atelge et al. (2020) report that the first projects for biogas production took place by the end of the 19th century, followed by the installation of medium-scale biodigesters in the 1930's. The authors point out that biogas cannot compete with conventional energy sources for technical and financial reasons, but such investments are beneficial when managed in an integrated manner with other matrixes, mainly in developing countries. In fact, some technologies have been tested in urban areas with positive results (RUPF et al., 2017), especially when the gas production systems are decentralized and coupled to recycling programs, with popular participation in the process of collecting organic waste and return to the gas or electric grids (ANYAOKU; BAROUTIAN, 2018).

In Brazil, the use of biodigesters is predominant in rural zones. Even so, this practice of waste valorization is still little exploited, once the lack of an institutional structure for public policies does not favor the creation of an efficient market for the use of biodigesters. This even affects the existing biogas plants, which have run into technical difficulties (SILVA; SOARES; SEO, 2016).

In face of the exposed above, this study presents the main models of biodigesters used in Europe, Asia, Africa and South America, relating them with the challenging contexts in which they are inserted in the cities.

2. OBJECTIVE

The objective of the present study is to present the main types of biodigesters used in Europe, Asia, Africa and South America, evidencing the contexts of energy supply and organic waste management, and the disparities expected in different localities.

3. THEORETICAL BACKGROUND

3.1 THE CHALLENGE OF THE ENERGY SUPPLY IN THE CONTEXT OF INTELLIGENT CITIES AND THE INCLUSION OF BIOGAS

According to Calvillo, Sánchez-Miralles and Villar (2016), urban energy supply requires more and more the use of renewable resources and planning based on the heterogeneity of social, environmental and economic conditions that exist in urban areas. The authors comment on the difficulties faced by agents involved in the management of energy grids when working with these variables simultaneously, thus being necessary an agenda that contemplates actions throughout all society layers, from public authorities to the population.

In relation to 2017, there was a 3.2% increase in energy production worldwide in 2018, according to the International Energy Agency (IEA, 2018a). In World Energy Balances: Overview, produced by IEA, transportation is reported to be in an overall picture the sector that most increased regarding energy use. This scenario bring to light the challenges associated with more environmentally clean and efficient sources, once oil-derived fuels are still the most recurrent, despite the growing use of biofuels in the last 20 years. In this sense, fuel production from different types of biomass is one of the main topics investigated to supply the increasing demand of energy associated with the urban transport sector, being bioethanol, biodiesel and bio-hydrogen the main renewable substances applied in different types of vehicles. Nevertheless, this is a productive chain with important obstacles to be overcome, e.g. a closer proximity of the biomass source to the fuel production intallations, and other technical and economic aspects (CHANG; HWANG; WU, 2017).

Regarding the use of electricity, in 2018 the world produced 3.9% more electricity than in 2017, being coal the main energy source for this use (38%), whereas renewable resources such as hydroelectricity and eolian energy represented together 21%, and biofuels and solid waste only 2.4% of the total generated electricity (IEA, 2018b). In the context of intelligent cities, the efficient electric energy use is directly related to the creation of new energy supply formats, which should be based not only on opportunities to the economic sector, but also on the universalization of the access to electricity, as defended by Masera et al. (2018). According to these authors, the efficient electricity use is the major objective of intelligent cities, besides the importance to investigate the opportunities associated with energy production from renewable resources, opening possibilities for a circular economy. The reuse of organic waste has the potential to reduce costs with urban waste management, once biogas production using such dejecta as substrate widens the energy source grids when it comes to cities, as the gas can be converted into thermal energy, which is in turn transformed into electricity, fuel, cooking gas and thermal energy for heating (DI MATTEO et al., 2017).

There is an important difference between biogas and biomethane. Biomethane is the purified form of raw biogas, and this process basically consists of removing chemical compounds, such as hydrogen sulfide (H_2S), carbon dioxide (CO_2), ammonia hydroxide (NH_3), and even water (RYCKEBOSCH; DROUILLON; VERVAEREN, 2011). This process reduces the possibility of problems related to the wearing of the equipment for gas generation, storage and distribution. This is a point of paramount relevance, because, depending on the purpose of the use, stages that involve burning can cause impacts at several levels, including the danger of explosions.

