Chapter 13
Current Efforts for the Production and Use of Biogas Around the World

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Abstract Biogas is a renewable energy source that can be generated from the digestion of a variety of organic materials and waste. Organic wastes used for biogas include animal manure, human excreta and other agricultural wastes, slaughterhouses and food industries residues or even urban solid waste. However, in some developed countries it has been used corn, barley, sunflower and sorghum as other energy sources. Biogas systems differ strongly between locations, form, cost structure and usage patterns. This difference is mainly related to the development condition of the country. When implemented properly, biogas systems can serve multiple purposes. Digesters are considered a clean and alternative technology that can help distant communities with their energy necessities by improving living conditions or even economical source. Considering this, the present chapter will be addressed: (i) Biogas production around the world; (ii) Feeding material used in different continents to generate biogas; (iii) usage of biogas produced.

Keywords Biogas substrates · Bioenergy · Anaerobic digestion
Renewable energy

13.1 Biogas Production Around the World

Biogas is the product of a biologically mediated process resulting from anaerobic digestion. Biogas consists mainly of methane (CH_4) around 50–70% and carbon dioxide (CO_2) in a concentration of 30–50%, where the concentration of CH_4 and CO_2 in biogas depends mainly on the substrate type (Angelidaki et al. 2018).

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In addition to CH_4 and CO_2, biogas also contains slight amounts of N_2 (0–3%), H_2O (5–10%), O_2 (0–1%), H_2S (0–10,000 ppmv) and NH_3 (Angelidaki et al. 2018; Muñoz et al. 2015).

Biogas systems differ strongly between locations, form, cost structure and usage patterns. This difference is mainly related to the development condition of the country. An increasing number of biogas plants in operation have emerged worldwide, in recent years. Biogas production is concentrated in Europe and in the United States (REN21 2018) however, the majority of anaerobic digesters are implemented in Asia, where the most of them have been used in rural communities for cooking and lighting (KC et al. 2014; Vasco-Correa et al. 2018). In Europe the number of biogas plants has increased (Fig. 13.1), with more than 14,500 biogas systems implemented, and the number is increasing (European Biogas Association 2014; Grando et al. 2017).

The clear leaders are Germany and Sweden, with digestors on the agricultural scale, with around 9000 of them, and its goal is to have about 10,000–12,000 digester by 2020 (Wilkinson 2011). However, other countries such as United Kingdom, Switzerland, United States, South Africa and Brazil also have built biogas plants (Fig. 13.2) (Angelidaki et al. 2018). In 2013, the number of biogas plants in Hungary, Czech Republic, Slovakia and Poland increased by 18% (Grando et al. 2017). Otherwise, in Latin America, it has increased the number of domestic biogas systems, especially in rural areas (Garfi et al. 2016; Grando et al. 2017).

In Africa the installation of biogas digesters were done in many countries such as Botswana, Cote d'Ivoire, Burkina Faso Burundi, Ethiopia, Rwanda, Senegal, Ghana, Guinea, Lesotho, Kenya, Namibia, South Africa, Nigeria, Zimbabwe and Uganda. The Africa Biogas Partnership Programme (ABPP) was created aiming to provide access to energy services in some African countries as Tanzania, Ethiopia, Uganda Kenya and Burkina Faso (SNV 2010).

In the United States there is a panorama for the anaerobic digestion industry increase with the potential to generate energy to 1.1 million houses using manure from 8000 dairy and hog farms (Vasco-Correa et al. 2018), nowadays there

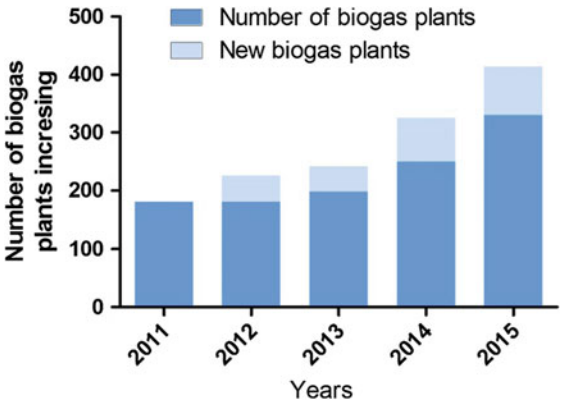

Fig. 13.1 Increasing biogas plants over years, all around the world (Angelidaki et al. 2018)