3.2 THE IMPORTANCE OF THE VALORIZATION OF ORGANIC WASTE IN ENERGY PRODUCTION

Yazid et al. (2017) explain that the expansion of human populations led to a fast growing organic solid waste generation. Especially in more populated areas with fewer resources there has not been a structured planning for the valorization of such dejecta. Regarding the methods to add value to such effluents, the circular economy is considered by Maina, Kachrimanidou and Koutinas (2017) a relevant resource to supply the demands for organic waste management, notably the actions of the European Union and the United States to structure this logistics so as to extend the recycling of such material. The authors explain that the circular economy applied to organic waste in the context of developed countries aims to increase market opportunities associated with local energy grids.

In less-developed of developing areas, circular economy is also presented as having the potential to waste recovery, so much so as to mitigate an issue of larger proportions, once many countries in Africa and Asia, for example, have not developed strategies regarding the final destination of solid waste (FETENE et al., 2018).

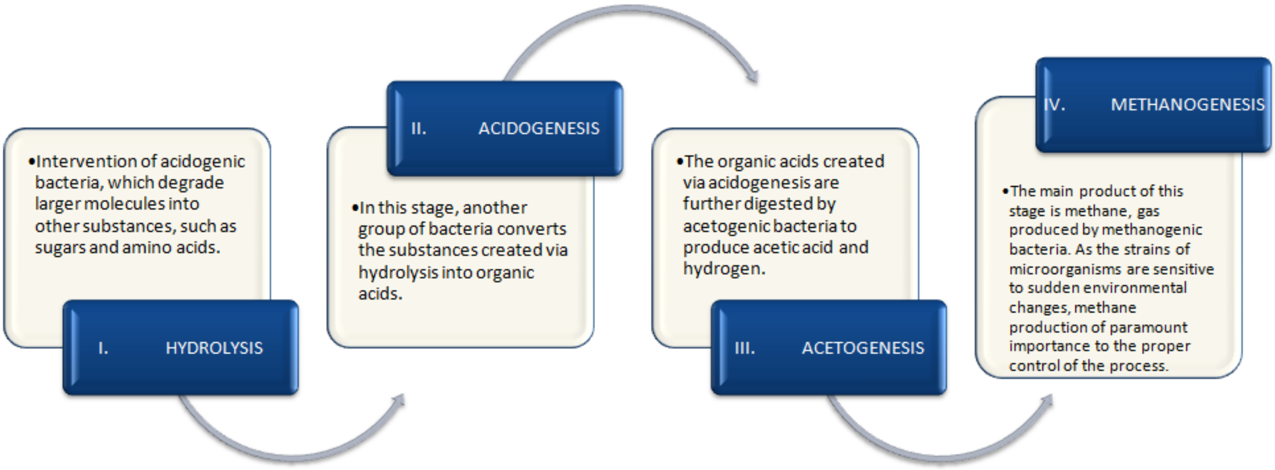
The International Energy Agency (IEA) cites biogas as one of the main renewable and efficient energy sources, in particular biomethane. Whereas biogas is the raw product resulting from anaerobic digestion and has an immediate and local use, biomethane is biogas treated via procedures that remove degrading substances, thus enabling handling, transportation and insertion of biomethane in natural gas networks. Still according to IEA, there is the perspective of a growing biogas application until 2040, being important to mention, besides biomethane production, applications in electric and thermal energy generation, building and agriculture (IEA, 2020).

According to Pleissner (2018), part of the process of organic waste reuse is directed to the decentralized (electric) energy production. It is worth mentioning the attenuation of pollutant emissions in soils and atmosphere, once landfills promote the percolation of substances that degrade organic matter into the soil, and the exposition of residues, causing the emission of polluting gases. The author also points out that landfill practices lead to the deforestation of green areas.

3.3 THE ANAEROBIC DIGESTION AND IMPORTANT ASPECTS FOR THE INSTALLATION OF BIODIGESTERS

Bajpai (2017) describes the anaerobic digestion as a series of chemical, physical and biological processes that degrade the organic matter in the absence of oxygen. The four key stages of the anaerobic digestion are represented in Figure 1.

Figure 1. Stages of the anaerobic digestion.



- Intervention of acidogenic bacteria, which degrade larger molecules into other substances, such as sugars and amino acids.

- In this stage, another group of bacteria converts the substances created via hydrolysis into organic acids.

- The organic acids created via acidogenesis are further digested by acetogenic bacteria to produce acetic acid and hydrogen.

- The main product of this stage is methane, gas produced by methanogenic bacteria. As the strains of microorganisms are sensitive to sudden environmental changes, methane production of paramount importance to the proper control of the process.

Source: Elaborated by the authors from data proposed by Bajpai (2017).

There is a basic structure in biodigesters that consists of an inlet box, into which the substrate flows, followed by a chamber where the anaerobic digestion takes place. When possible, the process is controlled by a gas storage compartment and an outlet box, both for the gas and the digestate (FRIGO et al., 2015). The document *Fundamentos do Biogás* prepared by the *Centro Internacional de Energias Renováveis* (CIBiogas – International Center for Renewable Energies) explains that the production of biogas inside the biodigester is proportional to the quantity of total solids available in the substrate. It is important to stress that the smaller the particles present in the substrate, the easier the biogas generation, because the contact of the bacteria with the solid waste particles is favored. Another important aspect to be considered is the hydraulic retention time: the lower this index, the less time the process will take to generate the biogas (CIBiogas, 2020).

The size of the equipment varies according to a series of factors, depending on the biogas demand. Roy et al. (2018) note that it is important that the biodigesters supply the local demand. Technical, economic and environmental criteria vary according to the region and local characteristics (rural *vs*. urban). Biodigesters are usually smaller in developing regions, aiming at domestic use, i.e. electricity and cooking gas, whereas in better structured areas, biogas is much more valued, as a consequence of the investments made for the installation of biodigesters (SCARLAT; DALLEMAND; FAHL, 2018).

4. METHODOLOGY

The present study is based on a bibliographic research. Macedo (1995) describes the term conceptualizing it as a search in the literature within a certain theoretical framework, with the objective to bring to light the main works associated with the object of study, so as to allow further analysis and elaboration of an updated panorama. Once the data presented in this study vary according to the locality and period in which they were collected, it is indispensable to report information that is in accordance with the global reality of the object of study.

4.1. METHOD OF ANALYSIS

For the research on the present use of biodigesters in the world, the “Academic Google”, “Scielo” and “Science Direct” databases were used by crisscrossing the following key words: “biodigester”, “anaerobic digestion”, “intelligent cities”, “africa”, “europe”, “asia”, and “world”, intercalating the terms in Portuguese and English. Each study region was surveyed individually, and in each of these surveys 10 articles per page were filtered. The abstract of each of these ten articles were read, being later selected: 6 articles regarding Europe, 8 regarding Africa, 5 regarding Asian, and 7 articles regarding Brazil and other South-American countries. The articles selected from the reading of the abstracts were thoroughly read. The articles included in this study were those that contained relevant information for the development of the research. A time filter from 2017 to 2020 was also applied; in case articles of interest lacked in any of the years, articles from previous years were selected. Each selected article was thoroughly read and data were collected according to their relevance, independently of the topic in which the information was found. This approach was applied to each study region. A total of 26 articles were selected for the final compilation of the results.

5. THE RESULTS

In the following section, the information collected in the literature on the main types of biodigesters used in Europe, Asia, Africa, Brazil, and other South-American countries is presented.

5.1 CONTEXT OF THE USE OF BIODIGESTERS IN THE WORLD

In European countries, the number of biodigesters increased between 2010 and 2016 in urban areas, in particular in Germany, as the European country with the highest capacity of biogas production, mainly directed to rural areas (SCARLAT; DALLEMAND; FAHL, 2018). According to Gromke et al. (2018), Germany concentrates biogas plants in rural areas for large-scale production of electric energy and biogas purification to biomethane. Lauer and Thrän (2017) point out that in relation to cost-effectiveness, German biogas plants promote long-term cost reductions thanks to storage networks and combined electric and thermal energy units, once the interval between gas production and use can cause gas losses.

The equipment that predominates in Europe is the Continuous Stirred-Tank Reactor (CSTR), which permits continuous substrate feeding. The main structure consists of an agitation system, which enables mixing of different substrates with variable total solids quantities. This is an advantage, because it is important that smaller particles be concentrated in the substrate for a better adhesion of microorganisms. Amaral, Steinmetz and Kunz (2020) explain that in this type of biodigester the internal structures are equipped with heating coils, aiding the control of not only the substrate temperature, but also of other chemical parameters, such as pH.