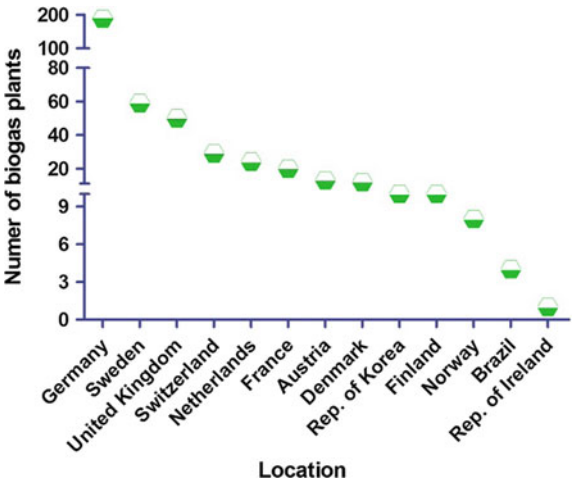

Fig. 13.2 Location and number of existing biogas plants (Angelidaki et al. 2018)

are approximately 250 real scale anaerobic digesters, around 1250 wastewater treatment plants and 38 industrial plants (Vasco-Correa et al. 2018). In addition, there are nearly 2500 wastewater treatment plants with capacity to produce biogas, however, a huge number are not using the biogas produced (American Biogas Council 2017; Vasco-Correa et al. 2018).

North America has increased the interest in implementation and use of anaerobic digestion. Canada has more than 100 biogas systems. In addition, Mexico also increased the interest in biogas plants implementation and in the use of existing biogas for energy generation rather than burning, is increasing (Alemán-Nava et al. 2015; CBA 2017).

In the Latin America despite the significant potential of anaerobic digestion, its operation has been slow. To fill this gap, was created in 2009 the Network for Biodigesters in Latin America and the Caribbean (RedBioLAC), aiming to improve information of this tools in the country (Garfí et al. 2016). RedBioLAC has helped in the installation of several agricultural and household biogas power plant in Ecuador, Costa Rica, Nicaragua, Mexico and Peru; besides, in Bolivia more than 1000 household biogas plants were implemented (Kapoor and Vijay 2013; Grando et al. 2017).

13.2 Feeding Material Used in Different Continents to Generate Biogas

Anaerobic digestion could be used for treatment of liquid and solid waste, and all around the world, many different substrates have been used in anaerobic digestion for biogas production (Fig. 13.3): agricultural waste, agricultural crops (barley, sunflower and sorghum), manure, human excreta, municipal solid waste, food

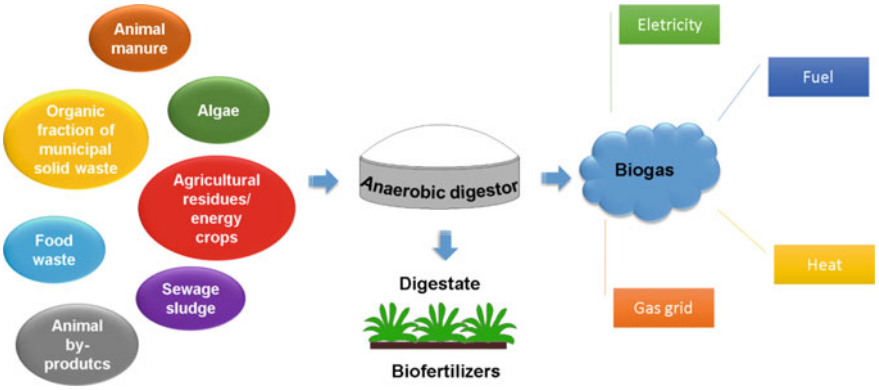

Fig. 13.3 Schematic representation of substrates used for biogas production and its application

residues, effluent and industrial effluents (from the most different origins, as food industry, wine sector, cassava), almost all materials with high organic load could be used (Krzywika and Szwaja 2017; Guerini Filho et al. 2018).

According to the Global Intelligence Alliance (2010), the potential materials for biogas production worldwide are: 75% in crops, manure and by-products; 17% in municipal wastewater and industrial effluent; and 8% in manure treatment plants. However, according to Global Methane Initiative (2018), the actual distribution of biogas plants, are majority represented by systems fed with municipal solid waste, followed by agriculture manure and wastewater reuse (Fig. 13.4).

Sometimes the substrates need to pass by a pre-treatment step, for example microalgae (Passos et al. 2014), poultry litter (Costa et al. 2012), corn stalks (Venturini et al. 2018) and corn stover (Bondesson et al. 2013); or be co-digested, when materials are put together aiming to improve the plant efficiency and synergistic effects (Luostarinen et al. 2011), for example swine carcass/swine manure (Tápparo et al. 2018), manure/lignocellulosic materials (Tsapekos et al. 2017), food residues and straw (Yong et al. 2015).

Europe has mainly two operation systems for digesters: "centralized" systems and "agricultural scale" digesters. Centralized system or set codifies the livestock manure of various farms with other organic materials, such as food, domestic and agricultural waste. In this model, a part of the digested is returned to farms where can be utilized as fertilizer, or sold to other producers (Holm-Nielsen et al. 2009; Wilkinson 2011; Vasco-Correa et al. 2018). Denmark is a innovator in the development of "centralized" or biogas systems, with about 150 biogas plants and 20 centralized systems, and they plan to upsurge their capability by 50% by 2020 (Holm-Nielsen et al. 2009; European Biogas Association 2015). These centralized plants have large capacity digesters up to 8000 m^3 (Nielsen and Angelidaki 2008). In Denmark the main substrate is manure with other co-substrates added to increase yield (Skovsgaard and Jacobsen 2017).

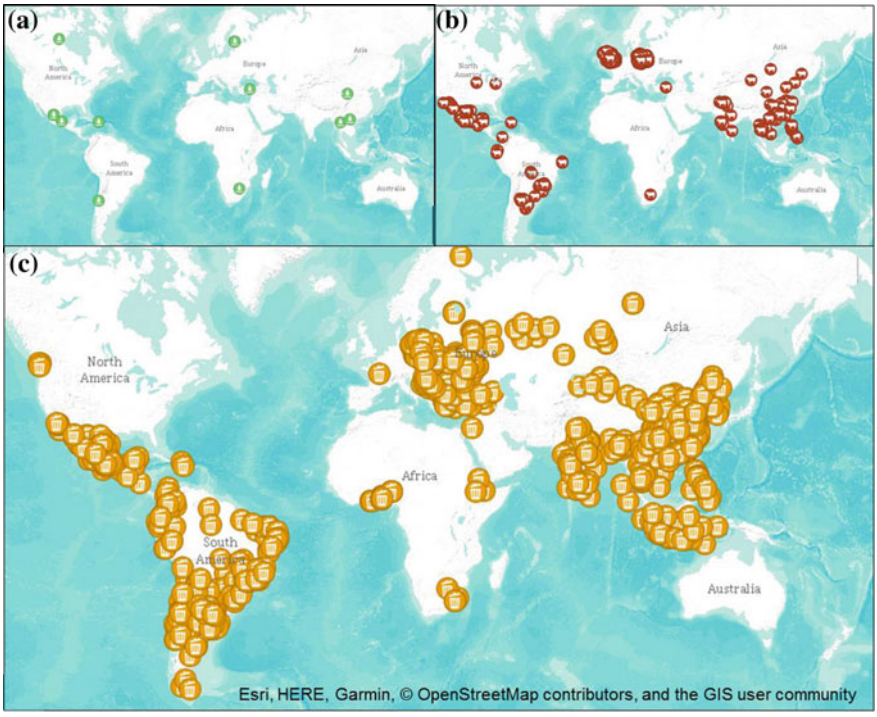

Fig. 13.4 Global distribution of materials used as biogas substrates: **a** wastewater reuse; **b** agriculture manure; **c** municipal solid waste (Global Methane Initiative 2018)

Biogas digesters have utilized a huge diversity of substrates along of African countries from north to south such as industrial effluent such as sugar cane bagasse (lignocellulosic waste from sugar mills and agricultural processing), animal dung and human excreta, chicken and dairy farms, public latrine, industrial wastewater and municipal solid wastes in north of Africa, as in Egypt (Tuesorn et al. 2013). Human and animal excreta are considered the most common feedstock material for anaerobic digestion and biogas production especially in central and south of Africa using the Chinese and Indian digester model (Omer and Fadalla 2013).