A study of Hansen, Mathiesen and Skov (2019) shows that the German energy grid will be 100% renewable until 2050. The authors suggest that energy production via biomass is viable for the electricity, transport and heating sectors, highlighting that organic waste is the key element for this chain. The European continent is an active agent in intelligent cities structuring The movements taken with actions and research directed to projects for the conversion of organic matter into energy are an important contribution to the quest for sustainable energy efficiency (VASSILEVA; CAMPILLO; SCHWEDE, 2017).

In the African continent, specifically in South Africa, underground biodigesters are used in rural areas. The structures are simple, made of brick, cement and mortar; nevertheless, the disadvantages are associated with the quality of the gas thus produced, once there is no control on important parameters. The raw material used in the building of the biodigesters is fissure-prone, limiting the useful life of the equipment (MUTUNGWAZI; MUKUMBA; MAKAKA, 2018). The majority of the African countries use fixed-dome biodigesters and Indian models, because they are easier to handle, even if they are very inefficient, due to the lack of a general planning (MSHANDETE; PARAWIRA, 2009).

According to Deganutti, Palhaci and Rossi (2002), the Indian-type biodigesters work with a low concentration of total solids and must be fed in sort periods of time, being more indicated for rural areas where animal excreta is collected at different times of the day. Also known as floating-drum biodigesters, they are composed of an inlet box, through which the substrate flows to a chamber separated by a barrier and a drum that floats on the substrate, making the pressure inside the biodigester more constant. Andrade, Ranzi and Muniz (2002) describe the structure as very simple, devoid of agitation instruments or control of physical or chemical parameters.

According to Pérez et al. (2014), the fixed-dome model is composed of a cylindrical chamber with inlet and outlet compartments, respectively for substrate and gas. The gas is stored in the upper part of the chamber, and the whole structure is built underground. This type of biodigester is also made of cement, the higher costs being associated with building and maintenance personnel.

However, the fixed-dome model faces relevant obstacles when installed in very vulnerable areas, such as the Republic of Cameroon, where biogas plant projects failed due to the lack of water supply for the substrate, increasing total solids and making the operation of the equipment inefficient (MUNGWE et al., 2016). There is a promising field for the inclusion of biodigesters in clean energy productivity actions in parallel with the solution of the waste problem, but barriers are created by the lack of regulatory norms (NEFEDOVA et al., 2020; SEMELANE; TAZVINGA; NZAKI, 2018).

In general, Asian countries use domestic fixed-dome biodigesters, such as Vietnam (ROUBÍK et al., 2017) and Cambodia, which are still rural countries with difficult access to universal energy (HYMAN; BAILIS, 2018). According to Deng et al. (2017), China is pioneer in the use of biodigesters. The authors report not only the use of CSTR biodigesters, but also the Upflow Anaerobic Sludge Blanket (UASB) models in China, thanks for the fact that UASB is very efficient in handling sewage and industrial waste. UASB contains mechanisms to manipulate ascending substrate flow and can store large biomass quantities, which decreases hydraulic retention time and promotes large gas production.

Norms associated with the standardization of biogas production have existed in China since the 1970’s, and were modified in 2015 to encourage investments in the market, serving as basis to other Asian countries. However, some structures that contemplate partnerships with public authorities are still lacking (WANG et al., 2020).

India is another reference for the use of biodigesters. Thomas et al. (2017) describe some recurrent models, such as Khadi and Village Industries Commission (KVIC), which adopts the standards of the common floating-drum biodigester. It is followed by the Deenbandu model, built with cheaper materials. Its shape is circular, which enables the creation of a small compensation chamber; workforce is required to remove the exceeding slurry. Thomas et al. (2017) also mention the small-scale Pragati model, which produces biogas for domestic use.

Freitas et al. (2019) report that in Brazil and in other South-American countries, the main types of biodigesters used are the Indian, Chinese, UASB and CSTR. Particularly in Brazil, the Canadian, also known as covered lagoon, stands out It consists of a landfill built close to the surface; gas is stored under an impervious cover. The authors explain that this type of biodigester is more adequate for industrial and agricultural-industrial projects. Canadian models made of steel have been increasingly used.