Anaerobic digestion use large quantities from energy crops such as corn, barley, sunflower and sorghum in sub-Saharan Africa, and have been used for warmth and energy production and the effluent can be used after recycling as a minor eco-friendly biofertilizers for agriculture purposes (Al Seadi et al. 2008). Jatropha (*Jatropha curcas* L.), is considered a promising crop for Africa's Biofuel Production in almost nine African countries, as Ghana, Madagascar, Burkina Faso, Lesotho, Malawi, Namibia, South Africa, Swaziland and Zambia, and was successfully used to produce biogas (Hendroko et al. 2015; Jabłoński et al. 2017). In Egypt, there is a huge amount of biomass with potential for using in biogas production (up to 40 million ton) however about 52% of this biomass has been direct

burned. The prevalent form of biomass use in Egypt is biogas in rural areas, where substrates used are rice straw and maize (Bakker et al. 2013; Cooper and Laing 2017). Nevertheless, the amount of biogas produced depends on many issues as the feedstock material amount, the substrate, the time and temperature of digester (Amigun et al. 2012).

In the United States, anaerobic digestion is well established in terms of using manure sludge as a substrate, with about 90% of anaerobic digestion plants implemented in the last years, where most of them (86%) use dairy manure as the main raw material (Edwards et al. 2015; Vasco-Correa et al. 2018). However, some researchers have highlighted the potential of using municipal solid waste, yard waste, paper and paper board (Linville et al. 2015).

In Latin America, it has been used food waste, in small-scale systems. However, there is an enormous potential for using agriculture residue, manure (swine and cattle) vinasse and cassava (REN21 2018).

13.3 Use of Biogas Produced

The biogas sector differs considerably in different parts of the world. Plant size ranges from small-scale households to large plants. Biogas is used in other ways in large parts of the world (IGU 2015). When implemented properly, biogas systems can serve multiple purposes, once that it could be used directly or in diverse ways; biogas could be used for heat, however the most frequent usage is for electricity generation (Vasco-Correa et al. 2018, 2018). Besides, in the context of circular economy, the digestate could be reused as biofertilizer to cultivate crops that could be used on biogas generation.

In 2000, the global energy generation from biogas was about 280,000 TJ and reached almost 1.3 million TJ by 2014, with an typical annual increase of 13.2% in of biogas production (International Energy Agency 2016; Vasco-Correa et al. 2018). In 2013, biogas generation was projected at about 59 billion m^3, with almost half of what has being produced in the European Union (World Bioenergy Association 2017; Vasco-Correa et al. 2018). The global installed capacity for energy production (Fig. 13.5) shows that the capacity increased all around the world in the last 10 years, with Europe been the leader, followed by North America, Asia, South America, Africa and Central America and Caribbean (IRENA 2018).

In Denmark, Finland, Iceland, Norway and Sweden biogas usage is still partial, with Sweden and Denmark taking the lead in their production. While these countries have similar characteristics, the biogas usage is diverse: in Denmark, biogas has been used in coproduction plants, whereas in Sweden it is generally converted to motor fuel (Nordic Energy Research 2010). Anaerobic digestion full-scale farm plants generally present a digester capacity of 200–1200 m^3, and are frequently built on dairy or swine farms (Weiland 2003), where animal manure from different farms are co-digested with agricultural wastes and crops (Wilkinson 2011; Vasco-Correa et al. 2018).

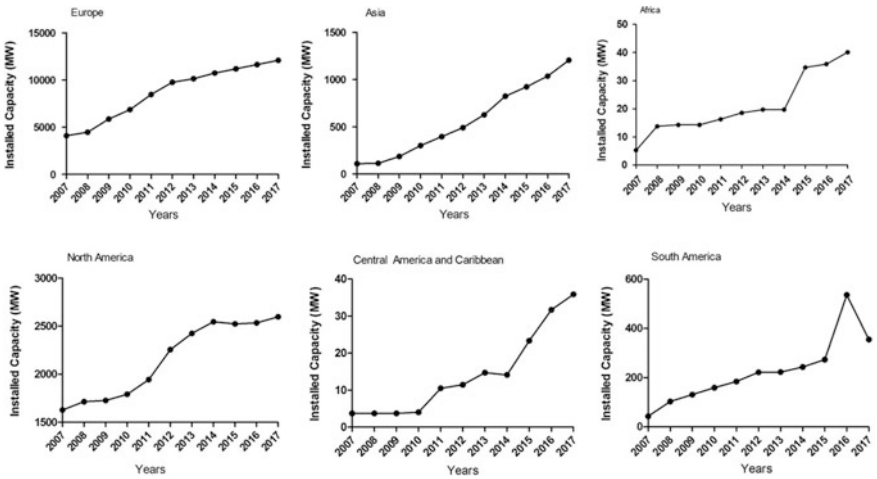

Fig. 13.5 Installed capacity (MW) from all biogas plants installed around the world

In Poland, the potential energy production (39.44 PJ) from biogas could be able to cover 7.5% of the country's energy requirement (Igliński et al. 2012; Grando et al. 2017). Besides the huge amount of challenges on power generation, biogas industry increased in recent years, because Poland could cover about 47% of domestic request for natural gas (Bielski and Marks-Bielska 2015; Grando et al. 2017). Sweden stands out as the country that mainly updates biogas for use as a vehicular fuel (International Gas Union 2015).

Bio-power production (electricity) reached 33 MW in Africa while 10.4 GW in Europe. Africa has large volumes of wastes but biogas production is still less developed than in other regions all over the world. Most of the biogas plants are being used for both cooking and lighting along African countries.

Asia has the highest number of biogas systems implemented, majority of them as domestic digesters that have been used in rural area for cooking and lightning (KC et al. 2014; Vasco-Correa et al. 2018). Latin America rural areas could also use household digesters, but this technology has only been successfully installed in latest years (REN21 2018) with increasing numbers of household biogas plants mainly for cooking and heating (Garfi et al. 2016).

The United States showed shy implementation of anaerobic digestion, with about 2100 current operating plants (American Biogas Council 2017), however, the operating plants use biogas generated for electricity generation and fuel boilers (Edwards et al. 2015).

Full-scale biogas systems have been constructed to use palm oil mills wastes generated in farms in Argentina, Colombia and Honduras (Kapoor and Vijay 2013). Brazil had 127 biogas plants using agroindustry residues, biosolids, sewage, and landfill gas, producing about 584 billion m^3 biogas/year, representing 3835 GWh

Table 13.1 Biogas production profile around the world

Countries/ regions	Feeding material	Biogas generated or potential (m^3/year)	Destination of biogas	References
European Union	Sewage sludge, landfill, manure, Agriculture crops and waste	18,207 mil	Electricity, heat	European statistics (2017)
China	Wastewater, food waste	15 billion	Electricity, cooking, lighting	IRENA (2018)
India	Lignocelulotic, agriculture crops, food waste, wastewater	10 billion	Cooking	Ministry of New and Renewable Energy (2014)
Africa	crops, wastewater	12.8 billion	Organic solid wastes	Rupf et al. (2015)
United States	Manure, landfill, wastewater	18.5 billion	Electricity	US EPA (2017)
Brazil	manure, industrial residues, biowaste, sewage sludge	584 billion	Electricity	REN21 (2018)
Uruguay		54–84 million	Electricity	López (2016)
Colombia		6000 million		López and Borzaccooni (2017)

of energy in 2015 (International Energy Agency 2016; REN21 2018; Scarlat et al. 2018) In the last years, the biogas electricity production capacity increased from 196 MW in 2015 to 450 MW in 2016 (IRENA 2018) (Table 13.1).

13.4 Final Remarks

Biogas has a huge potential as an alternative energy source, and also could help with many different waste/residues destination. However, the improvement of this technology will depend on the interactions between diverse areas as agriculture, rural development, energy production and policies. Besides, it is of special concern the technology transference know-how and adaptation to the local conditions, once that the well working state of anaerobic digestors is directly influenced by environmental parameters as temperature.

Otherwise, biogas production is a ecofriendly technology, that has the advantage of generate a digestate rich in nutrients, that make its and excellent biofertilizer or soil conditioner.

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