In Brazil, the use of biodigesters is concentrated in rural areas. One must take into account that high quantities of organic waste is created via agricultural activities, serving as substrate for biogas production (SANTOS et al., 2018). Brazil is favored by a variety of renewable energy options, in particular hydroelectricity. According to Silva, Neto and Seifert (2016), most of the energy production via biomass is focused on ethanol, placing Brazil in a relevant position regarding the environmentally clean fuel production chain. On the other hand, organic waste is not fully used for other types of energy conversion.

The covered lagoon model is also used in Bolivia, with biogas production directed to rural regions and domestic use (SCHNEIDER et al., 2020). In Argentina, the use of biodigesters of the covered lagoon, CSTR and UASB types are used. It is worth mentioning, however, that the country does not rely on large-scale biogas plant installation projects (CARUANA, 2019).

According to Vasco-Correa et al. (2018), the development of projects of energy production via biomass in Latin America has been below the potential envisaged for the region, mainly represented by the variety of substrates. Wu et al. (2019) point out that an increased production of bioenergy in the South American continent can bring relevant benefits to the economy and environment, mainly boosting rural areas.

The panorama presented above is summarized in Chart 1.

Chart 1. Main types of biodigesters used in the study regions.

Authors	Region	Main types of biodigesters
Amaral, Steinmetz and Kunz (2020)	Europe	CSTR – Continued Stirred Tank Reactor. It includes a system of agitators, thus reducing the costs with waste pre-preparation.
Mutungwazi, Mukumba and Makaka (2018); Mshandete and Parawira (2009)	Africa	Indian-type model, fixed-dome and other underground structures made of bricks, cement and mortar.
Deng et al. (2017)	Asia	CSTR and UASB – Upflow Anaerobic Sludge Blanket, the latter being installed mainly for industrial waste handling in China. Similarly to CSTR, UASB has mechanisms to control the substrate flow, increasing the quantity of biomass fed in the equipment. KVIC – Khadi and Village Industries Commission and Deenbandu are used in India, despite their simple and limited structure.
Freitas et al. (2019); Schneider et al. (2020); Caruana (2019)	Brazil and other South-American countries	UASB, CSTR and covered lagoon. The covered lagoon or Canadian model has a simple plastic cover and is usually fed with residues from agricultural activities and animal dejecta.

Source: Prepared by the authors, 2020.

6. CONCLUSION

The discussion about urban structuring, taking into account population growth and the enlargement of urban perimeters, brings to light complex challenges, as far as energy supply and efficient solid waste management are concerned. In this sense, the present study presents different types of biodigesters used in some regions of the world and the main obstacles related to the installation of such structures, besides the advantages to be gained with organic waste recycling and exploitation of biogas. The results show a notable difference between the biodigester models used in the study regions.

In Europe, biogas production is inserted in governmental actions that stimulate gas generation, in particular in rural areas, with the installation of biodigesters built adopting more complex technologies for a better use of the substrate and gas distribution. In Asia, the large use of Chinese and Indian technologies is striking, being China and India pioneers in the application of biodigesters. On the other hand, the models mostly used in Africa are comparatively simple and therefore limited to small biogas productivities of worse quality. Rural areas predominate over urban areas in the majority of the African countries, which are disfavored by the lack of a universal energy supply. Such scenario is also observed in other Asian countries, which present structural conditions similar to those of the African countries.

Brazil has a huge potential to expand its energy matrix from organic waste recycling for biogas production, thanks to a wide rural activity and the possibilities of adequate planning of actions that contemplate the stimulation of such productivity. However, such opportunities have not been fully explored. In other South-American countries, biodigesters are not recurrently used, because, among other factors, the energy matrix in these countries is dependent on the fossil fuels market as a whole.

Therefore, there is an undeniable inequality in the way in which developed and undeveloped countries manage the sustainable planning of their cities, and consequently the conversion of solid waste in clean and efficient energy. Besides, the main obstacles that are observed are related to the lack of proper plans of action that involve all the society layers to promote advances in the application of biodigesters in intelligent cities.

The present study present a brief panorama on biodigester models in the context of intelligent cities. More detailed studies are relevant for future articles, focusing on an empirical approach that explores the participation of stakeholders in the process.

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